MIRA

Climate Report 2015

about observed and
future climate changes
in Flanders and Belgium

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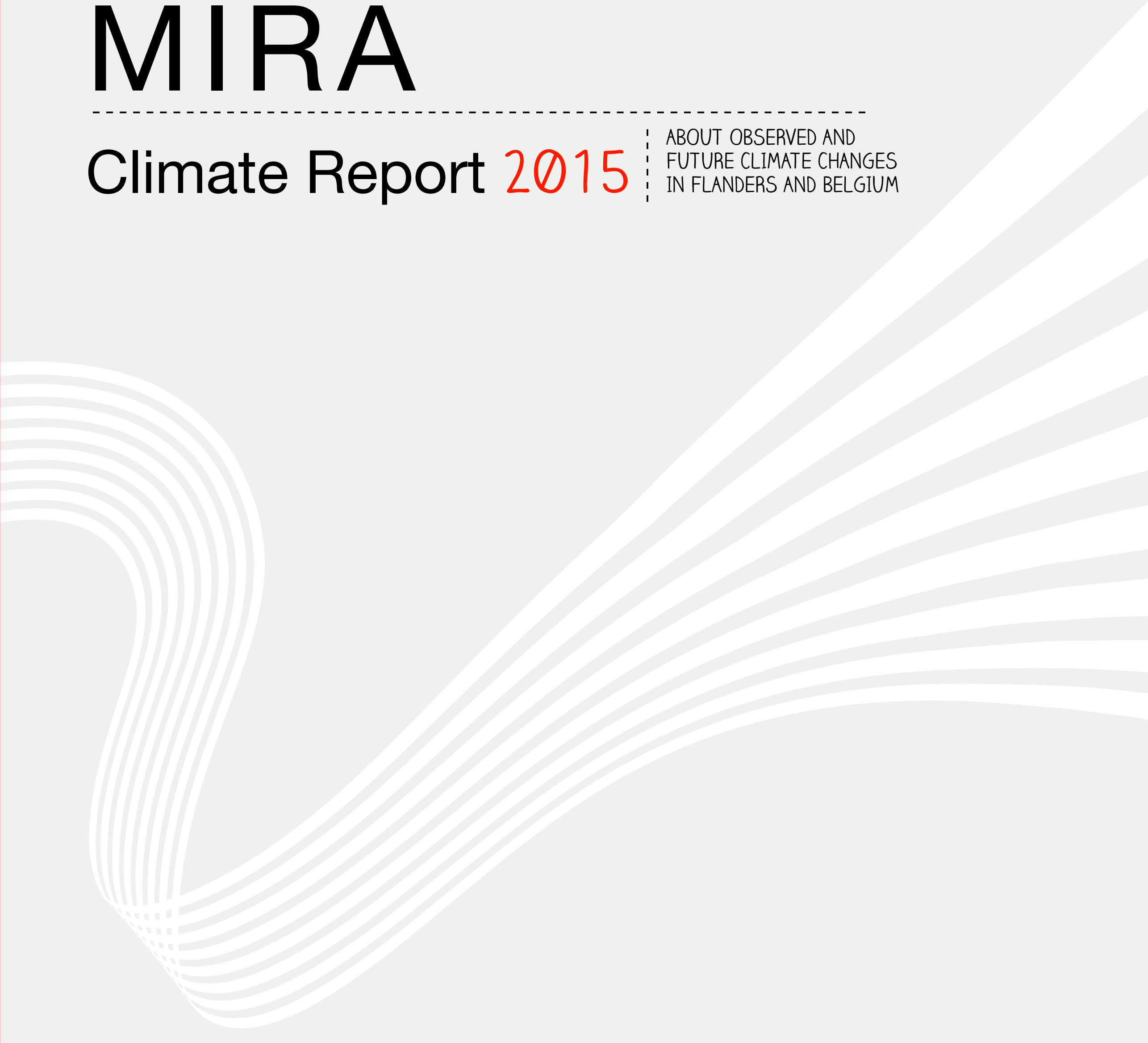
Climate Report 2015

ABOUT OBSERVED AND FUTURE CLIMATE CHANGES IN FLANDERS AND BELGIUM



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SUMMARY

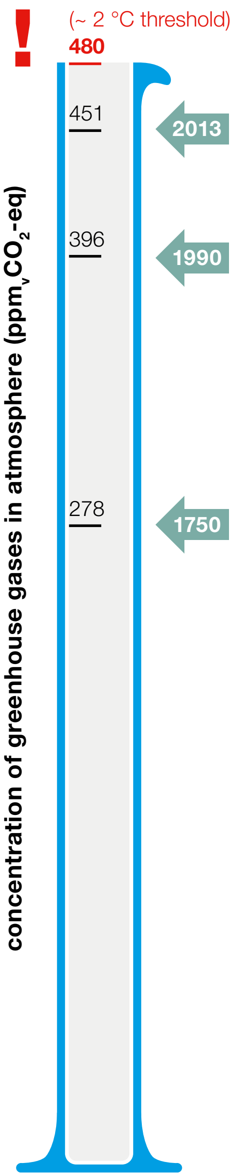
‘To what extent is climate change already noticeable in Flanders and Belgium?’ and ‘What are the expectations for the future?’, these are the central questions that this MIRA Climate Report 2015 seeks to address. The report begins with an explanation of the mechanism that is at the basis of global climate change. It then searches for signals of climate change in existing datasets, specifically for Flanders and Belgium. In this context, the focus on urban heat island effect and droughts is relatively new. The future scenarios are based on the most recent scenarios of the IPCC (the Intergovernmental Panel on Climate Change of the United Nations). The report examines for the first time potential spatial differences within Flanders and surroundings. Attention is also paid to possible effects of climate change on public health and water management. Next, the importance of so-called tipping points is highlighted. These are abrupt changes in the climate system that may occur as a result of global warming. The report ends with a number of considerations on how policy can deal with the uncertainties inherent in the issue of climate change.

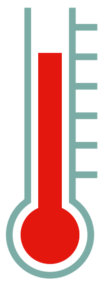
Observed climate change

In spite of important natural fluctuations, the effects of climate change are already visible in a number of indicators. The annual average temperature in Uccle, for example, is now almost 2.4 °C higher than in the pre-industrial period. The average temperature in all four seasons has risen, with the greatest rise being recorded in spring. Potential evapotranspiration - an indication of evaporation - has increased with temperature. For the number of days with (extremely) high and (extremely) low temperatures, the picture is much less clear. The number of tropical days (maximum temperature ≥30 °C) has statistically increased since 1968, but the increase in the number of summer days (maximum temperature ≥25 °C) is not statistically significant. Also the downward trends for the number of days of frost (minimum temperature <0 °C) and days of ice (maximum temperature <0 °C) are not statistically significant. The number of heat waves and their length exhibits a wavy pattern with a first maximum in the 1940s and a clearly upward trend line since the 1970s.

The amount of precipitation shows very high variability over time. Moreover, there have been longer periods with more precipitation, *e.g.* around 1920, 1960 and 2000. Over an even longer period, the annual amount of precipitation in Uccle shows a slow, but significant, rising trend. Today, the trend line is almost 13 % higher than at the beginning of meteorological measurements in 1833. As regards precipitation per season, a significant increase was recorded only for the winter. The number of days with heavy precipitation (1951-2013) and the maximum amount of

Climate trends detected in Belgium until 2014



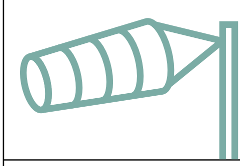


temperature

- annual average temperature +2.4 °C with respect to pre-industrial period
- 18 warmest years since 1833 are in the period 1989-2014
- all seasons are becoming warmer: spring +3.0 °C, other seasons +1.9 to 2.1 °C
- increase in number of tropical days (T_{max} ≥30 °C) in a year: 1 day extra per 17 years
- frequency of heat waves shows a wavy pattern. Since the 1970s there has been an increase from 1 every 3 years to 1 every year now. Also the length of heat waves has increased.

evaporation & precipitation

- potential evapotranspiration (measure of evaporation) is now a quarter higher than at the end of the 1970s
- the precipitation deficit (for humans, animals and plants) or the difference between precipitation and evaporation exhibits no clear trend, nor do the characteristics of drought periods
- trend in annual average precipitation is now 13 % above the level at the beginning of measurements (1833)
- only in winter does the precipitation increase; no or hardly any change is measured in the other seasons
- also the number of days with measurable precipitation is increasing (only in winter), but snow is less frequent
- the number of days with heavy precipitation has increased from 3 to 6 days per year since the early 1950s
- also the maximum precipitation measured in a consecutive period of 5, 10 or 15 days within a year is increasing



wind

- since the 1960s the average wind speed inland has decreased: -10 to -15 % over 5 decades
- number of days with wind surges above 70 km/h exhibits no clear trend, nor do the highest measured wind speeds

maritime climate

- annual average sea level is increasing, *e.g.* in Ostend the long-term trend is 11.5 cm higher than in the early 1950s
- wave height and wind speed at the coast exhibit no clear trend
- seawater temperature on the Belgian side of the North Sea is increasing at a rate of 0.034 °C/year

Source: MIRA based on RMI, VMM, KU Leuven, PSMSL, Agentschap Maritieme Dienstverlening en Kust, NOAA, IPCC and EEA precipitation in 5, 10 and 15 days (1880-2013) have also increased significantly.

The availability of (fresh) water for humans, animals and plants depends on precipitation and on evaporation. If evaporation exceeds precipitation, a precipitation deficit may occur. The difference between precipitation and evaporation can therefore serve as an approximate indicator for drought stress in plants. This precipitation deficit shows no significant trend. Also the analysed characteristics of periods of drought appear not to have changed significantly.

Until the 1960s, the annual average wind speed in our country had remained rather stable. Since then, it has begun to decrease. The current annual average is 10 to 15 % lower. No clear trend is apparent for the occurrence of days with wind gusts greater than 70 km/h, nor for the highest measured wind speeds.

The statistical analysis of the values measured at the Belgian coast shows that the annual average sea level in 2013 is significantly higher than at the beginning of the time series. The trend line for Ostend in 2013, for example, lies 115 mm higher than in 1951. The temperature of seawater has also increased. The wave height and the wind speed at the coast, by contrast, show no clear trends.

Urban heat island

The temperature in cities is generally higher than in the surrounding rural areas. As a result, city dwellers are more exposed to heat stress during heat waves. This leads to an increased mortality rate, especially among the elderly and children. Causes of the heat island effect include reduced vegetation (and therefore less cooling through evaporation), trapping of radiation between buildings, comparatively limited heat exchange between city and atmosphere, high thermal inertia of urban materials and heat that is released during heating and cooling of buildings and in traffic.

The urban heat island effect for Antwerp could be illustrated with measurements in the period 2012-2014 and with urban climate modelling in the period 2000-2012. In addition, the urban heat stress for the whole of Flanders and surroundings was mapped by satellite images. Compared with the countryside, the night temperature is in particular higher in cities. This difference amounts, on average, to a few degrees, with peaks of 7 to 8 °C and more. Heat waves therefore occur more frequent and more intense in cities. A strong connection likely exist between the degree to which a city is sealed and the intensity of the heat island effect. Flemish cities with a relatively large heat island effect are Antwerp, Ghent, Kortrijk, Mechelen, Roeselare and Bruges. In Antwerp, a significantly higher percentage of the population is exposed to higher temperatures than in other cities.

Future climate change

The IPCC has defined four possible scenarios for global greenhouse gas concentrations until 2100. The most extreme scenario is characterised by the absence of climate policy and sharply rising greenhouse gas emissions. This scenario could lead to an increase in the average temperature on Earth between 3.2 and 5.4 °C by 2100 compared to the period 1850-1900. The least extreme scenario is based on important reductions in greenhouse gas emissions. Here the increase in global temperature could be limited to 0.9 to 2.3 °C. The total temperature range of these scenarios is highly likely to include the actual future temperature evolution. Yet it is not possible, nor is it the intention, to calculate for each of these four scenarios the degree to which they are likely to become reality. The recent global greenhouse gas emissions clearly connect almost seamlessly with the path of the most extreme scenario.

Around 200 global climate model simulations are available for this Climate Report 2015. These global simulations are too rough on a spatial and temporal scale to map, for example, periods of extreme precipitation and spatial variations within Flanders. That is why they will be further refined both in space and in time. To conduct specific, local impact analyses of climate change, global, regional and local climate models are combined with a statistical downscaling technique. Thus, based on the global simulations for this report, three climate scenarios have been derived: high, medium and low. The table in this summary gives an overview of the main results per scenario. The bandwidth between the high and the low climate scenario indicates, per parameter, the potential climate change that is expected in Flanders and Belgium. Again, the likelihood of the scenarios cannot be determined here. There is even an unknown but probably small chance that the future climate change falls outside these scenarios. The medium climate scenario corresponds to the median of all the model simulations, but is not necessarily the most likely scenario.

The climate scenarios for Flanders indicate an increase in the annual average temperature by 0.7 to 7.2 °C over a period of 100 years. The spread between the low and high climate scenario is greater in the summer months than in the winter months. The spatial differences within Belgium are small. In the high scenario, the number of extremely hot days increases sharply, whereas the number of extremely cold days decreases sharply. In the low scenario, the differences with the present climate for these temperature extremes are very small. The increase in the number of extremely hot days is most pronounced in the centre of the country, whereas the decrease in the number of extremely cold days is greatest in the Ardennes. The increase in heat stress will be greater in urban areas than in rural areas; not only because cities already have higher temperatures during heat waves, but also as a result of the future expansion of the actual cities. Together with the increase in temperature, an increase in potential evapotranspiration is expected.

Two of the three climate scenarios show an increase in precipitation in the winter months. This increase may amount to +38 % over 100 years and appears to be attributable not so much to an increase in the number of wet days, but rather to an increase in the amount of precipitation per day. Closer to the coast, the increase in winter precipitation is also greater and two of the three climate scenarios indicate a decrease in precipitation in the summer months. This decrease may amount to -52 % over 100 years, it increases southwards and appears to be attributable primarily to a sharp decrease in the number of wet days. Furthermore, it appears that during the summer months the most exceptional rainfall is expected to increase most sharply in precipitation intensity.

Overview of possible climate change for Flanders and Belgium according to the low, medium and high climate scenario, over 30, 50 and 100 years

change for	over number of years	climate scenario			additional info
		low	medium	high	
annual average temperature	30	+0.2 °C	+1.1 °C	+2.2 °C	The coast has a mitigating effect on warming, but the effect is small with respect to the expected climate change.
	50	+0.3 °C	+1.8 °C	+3.6 °C	
	100	+0.7 °C	+3.7 °C	+7.2 °C	
average number of extremely hot days per year	30	0	+5	+19	The number of extremely hot days increases the most in the centre of Belgium.
	50	0	+8	+32	
	100	0	+16	+64	
average number of extremely cold days per year	30	0	-2	-10	The number of extremely cold days decreases the most in the Ardennes.
	50	-1	-4	-17	
	100	-1	-7	-33	
total winter precipitation	30	-0.4 %	+3 %	+11 %	Winter precipitation increases more along the coast.
	50	-0.6 %	+6 %	+19 %	
	100	-1 %	+12 %	+38 %	
total summer precipitation	30	-16 %	-4 %	+5 %	Extreme summer precipitation intensities may increase significantly. Spatially, a north-south pattern is emerging with greater desiccation in the south of the country.
	50	-26 %	-7 %	+9 %	
	100	-52 %	-15 %	+18 %	
number of wet days in winter	30	-1 %	+0.5 %	+2 %	
	50	-2 %	+0.8 %	+4 %	
	100	-5 %	+1.5 %	+8 %	
number of wet days in summer	30	-12 %	-5 %	+1 %	
	50	-21 %	-8 %	+2 %	
	100	-41 %	-15 %	+4 %	
total potential evapotranspiration in winter	30	+0.5 %	+3 %	+11 %	
	50	+1 %	+6 %	+18 %	
	100	+2 %	+12 %	+35 %	
total potential evapotranspiration in summer	30	+0.5 %	+5 %	+14 %	
	50	+1 %	+8 %	+23 %	
	100	+2 %	+17 %	+47 %	
daily average wind speed in winter	30	-8 %	0 %	+3 %	
	50	-14 %	-0.5 %	+6 %	
	100	-28 %	-1 %	+11 %	

Source: KU Leuven in MIRA Study Report 'Actualisatie en verfijning klimaatscenario's tot 2100 voor Vlaanderen' (2015)

For the average wind speeds, both in winter and in summer, and the average wind direction, no significant changes are expected in Belgium this century. The wind speed during the most violent storms, however, will probably increase by 0 to 30 % in winter.

For the Belgian coast, the Flemish Climate Policy Plan 2013-2020 estimates that the sea level will increase, on average, by 60 to 200 cm. These 200 cm are mainly used to demonstrate the need for 'robust' measures, although scientifically there is little reason to assume such an increase over a period of 100 years.

Potential effects of climate change, today and in the future

Climate change may have a broad range of effects. In this report, the focus is on the effects for water management and public health, more specifically via heat wave victims and via the impact on air quality. The specific impact of the new climate scenarios for Flanders has only been partially quantified. This implies that the actual effects of the latest climate projections for specific sectors are sometimes not yet known. However, in the past years - as reported in MIRA's Environment Outlook 2030 and for the preparation of the flood risk management plans - quite a number of impact models have been developed with the climate scenarios. Based on the (rather limited) differences between the old and the new climate scenarios, a number of indications regarding the potential effects can be provided.

The number of problematic floods has increased significantly since 1970, both worldwide and in Belgium. Climate change is only one of the possible factors responsible for this increase. In fact, the rise in population and welfare determines to a great extent the damage caused by floods. Improved data collection may also play a role. The total surface area of recently flooded areas amounts to approximately 5 % of Flanders. Based on models, it has been determined that - with the present climate and soil use - 7.5 % of Flanders has a low probability of flooding. The probability is high for slightly more than 2 %. The annual average damage by floods for the whole of Flanders is currently estimated at over 50 million euros.

The expected sea level rise and the increased storm surge will make floods at the coast more likely. This also applies along the banks of rivers connected to the North Sea (*e.g.* the Scheldt). Especially with strong north-westerly wind, an extreme storm surge may occur in combination with heavy rainfall inland, which may result in even greater increases in water levels and flooding flow rates. Higher water levels may not only lead to floods from rivers, but may also limit the drainage capacities of polders and water reservoirs. The analyses of floods of unnavigable watercourses showed that, in the case of a moderate ('medium') climate scenario, the most important effect of climate change is that it increases the probability of flooding over time, whilst socio-economic growth further exacerbates the effects of a flood. Various policy strategies can, however, eliminate the increases in the risks in part or in whole and even lead to significantly lower risks than those in 2010. All of this demonstrates the importance of the preparation and implementation of the Master Plan for Coastal Safety, the Sigma Plan and the flood risk management plans.

The flooding probability and risks for Flanders were only recently determined, so that no reports are available on past evolutions. Yet the analysis of high water discharges doesindicate that, at the regional level, highly exceptional high water discharges, and therefore also the associated risk of flooding, have become slightly less exceptional over the last two decades. To what extent this is due to climate change or other factors (*e.g.* changes in land use, paving) is not yet clear. Moreover, the available datasets are still too recent to allow a distinction to be made between multi-annual climate fluctuations and actual climate trends over a much longer term. At the local level, the trends appear to differ considerably, which would suggest that local factors may play an even bigger role and/or that incidental fluctuations mask the trends.

Previous extrapolations of climate scenarios indicate a future decrease in low water discharges for all studied river basins in Flanders. One of the main conclusions of the Environment Outlook 2030 was therefore that the probability of severe water shortage will increase in the future. The new climate scenarios, however, expect higher evapotranspiration during the summer months, which could lead to even lower low water flow rates. From the analysis of seven monitoring stations on larger, unnavigable watercourses, however, it could not be concluded that Flanders is currently already experiencing an overall increase in the low water problem.

The climate scenarios for the summer period indicate a strong increase in extreme short rainfall events, especially in the case of the high climate scenario. This will place additional burdens on sewerage and other drainage systems in the future. In addition to the larger dimensioning of sewers, buffer basins and other water reservoirs, it is important to limit the inflow of rainwater into sewers, for example by means of water-permeable paving and infiltration facilities. Better alignment between urban water management, urban design, land and green area management and spatial planning, is also required.

The summer of 2003 was probably the hottest summer in Europe since the year 1500, resulting in nearly 72,000 additional deaths. In Belgium, an excess mortality of approximately 2,000 was recorded. Also in

1994, 2006 and 2010 almost 1,000 people or more died because of extreme temperatures in our country. The efficiency of awareness raising and monitoring systems in bringing down the number of victims was illustrated in 2013 when no significant increase in the number of deaths was recorded during a prolonged period of hot weather.

Not only pollutant emissions, but also changes in climate have an impact on air quality. The formation of ozone is influenced by the temperature and the ozone concentrations during heat waves are generally high. The concentration of particulate matter depends on the mixing of the various air layers in the atmosphere and will therefore increase in conditions of still air and during periods where vertical mixing in the atmosphere is limited. The concentration of particulate matter in ambient air is also influenced by the precipitation frequency and intensity. The transport of other pollutants is influenced by the prevailing wind conditions. A comparison between 2007 (approach for present climate) and 2003 (approach for future climate) has already shown for Flanders that if climate change persists, greater emission reductions will be needed if the objectives for ozone peak concentrations and particulate matter are to be achieved. Recently it was also demonstrated that the expected climate change under a moderate global greenhouse gas scenario will cause the daily average ozone concentrations in our country to increase by up to 10 % by 2030. The greatest increases are expected to occur in the vicinity of major roads and in the centres of the cities.

Tipping points

Climate scenarios are based on slow evolutions of, amongst others, temperature and precipitation, which follow the rising greenhouse gas concentrations with a certain delay. In addition to these slow evolutions, climate change may also lead to more abrupt changes. Various elements of the climate system react disproportionately strong to disruptions. Mechanisms are often triggered as soon as certain threshold values (‘tipping points’) are exceeded and self-reinforcing mechanisms are at play that involve a transition from one, more or less stable, state to another state. Once a snow or ice mass, for example, begins to melt, less sunlight will be reflected and dark surfaces will warm up even more, resulting in increased warming up and melting down. Such climate transitions are only to a limited extent accounted for in today’s climate scenarios. As a result, the risks of climate change are probably still being underestimated.

Of all the climate elements that are relevant for Europe, the Arctic sea ice and the Alpine glaciers are the most vulnerable. The sea ice cover in the Arctic has already been halved since 1950 and is expected to diminish further, with major ecological and geopolitical consequences. The ice volume of the Alpine glaciers is today less than half the volume in 1850. Even a scenario where the increase in global average temperature remains below 2 °C, will lead to the almost total loss of the Alpine glaciers with far-reaching consequences for *e.g.* water availability in summer.

Melting down of the Greenland and West Antarctic ice sheets may lead to a significant rise in the seawater level. Yet for the Greenland ice sheet to melt down completely, the temperature would have to exceed the threshold value by a few degrees (an increase by 1 to 4 °C with respect to the pre-industrial age) for a full millennium. Because the climate system is a globally linked system and because globalisation continues to increase, climate changes far outside of Europe may also have effects in Flanders.

Dealing with uncertainties

The climate scenarios span a range that is highly likely to include the future reality, although uncertainties still remain high. The exact likelihood of occurrence of a given climate scenario is, in fact, not known. Moreover, there are known processes and mechanisms that cannot yet be explicitly taken into account (*e.g.* exceedance of tipping points). There are also uncertainties that are not even known to exist. The effects of climate scenarios, however, can effectively be calculated. If a given scenario has major effects, it is important that these are taken into account in policy and management. In doing so, it is necessary to provide for the possibility of making adjustments - at as limited a cost as possible - as climate knowledge develops. Decisions must also be effective and cost efficient, regardless of the precise evolution of the climate.

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INTRODUCTION

‘The Earth is warming up, and this global warming is related to the emission of greenhouse gases of human origin.’ This unambiguous conclusion is central in the fifth assessment report of the Intergovernmental Panel on Climate Change (IPCC). The global warming is clearly apparent from observations of the increase in the average global temperatures of atmosphere and oceans, the widespread melting of snow and ice, and the rise in the average global sea level.

The IPCC was founded in 1988 by the World Meteorological Organisation (WMO) and the United Nations Environment Programme (UNEP). It is an independent body whose mission is to periodically assess scientific knowledge related to climate change. In 1990, the first assessment by the IPCC formed the basis for the Climate Convention of the Earth Summit in Rio de Janeiro (Brazil, 1992). The second scientific final report (Second Assessment Report or SAR, 1995) provided sufficient arguments to justify the addition of a Protocol to the Climate Convention. This Protocol was approved at the Kyoto (Japan) Climate Conference in December 1997 and was the first agreement to impose binding obligations for the reduction of greenhouse gas emissions. It was followed in 2001 by the Third Assessment Report or TAR and in 2007 by the Fourth Assessment Report or AR4. From report to report, evidence of human influence on global warming continued to mount.

After AR4, the IPCC launched the development of a new set of scenarios for the potential increase in the concentration of greenhouse gases in the atmosphere. Unlike previous scenarios in which no climate policy was assumed, the new Representative Concentration Pathways or RCP scenarios focus on the effects of different levels of policy ambitions. The bandwidth considered by these scenarios varies from scenarios with limited measures and limited technological breakthroughs to scenarios with a very ambitious climate policy. The RCP scenarios are at the basis of the latest, fifth IPCC report, which was published in different issues in 2013 and 2014 (Fifth Assessment Report or AR5).

In 2009, the Environment Outlook 2030 of the Flanders Environment Agency (VMM) brought together the existing scientific knowledge on climate change in Flanders and its potential effects until 2100 (Brouwers *et al.*, 2009). The climate scenarios derived in this document were still based on the old SRES scenarios (Special Report on Emissions Scenarios, 2000) of the IPCC. Now that the RCP scenarios have already for some years been available for extrapolation with various climate models, the Environmental Reporting unit (MIRA) of VMM, together with colleagues from the Flood Management unit of VMM and scientists from KU Leuven, VITO and RMI, have bundled the latest scientific insights into climate change in Flanders, in this MIRA Climate Report 2015. In addition to the new RCP scenarios, this report also makes use of the capabilities to extrapolate climate scenarios with high temporal and spatial resolution for Flanders (and Belgium). This enables the set of climate scenarios for Belgium and Flanders to be updated and refined and to formulate answers to questions about spatial differences and about changes in the occurrence of extreme weather conditions. In this way, the VMM also deepens the knowledge of one of the six megatrends identified for the environment in Flanders, in the ‘MIRA Future Outlook Report 2014 – Megatrends: far-reaching, but also out of reach?’ (VMM, 2014a). In that report, megatrends were considered to be autonomous global developments that need to be taken into account if Flanders wants to have an adequate, resilient and successful (environmental) policy. Megatrends are already apparent, long-term change processes with a very broad scope and decisive, far-reaching and critical implications.

The MIRA Climate Report 2015 brings together and interprets existing knowledge for the purpose of achieving the broadest possible flow of climate knowledge in Flanders. In addition to the annually updated climate indicators on the MIRA website (www.environmentflanders.be), this report is mainly based on two study reports that were carried out on behalf of MIRA between the second half of 2013 and the beginning of 2015:

- van Lipzig N.P.M. & Willems P. (2015), *Actualisatie en verfijning klimaatscenario's tot 2100 voor Vlaanderen*, study commissioned by Flanders Environment Agency, MIRA, MIRA/2015/01, KU Leuven in collaboration with RMI. Available at www.milieurapport.be.
- De Ridder K., Maiheu B., Wouters H. & van Lipzig N. (2015), *Indicatoren van het stedelijk hitte-eiland in Vlaanderen*, study commissioned by the Flanders Environment Agency, MIRA, MIRA/2015/05, VITO and KU Leuven. Available at www.milieurapport.be.

For more information, we refer the reader to the extensive reference lists in both reports.

In Chapter 1, we discuss the mechanism of an intensified greenhouse effect. Chapter 2 zooms in on climate change as it is already being observed in Flanders and Belgium. Chapter 3 presents the set of updated and refined climate scenarios. For each of the various climate parameters (temperature, precipitation, wind and sea climate), these scenarios provide an insight into the possible evolution of both averages and extremes (including heat and cold waves, periods of drought, heavy precipitation and storm surge) throughout the coming decades. The time horizon used for this purpose covers both the medium (2030/2050) and long (2100) term. This chapter also dwells on possible differences in climatic changes within Flanders and Belgium. Changes in the climate have an important impact on society. This aspect is addressed in Chapter 4. When climate change also results in certain tipping points being exceeded, this may also trigger self-reinforcing mechanisms that could have an even far greater impact. These and other climate aspects that are difficult to quantify are addressed in Chapter 5, together with a number of recommendations for policy makers for dealing with uncertainties. Finally, Chapter 6 summarises the information sources of the MIRA Climate Report 2015.

1 INTENSIFICATION OF THE NATURAL GREENHOUSE EFFECT

1 INTENSIFICATION OF THE NATURAL GREENHOUSE EFFECT[1]

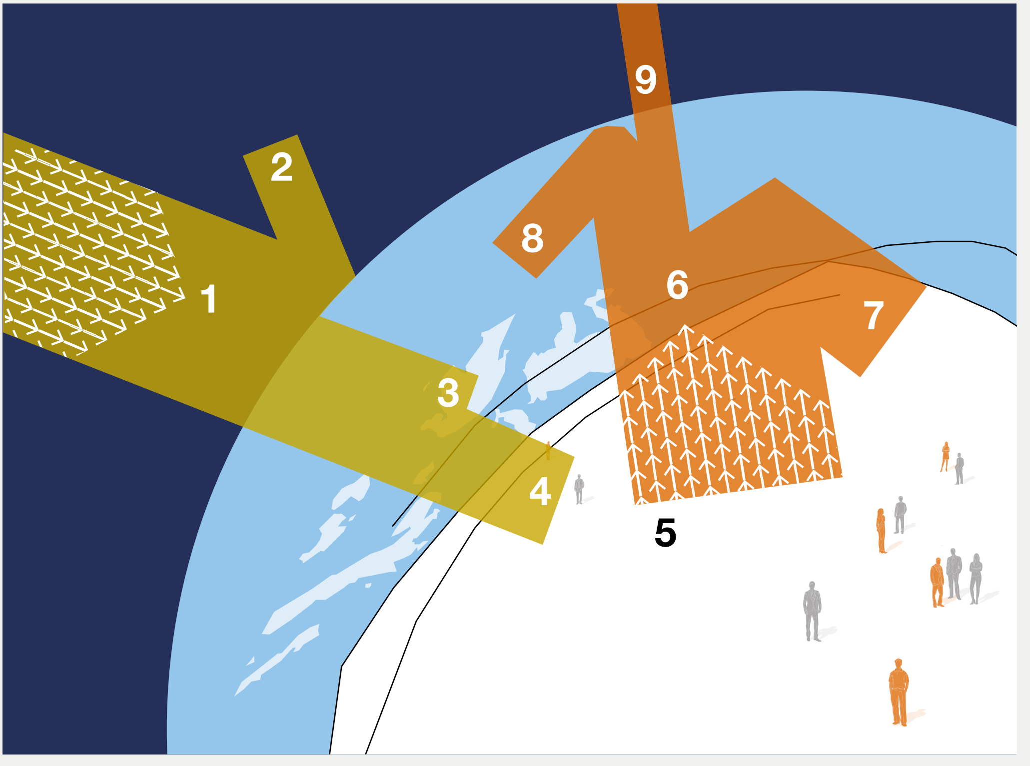
1.1 Mechanisms

Certain gases in the atmosphere allow incoming solar radiation to pass, but absorb the thermal infrared radiation emitted by the earth's warmed-up surface. This natural phenomenon is known as the greenhouse effect. Life on Earth owes its existence to this greenhouse effect: otherwise, the average temperature on Earth would be -18 °C, instead of the present +15 °C. The main natural greenhouse gases are water vapour (H_2O), carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). The concentration of these gases in the atmosphere is the result of numerous dynamic processes and cycles that interact with each other.

The earth's heat balance is schematically represented in Figure 1. Incoming solar radiation is made up to large extent of visible light (wavelength 400 to 700 nm) and ultraviolet light (wavelength 10 to 400 nm). Slightly less than half of the solar radiation is in the near-infrared part of the spectrum (wavelength 700 to 2,500 nm). The average amount of energy that is thus irradiated onto the earth's surface is approximately 340 W/m^2. Of this amount, 51 % is absorbed by the earth's surface (both by land and by oceans). The remainder has already been reflected by the atmosphere, clouds and the earth's surface (30 % combined) or absorbed by the atmosphere and clouds (19 % combined). The absorption of incident sunlight causes the earth's surface to warm up, so that the Earth itself exchanges energy with the atmosphere. This is done by means of radiation, transport of heat by turbulent mixing, and evaporation. Due to its characteristic temperature, the earth's surface emits infra-red radiation (wavelength 2,500 to 1,000,000 nm) that has a longer wavelength than the incoming solar radiation. Greenhouse gases allow the incoming short-wave radiation to pass almost completely, but absorb virtually all of the infra-red radiation emitted by the Earth. These molecules then emit infra-red radiation themselves in all directions, *i.e.* both to the earth's surface and into space. The greenhouse gases thus only impede the release of heat, but they do not stop it, as half of their own radiation is directed into space. The greenhouse effect causes the earth's surface temperature to rise (from -18 °C to +15 °C) until the moment that the heat radiation at the top of the absorbing layers into space is in balance with the incoming solar radiation at that level. The more greenhouse gases in the atmosphere, the higher the temperature at the earth's surface at which this balance is established.

1 This chapter is mainly based on the MIRA Themabeschrijving Klimaatverandering and some environmental indicators, available at http://www.milieurapport.be/nl/feitencijfers/milieuthemas/klimaatverandering/. It also contains the various (scientific) sources on which this material is based. Other sources are cited in the text.

Figure 1: *The role of greenhouse gases in the earth's radiation and heat balance*



1 = incident solar radiation;
2 = reflection of a portion of the radiation by the atmosphere and clouds;
3 = absorption of solar radiation, with partial warming-up of the atmosphere;
4 = rays that reach the earth's surface;
5 = the Earth absorbs the radiation, warms up and in turn emits infra-red radiation;
6 = this infra-red radiation is absorbed by the greenhouse gases;
7 = a portion of that radiation is reflected by the greenhouse gases and absorbed by higher layers of the atmosphere (8);
9 = the rest disappears into space.

Source: www.klimaat.be

The climate on Earth is influenced by each factor that affects:

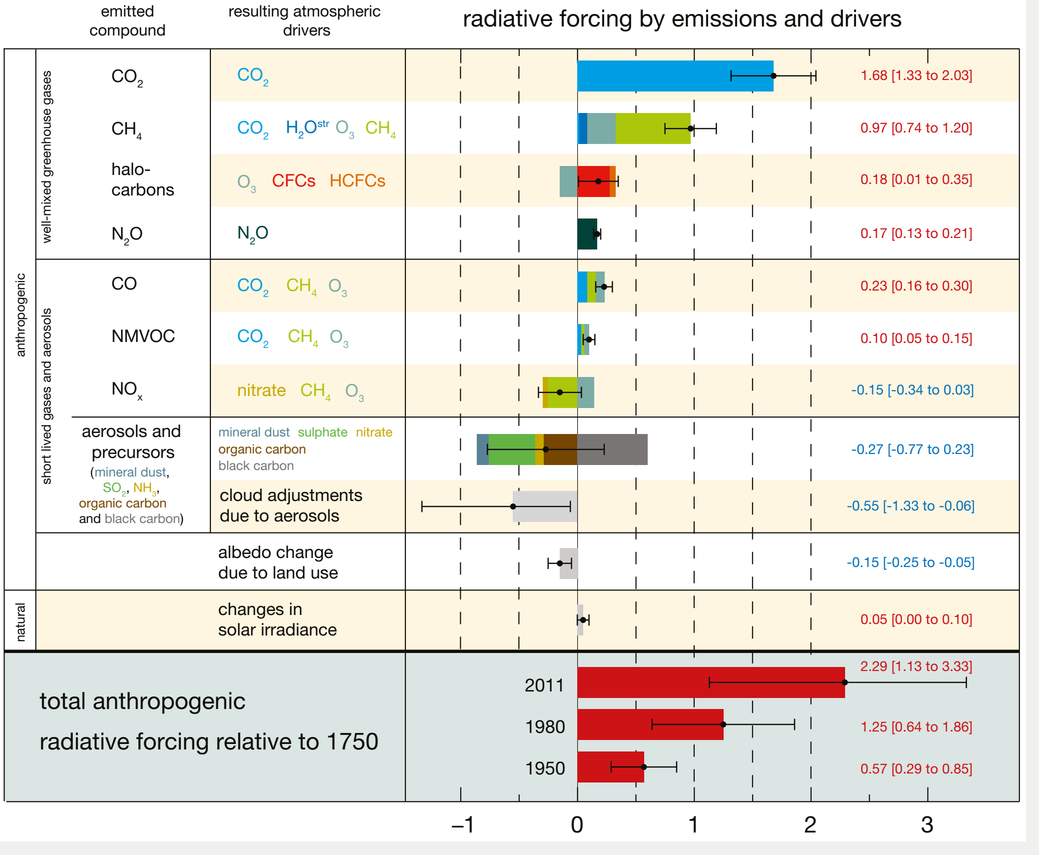
- the amount of absorbed solar radiation: *e.g.* the eleven-year solar cycle, variations in the earth's orbit around the Sun;
- the amount of heat absorbed and emitted by the Earth: *e.g.* an increase in the concentrations of greenhouse gases or the change in the concentration in relation to altitude (*e.g.* for water vapour), the presence of aerosols (volcanic eruptions, industrial emissions of sulphur oxide);
- the physical dispersion patterns across the earth's surface: *e.g.* a change in the present temperature distribution in the atmosphere and the oceans may alter weather patterns and ocean currents.

As a result of the interaction of these numerous factors, the climate is characterised by a great natural variability. However, the AR5 of the IPCC shows that the increase of the atmospheric CO_2 concentration since the industrial revolution (after 1750) is by far the major cause of global warming. The change in solar and volcanic activity only contributes to a limited extent to global warming in the industrial era. The disturbance of the earth's heat balance by man or the total radiative forcing of anthropogenic origin since 1750 (see paragraph 1.2.4) has been positive (2.29 W/m²), and has led to a net accumulation of energy in the climate system (Figure 2). The radiative forcing that has been correlated with an increase in the concentration of greenhouse gases (mainly CO_2, CH_4 and N_2O) since 1750, is in the order of 3 W/m². It is offset in part by the radiation effect of aerosols (in the order of -0.8 W/m²). Stratospheric aerosols (associated with volcanic activity) and variations in solar activity only contribute to a minor extent to the important radiation effect since the beginning of the industrial revolution (with the exception of a few short periods following major volcanic eruptions).

Anthropogenic emissions have led to an increased concentration of greenhouse gases in the atmosphere. This increased concentration intensifies the natural greenhouse effect and thus leads to an increase in the average temperature on Earth and global climate change. Because most greenhouse gases remain in the atmosphere for several decades or (much) longer and it also takes a long time before a new energetic balance is established, the temperature will continue to rise for some time after the concentration of greenhouse gas has stabilised. However, the lower the level at which concentrations are stabilised, the lower the eventual temperature increase.

Such a temperature increase may lead to a shift of the earth's climate zones and may have a very important impact on the frequency and severity of extreme phenomena in certain regions, such as heat waves and prolonged droughts. The expansion of the warming seawater and the (partial) melting of ice caps on land will cause an increase in the sea level with a greater risk of flooding in lower-lying areas. Higher temperatures will lead to an increased worldwide incidence of diseases such as malaria and yellow fever. These large-scale changes interact in the long term with natural variations on time scales from a few days to a few decades.

***Figure 2:** Global average radiative forcing in 2011 compared with 1750*



Source: IPCC (2013) AR5-WG1-Summary for policy makers (see http://ipcc.ch/pdf/assessment-report/ar5/wg1/WGIAR5_SPM_brochure_en.pdf)

Characteristics of the disruptive process of climate change include the global nature, the uncertainties associated with the complexity of the process and the feedback mechanisms that can reinforce the processes (*e.g.* higher temperatures lead to increased water vapour in the atmosphere, thereby intensifying the greenhouse effect, which in turn leads to even higher temperatures) or slow them down. Other characteristics of this disruptive process are: a potential for major irreversible damage, a long lifetime of the gases in the atmosphere, a significant time lag between emissions and effects (due to, amongst others, the buffer effect of the oceans) and large regional variations in causes and especially effects.

1.2 Greenhouse gas concentrations in the atmosphere are increasing

1.2.1 Human influence

Especially since the Industrial Revolution (after 1750) humans have progressively introduced increasingly greater quantities of greenhouse gases into the atmosphere through the combustion of fossil fuels (CO_2 and N_2O), cattle breeding (CH_4 and N_2O), waste processing (CH_4) and chemical processes in industry (N_2O). As a result of worldwide deforestation and the associated combustion, large carbon reservoirs in wood and soil are also being converted to greenhouse gases (mainly CO_2) that are released into the atmosphere. In addition, new substances such as chlorofluorocarbons (CFCs), their substitutes such as soft hydrogenated chlorofluorocarbons (HCFCs) and hydrofluorocarbons (HFCs and PFCs), used as coolant and propellant, and sulphur hexafluoride (SF_6) contribute to the greenhouse effect. SF_6 is found in certain electrical switching systems and in sound-insulating double glazing.

The IPCC attributes, with more than 95 % certainty, the increasing atmospheric concentration of greenhouse gases in the 20^{th} and in the beginning of the 21^{st} century to human activities. While the majority of greenhouse gases are emitted in industrialised (including Europe, US, Canada) and emerging countries (China, India), the concentration of greenhouse gases is virtually equal throughout the world. The reason for this is that their lifetime in the atmosphere is long enough to obtain homogeneous mixing. There is no spatial relationship between emissions and effects.

Despite the global mechanism, the expected climatic effects vary considerably between geographic regions (see also Chapter 2 and further chapters) and their impact is dependent on local vulnerability. Moreover, countries that currently emit little greenhouse gases are often the most vulnerable to the effects of climate change.

1.2.2 Commitment to keep the temperature rise below 2 ˚C

Both at global level (Copenhagen Accord of December 2009 in the framework of the United Nations Climate Change Conference or UNFCCC, endorsed at the Climate Summit in Cancun end 2010) and within the EU (*e.g.* decision of the Environment Council of October 2008), policy makers agree that the global average temperature increase must be limited in the longer term to 2 ˚C above the pre-industrial level (reference year 1750). Flanders, via its Flemish Climate Policy Plan 2013-2020, is also committed to the objective of not increasing the global average temperature by more than 2 ˚C by 2050 with respect to pre-industrial times (VKP, 2013). To this end, a decrease in the emissions of greenhouse gases by developed countries from 25 to 40 % by 2020 and from 80 to 90 % by 2050, with respect to 1990, is required. At the end of 2015 a new global climate agreement will be negotiated in Paris at the 21^{st} climate conference of United Nations (COP-21). In the run-up, the European Council reached an agreement in October 2014 on a binding internal European reduction target for greenhouse gas emissions of at least 40 % by 2030 with respect to 1990. This reduction target is a tightening with regard to the target by 2020 (-20 % with respect to 1990), especially because all reductions after 2020 will have to be achieved within the EU itself.

To keep the likelihood of a global temperature increase beyond 2 °C at 50 % or less, the CO_2 concentration must stabilise below 400 ppm_v, and the concentration of all Kyoto gases combined (CO_2, CH_4, N_2O, HFCs, PFCs and SF_6) must remain below 480 ppm_v. For all greenhouse gases combined (with in addition to the Kyoto gases, also CFCs, HCFCs, ozone and aerosols), a ceiling of 450 ppm_v is put forward. This is less than the 480 ppm_v for Kyoto gases because most aerosols do not have a warming but a cooling effect. To allow these ceilings to be complied with, global emissions of greenhouse gases must be reversed from an upward to a downward trend already within two decades.

1.2.3 Concentration of most greenhouse gases continues to increase

Of all carbon dioxide (CO_2) emitted by human activities, about one quarter is absorbed by the oceans and another quarter by the biosphere (including plants). The other half of the CO_2 emissions remains in the atmosphere.

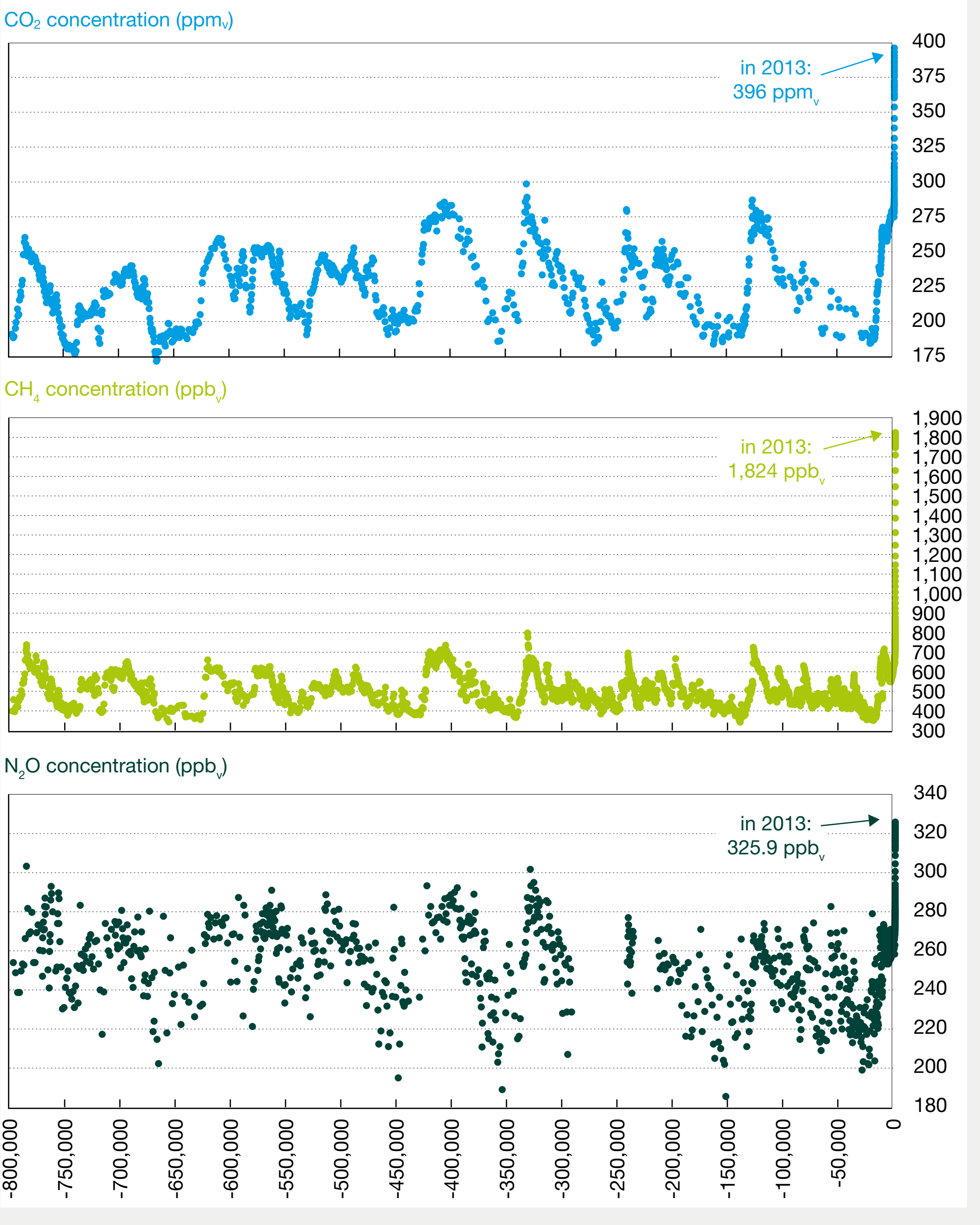
In 2013 the average atmospheric CO_2 concentration was 396 ppm_v, a 42 % increase compared with the pre-industrial concentration of 278 ppm. In that year the concentration still increased by 2.9 ppm_v, a growth rate that is significantly higher than in the 1990s (on average 1.5 ppm_v/year) and during the past decade (on average 2.0 ppm_v/year). The present CO_2 concentration is the highest of the past 800,000 years (Figure 3, top). Also the present rate of increase is the highest of the past 30 years. At this rate, the annual average CO_2 concentration will exceed the threshold of 400 ppm_v already in 2015 or 2016. This is caused by the growing emissions at global level. Moreover, there are indications that also the biosphere on Earth is absorbing increasingly less CO_2.

For methane (CH_4) the atmospheric concentration in 2013 amounted already to 1,824 ppb_v or more than double (+153 %) the value of the pre-industrial period (722 ppb_v) (Figure 3, middle). Between the early 1980s and 2006 the annual increase declined from 16 ppb_v to 0 ppb_v or even a slight decrease in the early 2000s.

In the meantime, the concentrations are increasing again by around 5 ppb_v per year. Causes for this renewed increase are the increased emissions from wetlands (*e.g.* marshes) due to the higher precipitation in the tropics and anthropogenic emission sources in the middle of the northern hemisphere. Atmospheric CH_4 concentration are higher today than at any time during the past 800,000 years. Some 60 % of the methane emissions, including the use of fossil fuels, cattle breeding, rice production and landfills, are of anthropogenic origin.

In 2013, the atmospheric concentration of nitrous oxide (N_2O) was 326 ppb_v, which is 21 % more than the concentration during the pre-industrial period (270 ppb_v) and the highest level in at least a thousand years (Figure 3, bottom). Only 40 % of global nitrous oxide emissions is of anthropogenic origin, mainly through the use of fertilisers, and also in industrial processes and in the combustion of biomass. The increase in the last year (0.8 ppb_v) was in line with the average of the last 10 years (+0.82 ppb_v/year).

***Figure 3:** Variation in the atmospheric CO_2, CH_4 and N_2O concentration between 800,000 BC and 2013*



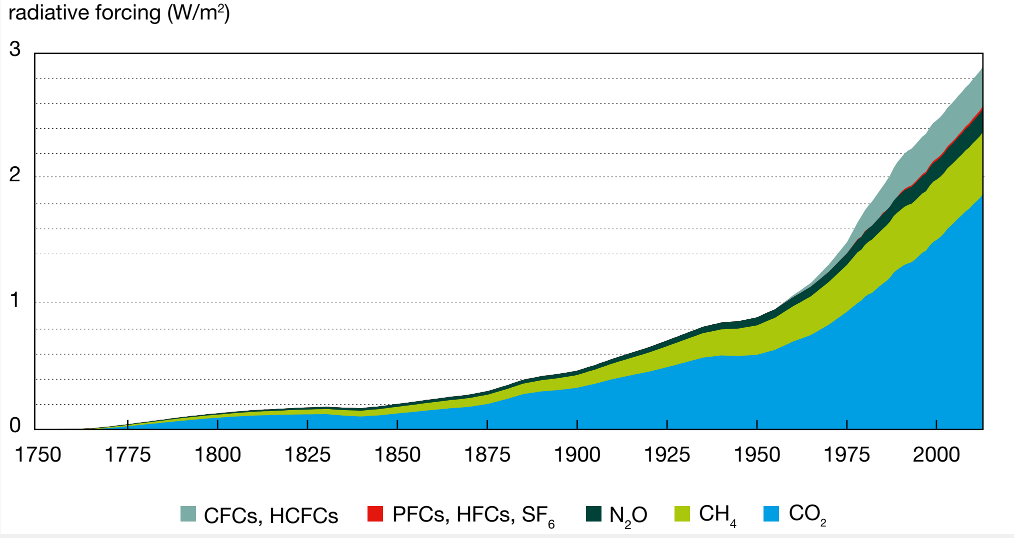
Source: MIRA based on Lüthi *et al.* (2008), Loulergue *et al.* (2008), Schilt *et al.* (2010), EEA (2004) and WMO (2014a)

1.2.4 Disturbance of heat balance continues to increase

Changes in concentrations of greenhouse gases and aerosols lead to a disturbance of the earth's radiation balance. This disturbance is called radiative forcing, with reference to the anthropogenic origin (forcing house) and the radiation effect. Radiative forcing can be positive (warming of the bottom atmospheric layer) or negative (cooling).

Figure 4 gives an overview of the increase in the atmospheric concentration of the main long-lived greenhouse gases since 1750, recalculated to the corresponding radiative forcing in W/m². It shows a clear acceleration since the beginning of the 1950s when energy use increased significantly and CFCs and related gases began to be used (among other things, as coolant and propellant). The figure demonstrates that CO_2 has the greatest contribution to global warming, but that the contribution of the other gases is not negligible either. The three main greenhouse gases together account for 88 % of the increase in radiative forcing since the beginning of industrialisation (1750): 65 % for CO_2, 17 % for CH_4 and 6 % for N_2O. Even after 1990, the reference year for the Kyoto Protocol of 1997, the combined warming effect of the main greenhouse gases in our atmosphere continued to increase by 34 %. CO_2 accounts for 80 % of this increase.

Figure 4: *Increase in the radiative forcing of greenhouse gases in the global atmosphere since 1750 (1750-2013)*



Source: MIRA based on NOAA (2014), IPCC (2014) and EEA (2015)

In addition to the gases whose emissions are regulated by the Kyoto Protocol (CO_2, CH_4, N_2O, SF_6, PFCs and HFCs), CFCs and HCFCs also play a non-negligible role in the atmosphere's heat balance. CFC and HCFC emissions were already curtailed in the Montreal Protocol of 1987 because they also contribute to the depletion of the stratospheric ozone layer. The effect of emission reduction measures has in the meantime resulted in a reduction in the concentration increase and for some gases even already in a concentration decrease. CFC-11 and CFC-12 are the two most important gases from this group, and their concentrations have been declining since the early 1990s and 2005 respectively. The concentrations of HCFCs and HFCs, by contrast, are increasing rapidly, even if their share in the total radiative forcing still remains limited.

Conversion of the radiative forcing in Figure 4 to CO_2-equivalent (CO_2-eq) shows that the concentration of the Kyoto gases has evolved from 396 ppm_v CO_2-eq to 451 ppm_v CO_2-eq, between 1990 and 2013. This means that in 23 years already two-thirds of the margin to the ceiling of 480 ppm_v CO_2-eq has been used up.

In addition to the above-mentioned long-lived greenhouse gases, other gases also play a role in the heat balance of our atmosphere:

- tropospheric ozone and aerosols: ozone intensifies the greenhouse effect, whereas most aerosols have a cooling effect. Due to the air quality policy, independent from the climate policy, it is to be expected that the concentration of aerosols in the ambient air will decrease, so that their cooling effect will diminish. Compared with the substances falling under the Kyoto and Montreal Protocols, ozone and aerosols have a very short lifetime in the atmosphere (often only a few days or weeks). Their concentrations globally exhibit great differences and their average concentrations and effect on the earth's radiation balance can be only determined with great uncertainty. That is why they are not included in Figure 4;
- water vapour: this gas actually has the greatest contribution to the natural greenhouse effect, but unlike the other greenhouse gases the direct anthropogenic influence on its concentration is minimal and the lifetime of water molecules in the atmosphere is much shorter than that of the other ('long-lived') greenhouse gases. That is why water (vapour) is not considered in the monitoring of radiative forcing.

2 ALREADY OBSERVED CLIMATE CHANGE

2 ALREADY OBSERVED CLIMATE CHANGE[2]

An increased concentration of greenhouse gases in the atmosphere leads to an increase in the average temperature on Earth, causing a shift of the climatic belts and changes in extreme weather events. We will examine to what extent various climate indicators for Flanders and Belgium have already been subject to change, and assess the curve of these indicators against developments within Europe and worldwide.

In this chapter, the available datasets for a large number of indicators were subjected to a statistical analysis by MIRA. Where statistically significant trends or differences are found, the related statements have a confidence level of at least 95 %. Where possible, the trend line is determined using a method that does not impose any assumptions on the shape of the trend line. The result can therefore be both a non-linear and a linear trend line. In addition, the 95 % confidence interval for the location of the trend line is represented. The analysis method used also provides information about the speed of the change and the differences between the last measurement and the previous measurements. Where this method cannot be applied, a method based on linear regression is used.

2.1 Temperature

2.1.1 Annual average temperature

Average temperature rise may be maximum 2 °C

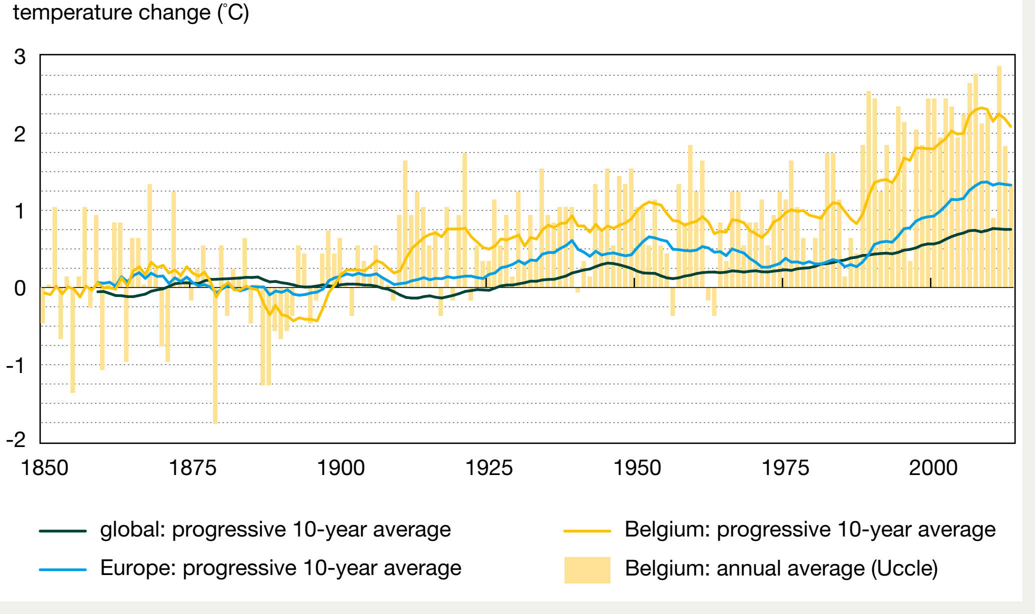
The United Nations Framework Convention on Climate Change (UNFCCC) of 1992 states that the concentration of greenhouse gases in the atmosphere should be stabilised at a level that would prevent dangerous human disturbance of the climate system. This should be achieved within a time frame that allows ecosystems to adapt naturally to climate change, to ensure that food production is not threatened, and to enable economic development to proceed in a sustainable manner. In the EU, it was agreed in 2008 that, to this end, the global annual average temperature is allowed to increase by no more than 2 °C compared to the pre-industrial level. Since the end of 2010, the countries under the United Nations Framework Convention on Climate Change have also adopted the stabilisation target of 2 °C. Because (certainly within Europe) the average annual temperatures in the pre-industrial period 1750-1799 were very similar to those in the period 1850-1899 and in this last period measurements for a lot more locations are available, 1850-1899 is generally used as the reference period for assessment against the 2 °C target.

2 This chapter is mainly based on the MIRA indicators of the environmental theme Climate Change and some environmental indicators, available at http://www.milieurapport.be/nl/feitencijfers/milieuthemas/klimaatverandering/. Paragraph 2.1.4 is based completely on De Ridder *et al.* (2015). Other sources are cited in the text.

Human activity drives up global temperature

The average global surface temperature on Earth increased by almost 0.8 °C between 1850 and 2013 (Figure 5). This means that already more than one-third of the margin to the stabilisation target of 2 °C has been used up. Despite a few short periods of cooling (end 19th century, 1920s and 1950s), the annual average temperature on Earth has increased significantly over the last 140 years. This increase is unusual in terms of both size and speed, and far exceeds the natural climatic variations of the last thousand years. The last three decades were warmer than all previous decades since 1850. Moreover, the northern hemisphere appears to warm up more rapidly than the southern hemisphere. A provisional analysis of the most recent measurement data further indicates that the global temperature increased even further in 2014, and that with an annual average temperature of 14.57 °C, 2014 was the warmest year since the beginning of the measurements (WMO, 2015).

Figure 5: *Deviation of the annual average temperature in Belgium, Europe and worldwide (1850-2013)*



As reference period for assessment against the 2 °C target, the measurements in the period 1850-1899 are used. The temperature change is expressed as 1) the deviation of the average annual temperature with regard to the average temperature during the reference period 1850-1899, 2) the progressive ten-year average of the deviation with respect to the same reference.

Source: MIRA based on RMI, EEA and UK Met Office Hadley Centre and Climate Research Unit

Especially since the 1970s the temperature has risen increasingly to a level of 0.24 °C per decade. During the last 10 to 15 years, however, the earth's surface has warmed less rapidly. This reduction in the recent temperature increase is attributed almost proportionately to natural causes (more volcanic eruptions and a period of reduced solar activity) and to a cooling contribution by the internal variability in the earth's climate system (redistribution of heat in deeper ocean layers). The annual average temperature on Earth nevertheless continues to rise, so that the 29 warmest years since 1850 all fall in the period from 1980.

The IPCC attributes the increase in global temperature in the last decades mainly to anthropogenic activities whereby the emission of greenhouse gases has led to an increase in the concentration of greenhouse gases in the atmosphere. Also natural factors such as the change in sun and volcano activity influence the annual average temperature on Earth, but these factors cannot account for the substantial warming of the last 50 years.

Warming in Europe is even greater

Above the European land surface, the temperature has increased even more strongly than the global average: an increase by 1.3 °C as compared to the pre-industrial reference (Figure 5).

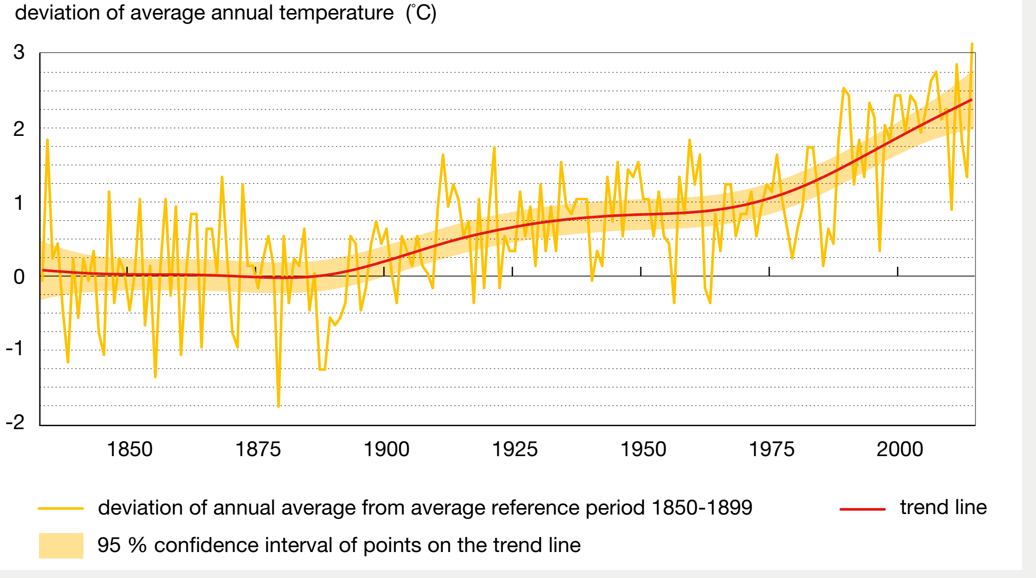
Until now, 2007 and 2008 went on record as the warmest and second warmest years, respectively, since 1850. However for 2014, the first analyses for the European land surface suggest an absolute temperature record with an annual average of approximately 11.22 °C (Photiadou *et al.*, 2015). 2012 and 2013 fall just outside the top ten of warmest years on the European continent. And the eighteen warmest years since 1850 all fall within the period 1989-2013.

Belgium (Uccle) is now almost 2.4 °C warmer than in the pre-industrial period

In Belgium too, the measurements show a clear upward trend (Figure 5). The statistical analysis of the annual average temperature in Uccle (Figure 6) indicates a significant rise in temperature since the end of the 19th century. Halfway the 20th century, the increase almost stopped, but since the 1960s the temperature began to rise increasingly faster, up to +0.4 °C per decade. Since the early 1990s the speed of the increase has stagnated: the trend line of the annual average temperature continues to increase at the same rate of almost +0.4 °C per decade. The trend line of the annual average temperature shows that in Uccle it is now on average almost 2.4 °C warmer than in the pre-industrial period (Figure 6).

The eighteen warmest years since the beginning of the measurements in Uccle (1833) all fall in the period 1989-2014. Also, the absolute record year was 2014 with an annual average of 11.9 °C. In Belgium (Uccle), the top three of warmest years is completed by 2011 (11.6 °C) and 2007 (11.5 °C).

Figure 6: *Annual average temperature expressed as deviation from the average in the period 1850-1899 (Uccle, 1833-2014)*



Source: MIRA based on RMI

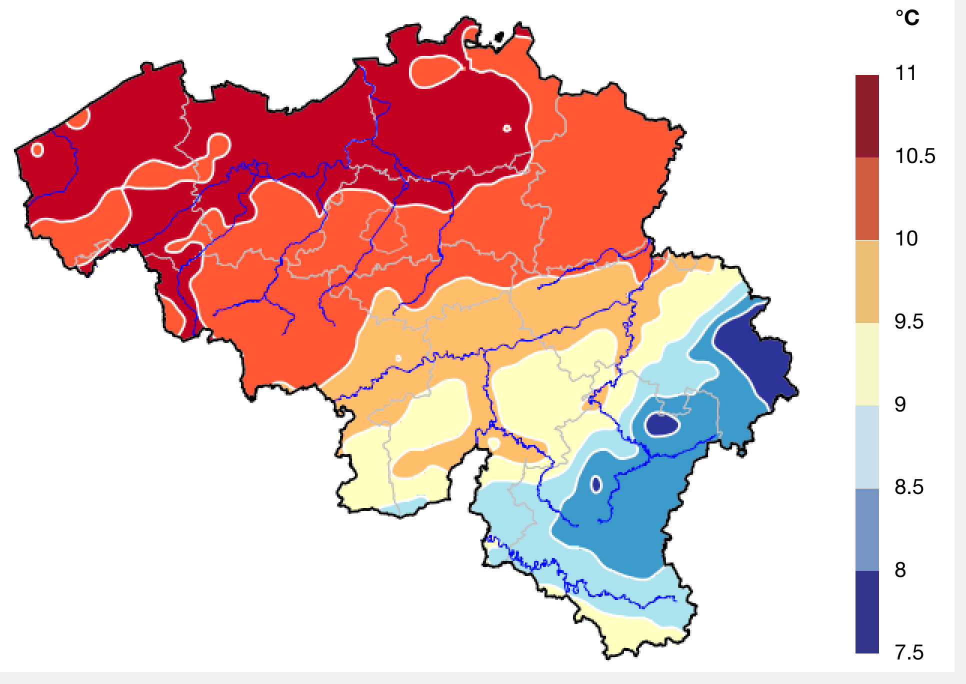
Impact of urbanisation

Analyses by the RMI, KU Leuven and VITO show that the temperature increase in Uccle may, to some extent, also have been caused by the so-called heat island effect (see paragraph 2.1.4). Thus, a quarter of the temperature increase in summer, recorded in Uccle between 1960 and 1999, is attributed to the intensification of the urban effect in the Brussels Capital Region (RMI, 2015a). Urbanisation of the landscape causes a change in the local wind climate and involves the use of materials that better capture the heat, such as concrete and asphalt. This leads, especially at night, to the creation of heat islands, whereby the city cools more slowly than the surrounding countryside.

Spatial patterns

In 2015, the RMI launched a Belgian climate atlas that maps the spatial spread of different meteorological parameters for the present climate. It is based on the 30 year reference period 1981-2010. Figure 7 shows that the annual average temperature increases from the south-east to the north-west of our country, and from 7.5 ˚C on the High Fens and some of the highest points of the Ardennes to over 11 ˚C in the Campines region. The annual average for the Belgian territory as a whole amounted to 9.8 ˚C in the period 1981-2010. The hottest and coldest months were July (17.8 ˚C) and January (2.5 ˚C) respectively. The recorded daily maximum and minimum temperatures invariably exhibit variations of around 4 ˚C within the Belgian territory, regardless of the month or season. Their distribution is mainly determined by two factors: the distance to the sea and the altitude. The temperature of the seawater changes extremely slowly, which mitigates and delays the seasonal variation of the temperature at the Coast: winters are milder and summers cooler than inland. Outside the coastal region, the temperature drops on average by 0.6 °C with every 100 m difference in altitude.

Figure 7: *Spatial pattern in annual average temperature under the present climate (Belgium)*



Here, the present climate has been determined for the reference period 1981-2010.

Source: RMI (2015b)

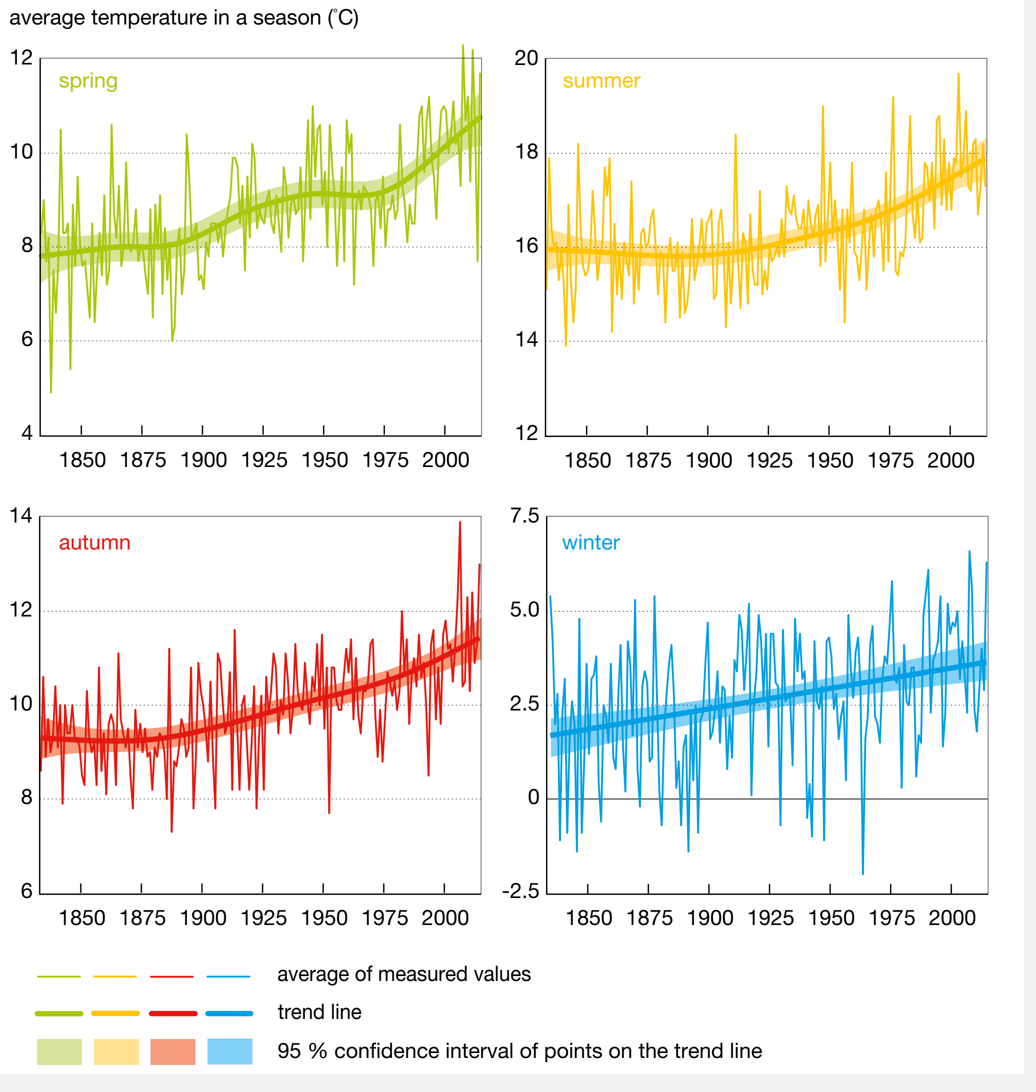
With the exception of the coastal area, the spatial distribution of the number of days with extremely high temperatures (summer and tropical days; see paragraph 2.1.3) closely resembles the pattern in Figure 7. The highest values are recorded in the Campines and the lowest values on the High Fens and some of the highest points of the Ardennes, with also a positive gradient from the Coast to the inland areas in Low and Middle Belgium. The occurrence of days with extremely low temperatures (frost and ice days; see also paragraph 2.1.3) appears to be little influenced by the proximity of the sea and is relatively uniformly spread across Low and Middle Belgium. In High Belgium, by contrast, there are significant variations, with the highest values being recorded on the High Fens (RMI, 2015b).

2.1.2 Seasons

The time series indicate that all seasons are becoming warmer in our country. Figure 8 indicates a significant increase for the four seasons. There are, however, also differences:

- the temperature rise is strongest in spring, and the pattern of the increase is very similar to that of the annual average temperature. The trend line indicates that the spring temperature in 2014 is already 3.0 °C higher than in 1833. Over the last 10 years, the increase was still 0.4 °C;
- in the summer months, the temperature rises more gradually. The summer temperature is 1.9 % higher than at the beginning of the measurements. Also in recent years, the increase remains significant, and the increase rate has in the meantime reached 0.3 °C per decade;
- the spring temperature is now 2.1 °C above the level of 1833, and is currently increasing by almost 0.3 °C per decade. This increase, too, has remained significant during the last years;
- of the four seasons, winter shows the greatest variation in average temperature. Over the years, however, the winter temperature also shows a significant increase: 2.0 °C higher in 2014 than in 1834. The significant increase rate has in the meantime reached 0.1 °C per decade.

Figure 8: *Average temperature in spring (top left), summer (top right), autumn (bottom left) and winter (bottom right) (Uccle, 1833/1834-2014)*



The winter of year X consists of the months of January and February of year X, together with the month of December of year X-1.

Source: MIRA based on RMI

2.1.3 Heat waves and other temperature extremes

The vulnerability of people and nature to climate change is determined not only by changing annual and seasonal averages, but also, and even more so, by changing extremes. Moreover, extreme temperatures also increase exposure to various harmful substances such as tropospheric ozone and particulate matter. That is why we map the temperature extremes by monitoring the number of (extremely) hot and cold days in a year:

- frost days: days on which the minimum temperature is below 0 °C;
- ice days: days on which the maximum temperature is below 0 °C;
- summer days: days on which the maximum temperature is 25 °C or more;
- tropical days: days on which the maximum temperature is 30 °C or more.

Also the occurrence and the characteristics of heat waves are analysed.

Significantly more tropical days

When we look at the occurrence of the number of days with (extremely) high or low temperatures, a significant, linearly increasing trend is found only for the number of tropical days (Figure 9 top left): for the measuring point in Uccle we count, per 17 years, one extra tropical day in a year. The equally increasing trend for the number of summer days in a year is not statistically significant[3] (Figure 9 top right).

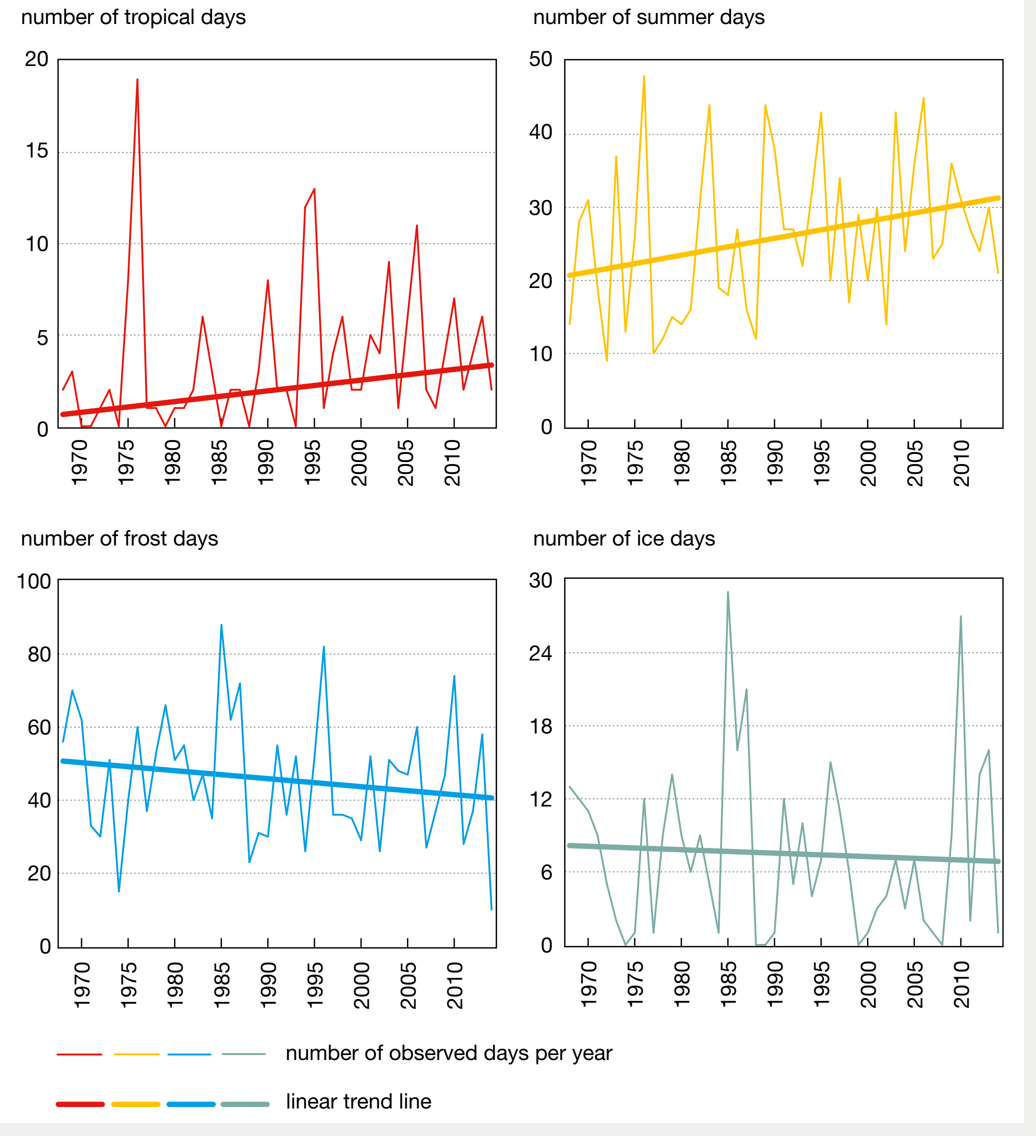
The figures at the bottom left and bottom right indicate a downward trend for the number of frost days and ice days respectively, but this trend too does not appear to be significant.

Heat waves now last twice as long in Western Europe

The most harmful climate effects in Europe are expected to come from the increased frequency and intensity of extreme events such as heat waves. Especially over the last two decades, the summer temperature on land within Europe appears to have increased significantly, as has the number of heat days (maximum temperature >35 °C), tropical nights (minimum temperature >20 °C) and heat waves. Thus, the average length of summer heat waves in Western Europe has doubled and the frequency of heat days even tripled since 1880. Days and longer periods of very low temperatures, by contrast, have become less frequent.

3 MIRA conducted this analysis on the measurements at the reference measuring point in a closed thermometer box. Data for these measurements are available only from 1968. An analysis by the RMI of a longer dataset with values from 1901 in a half-open thermometer shelter also reveals a significant increase for the number of summer days in a year. The same time series reveals also a significant decrease in the number of frost days (RMI, 2015a).

Figure 9: *Number of days with (extremely) high or low temperatures (Uccle, 1968-2014)*



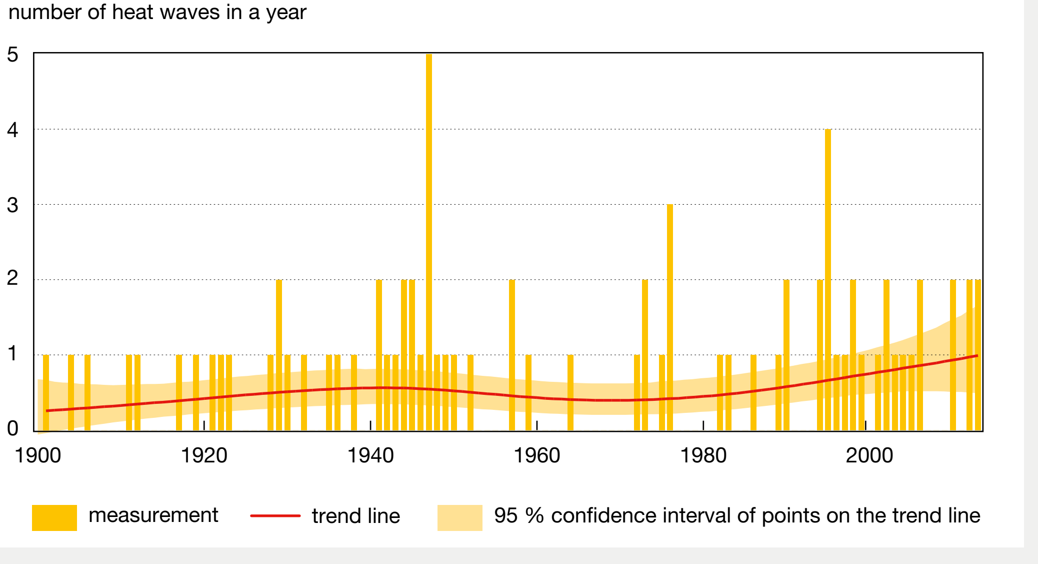
Source: MIRA based on RMI

The wavy pattern of heat waves

The number of heat waves shows great variability between years (Figure 10). A trend analysis produces a wavy pattern with an increase that has been sustained since the 1970s. In 2013, the number of heat waves was significantly higher than in the beginning of the 20th century. The frequency of heat waves has increased from on average one every three years to one per year. There was also a heat wave in 2014.

In addition to the number of heat waves, it is important to consider the length (number of days during heat waves in a year), the weight (the extent to which the temperature exceeds 25 ˚C) and the intensity (ratio between weight and length) of the heat waves. An analysis for the period 1901-2013 also reveals a wavy pattern for these three parameters, with an ascending trend line since the 1970s; however, it is only for the length of heat waves that the value recorded in 2013 is significantly higher than at the beginning of the 20th century (Figure 11): in the last 10 years of the time series (2004-2013) an annual average of almost 12 heat wave days was recorded, compared with a value of not even 3 days in the first 10 years (1901-1910).

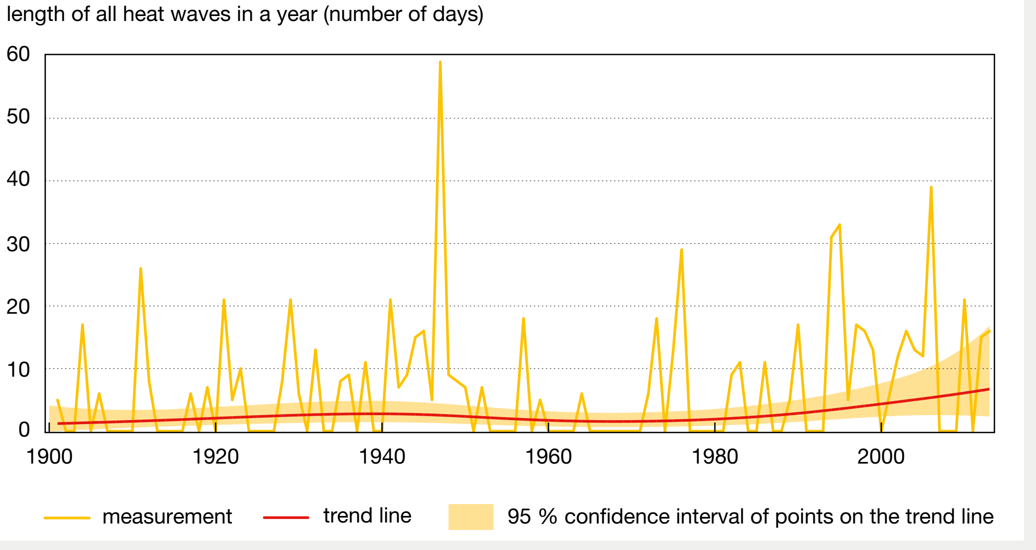
Figure 10: *Number of heat waves per year (Uccle, 1901-2013)*



A 'heat wave' is defined as a period of minimum five consecutive days with a maximum temperature of at least 25 ˚C, where the maximum temperature is greater than or equal to 30 ˚C for at least three days. This indicator has been built up on the basis of measurements in an open thermometer shelter. The closed shelter (which is currently the RMI reference) has only been used in Uccle since 1968.

Source: MIRA based on RMI

Figure 11: *Length of heat waves (Uccle, 1901-2013)*



A 'heat wave' is defined as a period of minimum five consecutive days with a maximum temperature of at least 25 °C, where the maximum temperature is greater than or equal to 30 °C for at least three days. This indicator has been built up on the basis of measurements in an open thermometer shelter. The closed shelter (which is currently the RMI reference) has only been used in Uccle since 1968.

Source: MIRA based on RMI

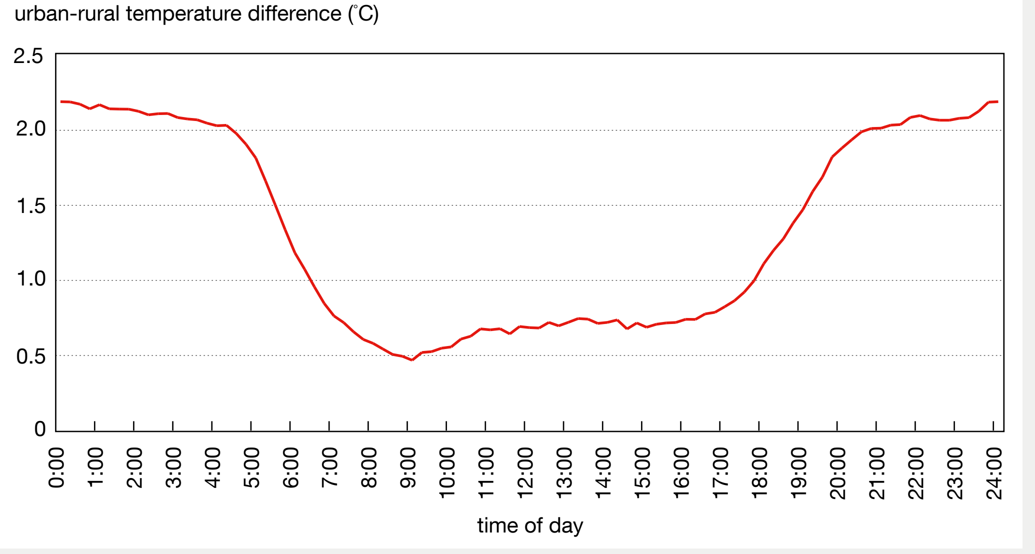
2.1.4 Urban heat island

The temperature in cities is usually higher than in the surrounding rural areas and city dwellers are thus more exposed to heat stress during heat waves. This so-called urban heat island (UHI) effect is further accentuated during heat waves under the influence of atmospheric conditions such as a cloudless sky and low wind speeds that often accompany heat waves. This leads to additional mortality, especially among the elderly and children (see also paragraph 4.1). Furthermore, the urban heat island phenomenon also influences energy use (increase due, among other things, to the use of air conditioning), and promotes algae growth in surface water. In the winter, by contrast, the mortality in cities is lower due to reduced exposure to cold temperatures.

"Hot in the city"

Especially at night, temperatures in cities are higher than in the countryside. On average, this difference amounts to a few °C (Figure 12), but also days with peaks of up to 7 to 8 °C and more are recorded. Heat waves are therefore more frequent and more intense in cities.

Figure 12: *Average daily temperature curve for the difference between city and countryside (Antwerp, April to September 2013)*



Source: VITO in MIRA Study Report 'Indicatoren van het stedelijk hitte-eiland in Vlaanderen' (2015)

The causes of the urban heat island include reduced cooling by evapotranspiration (due to the absence of vegetation), trapping of short- and long-wave radiation between buildings, relatively limited heat exchange between the urban fabric and the atmosphere, high thermal inertia of urban materials, and release of anthropogenic heat (due to, amongst others, building heating, use of air conditioning systems and traffic).

Although the urban heat island phenomenon has been known for more than 180 years, it has only recently gained in importance. This increased attention was the result, on the one hand, of the growth of urban areas and their populations, and, on the other hand, of the expected increase in heat stress due to global climate change.

Moreover, there are indications that health problems are mainly caused by the high minimum temperatures at night. People who have been exposed to heat stress during the day are unable to rest sufficiently at night and thus to recover sufficiently. That is why not only the daily temperature maxima have to be monitored, but also the daily minima which are substantially higher in cities than in rural areas. An analysis of the measurements in Uccle indicated that the number of days – actually nights – on which the minimum temperature does not drop below 15 ˚C, is significantly higher than in the beginning of the 20th century, especially during the last three decades (RMI, 2015a).

Urban heat indicator: heat wave degree days

The urban heat island effect can be translated into figures by means of the indicator 'heat wave degree days', which is calculated for a given year by:

- first determining on which days in the period from April 1 to September 30 of that year a heat wave occurs, based on the definition of the Federal Service of Public Health: "a period of at least three consecutive days with an average minimum temperature (average over the three days and not per day) higher than 18.2 °C and an average maximum temperature higher than 29.6 °C;
- and then, for these days, making the sum of exceedances of the threshold level of 29.6 °C by the daily maximum temperatures, and adding it to the sum of exceedances of the threshold level of 18.2 °C by the daily minimum temperatures.

This indicator thus provides a composite picture of the total duration and the weight of heat waves in a year. The indicator is shown for both an urban and a nearby rural location on a single graph so as to highlight the urban effect (Figure 13).

***Figure 13:** Heat wave degree days (Antwerp, 2012-2014)*

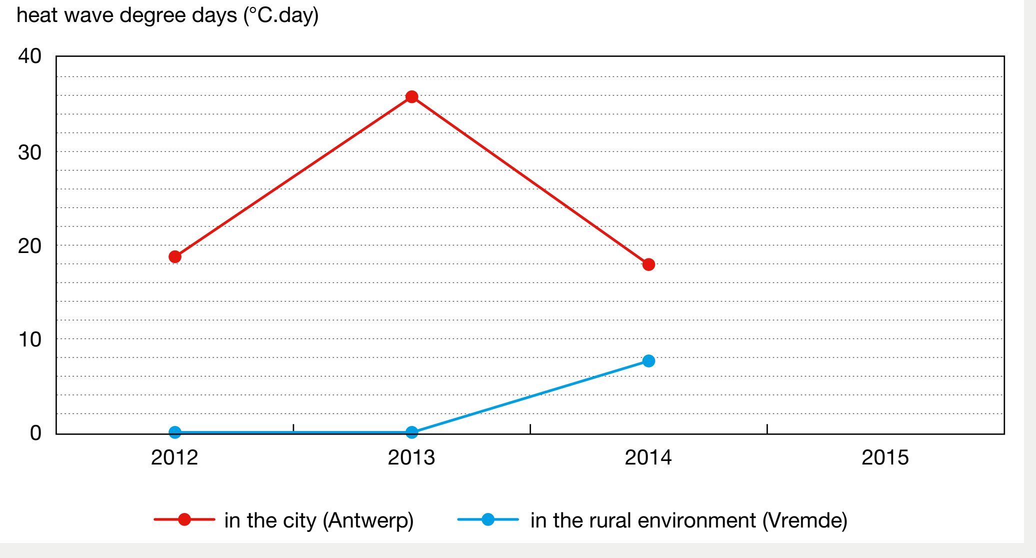


Figure compiled on the basis of values measured in Antwerp (urban) and Vremde (rural).

Source: VITO in MIRA Study Report 'Indicatoren van het stedelijk hitte-eiland in Vlaanderen' (2015)

The indicator can as yet only be used for Antwerp. No permanent datasets are yet available for other central-urban and surrounding rural locations. Moreover, the dataset for Antwerp only begins in 2012 and it is thus too early to draw any conclusions about the evolution in time of the urban heat island. However, the following elements can already be derived from the available data:

- in the city, two heat waves were recorded shortly after each other in 2013, and only one heatwave was recorded in 2012 and 2014. This explains the higher value for the city in 2013;
- when we look at the individual heat waves in the city (two in 2013, one in 2012 and 2014), they are all more or less of the same intensity with an indicator value of approximately eighteen heat wave degree days;
- what is remarkable, at first glance, is the fact that 2014 has the lowest indicator value for the city, but also the highest value for the rural location. An analysis of the time series shows, however, that in 2014 the rural site only just satisfied the criteria for a heat wave. Slightly lower temperatures would also have led to a value of zero degree days on the rural site for 2014.

Simulation (missing) datasets with a regional climate model

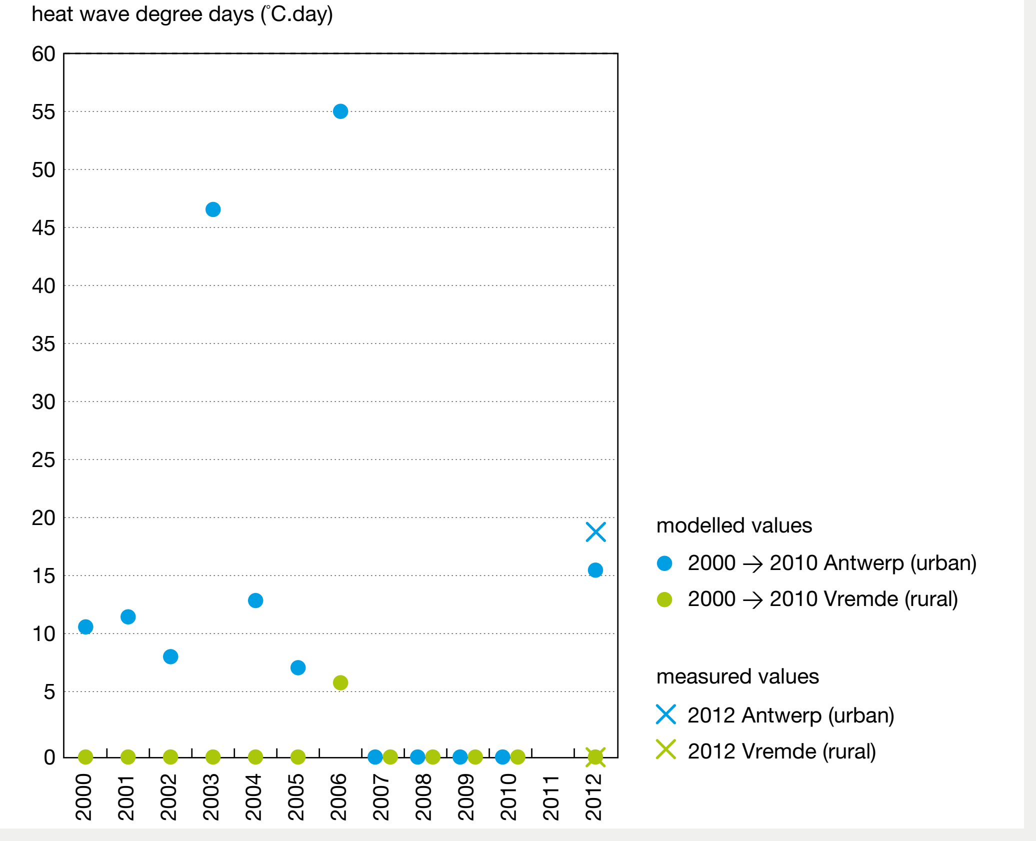
The above-described indicator is the most accurate because it is based on a direct measurement of the air temperature. However, this indicator can (as yet) only be calculated for one city (Antwerp), and only for a limited period (from 2012). Using a regional climate model (with a resolution of 2.8 km) with a specific urban module, it was possible to retroactively reconstruct the indicator rather accurately for longer periods (and several cities in Flanders). Figure 13 could thus be extended to produce the result shown in Figure 14.

In addition to the temporal variability, climate modelling can also be used to map the spatial variability of the urban heat island effect. It is clear, for example, that both for the historical years (2010-2014) and for the coming decades (see paragraph 3.2.4) significantly more heat wave degree days are recorded in the city centres than in the surrounding natural areas. Besides, in the rural areas the number of heat wave degree days equals zero in most of the years of the period 2000-2012. Except for the very warm summer of 2006 the minimum temperature in Vremde did not exceed 18.2 °C for three consecutive days. There also appears to exist great variability in time for the number of heat wave degree days in the urban areas, with peaks in the years 2003 and 2006. Furthermore, extrapolation of historical years with a regional climate model for Flanders shows that the number of heat wave days is strongly influenced by the size of the city.

Satellites are used to map urban heat stress in Flanders

In addition to measuring the temperature in ambient air, the urban heat island can also be studied using thermal infra-red satellite images. These have the advantage of being area-covering and available for longer periods. One drawback of these satellite images is that they show the temperature at the ground or the surface temperature, but not the ambient temperature (bottom air layer).

Figure 14: *Heat wave degree days based on urban climate modelling (Antwerp, 2000-2012)*

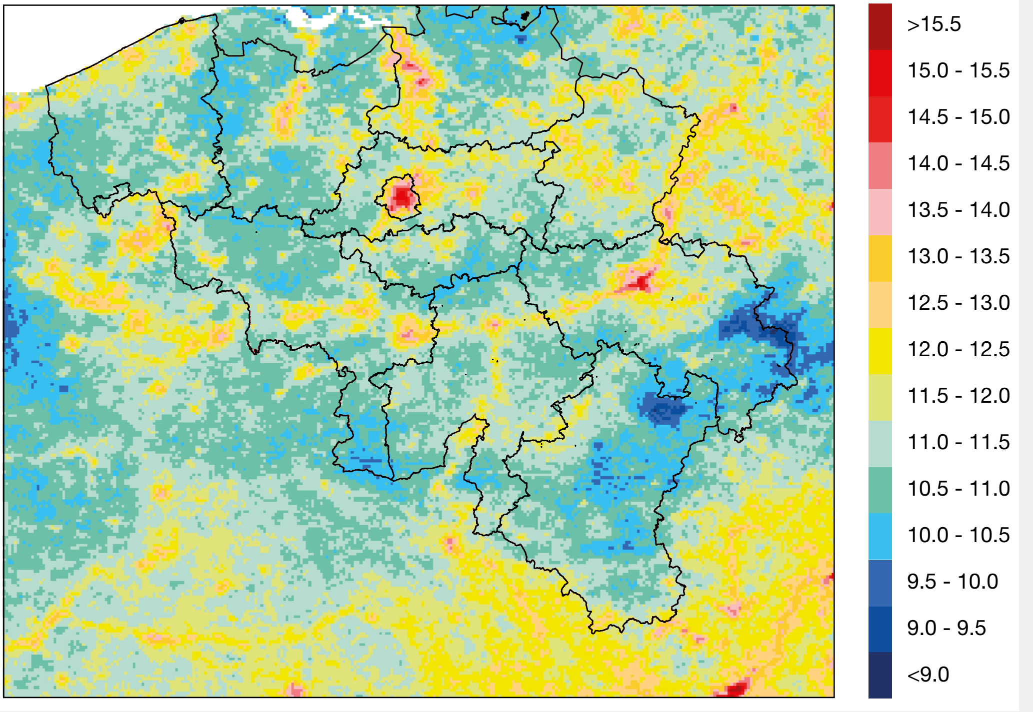


Source: KU Leuven and VITO in MIRA Study Report 'Indicatoren van het stedelijk hitte-eiland in Vlaanderen' (2015)

Heat stress is mainly determined by the ambient temperature, but there is a clear correlation between ambient temperature and surface temperature: higher surface temperatures contribute to warming of the bottom atmospheric layer. Green areas in the city thus have a lower surface temperature than the adjacent built-up area and infrastructure, and contribute to a lower air temperature in the close surroundings. However, due to turbulent mixing and large-scale atmospheric effects, the relation between surface temperature and air temperature is not easy to determine. A number of foreign studies nevertheless shows that areas characterised by the highest surface temperatures at night also have the highest excess mortality during warm periods.

Satellite measurements were used to create an image of the temperature at the ground (Figure 15). This allows hotspots for heat stress in Flanders to be identified.

Figure 15: *Annual average surface temperature (°C) based on satellite data (Belgium, 2013)*



Annual average surface temperature derived from the MODIS satellite sensors. The increased temperature in the cities is clearly visible.

Source: VITO in MIRA Study Report 'Indicatoren van het stedelijk hitte-eiland in Vlaanderen' (2015)

A clear correlation appears to exist between the population density and the heat island effect at the ground. For the cities in Flanders, on average 50 to 55 % of the spatial variability of the strength of the heat island can be explained by the population density of a city or municipality. An even stronger positive correlation appears to exist between the level of paving of a city and the strength of the heat island effect at the ground: on average 66 % of the variability at night between the cities in Flanders can be explained by this parameter. The cities in Flanders are to be classified according to the strength of the heat island effect as determined on the basis of satellite images for the summer period (April to September), into one of the following three groups:

- cities with a comparatively high heat island effect: Antwerp, Ghent, Kortrijk, Mechelen, Roeselare, Bruges;
- cities with a medium heat island effect: Sint-Niklaas, Aalst, Leuven, Turnhout, Ieper, Tienen, Geel, Hasselt and Genk;
- cities with a relatively low heat island effect: Aarschot, Sint-Truiden, Lier, Diest.

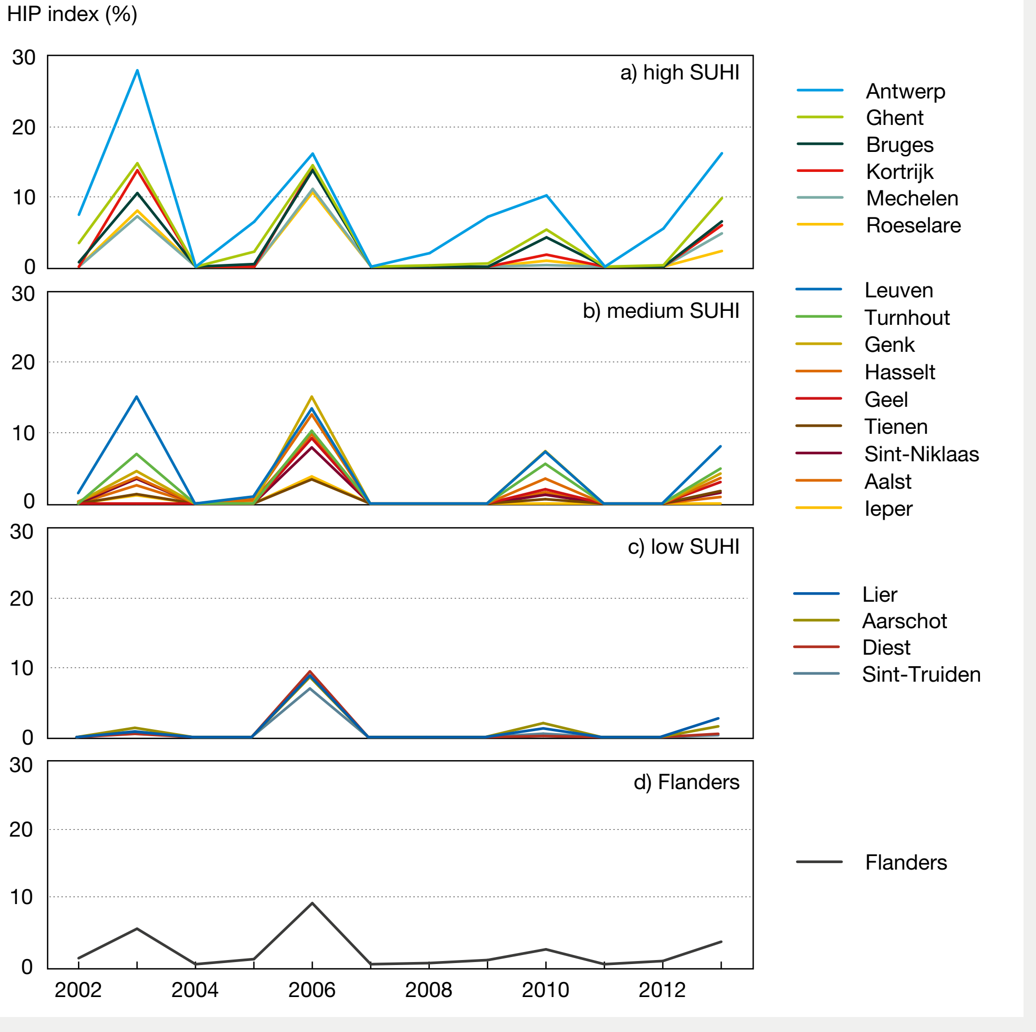
Satellite images can also be used to calculate derived indicators. Thus, the Hot Island Population Index or HIP index measures the percentage of the population of a city or region that lives in areas with surface temperatures that exceed certain threshold values. This gives us an insight into the number of people exposed to increased temperatures and increased heat stress. The HIP index for a city or region in a given year is determined by calculating the portion of the population that lives in an area with a surface temperature that is higher than 31.5 °C during the day and higher than 15.7 °C at night (during the months of April to September). These threshold values relate to the 95th percentile of the surface temperature during the day and at night in the urban areas within Flanders in the period 2002-2013. Figure 16 shows that the HIP index varies significantly among the city centres in Flanders; in Antwerp, a significantly greater fraction of the population is exposed to higher temperatures. A significantly higher exposure in years with very warm summers is also observed (2003, 2006).

How can we remedy the urban heat island?

It is important that the government's heat plans are aligned with the urban situation. Allowance must be made for the fact that heat waves are more frequent and more intense in cities. The specific social situation of city dwellers (*e.g.* more elderly people living alone) is important in this context.

For spatial planning in cities, it is also important to take into account the impact of the built-up area on the local climate, and consider measures to locally mitigate extreme temperatures, such as the use of vegetation and water surfaces. Research shows that above all, less paving and more greenery are capable of reducing the heat island effect in the city. The cooling effect of water surfaces appears to be less: water can absorb much heat, so that it will in effect be warmer than the ambient air, especially at night later in the summer. At such a moment water in the city is more likely to contribute to the heat in the city. Larger water surfaces can nevertheless provide cooling towards the end of the summer when they are oriented in the direction of the prevailing wind: cooling wind is allowed to penetrate deeper into the city (Rovers *et al.*, 2014).

***Figure 16:** Hot Island Population Index (HIP index) per city and for the whole of Flanders (Flanders, 2002-2013)*



SUHI = surface urban heat island

The index indicates, for each city, the average fraction of the population that during the summer period is exposed to an average surface temperature during the day above 31.5 °C and at night above 15.7 °C. The cities are divided into three categories with a high, medium and relatively low heat island effect respectively. The indicator for the whole of Flanders is shown at the bottom.

Source: VITO in MIRA Study Report 'Indicatoren van het stedelijk hitte-eiland in Vlaanderen' (2015)

2.2 Potential evapotranspiration

In addition to precipitation (see paragraph 2.3 below), the water availability for humans, animals and plants is also determined by evapotranspiration. Evapotranspiration is a collective term for losses of water from the soil and vegetation to the atmosphere. This includes all precipitation that goes into the atmosphere either directly by evaporation or indirectly via ecosystems. 'Potential evapotranspiration' (PET, expressed in mm precipitation per year) is the maximum possible evapotranspiration that occurs if sufficient water is at all times available at the surface or in the soil. This is, however, not always the case. During dry summer periods, the actual evapotranspiration is less than the potential evapotranspiration. The potential evapotranspiration is used. The actual evapotranspiration is difficult to quantify because it is highly area dependent and a function of the water availability at the surface and in the ground. A woodland area or a highly urbanised area will therefore have a highly different evapotranspiration.

Climate trends are best detected on the longest possible time series. The longest available dataset for PET in Belgium is that of Uccle. Daily data for PET have been recorded since 1901. The trend analysis was conducted on the complete time series, after calculation of the annual totals or the totals per growth season (from April to September).

Between the beginning of the measurements in 1901 and the end of the 1970s, the dataset of the annual totals does not show a clear trend. Since the beginning of the 1980s, however, the trend line for the annual PET has significantly increased (Figure 17). In 2014, the trend line was 130 mm higher than in 1901, which corresponds to an increase of about one quarter. As temperature is a determining factor for evaporation, it is no coincidence that the trend line strongly resembles that of the annual average temperature (Figure 6).

The PET in the growth season shows an analogous trend line. This increase, too, is significant. In 2004, the trend line was 92 mm higher than in 1901.

2.3 Precipitation

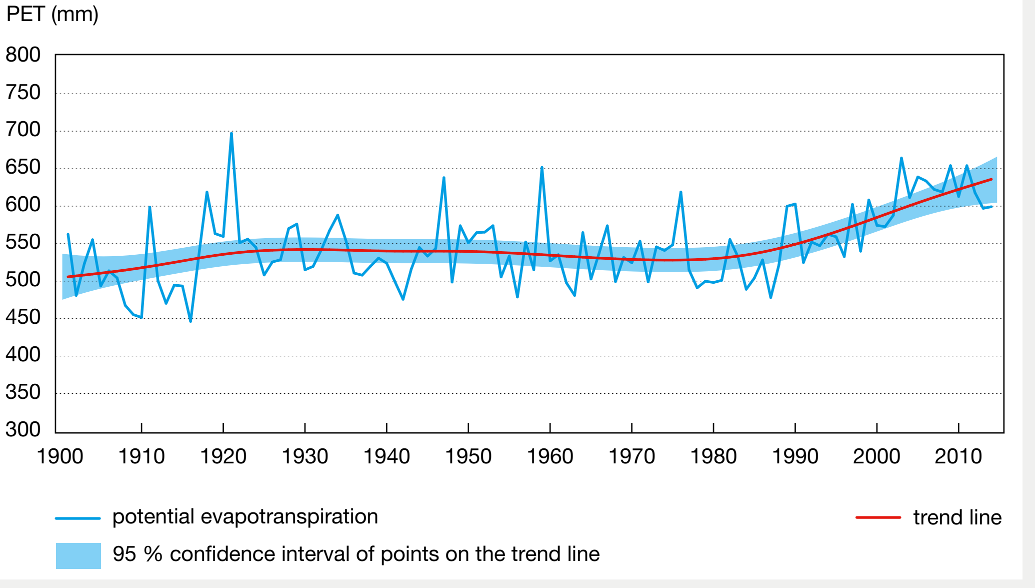
Increased temperatures on Earth lead to a disruption of the present climate. The indicators in this paragraph examine whether the ongoing climate change in our country is already causing changes in precipitation patterns.

2.3.1 Annual precipitation

Human contribution to changing precipitation patterns

Scientists have demonstrated that human activities are the main cause of the changes in precipitation on Earth, observed between 1925 and 1999. Between 40° and 70° north latitude – which also covers the major part of Europe, with the exception of Cyprus, Malta, Greece, the southern half of Spain/Portugal and the south of Italy – precipitation increased on average by 6.2 mm per decade. The contribution of human activities is estimated at 50 to 85 %.

Figure 17: *Evolution of the annual potential evapotranspiration (Uccle, 1901-2014)*



Source: MIRA based on RMI

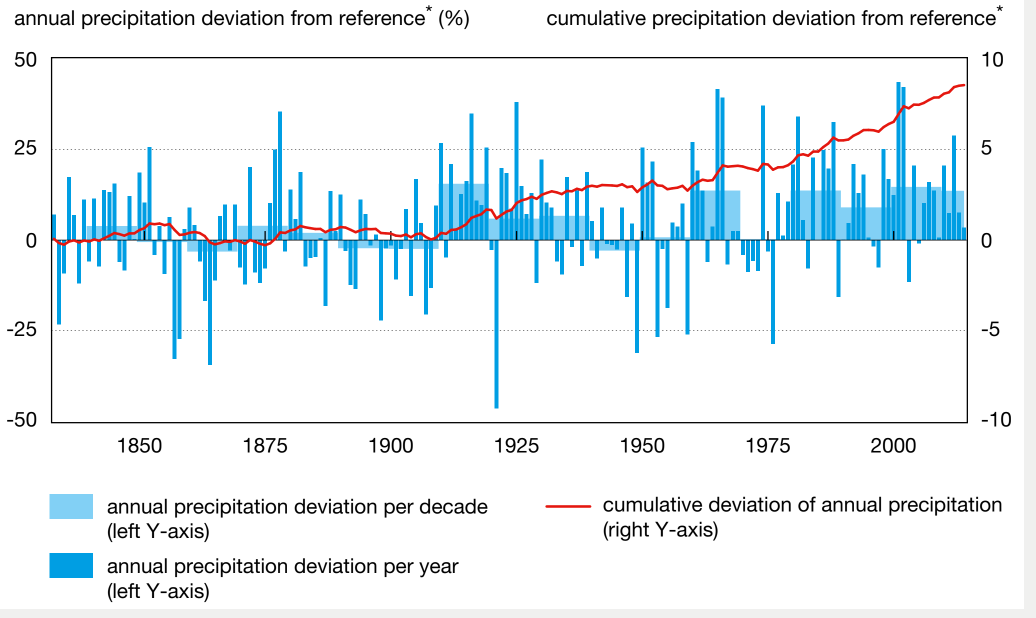
Meanwhile, in the greater part of the northern half of Europe, which includes Flanders and northern France, annual average precipitation appears to have increased further between 1960 and 2013. This increase is mainly caused by changes in winter precipitation. Yet large parts of southern Europe experience a decrease in precipitation, mainly due to less precipitation in the summer months.

Increasing precipitation in Belgium

Since the beginning of the observations in Uccle, 2001 and 2002 have been the absolute record years with amounts of precipitation of 1,088.5 mm and 1,077.8 mm respectively.

There are clearly increasingly more wet than dry years in our country. Figure 18 maps the deviation of the annual amount of precipitation from the average of 758 mm/year in the reference period 1850-1899 (see also paragraph 2.1.1). The trend towards wetter years is particularly apparent from the line representing the cumulated deviation. In the 19th century this line constantly hovered around zero. Since the beginning of the 20th century, however, a clear increase is seen, which becomes even more pronounced from the 1970s. For the first time since the beginning of the measurements, we also see six consecutive decades with an annual precipitation that exceeds that of the reference period.

Figure 18: *Precipitation per year and per decade (Uccle, 1833-2014)*



* annual average precipitation over the period 1850-1899, namely 758 mm

Source: MIRA based on RMI

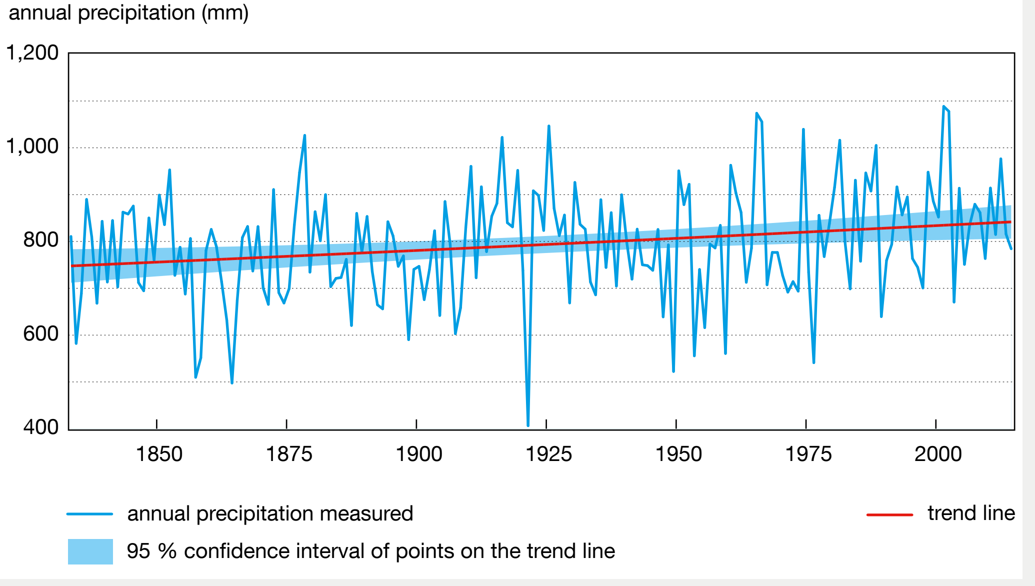
The amount of precipitation shows very high variability from year to year. Moreover, there have been longer periods with more precipitation, *e.g.* around 1920, 1960 and 2000. But statistical analysis of the whole time series can assist in detecting a long-term trend. The analysis shows that our country (measuring point Uccle) witnesses a slow but significant increase in the annual precipitation (Figure 19). This increase continues to increase by 0.55 mm/year or more than half a cm per decade. The trend line shows that the annual precipitation is currently around 94 mm higher than at the beginning of the measurements.

As in 2013, the annual total of 2014 is slightly below the long-term trend, with a total of 784 mm. 2012, by contrast, appeared to a very wet year (977 mm in Uccle) that fell just outside the top ten of wettest years since the beginning of the measurements in 1833.

Spatial patterns

Figure 20 shows the patterns in annual average precipitation within Belgium for the reference period of the present climate (1981-2010). These show that hardly any differences are recorded within Flanders. More towards the south of the country, however, the differences can increase significantly.

***Figure 19:** Analysis of evolution of annual precipitation (Uccle, 1833-2014)*



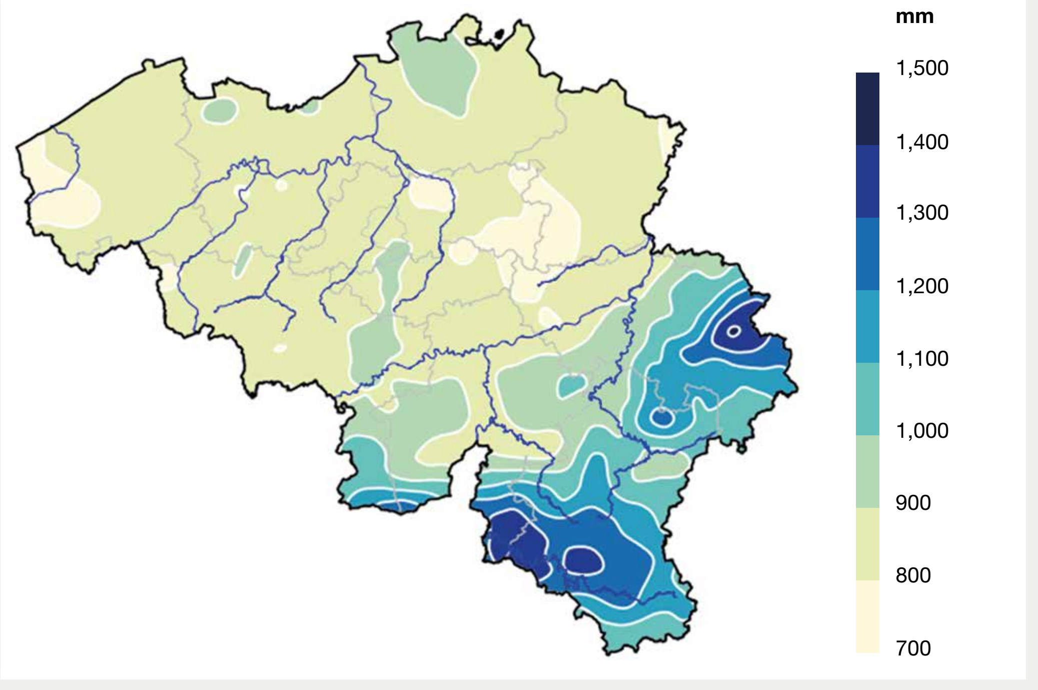
Source: MIRA based on RMI

The values evolve from 740 mm/year in the north of Haspengouw (the Sint-Truiden region) to more than 1,400 mm/year on the High Fens, or a doubling between the driest and wettest locations. The average annual precipitation for Belgium is 925 mm/year. In general, the annual average precipitation is influenced by the relief. On the one hand, the highest-lying sites exhibit, on average, greater amounts of precipitation than the lower-lying areas; however, on the other hand, the orientation of the slopes with respect to the prevailing rain-bringing winds (SW) also plays a role.

The monthly amounts of precipitation in the coastal region are generally among the lowest in the country. Only in the autumn is the amount of precipitation at the coast higher than in Low and Middle Belgium due to the higher temperature of the seawater. Also in the north of Haspengouw, there is little precipitation, except in the period from April to August. For the period from September through to December, it has the lowest amount of precipitation of the entire country.

Also the occurrence of days with normal (≥1 mm) to heavy (≥10 mm) precipitation exhibits a pattern that is quite similar to that in Figure 20 (RMI, 2015b).

Figure 20: *Spatial pattern in annual average precipitation under the present climate (Belgium)*



Here, the present climate has been determined for the reference period 1981-2010.

Source: RMI (2015b)

2.3.2 Seasons

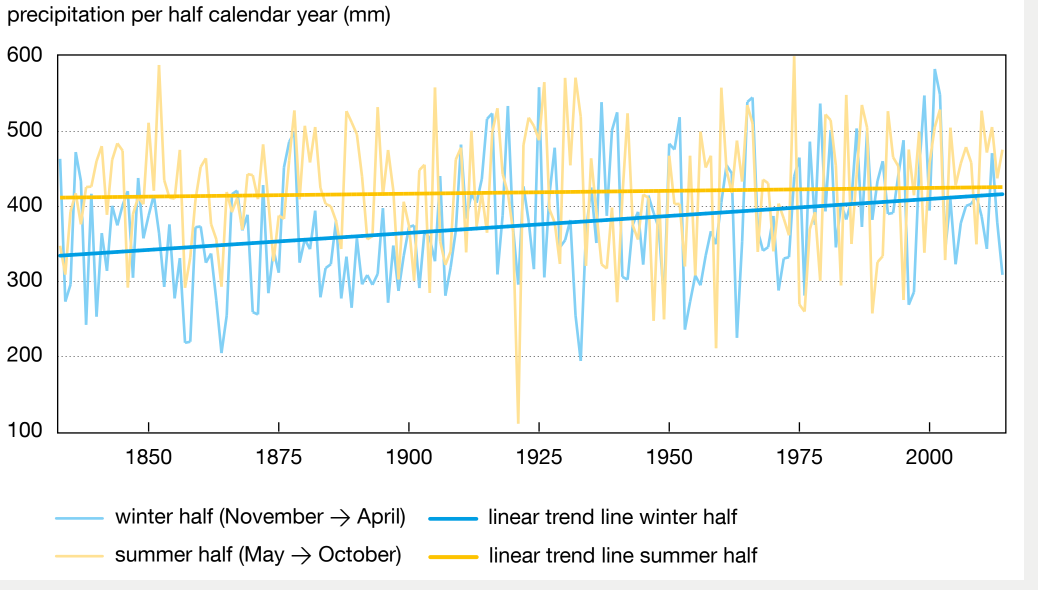
This indicator examines to what extent changes occur in the amount of precipitation per season or in the number of days with measurable precipitation (≥0.1 mm/day) in Belgium.

Wetter winters

Changes in precipitation not only manifest themselves by changing annual totals. Even more important for the potential impact are the shifts per season. In northern and western Europe, the most significant changes in precipitation occur during the winter months (+20 to +40 %).

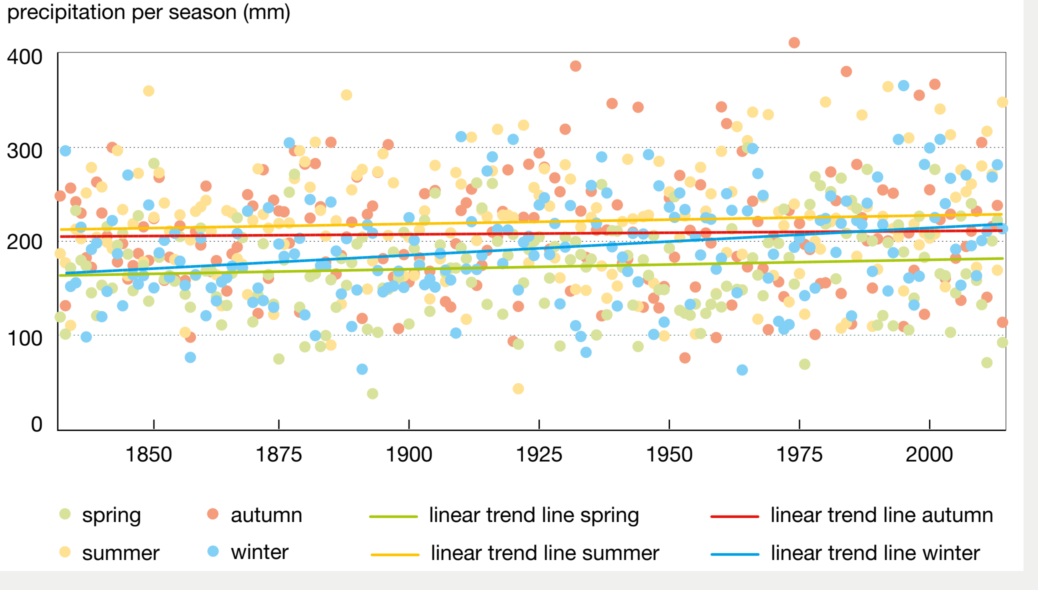
When we look at the complete dataset 1833-2014, a significant increase in the amount of precipitation in Belgium (Uccle) is only noticeable during the winter and winter year-half (Figures 21, 22). The amount of precipitation in the other seasons does not change or changes very little (Figure 22).

***Figure 21:** Amount of precipitation per half calendar year (Uccle, 1833-2014)*



Source: MIRA based on RMI

***Figure 22:** Amount of precipitation per season (Uccle, 1833-2014)*



The winter of year X consists of the months of January and February of year X, together with the month of December of year X-1.

Source: MIRA based on RMI

Also more precipitation days in winter

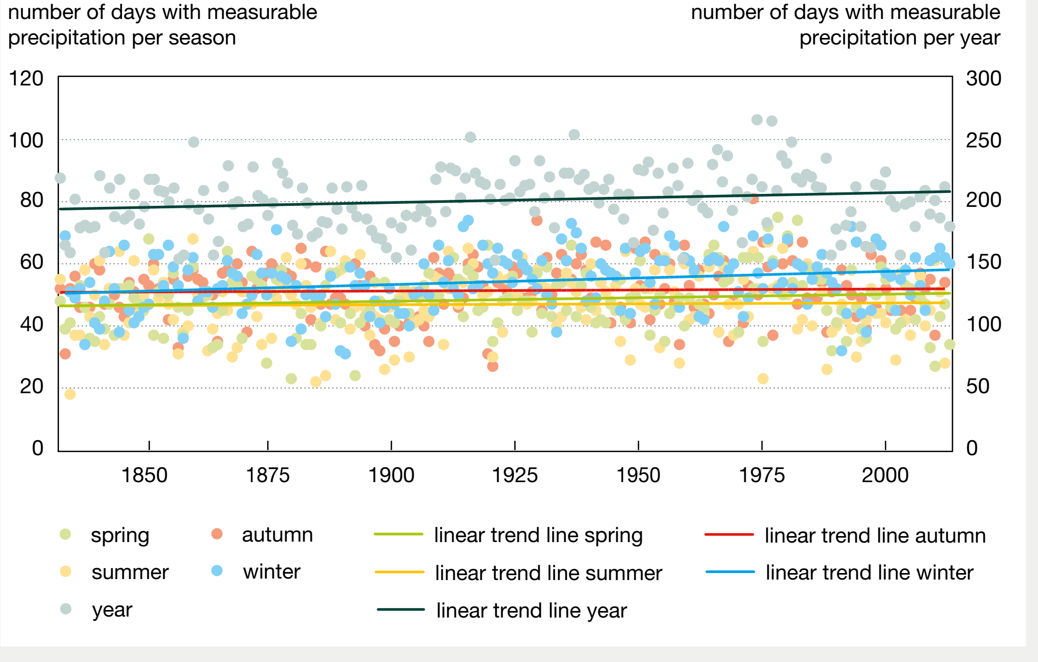
Belgium (Uccle) has on average 201 days with measurable precipitation per year (at least 0.1 mm/day). Extreme years were 1974 and 1977 with 266 and 265 precipitation days respectively (Figure 23).

The analysis of the precipitation data over the complete period 1833-2013 shows that the number of days with measurable precipitation in a year increased significantly. This increase manifests itself only in winter.

But it snows less

Finally, an analysis by the RMI shows that precipitation in the form of snow has clearly become less frequent in Belgium (RMI, 2015a). This is closely related to the rise in temperatures.

***Figure 23:** Number of days with measurable precipitation per season and per year (Uccle, 1833-2013/2014)*



The winter of year X consists of the months of January and February of year X, together with the month of December of year X-1.

Source: MIRA based on RMI

2.3.3 Precipitation extremes

In addition to the shift or change in annual and seasonal averages, it is important to gain insight into changes in the occurrence and the nature of periods of extreme precipitation. Periods with extreme amounts of precipitation may in fact lead to floods, whereas long dry periods may lead to desiccation of ecosystems and depletion of water reserves (see also Chapters 3 and 4).

Humans impact on extreme precipitation

In 2011, scientists were able to show for the first time that human activities contribute to the observed intensification of periods of extreme precipitation in the northern hemisphere. The frequency of periods of heavy rainfall has increased in most places on Earth. This corresponds with the warming and increase – at least since the 1980s – of the water vapour concentration in the atmosphere, both above land and above the oceans.

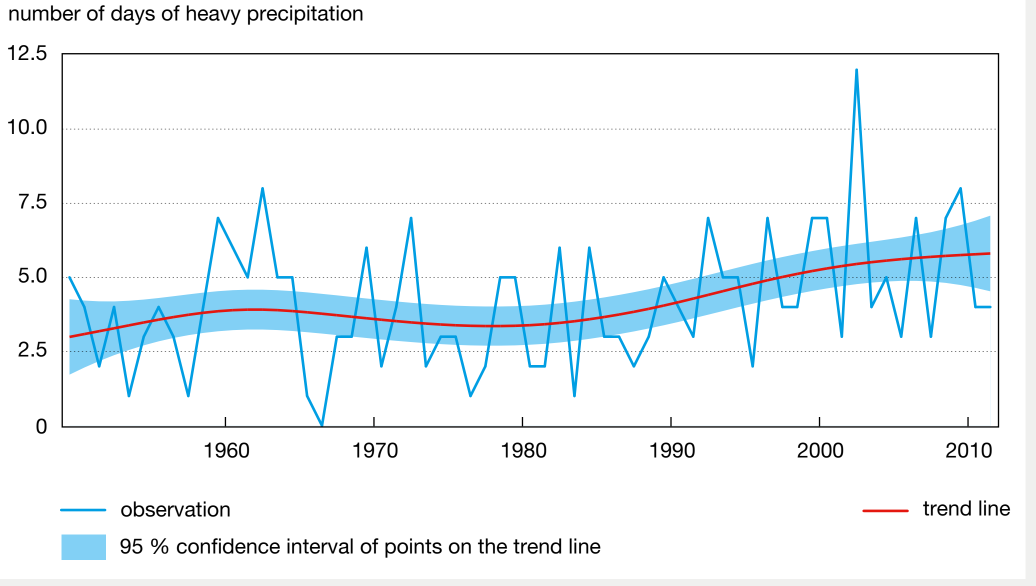
Doubling of the number of days of heavy precipitation

For Belgium (Uccle), the time series of the number of days of heavy precipitation (at least 20 mm/day) shows a clear trend: especially between the beginning of the 1980s and the end of the 1990s the number of days of heavy precipitation increased significantly. In the meantime, a year has already twice as many days of heavy precipitation as in the beginning of the 1950s: over six decades the average number has increased from three to six. The record year was 2004 with twelve days of heavy precipitation (Figure 24). Heavy rainfall occurs mostly in summer because of heavy thunderstorms that occur in a space of a few hours.

Changes in extreme precipitation can also be detected by measuring, per year, the maximum precipitation measured on one day[4] or over a consecutive period of five, ten or fifteen days (Figure 25). The analysis for the dataset 1880-2013 shows that the trend lines are slowly going up. Due to the greater variance in a small period, this increase is not significant for a one-day period, but for consecutive periods of five, ten and fifteen days the maximum amount of precipitation within those periods appears to be significantly higher in 2013 than in 1880, with +11 mm, +19 mm and +24 mm respectively. The RMI had already observed that the wettest periods longer than one week usually occur in winter, and that the minimum amount of precipitation that falls in a few days in winter has a tendency to increase.

4 Analysis for maximum precipitation per year measured within an even smaller time window of one hour, shows also only natural variations. The feeling that thunderstorms lasting one to several hours have recently become more intense and frequent, is therefore not corroborated by Uccle. With the evolution of the data in the coming years, these conclusions may perhaps have to be revised. Since the 1980s, measuring points nearer to the coast have already been recording a significant increase in the maximum daily precipitation in a year, also under the influence of the warming of the seawater (RMI, 2015a).

Figure 24: *Number of days of heavy precipitation (≥20.0 mm per day) (Uccle, 1951-2013)*



Source: MIRA based on RMI

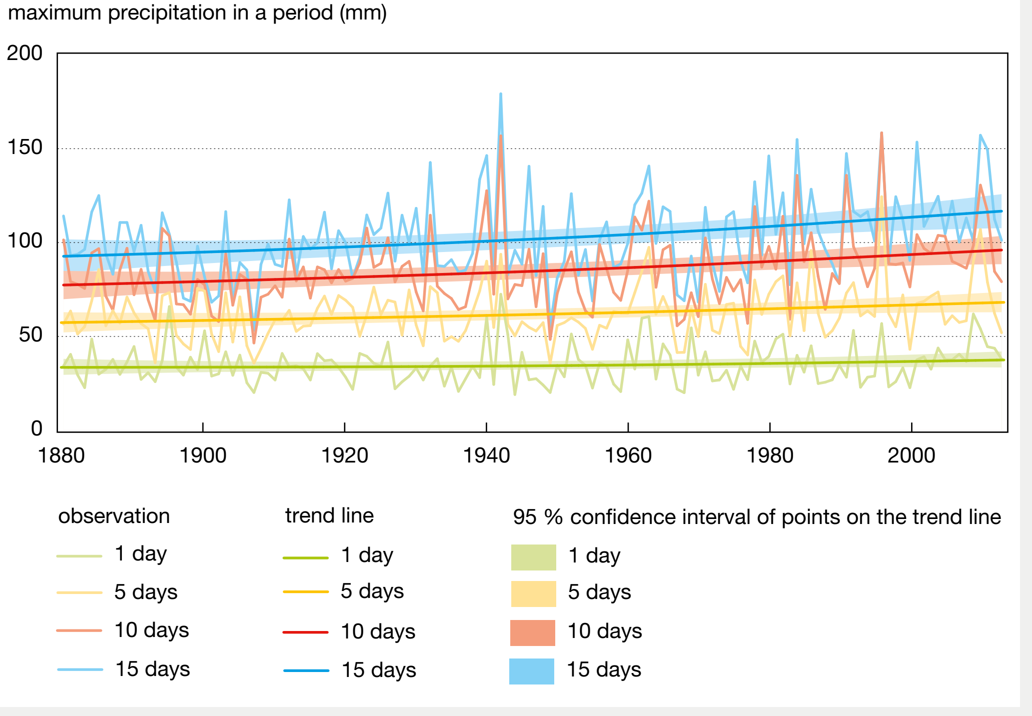
Cumulative precipitation deficit shows no clear trend

The precipitation deficit is the difference between precipitation and potential evapotranspiration (see paragraph 2.2). This deficit is determined per day and compares the amount of available water (precipitation) with the daily potential water demand from, amongst other, plants (potential evapotranspiration). The indicator can therefore also be used as an approximation of drought stress in plants.

Although the precipitation deficit is determined per day, this indicator is only meaningful if longer periods are considered. Stress in plants due to insufficient water availability in fact occurs only over longer periods. That is why the precipitation deficit is calculated as the sum of the daily precipitation deficit calculated over the entire growth season (April to September) in a year. When that sum becomes less than or equal to zero during the calculation period, the cumulative precipitation deficit remains zero.

When using the cumulative precipitation deficit as water stress indicator, one has to bear in mind that the indicator is a (strong) simplification of the actual system: not all of the rainfall will be available to the plant (a portion will run off, or infiltrate into deeper soil strata, or directly evaporate) and the plant will not always be able to achieve the full potential evapotranspiration (*e.g.* young plants or maturing maize exhibit limited evapotranspiration).

Figure 25: *Maximum amount of precipitation on 1 day or over a consecutive period of 5, 10 or 15 days (Uccle, 1880-2013)*



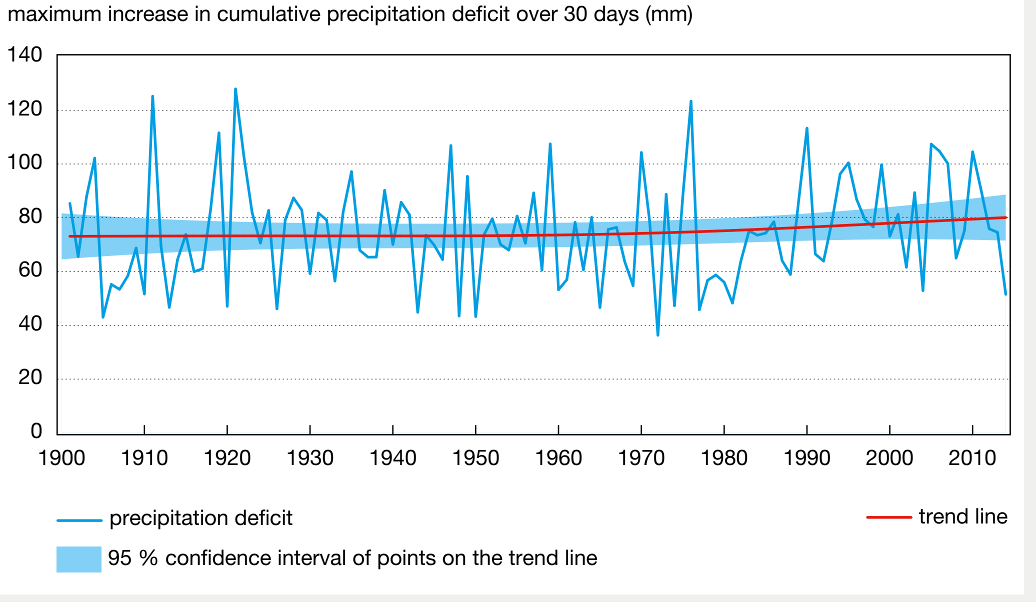
Source: MIRA based on RMI

A trend analysis has been conducted for the following variants:

- the maximum increase in the cumulative precipitation deficit over 30 and over 90 days (each time within the growing season);
- the annual cumulative precipitation deficit at the end of the growing season (on September 30th);
- the maximum value reached by the cumulative precipitation deficit during the growing season in a year.

The trend line for the maximum increase in the cumulative precipitation deficit over 30 days increases slowly, especially after 1980, but the current increase is not statistically significant (Figure 26). The results for the analysis of the maximum cumulative precipitation deficit over 90 days, the annual cumulative precipitation deficit at the end of the growth season and the annual maximum of the cumulative precipitation deficit are comparable: the trend lines increase slightly but they are not statistically significant. This is explained by the fact that the significant increase in potential evapotranspiration (see paragraph 2.2) is partly offset by a slight (not significant) increase in precipitation during the growing season. In addition, the large variation in the indicators for precipitation deficit complicates the detection of trends.

***Figure 26:** Evolution of the maximum increase in cumulative precipitation deficit over 30 days (Uccle, 1901-2014)*



Source: MIRA and VMM based on RMI

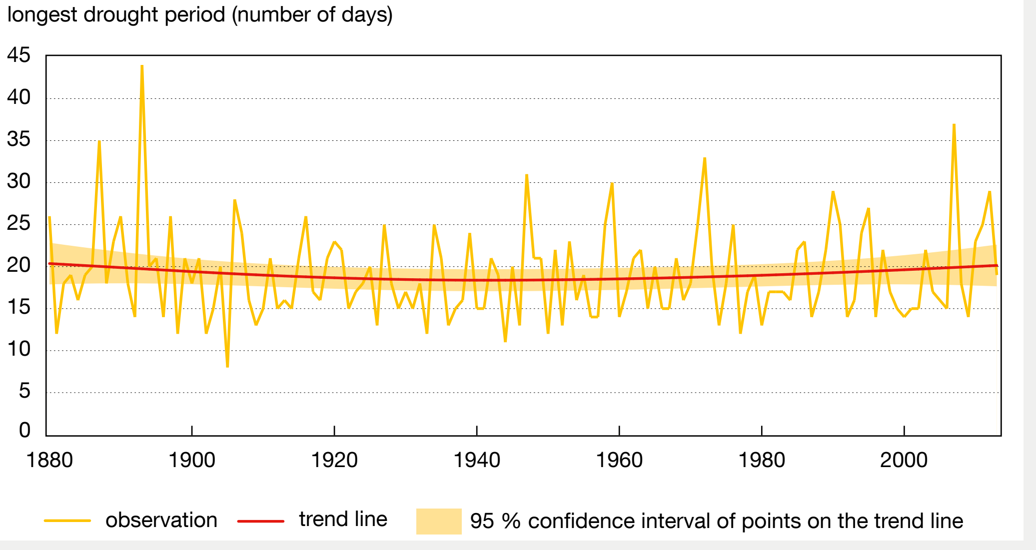
Intensity of periods of drought remains unchanged

Periods of drought also come under the heading of 'extreme precipitation'. The RMI defines a dry day as a day with maximum 0.5 mm of precipitation. An analysis of the maximum number of consecutive dry days in a year shows no significant trend for the measuring point in Uccle over the period 1880-2013 (Figure 27). This indicates that periods of drought have not become more intense since the end of the 19th century. The record years are 1893 and 2007, having periods of drought of 44 and 37 days respectively.

In addition to the analysis of dry periods on the basis of an absolute criterion – maximum 0.5 mm precipitation per day – it is also important to look at drought in a relative way. The precipitation observed in one or a number of months is then compared with the precipitation of the same month(s) in the reference period 1850-1899 using the 'Standardized Precipitation Index' or SPI (McKee *et al.*, 1993). A negative SPI corresponds to a drier-than-normal period, a positive SPI to a wetter-than-normal period. The negative SPI values are interpreted as follows:

- extremely dry: SPI ≤-2
- very dry: -2< SPI ≤-1.5
- moderately dry: -1.5< SPI ≤-1

Figure 27: *Longest period of drought in a year (Uccle, 1880-2013)*



Longest period of drought is expressed as the maximum number of consecutive days with precipitation of 0.5 mm or less in a year.

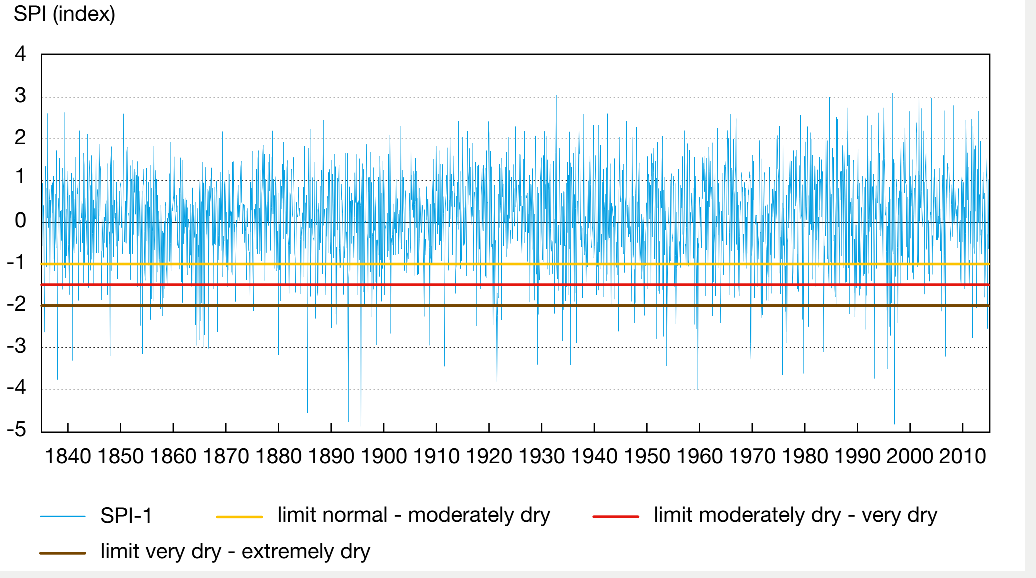
Source: MIRA based on RMI

Figure 28 shows the curve of SPI-1 (per month). The figure also shows the boundaries for the interpretation. To better show the extent of the problem, periods of drought from Figure 28 are further analysed using three derived indicators. For this, a period of drought is defined as a period that extends from the moment the SPI value becomes less than -1 until the moment the SPI value again becomes greater than zero. In practice, three derived indicators are considered, the results of which are first aggregated per decade because periods of drought do not occur that often:

1. drought magnitude: combines the length of the period of drought with the magnitude of the SPI value. For this value, the total sum per decade is then calculated. This is a good indicator to quantify the severity of a dry period;
2. length of the period of drought: the number of months over which the period of drought extends. For this value, the average per decade is calculated.
3. length of the drought-free period: length of the period that begins at the first month following the end of a period of drought and ends when a new period of drought starts. The average per decade is also calculated here.

None of the three derived indicators show a significant trend within the period 1835-2014. It can therefore not be stated that the drought magnitude, the length of the periods of drought or the length of the drought-free periods have increased or decreased since the beginning of the measurements.

Figure 28: *Evolution of the monthly Standardized Precipitation Index or SPI-1 (Uccle, 1835-2014)*



Source: MIRA and VMM based on RMI

2.4 Wind

Wind measurements are strongly influenced by the properties of the area surrounding the measuring point, such as the presence of buildings or trees, and the relief of the surrounding area. Any change in the surroundings can therefore complicate the trend analysis of these datasets. In Uccle, the average wind speed remained relatively stable until around 1960, after which it decreased continuously. Today, the annual average wind speed is approximately 15 % lower (RMI, 2015a). The impact of changing vegetation around Uccle is not known, but also at the measuring points in Zaventem and Saint-Hubert – where no significant changes in the surroundings have occurred since the 1960s – the average wind speed appears to have fallen by 10 %. This decrease in wind speed is recorded in all seasons, except in winter, the season in which the highest wind speeds generally occur (RMI, 2015a).

No clear trend is apparent for the occurrence of storm days - with maximum wind gusts of greater than 70 km/h - nor for the highest measured wind speeds. The intensity of storms has therefore not increased in Belgium over the last decades (RMI, 2015a).

2.5 Sea climate

2.5.1 Average sea level

The global sea level is influenced by a number of factors, including:

- change in volume of a water mass at changing temperatures;
- exchange of a water mass with ice sheets and glaciers on land;
- changes in storage of water on land (both surface water and groundwater).

A temperature rise (*e.g.* under the influence of greenhouse gas emissions of human origin) can lead to expansion of the seawater and melting of the ice sheets, resulting in a rising sea level and an increased risk of flooding in lower-lying areas. Also the exhaustion of groundwater reserves (under the influence of rising temperatures) contributes to the increase in sea level because pumped-up and used groundwater eventually mainly runs off to the sea.

Historical perspective

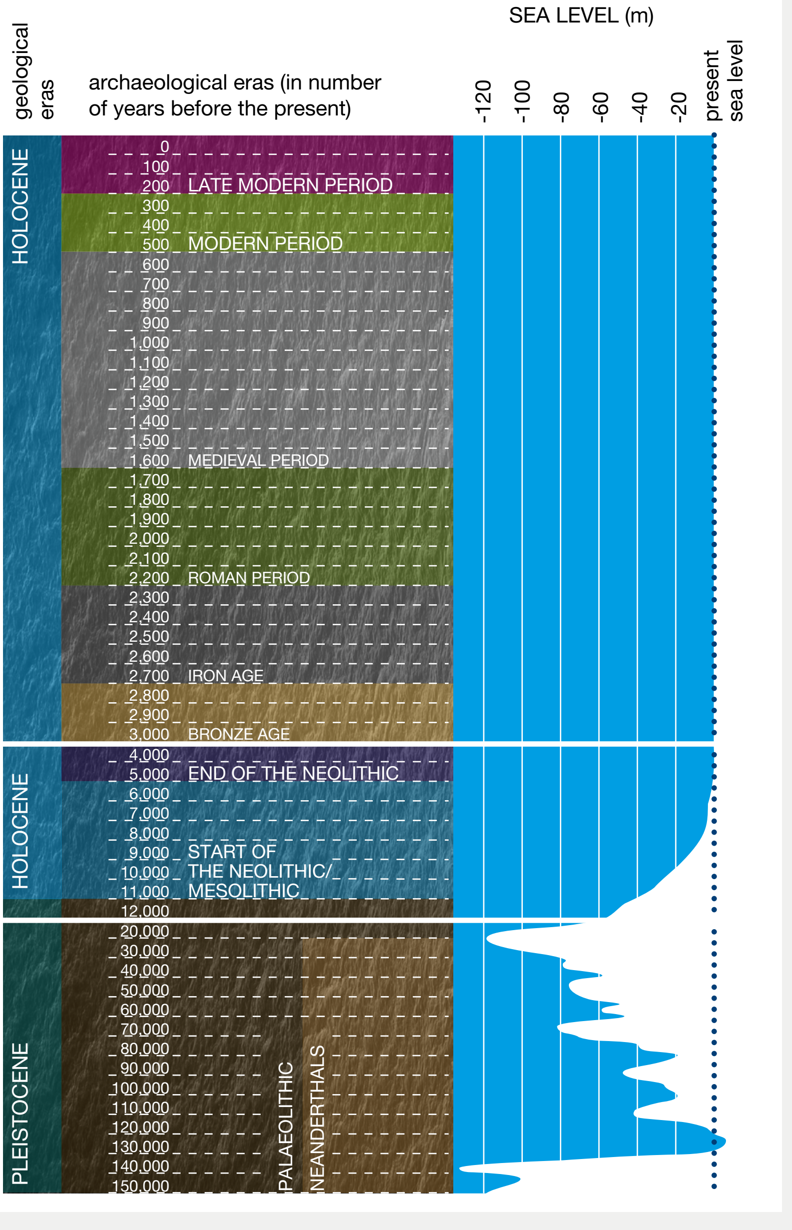
Overall, the global average sea level (including at our coast) has risen by some 120 m since the end of the last ice age, some 20,000 years ago. Combining archaeological and palaeontological finds with scientific literature, the Flanders Marine Institute (VLIZ) was able to find out how the sea level has changed throughout time (VLIZ, 2014). The result is the time line in Figure 29, which shows the variation of the sea level at our coast from 150,000 years ago until today. It appears that during the ice age the sea level was 100 to 200 metres lower than today. The last glacial maximum, when ice sheets were at their greatest extension, was reached approximately 20,000 years ago. Glaciers then covered large parts of northern Europe. Due to the storage of large amounts of (sea) water in the ice sheets, the sea level was spectacularly lower. At one point the North Sea region was even dried out. The present coast line, by contrast, has for the most part remained unchanged since the end of the 18th century.

Rise in sea level now already exceeds sustainability target

The United Nations Framework Convention on Climate Change of 1992 states that the concentration of greenhouse gases should be stabilised at a level that would prevent dangerous human interference with the climate system. This should be achieved within a time frame that, among other things, allows ecosystems to adapt naturally. Scientifically, this sustainability target for the sea level is translated into a maximum rise by 2 cm per decade.

In the 20th century, the average sea level on Earth rose annually by 1.7 mm. And, since the 1950s, a significant acceleration in the global sea level rise is likely in progress. The annual sea level increase is in the meantime already 3.4 mm per year (global average), and thus exceeds the previously mentioned sustainability target.

***Figure 29:** Historical evolution of the annual average sea level throughout the successive geological eras (Belgium, 150,000 years back in time)*



Note that the time line goes back in time first in steps of 100 years, then per 1,000 years and finally per 10,000 years. These periods are separated by a vertical white line.

Source: VLIZ (2014; http://www.sea-arch.be/nl/tijdlijn)

Belgian coast is following the global trend

Statistical analysis of the values measured at the Belgian coast shows that annual average sea level in 2013 is significantly higher than at the beginning of the dataset.

- in Ostend the sea-level trend line increased by 115 mm between 1951 and 2013;
- in Nieuwpoort the sea-level trend line increased by 81 mm between 1967 and 2013;
- in Zeebrugge the sea-level trend line increased by 42 mm between 1979 and 2013.

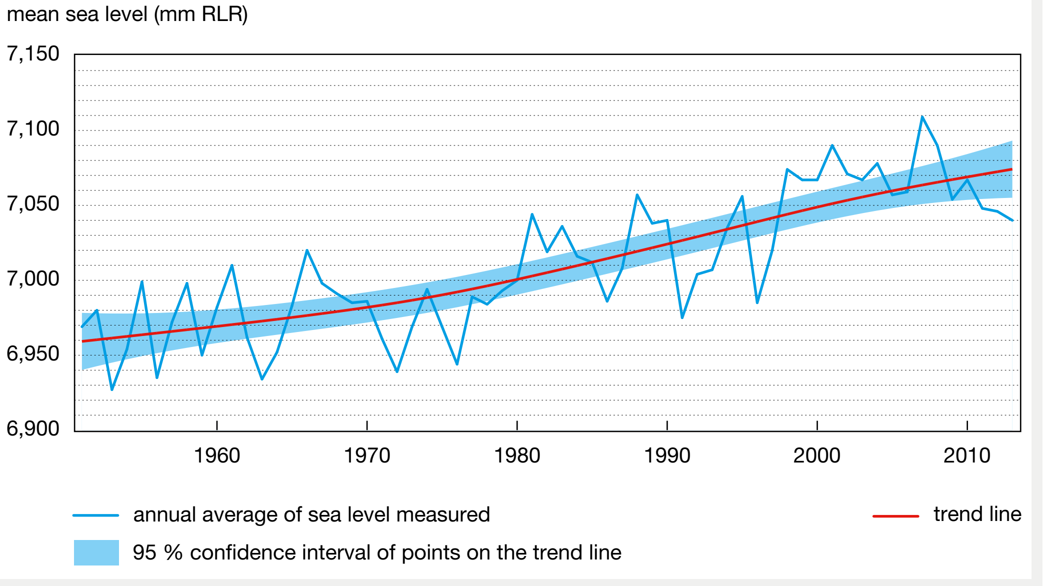
Ostend is the measuring point at our coast with the longest uninterrupted dataset. That is why this set is the most suitable to detect and quantify long-term trends. Initially, the sea level here rose rather slowly (by 1 mm/year). Yet since the mid-1960s it has risen steadily up to 2.5 mm/year in the middle of the 1990s. The increase has also remained significant in recent years, but the increase rate has fallen slightly to 1.7 mm/year (Figure 30). The speed with which the sea level rises therefore appears to be subject to multi-annual fluctuations, although it is clear that the sea level has risen. Over the previous decades, significant increases were also recorded for Zeebrugge and Nieuwpoort, but here the increase seems to have stopped in recent years. In addition to the impact of climate change, the sea level (both the average sea level and the high water levels) is also subject to a natural variation with an interval of 18.61 years, the so-called nodal tide. Due to a variation of the angle between the Earth, the Sun and the Moon, the sea level rises much more strongly in some periods than in others.

A recent study examined the extreme high waters in Ostend and the contribution of individual astronomical and storm surge components, trends and their long-term variations. It was found that the storm surge – alongside the increase in the annual average sea level – did not exhibit a separate or additional upward trend (Willems, 2014).

Vulnerable to floods

In Europe, Belgium appears, after the Netherlands, to be the most vulnerable to floods caused by the rising sea level: 15 % of the surface area in Flanders is located less than five metres above the average sea level. Moreover, the Belgian coast appears to be the most built up in Europe: in 2000, more than 30 % of the 10 km coastal strip was built up, and even almost 50 % of the strip up to one km from the coast. In West Flanders, 33 % of the population lives in low-lying polder areas vulnerable to floods caused by the sea.

Figure 30: *Evolution of the mean sea level at the Belgian coast (Ostend, 1951-2013)*



The sea level is expressed in mm RLR (Revised Local Reference). The data of a local reference (for the Belgian coast this is TAW, 'Tweede Algemene Waterpassing') are converted to the international reference level.

Source: MIRA based on Permanent Service for Mean Sea Level (PSMSL) and Agentschap Maritieme Dienstverlening en Kust

2.5.2 Seawater temperature, salinity, wave height and wind speed at sea

Together with the run-off of melting land ice to the sea, the thermal expansion of the sea water is the main cause of the already observed sea level rise. The temperature influences the density of the water and thus the currents and the sea level. In addition, the temperature influences the solubility of CO_2 in the seawater, and thus has a link with the composition of the atmosphere. In all the sub-areas of the North Sea (not only the Belgian part), the seawater temperature is rising. Moreover, a natural variability appears to occur with a period of seven to eight years. The increase in seawater temperature lies between 0.023 °C/year (in the northern North Sea) and 0.053 °C/year in the central North Sea and the southern North Sea. In the area closest to the Belgian coast, the increase is approximately 0.034 °C per year or 3.4 °C per century.

As concerns the wave height, the historical dataset in and near the Belgian part of the North Sea only suggests a natural variability with a period of approximately seven years. There is also a seasonal cycle: on average, there are higher waves in winter and lower waves in the summer months. A clear climate trend could not be demonstrated in the historical wave height and wind speed datasets.

2.6 Climatic variations

In addition to the identification of climate trends, it is important to bear in mind that the climate is subject to major, natural climatic variations on different time scales. As a result, short-term trends may deviate considerably from long-term trends, or short-term developments may be opposite to the long-term trend as a result of global warming.

Thus, the existence of variations of several decades in the occurrence of extreme precipitation was recently established for our country. This resulted in periods with more and higher extreme precipitation around the years 1910-1920, 1950-1960 and 1990-2000, and periods with less extreme precipitation in between (Willems 2013a; Willems 2013b). This may have an impact on statistical analyses of the results of climate models (see Chapter 3), which are based on limited datasets (typically 30 years or less). Hence it was found that the uncertainty on the use of a 30-year period is 11 % for the average precipitation and 37 % for the ten-year return periods (Brisson *et al.*, 2014). This means that when comparing two 30-year climate projections, 11 % of the change is potentially the result of climatic variations for the 30-year averages and 37 % for the 10-year return periods. This finding applies to point measurements. When changes occur over a larger region, the effect of climatic variations becomes smaller.

3 HOW CAN THE CLIMATE IN FLANDERS EVOLVE UNTIL 2100?

3 HOW CAN THE CLIMATE IN FLANDERS EVOLVE UNTIL 2100?[5]

3.1 About scenarios and climate models

3.1.1 New greenhouse gas scenarios

The new RCP scenarios (Representative Concentration Pathways) from the Fifth Assessment Report (AR5) of the IPCC cover four potential pathways for greenhouse gas concentrations in the atmosphere until the year 2100, and comprise a range of potential, future radiative forcing (see paragraph 1.2.4) (van Vuuren *et al.* 2011; Figure 31):

- RCP8.5: This is the business-as-usual scenario and is characterised by increasing greenhouse gas emissions in the time whereby the radiative forcing increases to 8.5 W/m² by 2100. The scenario is representative of scenarios that lead to high greenhouse gas concentrations in the absence of climate policy. RCP8.5 is a high energy-intensive scenario with high population growth to about twelve billion in 2100 and low technological development.

- RCP6.0: This is a scenario where the radiative forcing gradually increases and stabilises at 6 W/m² after 2100. It is characterised by a set of technologies and strategies to limit energy consumption and greenhouse gas emissions. There is, however, hardly any reduction in greenhouse gas emissions per unit of energy. This scenario assumes a medium projection for population growth to approximately nine billion by 2100.
- RCP4.5: This is a scenario where the radiative forcing gradually stabilises until it reaches 4.5 W/m² in 2100. Compared with RCP6.0, this scenario is characterised by a broader range of technologies and strategies to reduce greenhouse gas emissions. This scenario also assumes a medium projection for population growth to approximately nine billion by 2100. It mainly differs from RCP6 in that it assumes a sharp decline in greenhouse gas emissions per unit of energy. The use of bioenergy and carbon capture and storage is characteristic of RCP4.5.
- RCP2.6: This scenario is a so-called ‘peak and decline’ scenario where the radiative forcing first attains values of up to around 3 W/m² around the middle of this century, and subsequently declines to 2.6 W/m² by 2100. To attain these values, major reductions in greenhouse gas emissions are required. This scenario employs a medium projection for population growth to approximately nine billion by 2100. The low greenhouse gas emissions are characteristic of RCP2.6: strategies such as the combined use of bioenergy and carbon capture and storage will eventually even lead to net negative emissions.

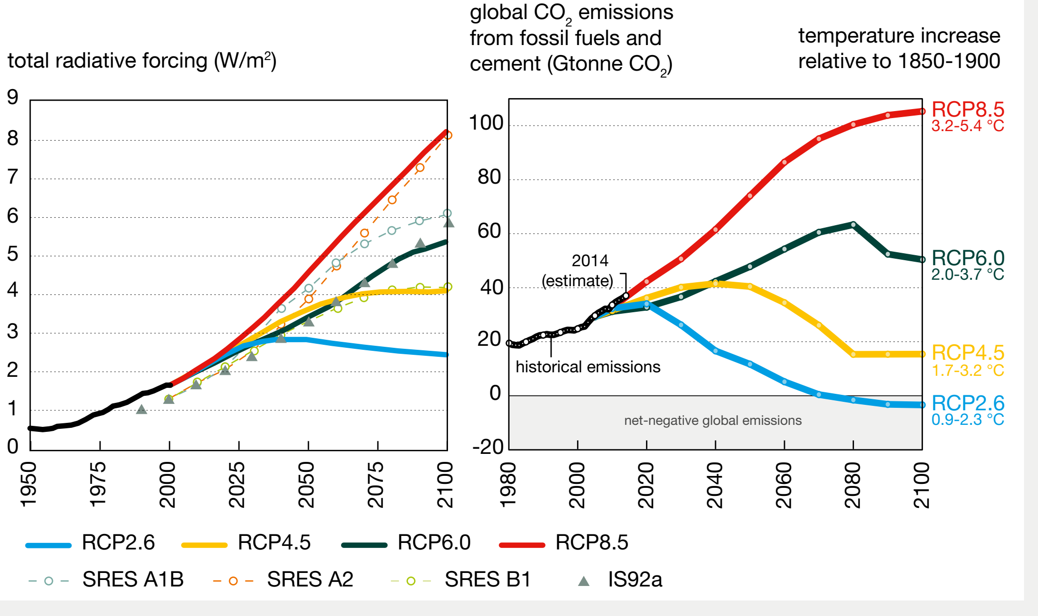
The above-mentioned assumptions for the four RCP scenarios are indicative. Another combination of assumptions may result in the same radiative forcing being obtained. This, however, also has the advantage that the RCP scenarios are representative of different emissions scenarios with a similar radiative forcing, so that not all of these

5 This chapter is mainly based on van Lipzig & Willems (2015), and on De Ridder *et al.* (2015). Other sources are cited in the text.

different emissions scenarios have to be extrapolated with the climate models. Figure 31 also shows how the new scenarios can be related to the previous internationally used SRES scenarios.

No likelihood or probability can be assigned to any of the RCP scenarios. They are four scenarios that represent potential future scenarios. It is however assumed that, based on current scientific knowledge, the total range of the scenarios is highly likely to encompass the actual future evolution. Of the full set of scenarios, RCP8.5 is the most extreme, but it is by no means unrealistic, as appears from the right section of Figure 31. When comparing the recent historical data on global greenhouse gas emissions with the RCP scenarios that were developed a few years ago, we see that they almost seamlessly follow the RCP8.5 scenario. This shows that there is as yet no reduction in global emissions through emission control measures.

***Figure 31:** Evolution of the radiative forcing according to the new RCP scenarios and the old SRES scenarios (left), and the global CO_2 emissions through the use of fossil energy sources and cement according to the new RCP scenarios, together with the observed emissions until 2014 (right)*



Source: IPCC (2013) and Global Carbon Budget (2014)

3.1.2 New global climate model simulations

The latest, fifth IPCC report of 2013 (Fifth Assessment Report or AR5) is based on a large number of new climate model simulations, using RCP greenhouse gas scenarios, but also the latest generation of climate models. These simulations were carried out within the internationally coordinated framework of the so-called Coupled Model Intercomparison Project No.5 or CMIP5, under which future climate projections based on global climate models (General Circulation Models of Global Climate Models or GCMs) are assessed and compared.

For this Climate Report 2015, some 200 global climate model simulations from the CMIP5 project are available for the four RCP scenarios (2.6, 4.5, 6.0 and 8.5). However, the GCMs have a rather coarse spatial resolution of on average 150 km, so that often only one grid cell is for the greater part located within our national borders. That is why for Flanders and Belgium only the results for the grid cell that also covers the main meteorological station of the Royal Meteorological Institute of Belgium (RMI) in Uccle were taken into consideration. The time resolution of GCMs is one day, which means that the scenario results include, for example, information about the largest amount of precipitation that is possible on a day in a year, but not about the precipitation intensities in very short periods (*e.g.* a thunderstorm or 'cloudburst').

3.1.3 New European climate models

Because an average spatial resolution of 150 km is quite low for regional applications, climate models with higher resolutions are also used. These are the so-called Regional Climate Models or RCMs. To keep the calculation times within acceptable limits, they are limited to a smaller area. At the edge of that area the results of a global climate model are superimposed.

For the European region the assessment and comparison of model results with RCMs is carried out in the framework of the EURO-CORDEX project, where CORDEX stands for Coordinated Regional Climate Downscaling Experiments. The regional climate models have a spatial resolution between 12 and 50 km, and their model output is available on a time resolution of one day.

3.1.4 New Belgian fine-meshed climate models

Because the spatial resolution of the European regional climate models is still too coarse for many applications, a number of Belgian research groups are developing fine-mesh climate models for the Belgian territory. It is known that convective summer storms, which are responsible for *e.g.* sewer floods, can only be described explicitly and accurately by climate models with a resolution of 3 to 4 km or finer. Also the accuracy of the hourly precipitation differences within a day, the estimation of periods of extreme precipitation and the precipitation patterns appear to be much more accurate with a spatial resolution of three km than with the above-mentioned GCMs and RCMs.

For Belgium the first climate model simulations with a spatial resolution of 3 to 4 km were carried out recently by:

- KU Leuven (Brisson *et al.*, 2015) using the COSMO-CLM model (CCLM) with a resolution of 3 km as part of the projects CLIMAQS (Climate and Air Quality Modelling for Policy Support) and MACCBET (Modelling Atmospheric Composition and Climate for the Belgian Territory), and
- the RMI (De Troch *et al.*, 2013) using the ALARO model with a resolution of 4 km.

3.1.5 Creation of climate scenarios for Flanders

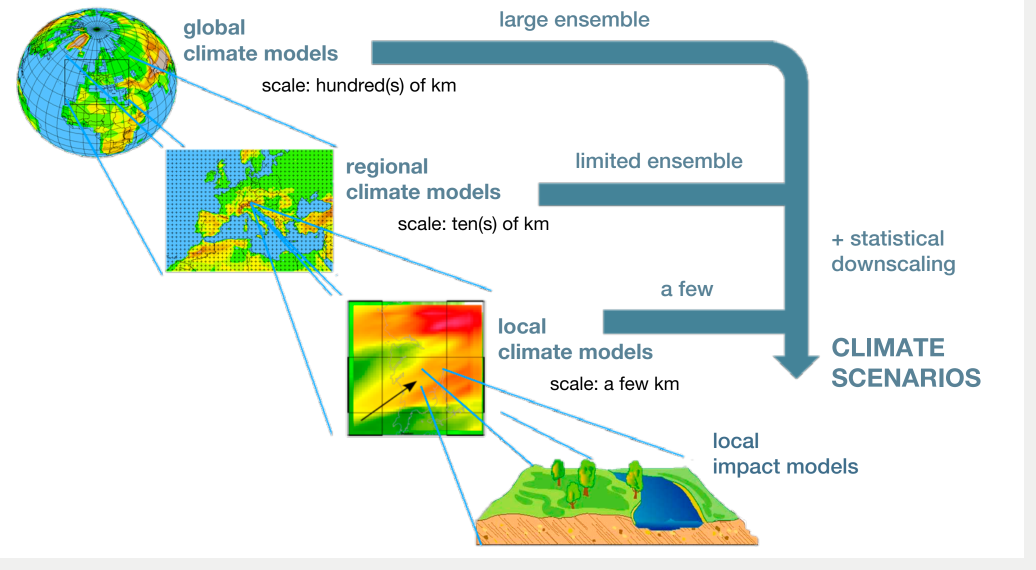
The two fine-mesh Belgian climate models – CCLM of KU Leuven and ALARO of the RMI – mainly provide more accurate and specific results for daily and hourly precipitation, periods of extreme precipitation, and spatial variations in precipitation within Flanders and Belgium. Calculations with fine-mesh models are therefore highly relevant because extreme precipitation can have a major impact on society.

Also the number of available regional climate model simulations for Europe (EURO-CORDEX; resolution 12 to 50 km) is still limited. Due to the great uncertainty in the output of individual climate models, climate scenarios are best based on a large set of climate model results. Because a large set is only available for coarse-scale global models and because no systematic differences were found in the climate change signal between these coarse-scale models and the finer-scale (regional European and high-resolution Belgian) models, mainly CMIP5 model results are used in this Climate Report to derive the climate scenarios for Flanders and Belgium. The CMIP5 climate model runs provide a general insight into the climate change signal for our region, and are supplemented with insights into spatial and temporal variation that are available from the European and Belgian models. The set of fourteen climate projections derived from higher resolution models for Belgium shows, for example, that mainly for extreme summer precipitation, the number of mm precipitation is simulated more accurately at higher model resolutions, both in space and in time.

Just as in the Environment Outlook 2030 (Brouwers *et al.*, 2009), three climate scenarios have been derived: high, medium and low. The new high and low climate scenarios are also based on the upper and lower limit of the 95 % confidence interval calculated on the basis of the full range of new available climate model projections for Belgium. The high and low climate scenarios therefore aim primarily to indicate, for each (climate) parameter, the bandwidth of the potential climate change that awaits Flanders and Belgium over the coming decades and towards the end of this century. The medium climate scenario corresponds to the median of all climate model projections. Notice that there is probably a small but unknown likelihood that the future climate change may be more extreme than what is encompassed by the three climate scenarios (see also Chapter 5). The three climate scenarios encompass the climate change signal for 100 years, and can therefore be considered being representative of the climate change of the year 2000 to the year 2099, but also from the year 2014 to 2113, etc.

To conduct specific, local impact analyses of climate change, global, regional and local climate models will often have to be combined with a statistical downscaling technique (Figure 32). This means that based on historical observations, the difference between the probability distribution of a given climate variable on the coarse scale *(i.e.* that of the climate models) versus that on the fine scale (necessary for the impact analysis) is analysed. This difference is then applied to the climate model results for the future, so that also fine-scale climate model projections are obtained. Climate model projections obtained by statistical downscaling are mainly used for hydrological and hydraulic impact analyses.

Figure 32: *Schematic overview of the availability of climate models at different scales and of how these are combined with statistical downscaling methods to derive climate scenarios for local impact analyses*



Source: KU Leuven in MIRA Study Report 'Actualisatie en verfijning klimaatscenario's tot 2100 voor Vlaanderen' (2015)

3.2 Temperature

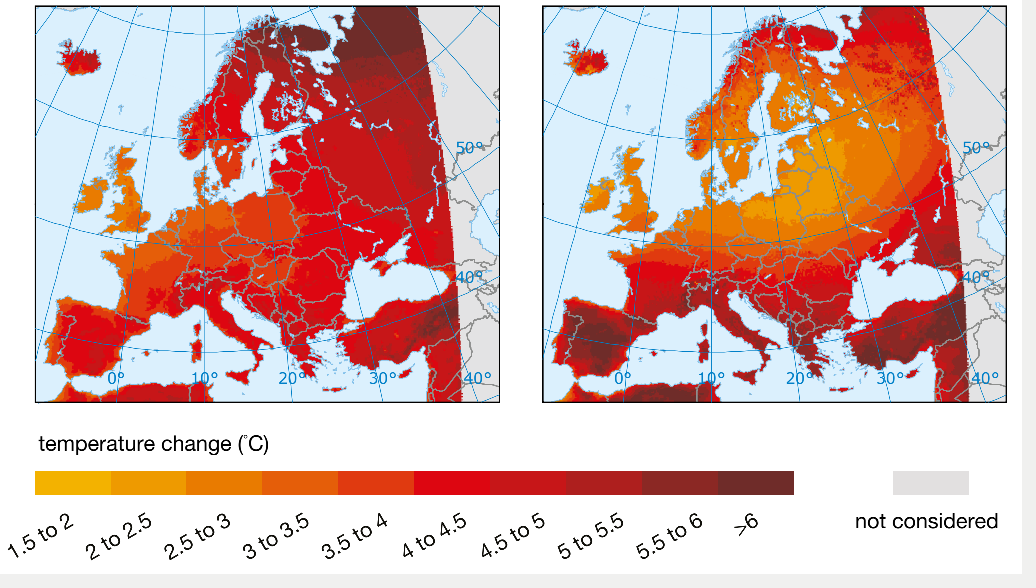
3.2.1 Average temperature

The degree to which the global average temperature will rise is greatly dependent on future greenhouse gas emissions. According to AR5 of the IPCC, the temperature increase for the end of this century (2081-2100 as compared to 1986-2005) will probably lie between 0.3-1.7 °C (RCP2.6), 1.1-2.6 °C (RCP4.5), 1.4-3.1 °C (RCP6.0) and 2.6-4.8 °C (RCP8.5) (IPCC, 2013). The polar regions and land areas will warm up more quickly than the global average.

For Europe changes in temperature are expected that exceed the changes in the global average (Figure 33). From the EURO-CORDEX multi-model set, an increase by approximately 2.4 ˚C for RCP4.5 and 4.1 ˚C for RCP8.5 is projected for a period of 100 years (end 20th century compared with end 21th century). The increase is greatest in the winter for north east Europe and Scandinavia and in the summer for southern Europe.

For Flanders three climate scenarios have been derived (low, medium, high). Unlike the IPCC scenarios (RCPs), the Flemish scenarios are not meant to estimate the effect of global emissions, but rather aim to comprise the uncertainty in climate projections for the future. In the low climate scenario, the temperature changes come close to zero. Certainly for the annual average temperature, the low scenario approaches the present climate. Under the high climate scenario, by contrast, the annual average temperature over 100 years in Uccle may increase by 7.2 ˚C (Table 1).

***Figure 33:** Projected change in the average temperature per year (left) and in summer (right) in the period 2071-2100 as compared to 1971-2000, for the RCP8.5 scenario*



Source: EEA (2014)

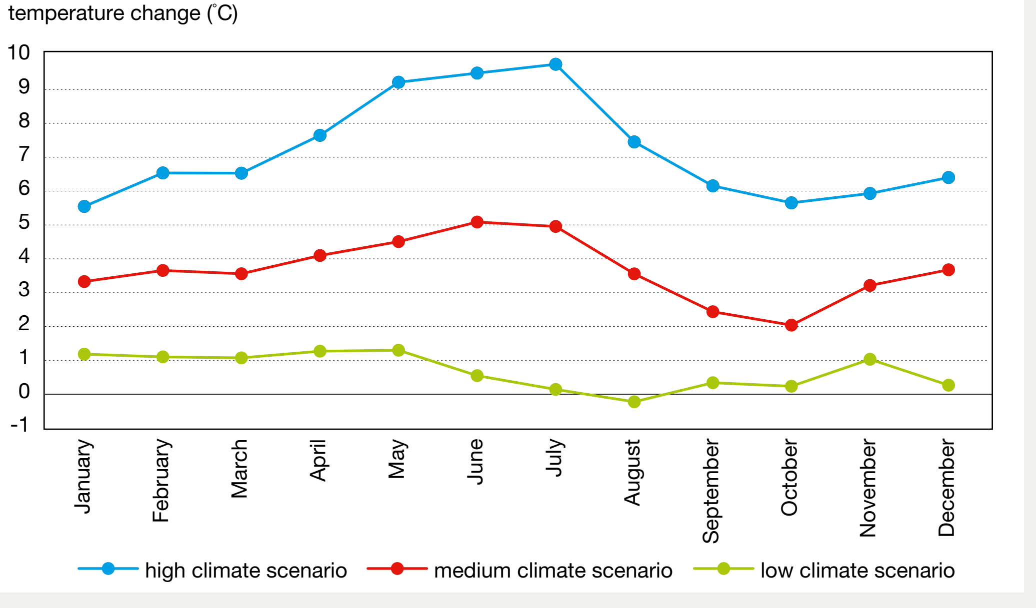
Table 1: *Climate scenarios for the absolute change in annual average temperature (Uccle, over 100, 50 and 30 years)*

	100 years	50 years	30 years
high	+7.2 ˚C	+3.6 ˚C	+2.2 ˚C
medium	+3.7 ˚C	+1.8 ˚C	+1.1 ˚C
low	+0.7 ˚C	+0.3 ˚C	+0.2 ˚C

Source: KU Leuven in MIRA Study Report 'Actualisatie en verfijning klimaatscenario's tot 2100 voor Vlaanderen' (2015)

When the annual average temperature increase is broken down over the 12 months of the year, increases are found in 100 years that vary on average between 0.9 ˚C and 6.2 ˚C over the winter months of December-January-February and between 0.2 ˚C and 8.9 ˚C over the summer months of June-July-August (Figure 34). The increases in seasonal and monthly averages can therefore be much more pronounced than the annual average increases.

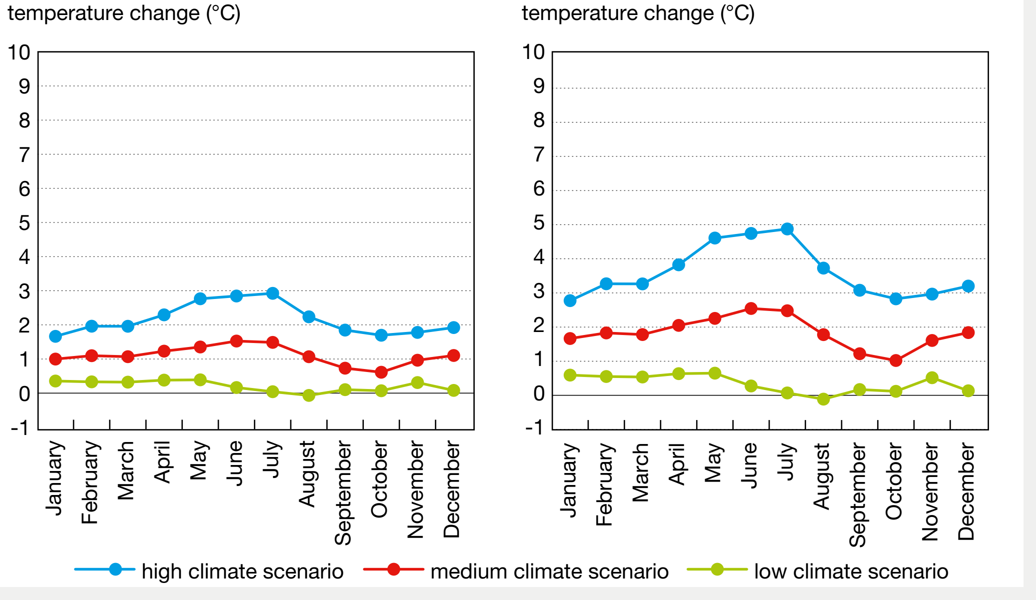
Figure 34: *Climate scenarios for the absolute change in monthly average temperature (Uccle, over 100 years)*



Source: KU Leuven in MIRA Study Report 'Actualisatie en verfijning klimaatscenario's tot 2100 voor Vlaanderen' (2015)

Over 50 and 30 years these increases are more or less proportionally lower (Figure 35, Tables 1 and 2). Over 30 years, for example, the increase in the annual average temperature in Uccle varies between 0.2 °C and 2.2 °C. The increase in the seasonal average temperature is between 0.3 °C and 1.8 °C for the winter and between 0.05 °C and 2.7 °C for the summer.

Figure 35: *Climate scenarios for the absolute change in monthly average temperature (Uccle, over 30 years (left) and 50 years (right))*



Source: KU Leuven in MIRA Study Report 'Actualisatie en verfijning klimaatscenario's tot 2100 voor Vlaanderen' (2015)

Table 2: *Climate scenarios for the absolute change in seasonal average temperature in winter and summer (Uccle, over 100, 50 and 30 years)*

	100 years		50 years		30 years	
	Dec-Jan-Feb	Jun-Jul-Aug	Dec-Jan-Feb	Jun-Jul-Aug	Dec-Jan-Feb	Jun-Jul-Aug
high	+6.2 °C	+8.9 °C	+3.1 °C	+4.5 °C	+1.8 °C	+2.7 °C
medium	+3.6 °C	+4.5 °C	+1.8 °C	+2.3 °C	+1.1 °C	+1.4 °C
low	+0.9 °C	+0.2 °C	+0.4 °C	+0.1 °C	+0.3 °C	+0.05 °C

Source: KU Leuven in MIRA Study Report 'Actualisatie en verfijning klimaatscenario's tot 2100 voor Vlaanderen' (2015)

3.2.2 Extreme temperatures

The annual, monthly and seasonal average temperatures provide an insight into the average increase over longer periods of time, but for many sectors the risks are primarily attributable to the occurrence of extremely warm or extremely cold days. That is why Table 3 indicates the change in the number of extremely warm days (with a daily average temperature above 25 °C), and the number of extremely cold days (with a daily average temperature below 0 °C).

Over 100 years the number of extremely warm days may increase by on average 0 (low scenario) to 64 days (high scenario) per year. Over 30 years, this increase may be maximum 19 days. Over 100 years the number of extremely cold days may decrease by on average 1 (low scenario) to 33 days (high scenario) per year. Over 30 years, this increase may be maximum 10 days.

Table 3: *Climate scenarios for the absolute change in the number of days per year with daily average temperatures above 25 °C (extremely warm days) or below 0 °C (extremely cold days) (Uccle, over 100, 50 and 30 years)*

	100 years		50 years		30 years	
	>25 °C	<0 °C	>25 °C	<0 °C	>25 °C	<0 °C
high	+64 (10)	-33 (33)	+32 (10)	-17 (33)	+19 (10)	-10 (33)
medium	+16 (4)	-7 (10)	+8 (4)	-4 (10)	+5 (4)	-2 (10)
low	0 (0)	-1 (3)	0 (0)	-1 (3)	0 (0)	0 (3)

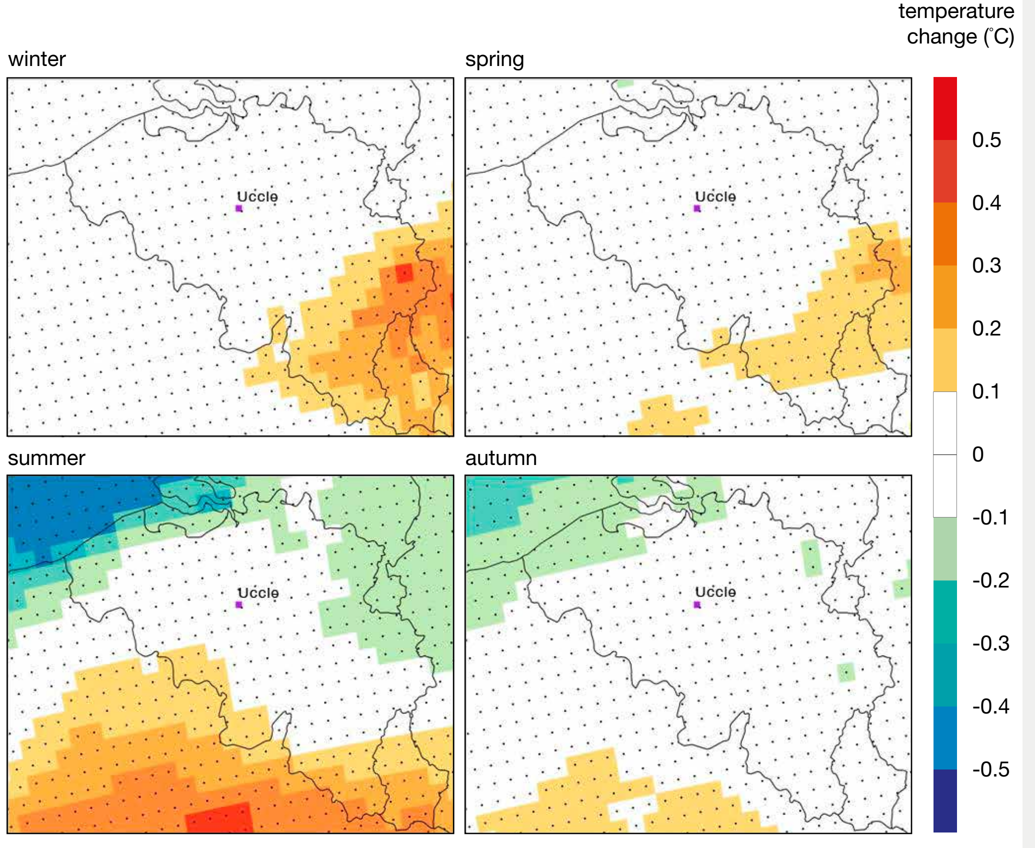
The values between brackets indicate the average number of days per year with a daily average temperature above 25 °C or below 0 °C in Uccle in the historical climate (1961-1990) as calculated in the control runs with the climate models. The differences between the three climate scenarios indicate the uncertainty in the results of these models, also for the control runs.

Source: KU Leuven in MIRA Study Report 'Actualisatie en verfijning klimaatscenario's tot 2100 voor Vlaanderen' (2015)

3.2.3 Spatial patterns

The projection of the annual average warming for the end of the century increases from north to south (Figure 36). However, this regional pattern is weak with respect to the expected change. In summer, the regional differences are greatest and the projections for the coastal areas are up to approximately 0.3 °C lower than in Uccle, and for Luxembourg up to approximately 0.3 °C higher. These differences are mainly determined by the proximity of the coast, which has a mitigating effect on warming.

***Figure 36:** Regional pattern of the temperature change at the end of the century with respect to Uccle*

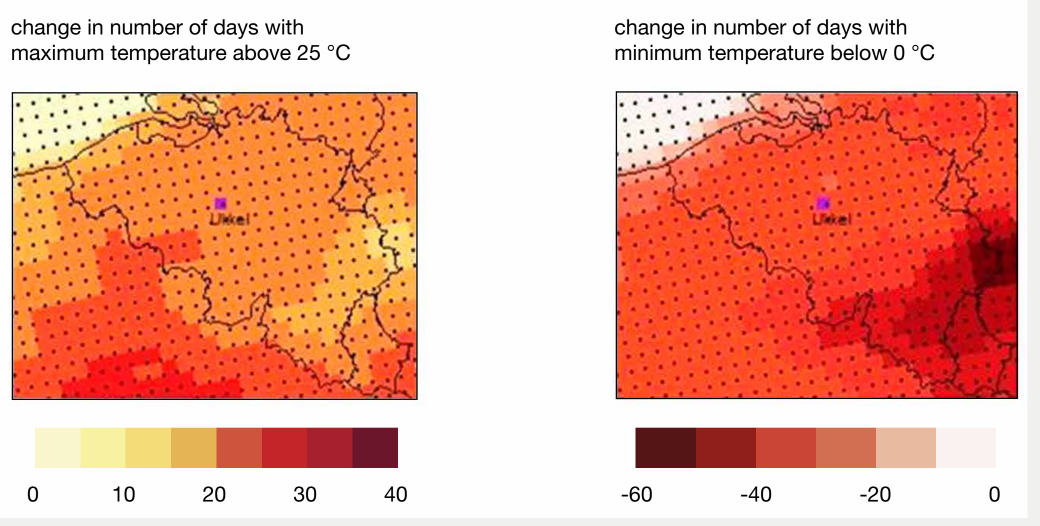


The dots indicate the significant areas, where two-thirds of the models indicate a change with the same symbol.

Source: KU Leuven in MIRA Study Report 'Actualisatie en verfijning klimaatscenario's tot 2100 voor Vlaanderen' (2015)

The regional differences become slightly more clear when we look at the change in the frequency of extremes at the end of the century. Thus, it appears that in 85 % of the model results available for Belgium, the sharpest increase in number of days with maximum temperatures above 25 ˚C is to be found in the centre, and weaker signals near the coast and in the Ardennes (Figure 37). The decrease in the number of extremely cold days with minimum temperatures below 0 ˚C, by contrast, is situated above all in the Ardennes, probably because this region has a higher number of cold days in the present climate.

Figure 37: *Regional pattern of the change in number of days per year above 25 °C (left) and below 0 °C (right) at the end of the century*



The dots indicate the significant areas, where two-thirds of the models indicate a change with the same symbol.

Source: KU Leuven in MIRA Study Report 'Actualisatie en verfijning klimaatscenario's tot 2100 voor Vlaanderen' (2015)

3.2.4 Potential evolution of the urban heat island effect

In order to perform an analysis of the potential evolution of the heat island effect in and around our cities, it is important to combine fine-mesh climate modelling with scenarios for urban expansion. Because urban heat stress in summer varies widely from year to year, this analysis also employs climate observations over a longer period (10 years). The calculation of the urban heat indicator is analogous to that for the temperature measurements discussed in paragraph 2.1.4, taking into account the duration as well as the weight of a heat wave.

Temperature and heat stress greatly depend on the environment. That is why for the further analysis of the heat island effect we use three different categories of environment depending on the level of petrification in the surrounding 100 km^2:

- urban: 50 % or more of the surface area is petrified (as in the centres of Brussels and Antwerp),
- sub-urban and peri-urban: 25 to 50 % of the surface area is petrified (centres of Ghent, Bruges and Kortrijk, and around the city centres of Antwerp and Brussels),
- rural: less than 25 % of the surface area is petrified (remaining Flemish territory).

The combined effect of climate change and urban expansion on the average number of heat wave degree days in a year is significant for the medium and high climate scenarios. The increase is most pronounced for the urban areas with respective increases from 14 to 70 degree days (medium climate scenario) and from 14 to 236 degree days (high scenario), and to a lesser extent for the sub-urban areas with increases from 8 to 42 degree days (medium climate scenario) and from 8 to 161 degree days (high climate scenario). For the rural areas, the increase is smaller in both scenarios: from 2 to 20 degree days for the medium climate scenario, and from 2 to 92 for the high climate scenario. It should be noted, however, that the average number of heat wave degree days for the future medium climate scenario in urban, sub-urban and rural areas invariably exceeds the number of heat wave degree days for the warmest summers from the recent past (2003 and 2006).

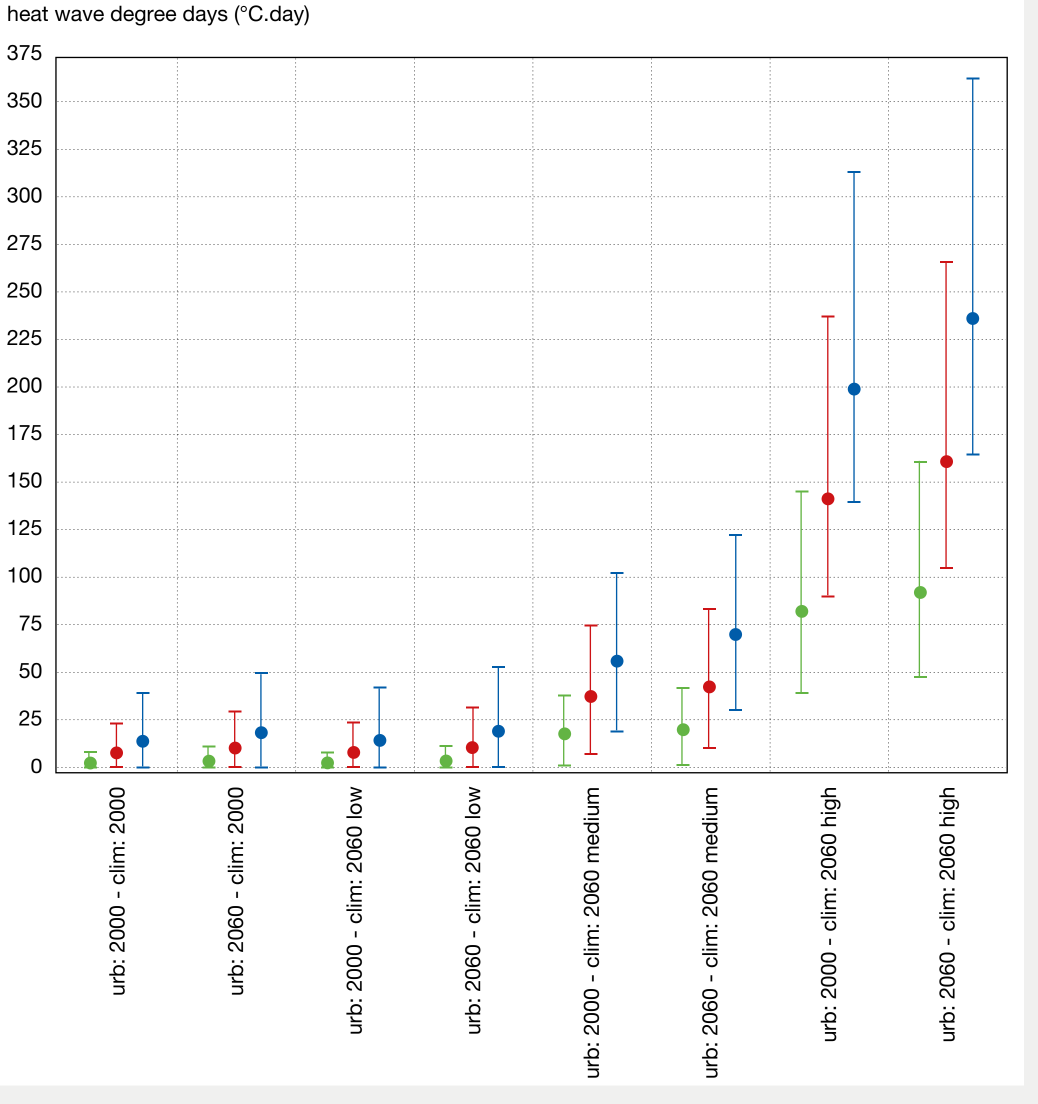
Hot summers like the one of 2003 are becoming far more routine. Already now, cities can act as hotspots of global warming, and urban expansion will further intensify those hotspots. The increase in urban heat stress due to urban expansion will be noticeable particularly in the actual city centres, even if the increase in petrification manifests itself primarily in peri-urban areas and adjoining rural areas. This is attributed to the increasing spatial extent of the heat islands around the city centres. At night, the air that is blown in the direction of the city centres is preheated more (or better cooled less) due to the increasing amount of heat stored in the city's periphery. This will eventually lead to a greater intensity of the heat islands in the city centres. This is also one of the main reasons why urban heat stress in larger cities is significantly greater than in smaller ones, as was already shown in paragraph 2.1.4. In addition, cities located more inland are more sensitive to the increase in heat stress than cities closer to the coast, *e.g.* Bruges versus Hasselt, due to the cooling effect of the sea.

Expressed in heat wave degree days, heat stress in Flemish cities is expected to increase over the coming decades by a factor 5, from a factor 1.4 for the best-case climate scenario to a factor 17.2 for the worst-case scenario (Figure 38 and 39). Two phenomena play a key role in this:

- global warming: greenhouse gas emissions are responsible for climate change with rising temperatures. As cities are already warmer during heat waves, they are the most vulnerable. The sharper increase in heat stress in cities as compared to rural areas is clearly visible in Figure 39 (compare top left map with maps below it);
- urban expansion: cities in Flanders continue to grow. As a result, the urban heat islands will increase in the future, both in size and in intensity (compare left maps in Figure 39 with right maps). Urban expansion causes a significant increase in urban heat stress, especially in combination with climate warming.

While the simulated increase in urban heat stress may seem drastic, it is confirmed by recent studies based on projections of global climate models from the Coupled Model Intercomparison Project No. 5 or CMIP5 (De Ridder *et al.*, 2015) referred to in paragraph 3.1.2. Thus, an analysis for a group of eight cities (Almada, Antwerp, Berlin, Bilbao, London, Rio de Janeiro, New York, Skopje) under the RCP8.5 climate scenario revealed that the 95th percentile of the minimum temperature at night in the summer will increase by on average 4.5 °C by the end of the century (2081-2100). The result is that the minimum temperature at night will exceed the nightly heat wave threshold of 18.2 °C far more often than is the case now (Lauwaet *et al.*, 2015). Another analysis for the same group of cities found that the expected number of heat wave days will increase tenfold by the end of the century; this increase was found to be consistent across the eight cities despite their great geographical and morphological diversity (Hooyberghs *et al.*, 2015).

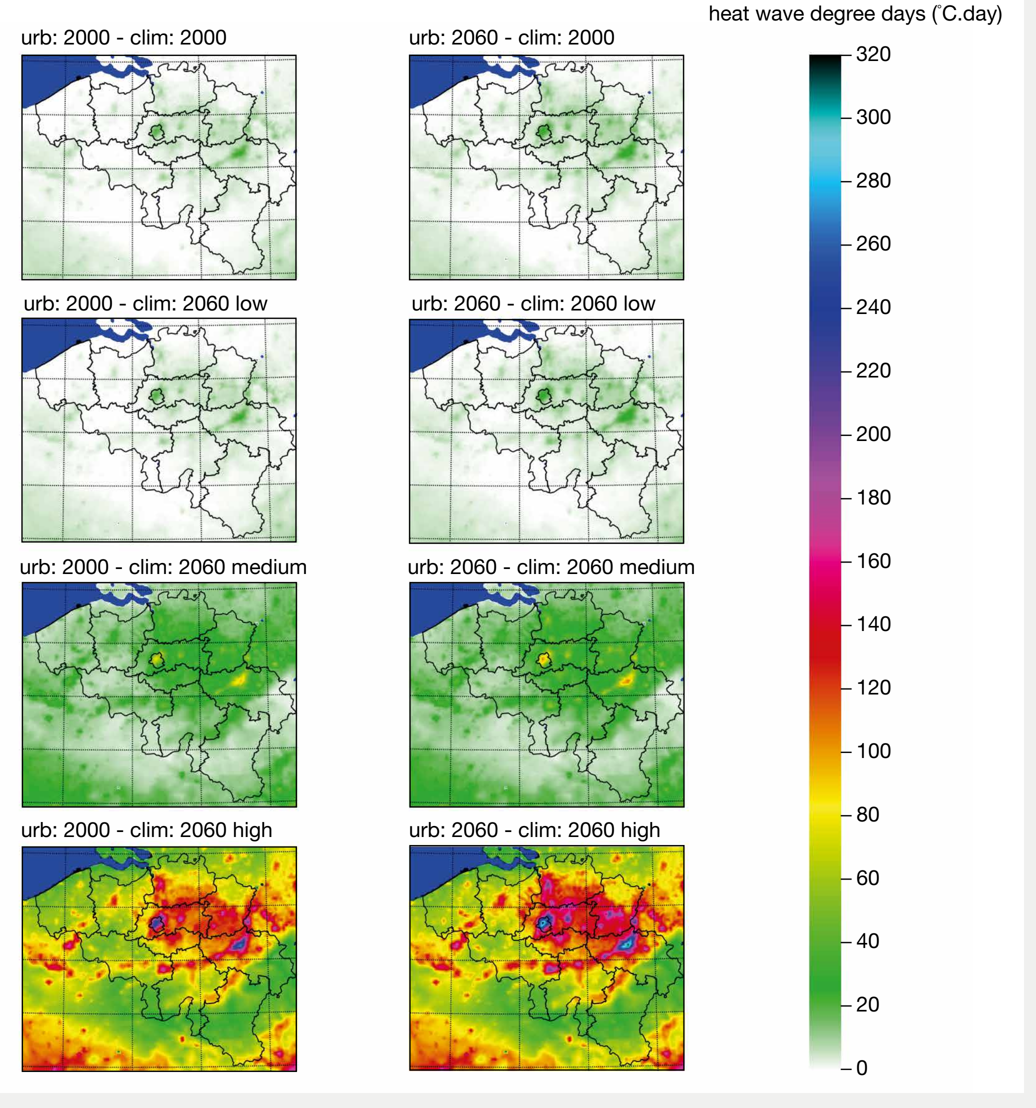
Figure 38: *Evolution of annual number of heat wave degree days for urban areas, peri-urban or sub-urban areas, and rural areas according to different climate scenarios (Flanders, 2000-2010 versus 2060-2070)*



Urban areas: blue symbols; peri-urban or sub-urban areas: red symbols; rural areas: green symbols.
The dots indicate the average values over ten years, the horizontal lines correspond to the 16th and 84th percentiles.
Clim: 2000 designates the recent past from 2000 to 2010, and clim: 2060 the climate in the period 2060-2070 according to the low, medium and high climate scenario respectively.
The heat stress is shown both for the urban land use of 2000 (urb: 2000) and for the expected land use in 2060 (urb: 2060).

Source: KU Leuven and VITO in MIRA Study Report 'Indicatoren van het stedelijk hitte-eiland in Vlaanderen' (2015)

Figure 39: *Potential evolution of the spatial heat stress indicator (Belgium, 2000-2010 versus 2060-2070)*



On the basis of urban climate modelling for the Belgian territory, the heat wave degree days were calculated as an average over 10 years for:

1. the recent past from 2000 to 2010 (clim: 2000, top maps), and
2. for the low, medium and high climate scenarios respectively in 2060-2070 (clim: 2060 – low/medium/high).

The heat stress is shown both for the urban land use of 2000 (urb: 2000, maps on the left) and for the expected land use in 2060 (urb: 2060, maps on the right).

Source: KU Leuven and VITO in MIRA Study Report ‘Indicatoren van het stedelijk hitte-eiland in Vlaanderen’ (2015)

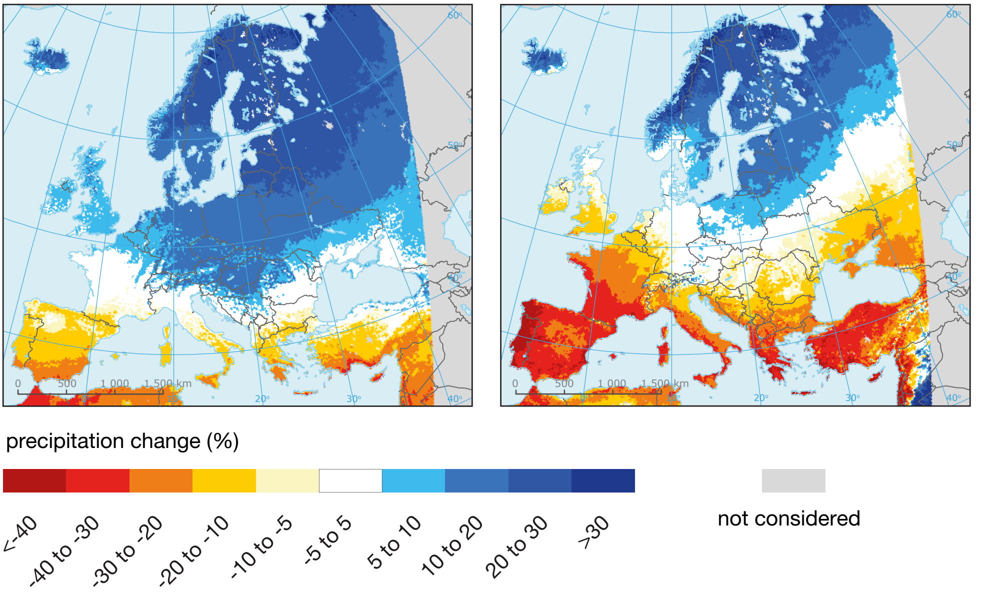
3.3 Precipitation and potential evapotranspiration

3.3.1 Average precipitation

The global water cycle will respond to global warming and the changes in precipitation will not be uniform across the Earth. In general, the contrast between dry and wet regions and between the seasons will intensify (IPCC, 2013). This pattern is also confirmed by the regional model results for Europe: by the end of this century a precipitation increase of up to 30 % is expected in Central and Northern Europe, and a decrease of up to 40 % in Southern Europe (Figure 40) in the RCP8.5 scenario. During the summer, the region where desiccation occurs moves up farther to the North. In the RCP4.5 scenario, a similar, albeit less pronounced, spatial pattern is expected.

These changes are consistent with what took place in Europe over the last 50 years: in Scandinavia and the Baltic states, annual precipitation has increased by more than 17 mm since 1960, whereas on the Iberian Peninsula, mainly in Portugal, precipitation decreased by 90 mm per decade (Haylock *et al.*, 2008).

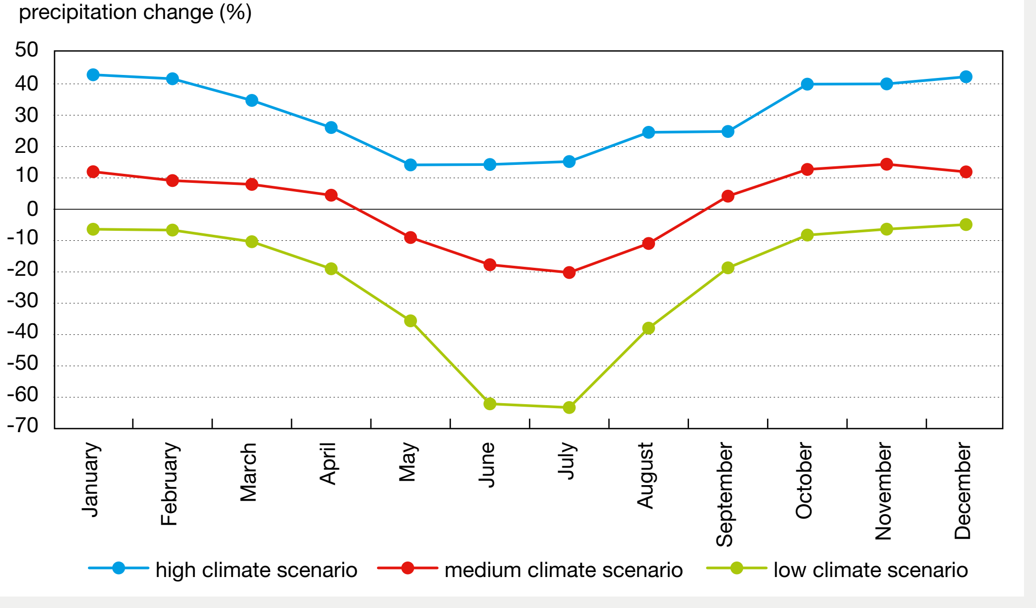
Figure 40: *Projected change in the total precipitation per year (left) and in summer (right) in the period 2071-2100 as compared to 1971-2000, for the RCP8.5 scenario*



Source: EEA (2014)

Belgium is located in a transition zone with wetting in the winter and desiccation in the summer and a slight increase in annual average precipitation (Figure 40). The derived climate scenarios for our country show relative precipitation changes between a status quo and +38 % in winter precipitation volume over 100 years, and between +18 % and -52 % in summer precipitation volume (Figure 41, Table 4). Over 30 years, the increase in the winter is between approximately 0 % and +11 % and the change in the summer between +5 % and -16 %.

Figure 41: *Climate scenarios for the change in monthly average precipitation (Uccle, over 100 years)*



Source: KU Leuven in MIRA Study Report 'Actualisatie en verfijning klimaatscenario's tot 2100 voor Vlaanderen' (2015)

Table 4: *Climate scenarios for the change in seasonal precipitation in winter and summer (Uccle, over 100, 50 and 30 years)*

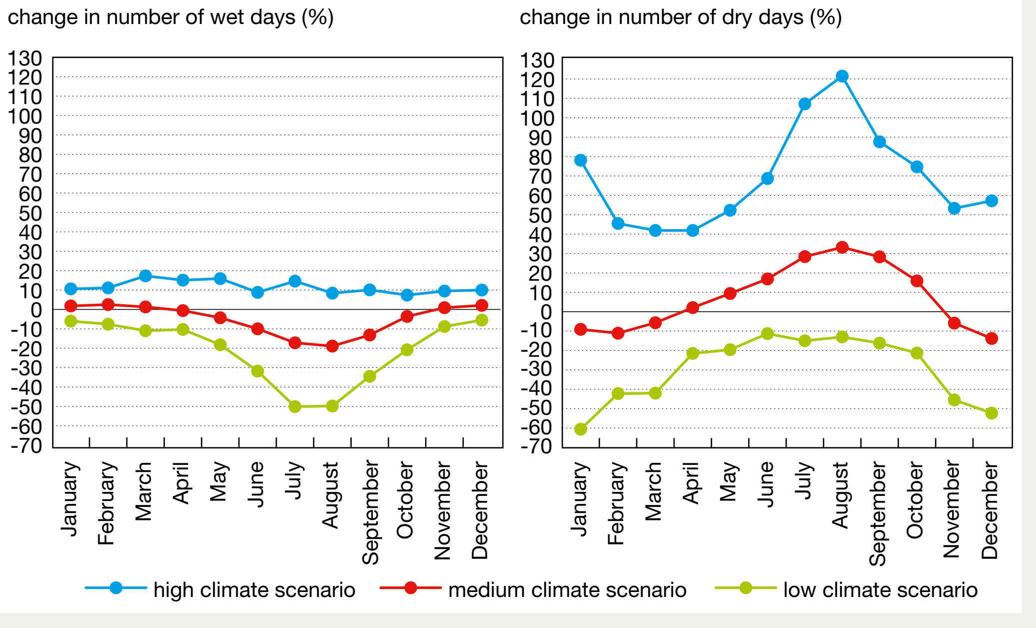
	100 years		50 years		30 years	
	Dec-Jan-Feb	Jun-Jul-Aug	Dec-Jan-Feb	Jun-Jul-Aug	Dec-Jan-Feb	Jun-Jul-Aug
high	+38 %	+18 %	+19 %	+9 %	+11 %	+5 %
medium	+12 %	-15 %	+6 %	-7 %	+3 %	-4 %
low	-1 %	-52 %	-0.6 %	-26 %	-0.4 %	-16 %

Source: KU Leuven in MIRA Study Report 'Actualisatie en verfijning klimaatscenario's tot 2100 voor Vlaanderen' (2015)

Figure 42 indicates the changes in the number of wet and dry days: if the daily precipitation is equal to or less than 0.1 mm, a day is considered dry, and wet if it is greater than 0.1 mm. The percentage increase in the number of wet days and decrease in the number of dry days is not identical because the number of wet or dry days in the present climate differs (other denominator in the calculation of the relative difference or the percentage change).

Figure 42 and associated Table 5 show that the changes in winter precipitation (average increase) are partly the result of changes in the number of wet or dry days. For the three climate scenarios, the change in number of wet days (Figure 42, left) is centred more around zero than is the change in total monthly or seasonal precipitation (Figure 41; Table 4). This means that the average increase in winter precipitation is not so much the result of a change in the number of wet days, but above all of changing daily precipitation intensities.

Figure 42: *Climate scenarios for the change in the number of wet days (left) and the number of dry days (right) (Uccle, over 100 years)*



The high, medium and low scenarios were calculated separately for the number of wet days and for the number of dry days. The number of wet days and the number of dry days with the same scenario therefore do not necessarily originate from the same climate model, and are therefore not necessarily consistent.

Source: KU Leuven in MIRA Study Report 'Actualisatie en verfijning klimaatscenario's tot 2100 voor Vlaanderen' (2015)

The situation for the summer is different. During the summer months, the number of wet days tends to decrease and the number of dry days tends to increase. Moreover, for the three climate scenarios, these decreases and increases are clearly not centred around zero. The least extreme climate scenario, for example, suggests only a slight decrease in the number of dry days or a slight increase in the number of wet days, whereas the most extreme scenario suggests a very sharp increase in the number of dry days (90 % over 100 years) or a sharp decrease in the number of wet days (41 % over 100 years).

Table 5: *Climate scenarios for the change in number of wet and dry days in winter and summer (Uccle, over 100, 50 and 30 years)*

		100 years		50 years		30 years	
		Dec-Jan-Feb	Jun-Jul-Aug	Dec-Jan-Feb	Jun-Jul-Aug	Dec-Jan-Feb	Jun-Jul-Aug
wet days	high	+8 %	+4 %	+4 %	+2 %	+2 %	+1 %
	medium	+1.5 %	-15 %	+0.8 %	-8 %	+0.5 %	-5 %
	low	-5 %	-41 %	-2 %	-21 %	-1 %	-12 %
dry days	high	+42 %	+90 %	+21 %	+45 %	+13 %	+27 %
	medium	-11 %	+28 %	-5 %	+14 %	-3 %	+9 %
	low	-44 %	-6 %	-22 %	-3 %	-13 %	-2 %

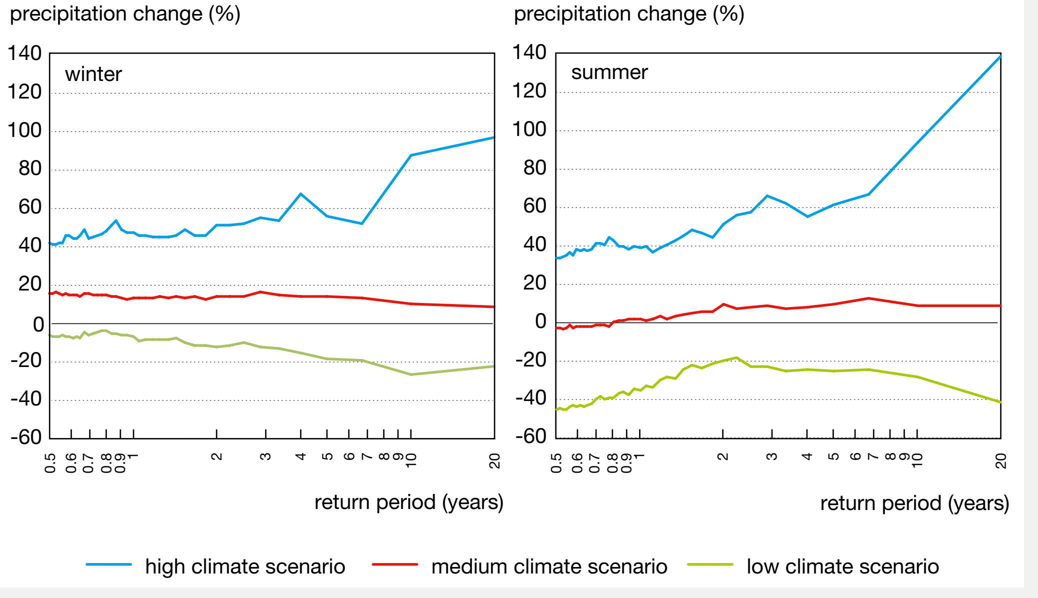
Source: KU Leuven in MIRA Study Report 'Actualisatie en verfijning klimaatscenario's tot 2100 voor Vlaanderen' (2015)

3.3.2 Extreme precipitation

For the precipitation extremes (daily precipitation intensities), the precipitation change is analysed as a function of the return period (Figure 43). When taking into account the higher uncertainty in the precipitation change for the greater return periods (*i.e.* greater difference between high and low scenario), the percentage precipitation change for the winter is found not to increase systematically with the return period for all scenarios: only for the high climate scenario an increase in the percentage change in precipitation intensity is found for higher return periods. For the summer, the medium and especially the high climate scenario suggest a systematic increase in the percentage precipitation change as a function of the return period.

For the winter months, Table 6 calculates the percentage precipitation change, averaged for all precipitation intensities with a return period greater than 0.1 years. This change varies from -10 % for the low scenario to +53 % for the high scenario over 100 years.

Figure 43: *Percentage change in precipitation intensities as a function of the return period both in winter (left) and in summer (right) with a changing climate (Uccle, over 100 years)*



Source: KU Leuven in MIRA Study Report 'Actualisatie en verfijning klimaatscenario's tot 2100 voor Vlaanderen' (2015)

Table 6: *Climate scenarios for the percentage change in winter precipitation intensities with return periods greater than 0.1 years (Uccle, over 100, 50 and 30 years)*

	100 years	50 years	30 years
high	+53 %	+27 %	+16 %
medium	+15 %	+8 %	+5 %
low	-10 %	-5 %	-3 %

Source: KU Leuven in MIRA Study Report 'Actualisatie en verfijning klimaatscenario's tot 2100 voor Vlaanderen' (2015)

For the summer months, averaging makes little sense, because the percentage change increases with increasing return periods (Figure 43, right; Table 7). For a return period of two years, for example, the change amounts to +43 % over 100 years. The more exceptional the precipitation, the greater the change: up to +62 % over 100 years for a return period of five years, up to +109 % for 20 years, etc. This means that during the summer months the most exceptional rainfall is likely to increase the most in intensity.

Table 7: *Climate scenarios for the change in precipitation intensities with return periods between 1 and 30 years in the summer (Uccle, over 100, 50 and 30 years)*

over 100 years						
	1 year	2 years	5 years	10 years	20 years	30 years
high	+38 %	+43 %	+62 %	+66 %	+109 %	+138 %
medium	-2 %	+4 %	+8 %	+13 %	+9 %	+9 %
low	-42 %	-29 %	-25 %	-25 %	-33 %	-41 %
over 50 years						
	1 year	2 years	5 years	10 years	20 years	30 years
high	+19 %	+22 %	+31 %	+33 %	+55 %	+69 %
medium	-1 %	+2 %	+4 %	+7 %	+5 %	+5 %
low	-21 %	-15 %	-13 %	-13 %	-17 %	-21 %
over 30 years						
	1 year	2 years	5 years	10 years	20 years	30 years
high	+11 %	+13 %	+19 %	+20 %	+33 %	+41 %
medium	-1 %	+1 %	+2 %	+4 %	+3 %	+3 %
low	-13 %	-9 %	-8 %	-8 %	-10 %	-12 %

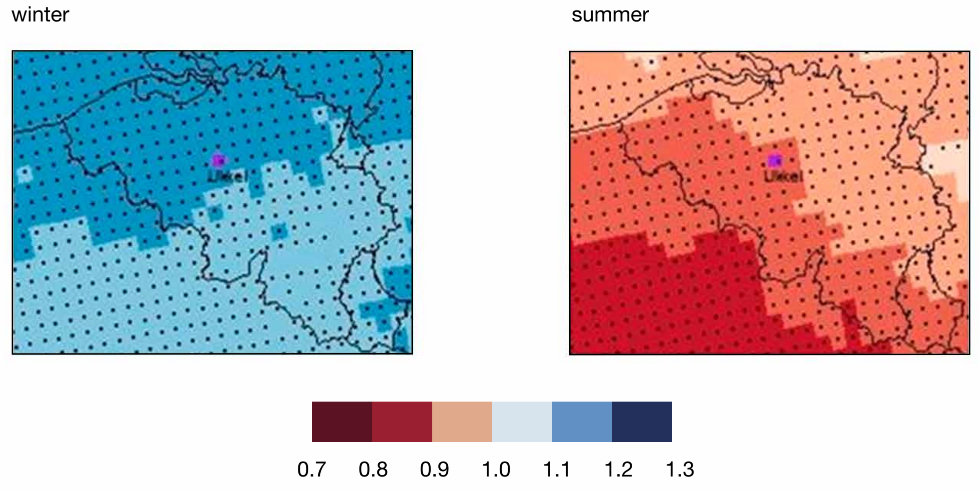
Source: KU Leuven in MIRA Study Report 'Actualisatie en verfijning klimaatscenario's tot 2100 voor Vlaanderen' (2015)

3.3.3 Spatial patterns

Different patterns of precipitation changes can be detected within Belgium. The closer to the coast, the larger the increase in winter precipitation becomes (Figure 44, left). This coastal effect is greatly dependent on the interaction between changes in air currents, the temperature contrast between land and sea, and the increase in temperature. Remarkably, the climate models that expect the greatest increase in precipitation near the coast are also those with the greatest temperature gradient between the North Sea and Uccle.

For the summer, a different spatial pattern is obtained (Figure 44, right): desiccation increases towards the south, which corresponds with the large-scale European patterns (see also paragraph 3.3.1).

Figure 44: *Precipitation change by the end of the 21st century (Belgium)*



The change is indicated by relative precipitation changes or perturbation factors.
The dots indicate the significant areas, where two-thirds of the models indicate a change with the same symbol.

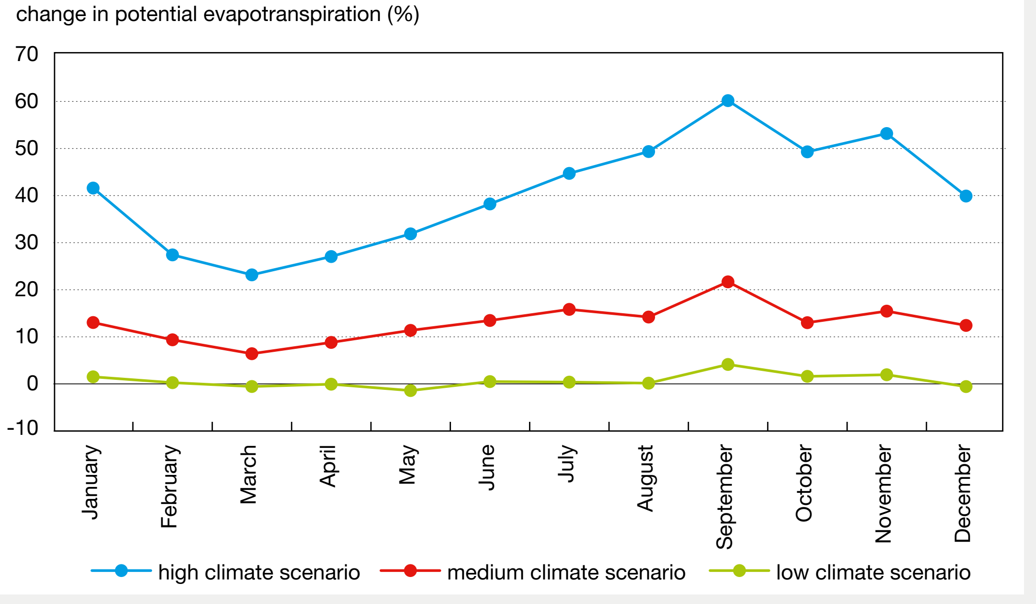
Source: KU Leuven in MIRA Study Report 'Actualisatie en verfijning klimaatscenario's tot 2100 voor Vlaanderen' (2015)

The number of days with daily precipitation above 10 mm were also analysed. In 75 % of the models, the number of days with such extreme precipitation increased by zero to fifteen days in the north of Belgium. For the south of Belgium, the models do not suggest such an increase of extremes, and the difference between the models was greater than the climate change signal.

3.3.4 Average potential evapotranspiration

For the potential evapotranspiration (see also paragraph 2.2), increases in accordance with the temperature increase are also expected (Figure 45, Table 8). This increase, averaged over the winter period, varies between +2 % (*i.e.* more or less status quo with respect to the present climate) and +35 %, and, averaged over the summer period, between +2 % and +47 % over 100 years.

***Figure 45:** Climate scenarios for the change in potential evapotranspiration (Uccle, over 100 years)*



Source: KU Leuven in MIRA Study Report 'Actualisatie en verfijning klimaatscenario's tot 2100 voor Vlaanderen' (2015)

***Table 8:** Climate scenarios for the change in potential evapotranspiration in winter and summer (Uccle, over 100, 50 and 30 years)*

	100 years		50 years		30 years	
	Dec-Jan-Feb	Jun-Jul-Aug	Dec-Jan-Feb	Jun-Jul-Aug	Dec-Jan-Feb	Jun-Jul-Aug
high	+35 %	+47 %	+18 %	+23 %	+11 %	+14 %
medium	+12 %	+17 %	+6 %	+8 %	+3 %	+5 %
low	+2 %	+2 %	+1 %	+1 %	+0.5 %	+0.5 %

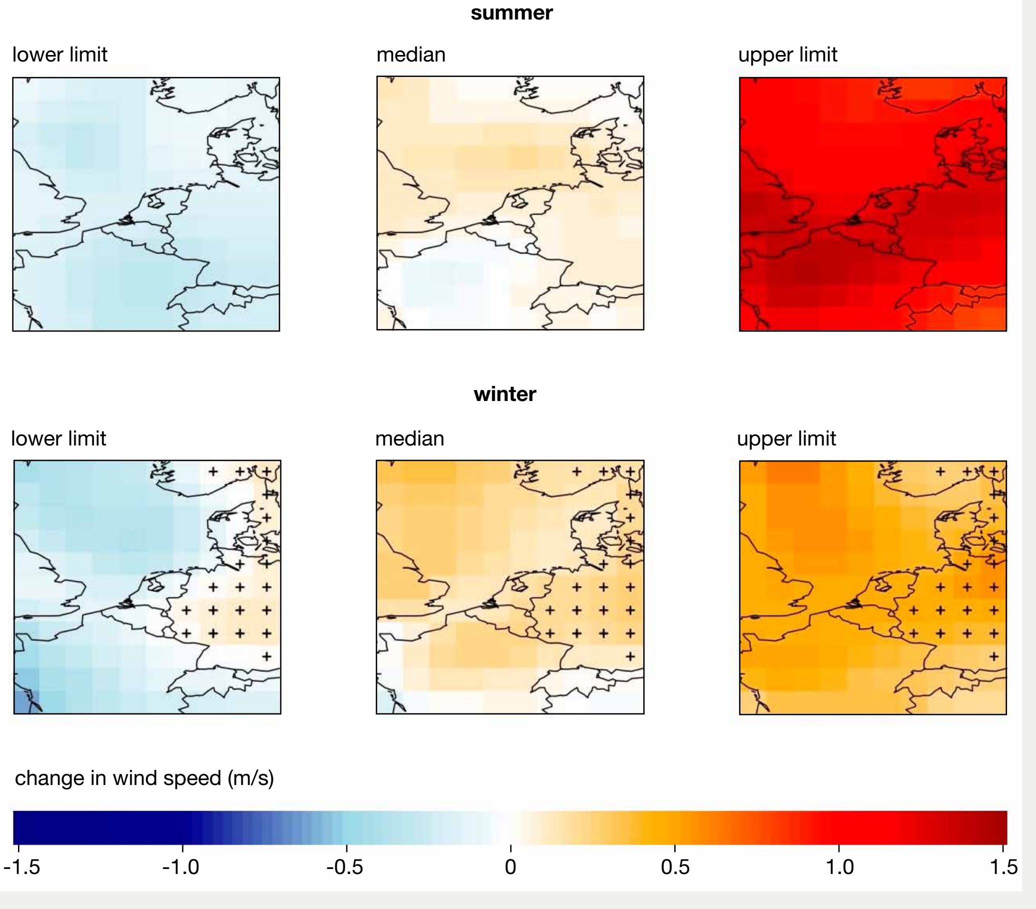
Source: KU Leuven in MIRA Study Report 'Actualisatie en verfijning klimaatscenario's tot 2100 voor Vlaanderen' (2015)

3.4 Wind

3.4.1 Wind speed

For Belgium, changes in wind are generally not significant (Figure 46) and there is great uncertainty about the direction and thus sign of the change (increasing versus decreasing).

Figure 46: *Changes in wind speed by the end of the 21st century (Belgium and surroundings)*

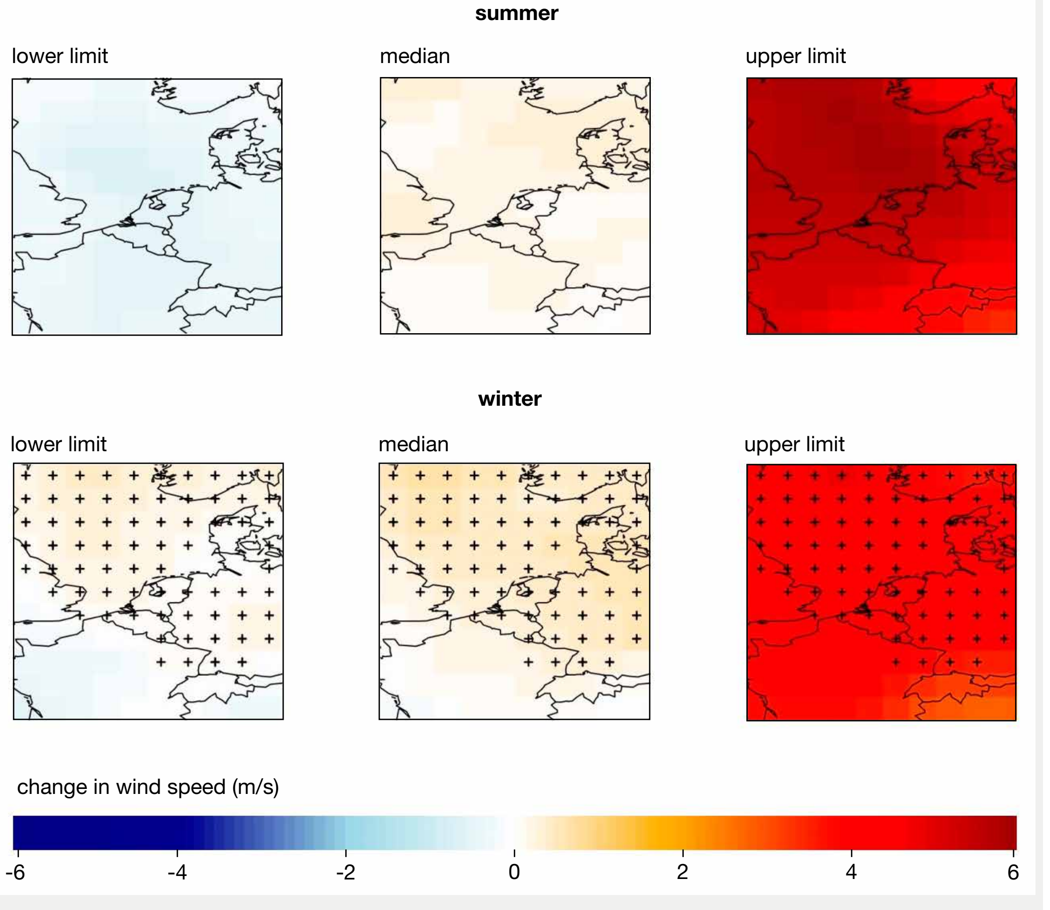


The above results reflect the output available from global climate models. The figures on the left indicate the lower limit of the available results, those in the middle the median, and those on the right the upper limit. There is a probability >66 % that the change remains within the lower limit and upper limit shown here. The crosses indicate the areas where the sign of the change is identical for both the upper and lower limits. This means that the sign of the change can be determined with a probability >85 %.

Source: KU Leuven in MIRA Study Report 'Actualisatie en verfijning klimaatscenario's tot 2100 voor Vlaanderen' (2015)

For the extremes, by contrast, a significant signal was found for Belgium (extreme wind speed is here defined as the 90th percentile of the wind speed: 9 m/s for the summer and 14 m/s for the winter): in the winter, over a period of 100 years, the wind speed during the most violent storms will increase by 0 to 30 % with a probability >66 % (Figure 47).

***Figure 47:** Change in extreme wind by the end of the 21st century*

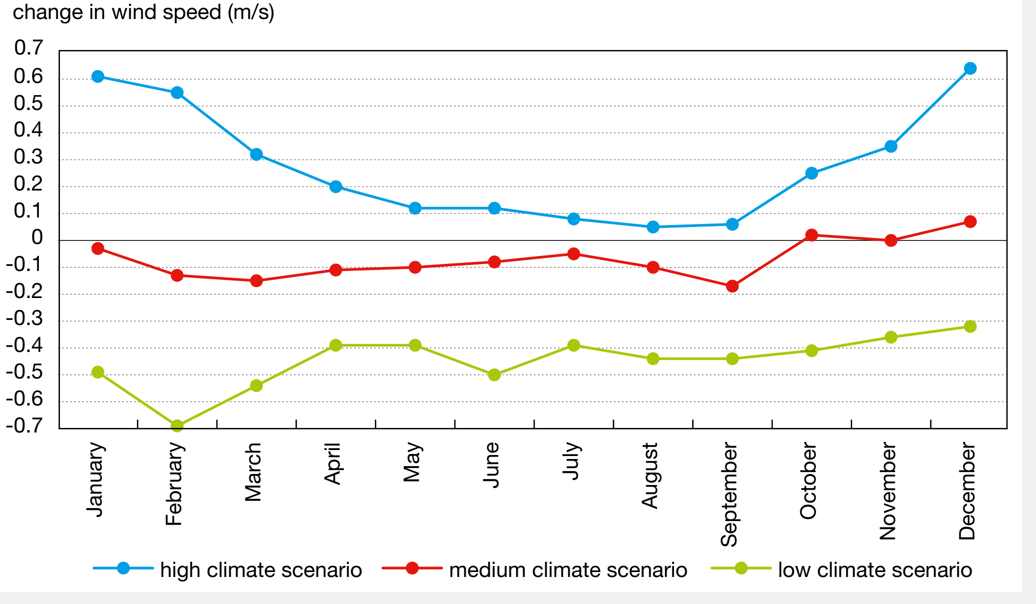


The extreme wind speed is defined here as the 90th percentile of the wind speed: 9 m/s for the summer and 14 m/s for the winter.

Source: KU Leuven in MIRA Study Report 'Actualisatie en verfijning klimaatscenario's tot 2100 voor Vlaanderen' (2015)

The fact that the wind speed for our region will change little is also apparent from the results of global climate models in Figure 48 and Table 9: the climate scenarios are more or less centralised around zero, with maximum changes in the winter months. Averaged over the winter, the average wind speed per day in the high climate scenario increases by 11 % and in the low climate scenario it decreases to 28 % over 100 years. In the summer months, these changes in wind speed are only half as large.

Figure 48: *Climate scenarios for the absolute change in wind speed (Uccle, over 100 years)*



Source: KU Leuven in MIRA Study Report 'Actualisatie en verfijning klimaatscenario's tot 2100 voor Vlaanderen' (2015)

Table 9: *Climate scenarios for the change in wind speed in winter and summer (Uccle, over 100, 50 and 30 years)*

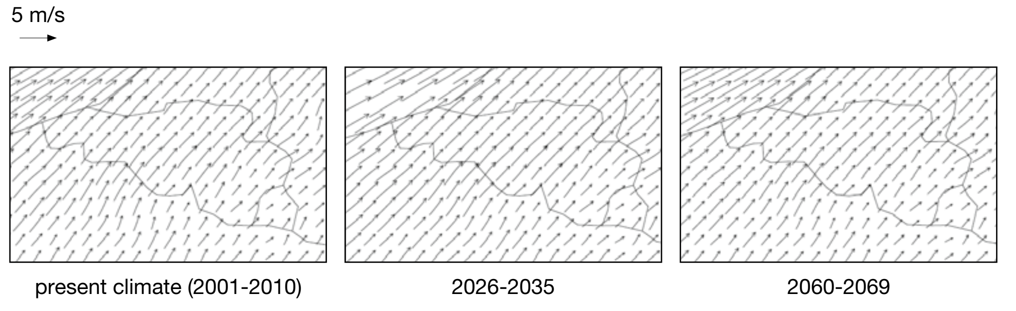
	100 years		50 years		30 years	
	Dec-Jan-Feb	Jun-Jul-Aug	Dec-Jan-Feb	Jun-Jul-Aug	Dec-Jan-Feb	Jun-Jul-Aug
high	+11 %	+6 %	+6 %	+3 %	+3 %	+2 %
medium	-1 %	-3 %	-0.5 %	-1.5 %	0 %	-1 %
low	-28 %	-16 %	-14 %	-8 %	-8 %	-5 %

Source: KU Leuven in MIRA Study Report 'Actualisatie en verfijning klimaatscenario's tot 2100 voor Vlaanderen' (2015)

3.4.2 Wind direction

Changes in the expected wind direction are also minor: no clear changes in the average wind direction are to be expected (Figure 49). On average, the wind will continue to come from the south-west.

***Figure 49:** The average wind direction in the present, the period around 2030 and the period around 2064 (Belgium)*



Source: KU Leuven in MIRA Study Report 'Actualisatie en verfijning klimaatscenario's tot 2100 voor Vlaanderen' (2015)

3.5 Maritime climate

3.5.1 Average sea level and storm surge

In the AR5 of 2013, the IPCC suggests an expected increase in the average sea level by 26 to 82 cm (2081-2100 with respect to 1986-2005) under the influence of global warming. The main contributions will come from thermal expansion of the seawater and the melting of glaciers and small ice sheets, but also from steady changes in the large ice sheets on Greenland and Antarctica. For the Netherlands, the latest scenarios of the KNMI predict a sea level rise at the Dutch coast of 50 to 100 cm by 2100 (KNMI, 2014).

For the Belgian coast, the following climate scenarios, derived by extrapolation of the historical trend (see paragraph 2.3.1), were put forward as part of the Flemish Climate Policy Plan 2013-2020 (VKP, 2013):

- a moderate scenario with an average sea level rise of 6 mm/year (or 60 cm until 2100);
- a warm scenario with an accelerated average sea level rise of 9 mm/year (or 90 cm until 2100);
- a worst-case scenario with an increase in the annual average sea level by 200 cm by 2100. This scenario is used mainly to demonstrate the need for "robust" measures, although scientifically there is little reason to assume such an increase over a period

of 100 years. These measures do, however, have an added value regardless of the scenario.

In addition to the average sea level, the evolution of the storm surge levels (with storms at the highest tide levels) is also important. That is why we also include two scenarios that were put forward by Flanders Hydraulics Research (2015). It is aimed for to defend our coast at least against a 'superstorm' with a return period of 1,000 years, *i.e.* a storm that occurs statistically once every 1,000 years. These climate scenarios constitute a guideline for the assessment of sustainable measures to reinforce the seawall until 2100:

- an average scenario: the annual average sea level increases by 24 cm by 2050 and by 64 cm by 2100, compared with 2000. The storm surge levels increase even more due to the increase in the tidal range: +30 cm by 2050 and +80 cm by 2100.
- a worst-case scenario: the annual average sea level increases by 36 cm by 2050 and by 192 cm by 2100, compared with 2000. The storm surge levels increase simultaneously by 45 cm and 240 cm respectively.

3.5.2 Currents and waves

Hydrodynamic models, wave models and sediment transport models show that currents may increase by up to 10 % for Nieuwpoort and that the waves near the beach may increase significantly.

The wave height also appears to exhibit a periodic natural variability. The historical dataset in and near the Belgian part of the North Sea only suggests a natural variability in wave height with a period of approximately seven years. There is also a seasonal cycle: on average, there are higher waves in the winter and lower waves in the summer months (VKP, 2013).

4 POTENTIAL EFFECTS AND ADAPTATION TO CLIMATE CHANGE

4 POTENTIAL EFFECTS AND ADAPTATION TO CLIMATE CHANGE[6]

Climate change will have a number of effects on society. One sector that is strongly influenced by climate is water management. In the next decades, extremely high river flow rates will occur more frequently in continental Europe, but decrease in parts of Southern Europe. There are also various studies in Flanders on specific river basins that model an increase in extreme flow rates. This is the case, for example, in the Meuse river basin. This increase in extreme flow rates will occur mainly during the winter in northern Europe due to the increase in winter precipitation. In the south of Europe there will be more, and more intense, drought periods. For all other regions, no significant patterns are detected.

Rivers will flood more often in the future. As more people settle in flood prone areas, more people and property will be exposed to the consequences of floods. The parts of Europe that are most sensitive to river flooding are the United Kingdom, and central and northern Europe, including Belgium.

Sea level rise may in the future lead to coastal flooding, which may affect coastal cities, port facilities and other infrastructure. Countries within Europe that will suffer the greatest damage in the absence of appropriate adaptation measures are the Netherlands, Germany, France, Belgium, Denmark, Spain and Italy. Adaptation of the coastal defences (*e.g.* dikes) may, however, greatly reduce the impact and the damage cost. Coastal defences are also expected to protect an ever-larger number of people and property, so that the loss as a result of floods may also be greater in the future.

Furthermore, various research projects in Europe have identified a few other consequences that are to be expected for water management with sustained climate change:

- in many river basins in Europe, especially in southern Europe, but also in certain regions of central Europe, including Belgium, replenishment of groundwater and the level of the water table will decrease sharply by the end of the century;
- in many rivers, *e.g.* the Meuse, higher temperatures in the summer favour conditions for algae growth, whilst drought leads to reduced dilution of pollution loads.

In addition, climate change also affects public health, nature, and the ecosystems, as well as various economic sectors. Some examples:

- overheating of buildings (homes, schools, hospitals) in the summer months, resulting in increased demand for cooling energy;
- more diseases and deaths as a result of the heat, especially among the elderly. The number of deaths due to cold, by contrast, will decline;
- after 2050 the wind energy in central and northern Europe will increase during the winter and decrease during the summer. For southern Europe, a decrease in both seasons is expected, whereby the energy production of wind turbines will decrease;

6 This chapter is mainly based on van Lipzig & Willems (2015) and the MIRA indicators of the environmental themes Climate Change and Water Quality at www.milieurapport.be. Other sources are cited in the text.

- longer drought periods will cause more trees to die and the forest area to decline, also in Belgium.

The specific impact for Flanders of the new climate scenarios described in Chapter 3 has not yet been quantified. This implies that the actual consequences of the latest climate projections for specific sectors are not yet known. However, in recent years quite a number of impact modellings have been conducted with the climate scenarios as reported in the Environment Outlook 2030 (Brouwers *et al.*, 2009) and for the preparation of the flood risk management plans (FRMPs). Based on the (rather limited) differences[7] between the previous and the new climate scenarios, we can provide some indications of these consequences.

A description of some already known effects of the climate change that has occurred thus far, is given below. Moreover, based on the most recent impact calculations, the future effects for some specific sectors are outlined.

4.1 Victims of heat waves

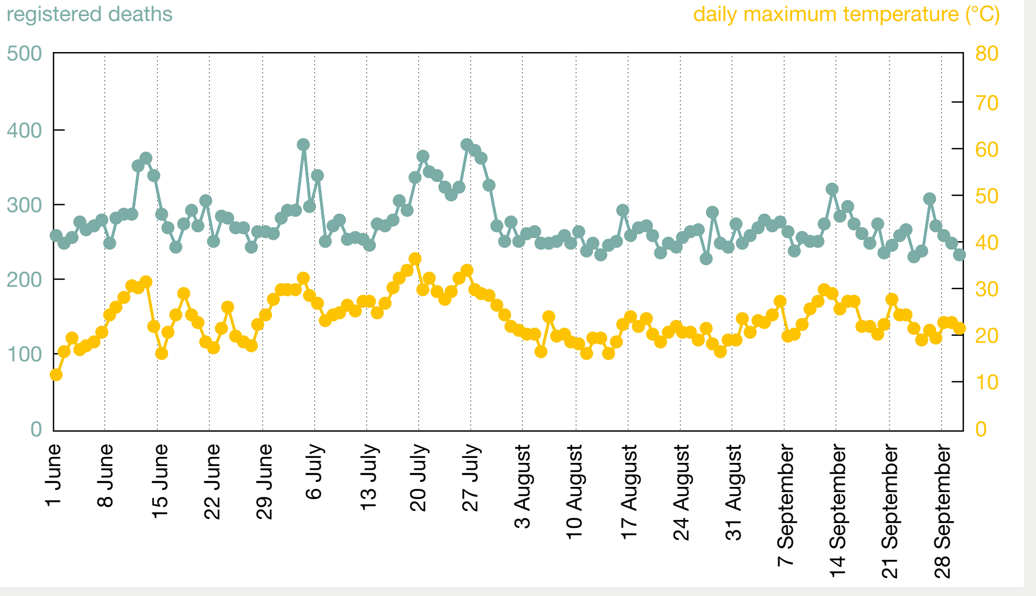
The correlation between temperature and mortality is U-shaped: mortality increases at temperatures far above or below the optimum temperature. This optimum is location-specific: the population of southern European countries is better able to deal with temperatures than inhabitants of our region.

Higher temperatures are responsible for increased mortality, especially for older people, people with cardiovascular diseases or respiratory problems, and children under four years old. This increased mortality is especially recorded during periods where the daily maximum temperature exceeds 25 ˚C (Figure 50). Such warm periods regularly coincide with periods where the health thresholds for ozone (0_3) and particulate matter (PM_{10}) are exceeded, which in turn contribute to increased mortality during periods of hot weather (see also paragraph 4.2).

7 When comparing the new climate scenarios for Flanders by 2100 as described in Chapter 3 and the previous climate scenarios from the Environment Outlook 2030 of MIRA (Brouwers *et al.*, 2009), we find that:
- the monthly average temperature changes remain comparable in order of magnitude. However, the bandwidth has increased. The model results used for the new scenarios suggest slightly higher increases for certain months and scenarios, especially for the first six months of the year (January to June) and for the high climate scenario. For these months, the new results are on average 3.3 ˚C higher for the high scenario and 1.5 ˚C for the medium scenario. For the low scenario the difference with the previous scenarios is minimal (on average only 0.1 ˚C lower);
- the winter and summer precipitation increases and decreases to the same extent;
- the changes in precipitation extremes are virtually identical;
- the potential evapotranspiration is assigned a significantly higher increase, especially for the high climate scenario.

For more detailed explanatory information on the similarities and differences between the 'old' and 'new' climate scenarios for Flanders, we refer the reader to van Lipzig N.P.M. & Willems P. (2015).

Figure 50: *Evolution of mortality rates and temperature in the summer of 2006 (Belgium)*



Source: Wetenschappelijk Instituut Volksgezondheid (2007)

In Europe, the summer of 2003 was probably the hottest summer since the year 1500. Although extreme weather events can also occur ‘accidentally’, human impact plays a major role. Research suggests that human activity doubles the risk of such a heat wave with a certainty of at least 90 %. Research regarding the number of heat deaths in the summer of 2003 shows that in twelve European countries an increased mortality was recorded in the months of June to September of that year. Total mortality in those four summer months was on average 6.99 % higher than in summer months in the reference years (1998-2002). In France, the excess mortality in the second week of August even amounted to 96.5 %. The total number of extra deaths in Europe during those four summer months amounted to 71,445. Moreover, the extreme temperatures also increased exposure to other harmful substances such as tropospheric ozone and particulate matter.

Especially in cities, people are exposed to heat stress as a result of climate change. Due to the blocking of wind and the retention of heat in concrete, asphalt and bricks, temperatures in cities can be even much higher than in the surrounding areas. Cities may thus develop into actual heat islands. Especially at night, the temperature difference with the surroundings may increase (see paragraph 2.1.4). Socio-economic factors also play a role in the increased sensitivity of city dwellers to periods of hot weather: examples are social isolation, homelessness, decreased mobility, lower incomes.

We have examined the excess mortality caused by heat waves in Belgium. This examination is based on analyses conducted by the Scientific Institute of Public Health (WIV). A heat wave is here defined as a period of at least five consecutive days where the maximum daily temperature in Uccle is 25 ˚C or more (summer days), and where the temperature on three of those days exceeds 30 ˚C (tropical days).

Belgium has had five summers with a prolonged heat wave since 1990:

- in the summer of 1994, a heat wave in combination with high ozone concentrations claimed many lives in six weeks time, with an excess mortality of 1,226 deaths;
- in 2003, our country experienced a major heat wave that lasted for fourteen days, and a second period of warm weather that lasted for thirtheen days. The excess mortality for these two periods amounted to 1,230 deaths. For the whole of the summer (June to September) of 2003, an excess mortality as high as 2,052 deaths was recorded. Also the ozone concentrations were very high;
- 2006 had two heat waves of five and 21 days respectively, and one other warm period of nine days. These three periods combined were responsible for an excess mortality of 1,263 deaths. Almost half of the victims were aged 85 or older;
- at the end of June and in the first half of July 2010, two heat waves followed each other in quick succession. The first heat wave lasted for 12 days and resulted in an excess mortality of 593 deaths. The second heat wave lasted for eight days and claimed 374 victims. In both periods the mortality was significantly higher than the reference level, with +20 % and +19 % respectively. Over 40 % of the victims were aged 85 or older;
- in the summer of 2013, especially the month of July was exceptionally warm. Between July 6 and August 4, 20 days with maximum temperatures above 25 °C, five days with maximum temperatures above 30 °C, and six days with minimum temperatures above 18 °C were recorded. The excess mortality in this warm period was nevertheless limited. Only in the age category of 85 years and older, a slight, but significant higher number of deaths were recorded (6.1 % higher than the expected mortality for this period of the year).

2007, 2008 and 2009 had no prolonged periods of hot weather, so that no significant excess mortality was recorded in the summer months. Also in the summer of 2011, the temperatures were mostly moderate. At the end of June, an excess mortality of 238 deaths was registered during a few consecutive days with maximum temperatures above 25 °C. The victims were mainly in the age category above 65 years. In the summer of 2012, a short peak in excess mortality coincided with a period of five consecutive warm days (with maxima above 25 °C) at the end of July and an excess mortality was also recorded during a heat wave in August.

The extraordinary mortality rate during heat waves is highest among elderly people and people that were already sick. Many countries have an ageing population, whereby the number of people that are sensitive to heat stress increases. This is yet another impact of climate change. Babies and young children are another potential risk group because their temperature regulation is not yet fully developed and dehydration may also occur sooner. Although it may be expected that a portion of the deaths during a heat wave occur in sensitive persons that would otherwise have died in the subsequent weeks or months, scientific research did not provide any suggestions in this regard: also after the summer months of 2003, the mortality rate continued to exceed that of the reference period.

Raising public awareness of heat-related risks and the installation of a monitoring system can substantially reduce the number of heat-related deaths. This is clearly illustrated by a comparison with the situation in France during the summer of 2003 and the subsequent summers. An analysis for the summer of 2013 shows that awareness raising is effective in Belgium, too. Although July and August were marked by prolonged periods of hot weather including two heat waves, no significant increase in the number of deaths was recorded. Specifically in cities, green spaces with sufficient vegetation and water surfaces can reduce the impact of periods of hot weather.

The impact of periods of hot weather is often less visible than the damage caused by, for example, floods or hurricanes. Yet exposure to heat appears to claim significantly more victims: compare, for example, the 1,500 victims of Hurricane Katrina of 2005 in the United States with the over 70,000 victims of the European heat wave in the summer of 2003. Heat stress is nonetheless not an isolated problem. In periods of extremely hot weather, cascades of all kinds of climate-related perturbations may occur. We illustrate this by means of a scenario that could occur in a city that is hit by a prolonged intense heat wave:

- the drought will cause the level of the watercourses to fall, thereby compromising the drinking water supply. Inland navigation will also experience problems;
- if the drinking water supply collapses, water distribution to vulnerable groups (*e.g.* single elderly people) is compromised, with the associated health effects;
- as a result of the drought, urban parks and other urban green spaces lose their cooling effect (stomata of plants close, evapotranspiration stops);
- the extreme heat causes railway tracks to buckle, resulting in disrupted train and tram services, so that commuters and goods cannot reach their destinations;
- drought, low water levels and the resultant shortage of cooling water, also compromise electricity production;
- the resultant power outages cause problems with refrigeration systems, *e.g.* in hospitals, which in the meantime become overwhelmed with heat victims;
- IT systems break down causing widespread chaos.

4.2 Impact on air quality

Reports from the European Environment Agency show that Flanders is one of the regions in Europe with the highest level of air pollution. Not only pollutant emissions, but also changes in climate have an impact on air quality:

- ozone formation is influenced by the temperature and high ozone concentrations are generally observed during heat waves;
- particulate matter is sensitive to the amount of mixing in the atmosphere and will therefore increase in conditions of still air and during periods where vertical mixing in the atmosphere is limited. Also the concentration of particulate matter in ambient air is influenced by the precipitation frequency and intensity;
- also the transport of other pollutants is influenced by the prevailing wind conditions, *e.g.* air blown in from industrialised areas.

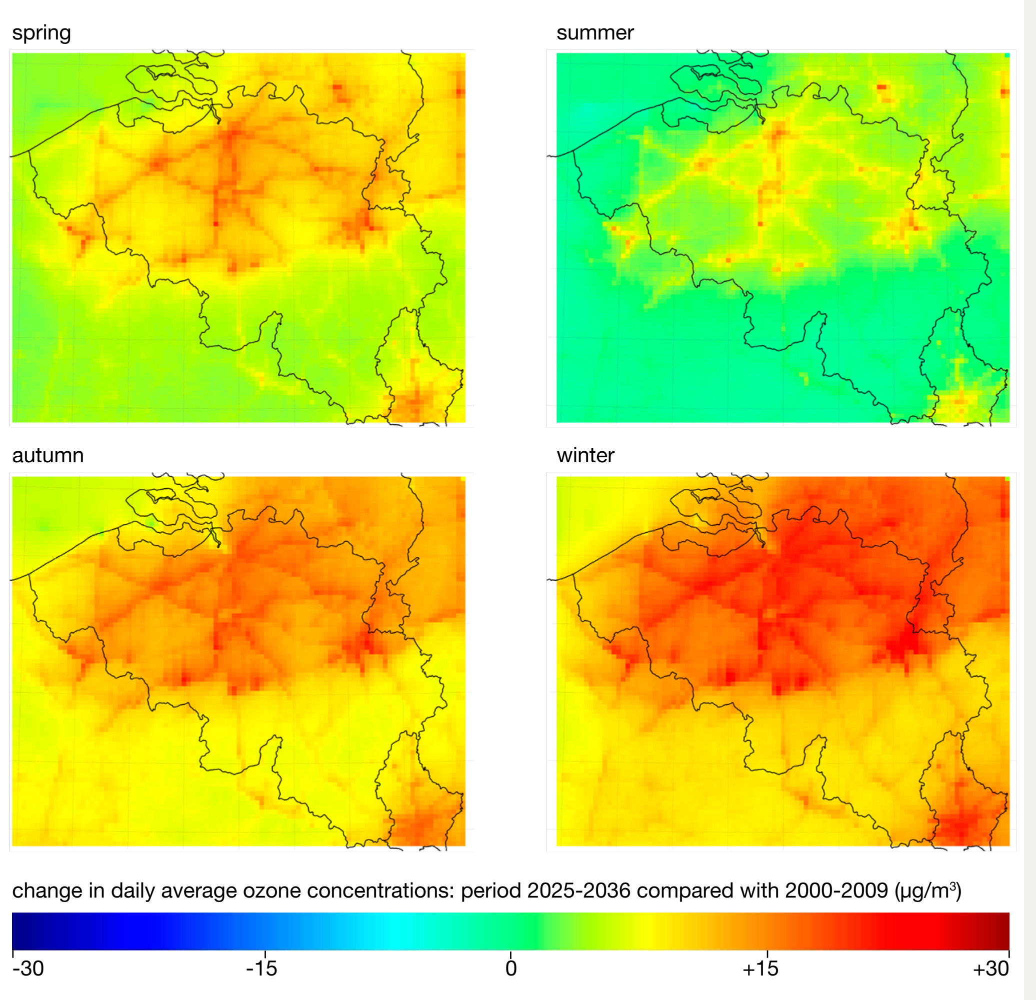
A number of studies has been carried out for Belgium that not only take into account the effect of climate change, but also the planned reductions of air pollutants emissions. An extrapolation of different emissions scenarios in combination with different meteorological conditions (MET year 2007 as approximation for the present climate, and MET year 2003 with a very warm summer as approximation for the future climate) shows that if the present climate persists, the ozone peak concentrations within Flanders will remain below the ceilings imposed by Europe for all emission scenarios. However, if climate change persists, substantial emissions reductions will be needed to remain below those ceilings: for the ozone peak concentrations, the differences in meteorological conditions between 2003 and 2007 appear to be far more important than the expected emissions reductions by 2030. To ensure compliance with the maximum ambient concentrations of particulate matter (PM_{10}), these two factors appear to be more or less equally important (Deutsch *et al.*, 2011).

While the meteorological conditions of 2003 may be considered as analogous for the future, their extrapolation does not yet produce a climate projection. It is therefore better to reckon with real climate scenarios for Flanders, as in Figure 51. The extrapolation of the RCP4.5 scenario of the IPCC shows that by 2030 a strong increase (up to +30 %) in ozone concentrations is to be expected. The greatest increases are expected to occur in the vicinity of major roads and in the centres of the cities. This increase is due to reduced ozone depletion - a process that occurs mainly at night - due to the reduction in NO_x emissions. The percentage increase is greater in winter than in summer (period with the highest O_3 concentrations) because the lower NO_x emissions also have negative effect on the formation of O_3 during the day under the influence of sunlight, a process that in Belgium is mainly relevant in the summer months. When emissions are kept constant and only the effect of the expected climate change in RCP4.5 is taken into account, the ozone concentrations increase much less sharply (to +10 % by 2030). This occurs under the influence of an increase in summer temperature and a decrease in summer precipitation, thereby facilitating the formation of O_3.

Other effects that have not yet been considered in the studies for our country may also play a role:

- downward transport of ozone from the stratosphere will, at our latitudes, probably result in an increased level of ozone at the earth's surface;
- increasing pollutants emissions in other parts of the world, notably Asia and America, may also affect the ozone concentrations in Flanders.

Figure 51: *Changes in daily average ozone concentrations by 2030 for the RCP4.5 scenario per season (spring, summer, autumn, winter)*



Source: Lauwaet *et al.* (2014)

4.3 Floods

4.3.1 Present occurrence of floods

Climate change only one of many factors

Both the number and the intensity of floods will increase under the influence of climate change. And while floods are nothing new to Flanders, it is noteworthy that Belgium has recently seen quite a few major floods. In many cases this involved areas that had not been flooded since time immemorial. Considered separately, none of these floods in Flanders is directly attributable to climate change. The scenario studies, however, indicate that climate change may influence the risk of floods in Flanders in the 21st century (see paragraphs 4.3.2 to 4.3.7).

Climate change (more intense precipitation periods and a higher seawater level) is, however, only one of the factors that determine the number of floods and the damage caused by them. In addition to the effect of climate change on the total flooding risk, changes in land use and population levels also play an important role.

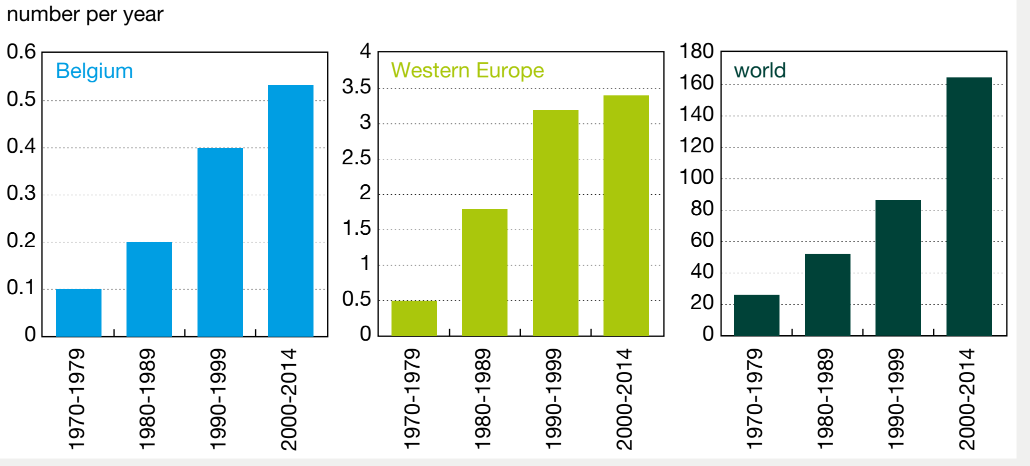
Number of registered floods per decade

The Centre for Research on the Epidemiology of Disasters, associated with the World Health Organisation and based at the Université Catholique de Louvain, maintains a database with information on the global occurrence of disasters. For a disaster to be entered into the database, it must fulfil at least one of the following criteria:

- ten or more people reported killed;
- 100 or more people reported affected;
- a declaration of a state of emergency;
- a call for international assistance.

A search of this database reveals that the number of registered floods since 1970 has increased significantly, both in Belgium, in Western Europe and in the world (Figure 52).

***Figure 52:** Evolution in the number of registered floods (1970-2014)*



Source: The OFDA/CRED International Disaster Database – www.emdat.be – Université Catholique de Louvain – Brussels – Belgium

In the period 1970-2012, floods worldwide represented 44 % of the number of registered disasters. These floods were responsible for 14 % of the registered deaths (out of a total of nearly two million) and 33 % of the economic damage caused by disasters (out of a total of almost 2,400 billion dollars (WMO, 2014b).

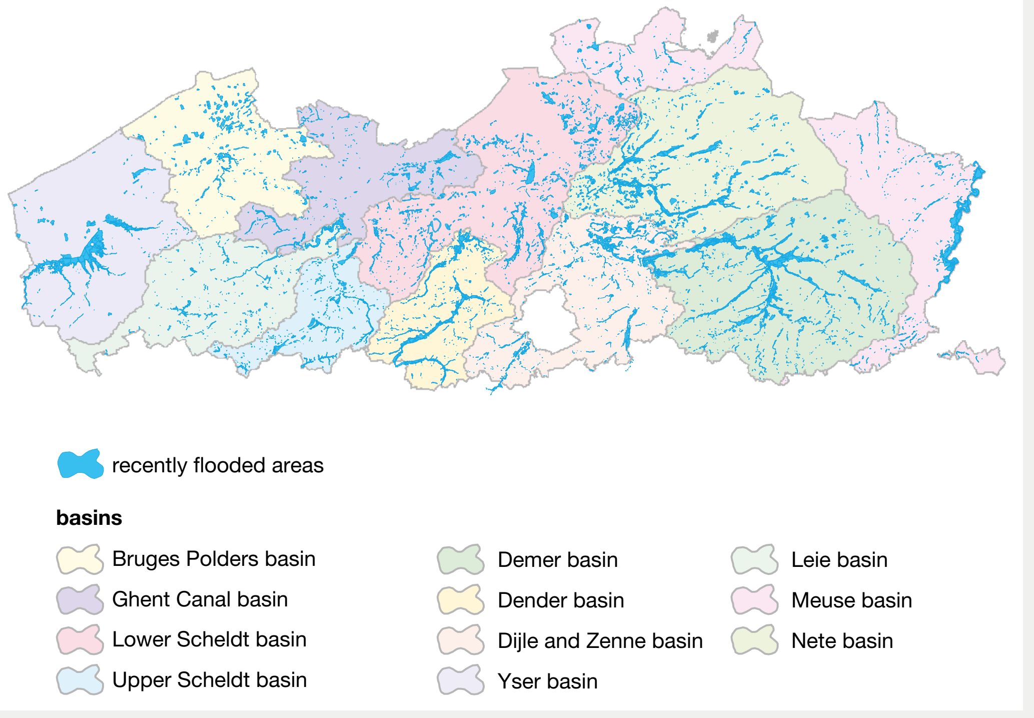
According to the European Environment Agency, floods caused 1,126 casualties in the period 1998-2009. More than three million Europeans were affected and the economic damage amounted to approximately 52 billion euros (EEA, 2010). Together with storms, floods are the natural disasters that cause the greatest amount of economic damage. Economic damage due to floods has increased over the past decades. This increase is caused by an increase in population and prosperity, but probably also because of better data collection and/or climate change.

Although there is solid evidence for anthropogenic climate change in Europe, there is still no final proof that climate change is the reason for a trend in flooding on a continental scale. What has been demonstrated is that the increased greenhouse gases emissions by man have contributed to the intensification of heavy precipitation in the northern hemisphere in the second half of the 20th century (see paragraph 2.3.3).

Recently flooded areas in Flanders

The map in Figure 53 shows that the total surface area of recently flooded areas represents almost 5 % of the Flemish territory. This map is an important policy instrument, among other things for advice concerning permits within the context of the 'Watertoets' and the production of flooding maps for protection against natural disasters.

***Figure 53:** Recently flooded areas (Flanders, 1988-2013)*



Source: VMM

Towards management of the flooding risks

In the past, it was often decided to drain the water as quickly as possible in periods of high water. History has taught that this does not reduce the flood danger, it just moves to downstream areas. In the European Flood Directive the emphasis is therefore on limiting:

- the economic consequences (the damage that is caused by flooding);
- the consequences for people and the social consequences (victims, those otherwise affected);
- the ecological damage;
- the damage to cultural heritage.

Risk calculations not only take into account the probability of a specific flood occurring, but also of its potential consequences (damage). The damage can vary greatly depending on the land use. The current policy is therefore focussed on allowing flooding to occur in areas where the damage is minimal. To do this, the four above-mentioned categories from the Flood Directive are considered.

For the calculation of both risk and damage, the LATIS software was developed by Flanders Hydraulics Research (Department of Mobility and Public Works of the Flemish Government) and Ghent University. This software can be used to determine the economic damage and the number of victims in the event of a flood. These results cover the whole geographical area of Flanders. At present, the software is being expanded with new modules (expected for 2016) which will also allow the calculation of the social, cultural and ecological impact of floods.

A broad community debate, supported by risk analyses, should lead to a selection of measures. Not only do the costs and benefits of the measures play an important role here, but also the distribution over the actors, including water managers, spatial planning and insurances, is significant. Flanders will include the selected measures in the new flood risk management plans by the end of 2015 as part of the river basin management plans.

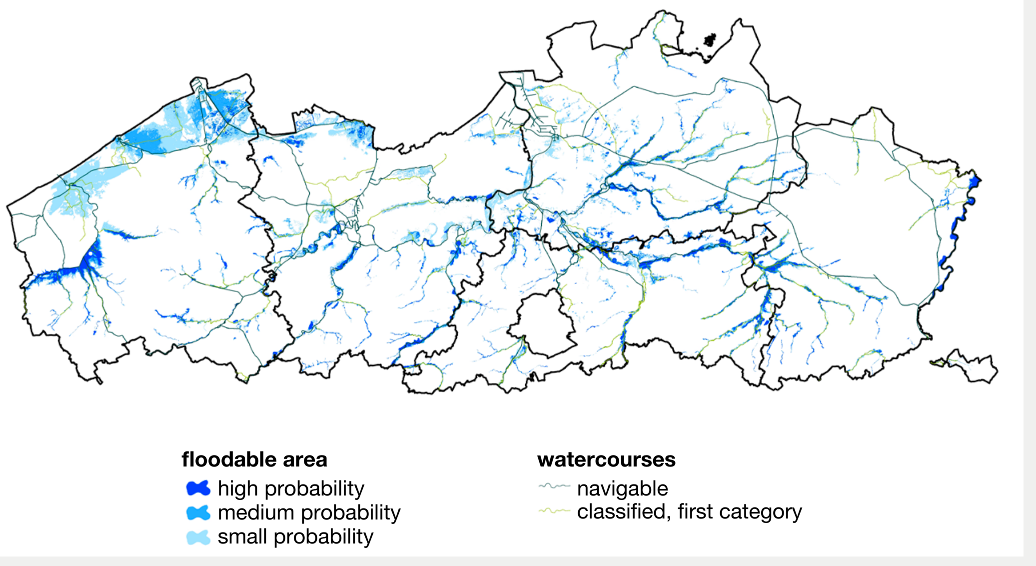
Present flooding hazard

The flood hazard maps describe the ‘physical properties’ of floods such as flood contours, water depths and flow rates. These are model-based maps on the basis of potentially high-risk watercourses. A map of the floodable area shows the areas where there is a flood hazard, both from the watercourses and from the sea (Figure 54). As opposed to floods from the watercourses, breach formation in the seawall has been considered for floods from the sea. The map shows the size of the flooding for three different flooding scenarios:

- a low probability or an extreme event corresponds to a return period of an order of magnitude of 1,000 years;
- a medium probability involves a return period of 100 years;
- a high probability corresponds statistically to an event with a return period of 10 years.

The area in Flanders that has a small probability of flooding covers a surface area of 102,610 ha. This amounts to 7.5 % of the total surface of Flanders. Furthermore, 2.35 % of Flanders has a high probability and 4.21 % a medium probability of flooding. Major basins with a medium and low probability of flooding are the Yser basin and the basin of the Bruges Polders. These are mainly floods from the sea as a result of breaches in the seawall.

Figure 54: *Flood hazard map for the present climate (Flanders, 2012)*



Low probability: extreme event with a return period on the order of magnitude of 1,000 years.
Medium probability: event with a return period of 100 years.
High probability: an event that occurs once every 10 years.

Source: www.waterinfo.be

The flood depths for floods with high probability usually vary between 25 and 50 cm. In a number of specific areas, *e.g.* at the confluence of two watercourses, the water depth on the flooded land surface may amount to one metre and in the winter bed of the Meuse even to more than two metres. For floods with medium probability, the water depth increases in most places by another 10 to 30 cm. For floods with low probability, another 10 to 50 cm with peaks of up to one metre and more should be added.

In the coastal zone, floods may lead to high flow rates (1 to 2 m/s) at sea dikes and at potential breaches in the seawall. The combination of high flow velocities, high rise rates and high water depths makes for a high risk of casualties. Peak values of flow velocities of up to more than 10 m/s are initiated on sea dikes in seaside resorts by high waves that break over the crown of the sea dike. This is the case with superstorms when the dry beach is inundated due to beach erosion and/or a very high water level. Such waves with their high velocities may cause many casualties near buildings on the sea dike.

Present flooding risk

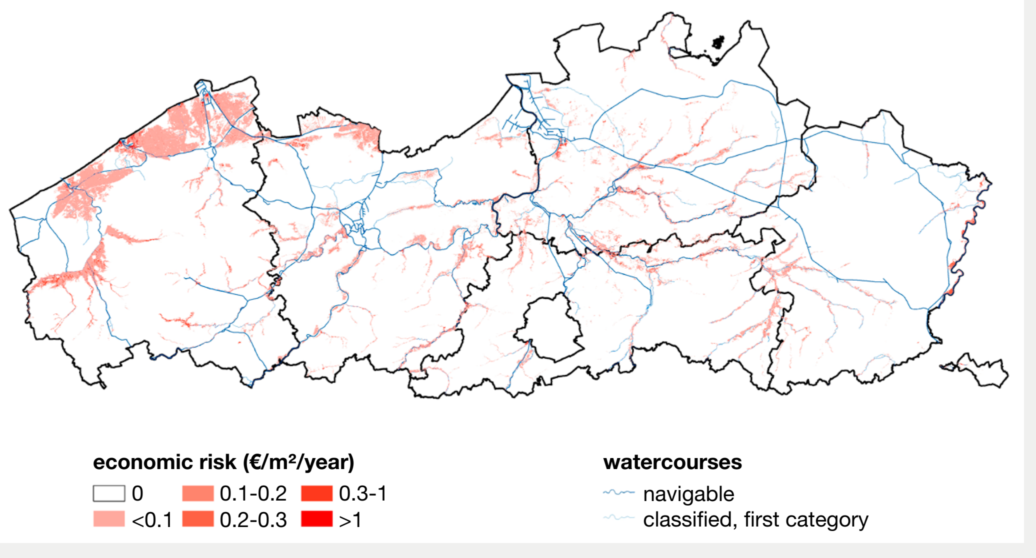
The flood hazard map in Figure 54 does not give any information regarding the consequences, vulnerability to or risk of floods. The European Floods Directive defines ‘flood risk’ as the combination of the probability of a flood event and of the potential adverse consequences for human health, the environment, cultural heritage and economic activity. On the basis of this definition, flood risk maps for Flanders have been drawn up that map the consequences for humans and the economy. Figure 55 estimates the annual average risk of economic damage in Flanders.

In Flanders, a total of more than 220,000 people may be directly affected by an extreme flood, *i.e.* a flood that occurs with a probability of once in 1,000 years. Of this number, more than 67,000 people live within the area of medium flood probability (once in 100 years) and about 10,000 within the area of high flood probability (once in ten years).

The annual average damage for the whole of Flanders amounts to over 50 million euros. The damage caused by a flood event of high probability is around 100 million euros, for a flood of medium probability it is around 660 million euros, and for a flood of low probability around 2.4 billion euros.

With floods of high probability, almost half of the floodable area is meadow land, slightly more than a quarter is nature, and about 13 % is arable land. Residential and industrial areas combined cover 3 % of the floodable area. The remaining areas are water, infrastructure and recreational areas. In the scenario of floods of medium and low probability, the proportions of meadow land and nature decrease and the proportions of land uses more sensitive to damage (residential and industrial areas, infrastructure, recreation and arable land) increase.

***Figure 55:** Economic risk due to flooding at the present climate (Flanders, 2012)*



Source: www.waterinfo.be

4.3.2 Floods at persistent sea-level rise in the coming decades

At the coast

Climate change increases the flood risks along the Belgian coast due to the rise of the average sea level (sea-level rise) and possibly also a changing wind climate (the wind climate determines the storm surge). Some Belgian and European research projects examined the consequences of a changing sea level and wind climate, including the probability of breach formation along the Belgian coast and the floodable area in the event of a storm with a return period of 1,000 years. The results suggest that the flood risk may increase already within a few tens of years - at a sea-level rise of half a metre - by a factor of ten with respect to the existing situation when the beach and the fore-shores are not raised simultaneously. The Netherlands and Belgium are furthermore the two most vulnerable European countries to floods as a result of a rising sea level: more than 85 % of the coastal area (up to 10 km inland) is located more than five metres below the sea level. In Flanders, about 15 % of the surface area (Coastal zone and Scheldt polders) is located less than five metres above the average sea level. That is why the Flemish Region is already planning to compensate a sea-level rise through a structural raising and reinforcement of the seawall by pumping sand to the beach and the fore-shore.

In addition to changing flood risks, changing water levels and water currents along the coast will lead to changes in *e.g.* coastal erosion, turbidity of the water, and therefore the available light, and the inflow of fresh water. Combined with the changes in the seawater temperature, this may lead to habitat changes and physiological effects in certain animal and plant groups, thereby affecting the food chains within ecosystems. The extent to which these effects would occur is not yet sufficiently known. For example, changes have already been observed in the amounts of cod and haddock (mainly displacements to the north), with, in addition to ecological consequences, an economic impact on fishing and tourism.

The sea-level rise also increases the salt load towards the shallow groundwater and the surface water along the coast (changes in the fresh water/salt water distribution). However, the fresh water lens in the dune belt plays an important buffering role in the intrusion of salt seawater into the hinterland.

Along the Scheldt and other watercourses

The sea-level rise and the higher storm surge increase not only the risk of floods along the Belgian coast, but also the risks along the rivers connected with the North Sea. This is the case in the Scheldt estuary, but also in the Yser basin, the polders and water reservoirs where the drainage facilities are limited. For these areas the flood conditions are also determined by a combination of the preconditions in the upstream and downstream areas.

An analysis of the atmospheric circulation patterns that are at the basis of extreme precipitation inland and extreme storm surge along the coast, suggests that these circulation patterns are not entirely independent. Especially north-westerly winds may create both a very extreme storm surge and extremely high precipitation inland. The city of

Dendermonde on the Scheldt is an example of a location where this interaction plays an important role. The same applies for the downstream part of the Dender (downstream of Aalst). Even though the Dender is not directly connected with the North Sea, there is a strong effect of the increasing high tide along the Scheldt through the barrage effect. In fact, during high tide periods, the barrages are unable to drain the upper discharge of the Dender. If increased precipitation leads to higher upper discharges, this will also result in strongly increasing volumes that need to be temporarily stored along the Dender during high tide periods. It was calculated that the combination of a medium scenario of +60 cm sea-level rise, a high scenario of +21 % storm surge and a high scenario of +30 % upper discharge would raise the Scheldt water level in Dendermonde by +1.8 m for return periods between 100 and 10,000 years. For a return period of 1,000 years, the volume of flooding water increases by a factor of four. In Dendermonde, the increase is mainly caused by the sea-level rise, but more upstream along the Dender the effect of the upper discharges gains in importance. In the area around Aalst, the effects of the upper discharges and the sea-level rise are more or less equal. For a worst-case scenario of a two metre sea-level rise, the effect is much greater.

In the preparation of the Coastal Safety Master Plan, which was approved by the Flemish Government in 2011, the Coast Department of the Agentschap Maritieme Dienstverlening en Kust takes into account the sea-level rise. If only the aspect of sea-level rise is considered, a sea-level rise of 60 cm reduces the return period of a flood along the Scheldt between Ghent and Vlissingen from 350 years (after full implementation of the 13^{th} and last flood control area in the first Sigma plan, notably the flood plain of Kruibeke-Bazel-Rupelmonde with a total surface area of 600 ha) to 25 years by 2100. This illustrates the importance of the implementation of the complete updated Sigma plan. To achieve the desired safety level - return period for a flood along the Scheldt on the order of magnitude of 4,000 years - another 4,000 ha of flood plain is required. In the new Sigma plan, which was revised on the basis of an optimal cost-benefit analysis - additional flood plains are planned by 2050 for a total of 1,325 ha, supplemented with 23 km of dike raising and a wall in Antwerp.

In addition to the changing flood risks, the changing water level along the coast and the changing upper discharges will lead to changes in the salt concentrations and in the border between salt and fresh water. As along the coast, this may also lead inland to changes in the habitats and to physiological effects for certain groups of animals and plants, that in turn can also have consequences for the food chain of ecosystems. The exact effects are not yet sufficiently known.

4.3.3 Floods at changing precipitation in the future

Effects of an increasing groundwater table

In addition to the threat posed by a rising sea level, the changing precipitation pattern in Belgium may also increase the risk of floods. The expected precipitation increase during the winter months will cause the groundwater level to rise periodically. This could offset, in part, the risk of drought in the summer months. An extrapolation of different climate scenarios suggests also for the winter months an increased discharge for our rivers: an increase by 4 to 28 % by 2100.This would lead to an increase in floods for the Scheldt, especially upstream of Dendermonde, and particularly when the increased river discharge falls in a period of water-saturated soils.

Effects for sewer systems

The climate scenarios for the summer period indicate a strong increase in extreme short rainfall events, especially in the case of the high climate scenario. This will place additional burdens on sewer and other drainage systems. Existing sewer systems were designed to flood or overflow only once every two years. In the future, they may flood or overflow twice as much: once per year instead of once every two years. For buffer basins or other at-source measures such as rainwater reservoirs, the high climate scenario for the summer with the most extreme summer storms requires 15 to 35 % additional storage capacity to maintain the spillway or overflow frequency at the present level. If the present storage capacity is retained, the return period of overflowing will decrease by a factor of four, for example from once every two years to twice per year, under the high climate scenario. To anticipate this, the Code of Good Practice for the Design of Sewer Systems was revised in Flanders in 2012.

Apart from the wider dimensioning of sewers, buffer basins and other water reservoirs, there is another way to maintain the return period of flooding or overflowing in sewers and buffer basins at the present level in the event of climate change. The rainwater inflow in sewers can also be limited through at-source measures such as water permeable paving, infiltration facilities and better alignment of urban water management, urban design, land and green areas management, and spatial planning. The additional infiltration of rainwater into the soil also benefits the replenishment of groundwater resources and helps prevent drought. Recently, a major step forward was made with the amended Regional Urban Planning Ordinance for Rainwater Tanks, Infiltration and Buffer Facilities, which makes individual infiltration mandatory for new construction and large-scale renovation projects as from 1 January 2014.

4.3.4 Effects of climate change versus changing land use

Not only the climate but also spatial planning is changing in Flanders. Satellite images, for example, reveal a clear urbanisation trend: the proportion of sealed surfaces in Flanders increased from 4 to 5 % in 1976 to around 10 % in 2000. In the period 2007-2009, the proportion of sealed soil further rose to 12.9 % or 175,967 ha. This puts Flanders far above the European average (1.8 %) and also above the whole of Belgium (7.4 %) and the Netherlands (7.3 %).

Also in the coming decades further paving of the soil cannot be excluded. Its effects on hydrology, whether or not in combination with climate change, were studied in Flanders for the river basin of the Molenbeek in the Dijle basin. The extrapolation of an urban expansion scenario with an increase in paving between 70 and 200 % suggests that the peak discharges in the watercourse may increase between 6 and 16 %. The impact of floods increases not only as a result of this increase in peak discharges, but also as a result of the changing land use in the actual flood plains (greater flood damage at the same water level). Finally, when comparing the effects of the climate scenarios with those of the urban expansion scenarios (both until 2050), the peak discharges along the watercourse are likely to be altered more by climate change than by urban expansion.

Earlier, a more general, first estimate of the economic consequences of the changing climate conditions along Flemish rivers had been made as part of the Environment Outlook 2030 of MIRA (Brouwers *et al.*, 2009). According to the high climate scenario applied at the time, the increase in the economic flood risk at the Flemish level was 33 %, but based on the low climate scenario it may also decrease by 56 %. Especially the Leie basin, the Upper Scheldt basin and the Demer basin would see a strong increase in the risk by a factor of two to three under the high climate scenario. For the Lower Scheldt basin the increase is smaller. In addition, these climate scenarios were assessed and combined with changing land use. This revealed that the changes in land use in the coming decades will cause an additional increase in the flood risk in Flanders of on average 3 to 10 % (depending on the land use scenario used). Yet for specific regions in Flanders this additional increase may be even higher, *e.g.* up to +100 % in the Leie basin and the Yser basin, especially due to the increase in housing and industry in flood plains, at the expense of arable and meadow land.

Also for the underpinning of the flood risk management plan for non-navigable waterways (VMM, 2014b), the effects of a moderate ('medium') climate scenario together with those of economic or demographic growth, were taken into account for a total of 47 regions. As a result of these developments, the economic risk in 2050 would on average be 42 % higher than in 2010. The number of persons running the risk of being exposed to flooding would, on average, increase by 54 %. There is, however, a large spread on both averages. The main effect of climate change is that it increases the probability of flooding with time, whereas the effect of socio-economic growth is that it makes the consequences of a flood more severe. Various policy strategies can nevertheless eliminate the increases in the risks in part or in whole and even lead to significantly lower risks than those in 2010.

4.4 Discharge and availability of water

4.4.1 Observed trends in discharges

We examine whether trends can be observed in the discharges via major, non-navigable waterways. First, we look at the discharges on a daily, monthly, seasonal and year (half) basis, for the seven monitoring stations spread across Flanders for which datasets longer than ten years are available. These are, however, still relatively short datasets to allow any effects of climate change to be observed. Furthermore, additional paving and water management measures may influence the discharges.

Next, an analysis is made of the relatively low water discharges, for the same monitoring stations. This analysis may provide indications about a possibly growing shortage of water in the relevant waterways. Finally, evolutions of high water discharges are examined, which may give clues about a possibly increasing flood hazard.

Daily, monthly, seasonal and year (half) discharges

Analysis of the measured values does not reveal a clear trend for any of the periods under consideration. In other words, none of the average daily/monthly/annual/seasonal and year (half) discharges shows a significant trend in the same direction for any of the seven stations. For each of the periods under consideration, more than half of the stations do not show any significant trend. There are as many stations (three) where there is either a significant increase or a significant decrease for at least one of the periods. The analysis therefore does not produce an unambiguous signal that is indicative of the effects of climate change and/or increasing paving.

Low water discharges

The *Standardized Streamflow Index* or SSI (Vicente-Serrano, 2012) is calculated analogously to the SPI (see paragraph 2.3.3), but instead of total precipitation, discharge data are used. The SSI should be interpreted in the same way as the SPI, and therefore tells us something about the extent to which the monthly discharge deviates from the monthly discharge in the reference period.

In three of the seven monitoring stations, none of the analyses produced a significant trend. In two of the seven stations, there are indications that the low water problem is increasing. Also in two of the seven stations, there are indications that the low water problem is decreasing. From this analysis it can therefore not be concluded that there is an increasing low water problem in Flanders today.

High water discharges

Here we examine whether specific high water discharges are more frequent in 2014 than before (up to and including 1996). For this purpose, the dataset was used to statistically determine the highest discharges that occur once every 2, 5, 10, 20, 50 and 100 years. The latter are the return periods, abbreviated as T. Next, the discharges were compared with the results from the same analysis on the complete datasets up to and including

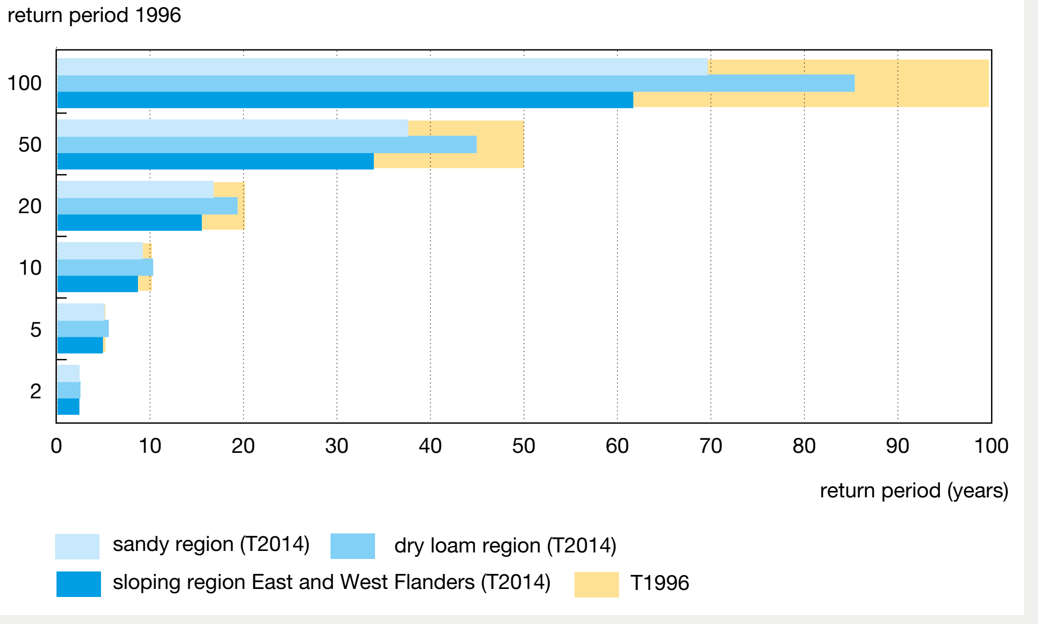
2014. In this way, we can check whether extreme discharges occur more or less frequently.

This analysis was not performed for each individual waterway, but for a hydrologically homogeneous region. This enables us to detect changes on a larger scale: non-navigable waterways located within a hydrologically homogeneous region may be assumed to exhibit a similar water discharge behaviour. For this exercise Flanders was divided up into three hydrologically homogeneous regions: the sloping region of East and West Flanders, the dry loam region, and the sandy region (Campines), with 46, 20 and 29 monitoring stations respectively. The polders are not included in this exercise because insufficient measurements were available.

Figure 56 shows the result of this analysis. It appears, for example, that a high water discharge in the sandy region which occurred up to 1996 once every 100 years, occurs already once every 70 years up to and including 2014. In general, for the low return periods (2, 5 or 10 years), no or only relatively small decreases in the return periods are observed. For return periods of 20 years and more, decreases are observed for each of the three hydrological regions: extreme discharges which occurred up to and including 1996 with a frequency of once every 20, 50 or 100 years, now occur more frequently, and this evolution is all the more pronounced as the length of the return period increases. Hence this analysis provides indications that very extreme high water discharges, and therefore also the associated flood risk, have become slightly less extreme over the last two decades. To what extent this is to be attributed to climate change or to other factors (*e.g.* changes in land use, paving) is as yet unclear. Moreover, the available time series are still too short to allow a distinction to be made between multi-annual climate fluctuations and actual climate trends in a much longer term.

Trends on a local scale (at the level of monitoring stations) can, nevertheless differ considerably. Eight of the fourteen monitoring stations show for all return periods (T) a statistically significant increase that varies from +3.0 to +9.7 % per decade for the twenty-year peak discharge. Three exhibit a significant decrease that varies from -0.6 to -8.0 % per decade and another three do not exhibit any trends. The two-year peak discharges show for eight monitoring stations a statistically significant increase that varies from +1.8 to +7.5 % per decade and for three monitoring stations a statistically significant decrease that varies from -1.0 to -6.0 % per decade. The three remaining monitoring stations do not exhibit any significant trend. The fact that increases are not found everywhere suggests that local factors may play an even bigger role and/or that incidental fluctuations mask the trends.

Figure 56: *Evolution of return periods for high water discharge in three hydrologically homogeneous regions (Flanders, 2014 versus 1996)*



Source: MIRA based on VMM

4.4.2 High and low water discharges along rivers at persistent climate change

Peak flows

The new climate scenarios for Flanders have not yet been extrapolated hydrologically, but when comparing the scenarios used in the Environment Outlook 2030 and the scenarios presented in this Climate Report 2015, the impact results on the peak discharges are expected to be comparable to the results known from already existing studies. Those studies showed that the impact on the peak discharges is still unclear and greatly dependent on the climate scenario.

With a high (or wet) climate scenario, these peak discharges increase significantly in winter; with a low (or dry) climate scenario, the peak discharges in winter remain virtually unchanged or even decrease to a limited extent. The latter is the result of the increasing evapotranspiration in addition to the increase in precipitation. Depending on the exact increase in precipitation in comparison with the increase in evapotranspiration, the balance may tilt from an increase to a status quo or decrease in peak discharges via watercourses. In the high climate scenario, the increase in peak discharges increases to 30-35 % over a future period of 100 years.

For smaller watercourses in highly urbanised areas, which respond quickly to extreme precipitation, this increase may even be several tens of percentage points higher. For the Maarkebeek stream, an increase in peak discharges of up to +100 % over 100 years was simulated. Moreover, there appears to be a clear correlation - which is even linear in the case of *e.g.* the Grote Nete and the Grote Laak - between the proportion of urbanised area in a river basin and the increase in peak discharges under the influence of the climate scenarios. The exact impact on hydrological extremes appears to be greatly dependent not only on the climate scenario, but also on the hydrological or precipitation discharge model used.

The new climate scenarios have not yet been extrapolated to the level of discharges from watercourses. However, the new scenarios have already been used to study the combined effect of the changing monthly precipitation and the potential evapotranspiration and their implications for water availability. The increase in precipitation in winter would, in spite of the increase in potential evapotranspiration, lead to an increase in water availability in winter and therefore to an increase in the flood risk during the winter months (Tabari *et al.*, 2015b).

Low water discharges

Earlier extrapolations of climate scenarios for Flanders indicate for all studied river basins a future decrease in the low water discharges along our watercourses. The decrease in the lowest summer discharges varies between -10 % and -70 % over a future period of 100 years, under the low climate scenario from the Environment Outlook 2030.

The combined analyses of precipitation and potential evapotranspiration suggest a decrease in water availability in summer and therefore a higher risk of droughts (Tabari *et al.*, 2015a; Tabari *et al.*, 2015b).

The unambiguous impact results on the evolution towards increased desiccation have received increasing attention in recent years. It is an issue that is as yet not well known among the wider public, but that has already become one of the priorities of the Flemish water managers and policy makers. Flanders and Brussels are, in fact, highly vulnerable to increasing desiccation. At present, water availability in Flanders and Brussels amounts to 1,100 to 1,700 m^3/person/year, which is very low by international standards and lower than in many Southern European countries (*e.g.* Spain, Portugal and Greece). This is explained by the high population density and our strong dependence on neighbouring regions for water availability. A great part of the water that is used for the drinking water supply (*e.g.* of the Meuse via the Albert Canal) in fact originates from France and Wallonia. Moreover, treaties have been signed with the Netherlands (for the Meuse and the Ghent-Terneuzen Canal) for the minimal downward flow rates required during dry summer periods. In some regions of Flanders, such as southern West Flanders, large amounts of deep groundwater are pumped up, which has drastically disturbed the natural groundwater situation. A further shift from groundwater to surface water abstraction is needed. According to the climate scenarios, however, the surface water availability could be reduced significantly in the future, especially during dry summer periods. Lower surface water availability also means poorer surface water quality due to the reduced dilution of pollutant loads, and therefore higher costs for processing surface water into drinking water.

Climate adaptation with regard to desiccation and low water is therefore required, taking into account great uncertainties for the climate scenarios and hydrological impact calculations (see also Chapter 5).

4.4.3 Effects of climate change for groundwater

The effects of the climate scenarios on the groundwater levels appear to be highly variable, both spatially and seasonally. A study carried out for the river basin of the Grote Nete and the Grote Laak found that for the winter season the change in groundwater level over 100 years varies from a few centimetres in the lower-lying valley areas to approximately one metre in the interfluvial and higher-lying areas: increases for the high scenario, decreases for the low scenario. The summer groundwater levels stagnate in the valley areas, but fall in the low scenario to approximately one metre in the higher areas of the river basin.

Another, even more detailed analysis for the river basis of the Kleine Nete indicated that the average annual groundwater replenishment will change between -20 % and +7 %. When averaged for all simulated climate scenarios, the change amounted to -7 %. Most climate scenarios suggested a slight increase in groundwater supply in winter and a slightly greater decrease in summer, resulting in a net decrease on an annual basis. Significantly decreasing groundwater levels were found for the months of September through to January. Here, too, greater groundwater effects were observed for the interfluvial and higher-lying areas and smaller ones for the lower-lying valley grounds. For valley areas, however, the ecological impact of these minor groundwater decreases is greater than for higher-lying areas. The decrease in groundwater levels up to and including January, in spite of the slight increase in groundwater supply in winter, is the result of the long-term constructive effect of the precipitation on the groundwater levels. A big decrease in summer precipitation can be felt into the winter months. At the end of the summer periods or autumn the groundwater levels are lowest; during these periods, decreases up to 10 % were found.

4.4.4 Effects for agriculture and related changes in river basin hydrology

The impact of climate change on agriculture is mainly reflected in the changed water availability in the soil (soil moisture content) and the increasing CO_2 concentrations in the atmosphere. The influence of these changes on crop growth was recently studied for Flanders at the field and parcel level. The crop yield can increase by up to 27 %, and the corresponding biomass by 23 %. This is mainly the result of the increasing CO_2 concentrations, which result in increased water productivity (production at the same water availability). The lower water availability in summer adversely affects crop growth, but the latter appears to be less important than the higher water productivity in the next decades. In the longer term, however, the effects as a result of more extreme temperature and precipitation periods will gain in importance, resulting in a net negative impact on agricultural production.

5 ABOUT TIPPING POINTS (IN CLIMATE CHANGE) AND DEALING WITH UNCERTAINTIES

5 ABOUT TIPPING POINTS (IN CLIMATE CHANGE) AND DEALING WITH UNCERTAINTIES[8]

5.1 Tipping points

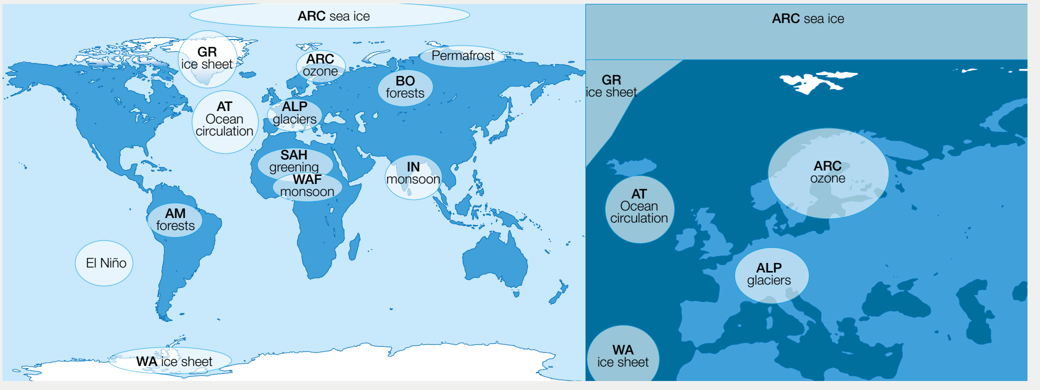
The climate scenarios presented in Chapter 3 are slow evolutions that follow increasing greenhouse gas concentrations in the atmosphere with some delay or mitigation. Most mechanisms are well known for this type of scenarios and rather accurate calculations can be made for the various climate parameters. However, for some time there has been growing awareness both within and outside the scientific community that severe global warming may also lead to more abrupt changes in the climate system.

Different elements in the climate system, such as ice sheets, are highly sensitive and respond strongly to the perturbing effects by humans on the climate system. These so-called tipping elements react disproportionately strong to perturbations and therefore potentially have a great impact on society. Mechanisms are often triggered as soon as certain threshold values (tipping points) have been exceeded, and in many cases self-reinforcing mechanisms are also at work. A prominent example of a self-reinforcing mechanism is the ice-albedo feedback: initial warming of the snow or ice mass induces regional melting. As a result, dark surfaces, notably brown coloured land or blue ocean, emerge. These dark surfaces reflect less sunlight, resulting, among other things, in increasing regional warming and additional melting.

Assessing the probability of a tipping element undergoing a transition, is essential for assessing the risks related to climate change. Traditionally, these transitions are estimated as having a low probability of occurrence, but a great impact on society. Recent research shows, however, that some of these tipping elements are already undergoing transitions and that there is a high probability of occurrence under the current projections of global temperature changes. Figure 57 designates the tipping elements that have an impact worldwide and in Europe.

8 This chapter is mainly based on van Lipzig & Willems (2015). Other sources are cited in the text.

Figure 57: *The various tipping elements in the climate system with an impact worldwide (left) and in Flanders (right)*

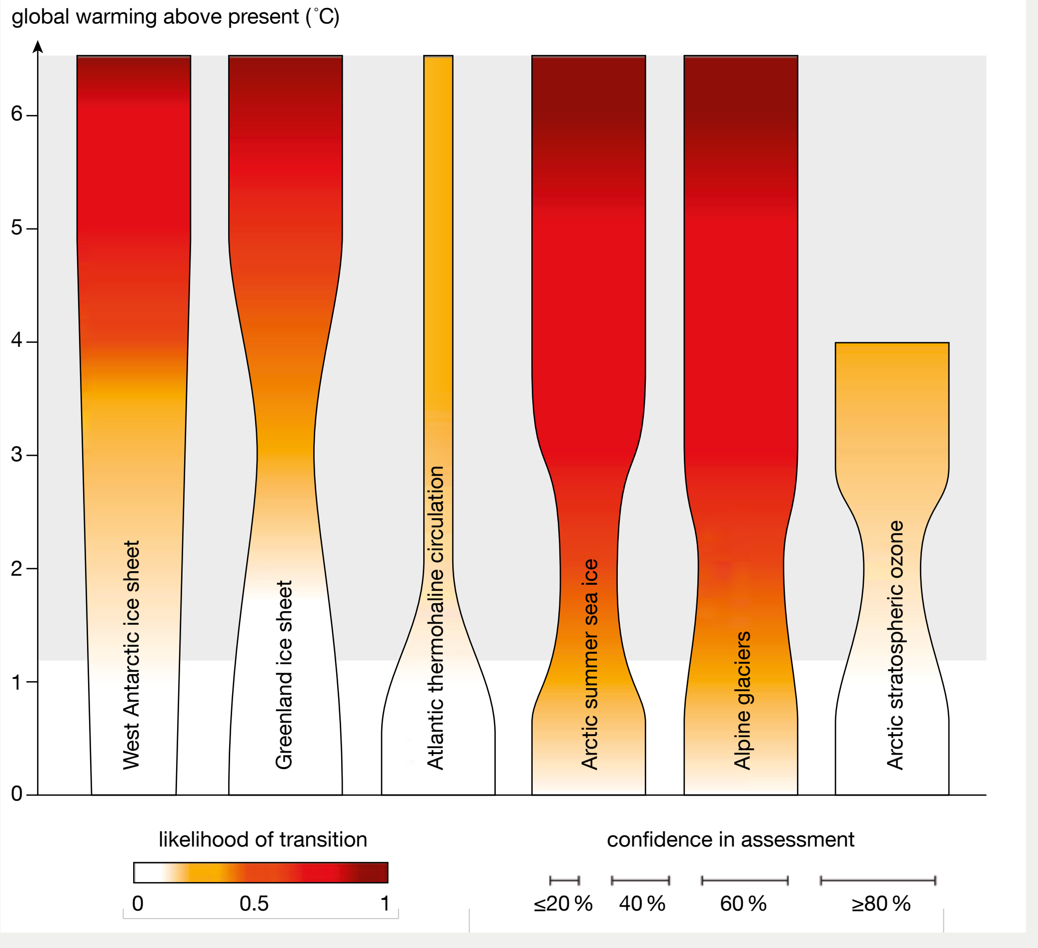


The various tipping elements are: Greenland (GR) ice sheet, West Antarctic (WA) ice sheet, Atlantic (AT) Ocean Circulation, Arctic (ARC) ozone, Arctic (ARC) sea ice, Alpine (ALP) glaciers, Boreal (BO) forests, Permafrost, Indian (IN) monsoon, West African (WAF) monsoon, El Niño Southern oscillation, Amazon (AM) forests, and Sahara (SAH) greening.

Source: Lenton *et al.* (2008) and Levermann *et al.* (2012)

The effects of transitions in these tipping elements will be noticeable both globally and regionally, but a clear quantification of these climate transitions is not yet available. That is why the tipping elements in the climate system with an expected impact in Europe are discussed separately here, together with an assessment of their relevance for Flanders insofar as is currently possible (figure 58).

Figure 58: *Assessment of the probability of tipping elements, relevant for Europe (x-axis), undergoing a transition as a function of average global warming of the Earth with respect to present conditions (y-axis)*



The colours refer to the probability of transition and the width reflects the reliability of the assessment.

Source: Levermann *et al.* (2012)

5.1.1 The Greenland and West Antarctic ice sheets

The Greenland and Antarctic ice sheets are losing mass at an accelerating pace: over the past decade, the Greenland ice sheet has lost six times as much mass as over the preceding decade. The average loss over the last decade corresponds to a sea level rise of approximately 0.6 mm per year, and thus accounts for approximately 20 % of the average global sea level rise within that decade. The estimates for the West Antarctic ice sheet are on the same order of magnitude. Self-reinforcing mechanisms play an important role in the evolution of the ice sheets: if an ice sheet loses mass, the height of the ice sheet will decrease, thereby causing the temperature to rise. This in turn increases ice loss through melting and possibly through acceleration of ice flows.

For the Greenland ice sheet, an increase in temperature by 2 °C to 4 °C above the pre-industrial levels will result in self-reinforcing mechanisms, leading to an almost total loss of ice (equivalent to a sea level rise of approximately 7 m). The latest study results no longer exclude an almost total loss of ice at a lower threshold value of 1 °C. The AR5 of the IPCC shows that this temperature threshold will be exceeded during this century. However, for complete melting, the temperature should be a few degrees higher than the threshold for a whole millennium, which implies that such melting is not irreversible. The maximum rate at which the Greenland ice sheet can disintegrate is estimated at 0.54 m sea level rise equivalent per century.

For the West Antarctic ice sheet, a detailed analysis is not yet available. Satellite observations show, however, that the glaciers are becoming thinner and the ice is retreating in some regions of West Antarctica. It can therefore not be ruled out that a partial disintegration which could lead to a separate/additional sea level rise by 1.5 m, has been initiated already. That is why in Figure 58 the risk for West Antarctica is estimated slightly higher than the risk for Greenland.

Most dikes can only be raised to a limited extent (often on the order of magnitude of one metre) and higher sea level changes would require a thorough revision of the infrastructure. Most coast lines, however, cannot be protected against sea level changes of a few metres.

5.1.2 Arctic sea ice

The authors of Figure 58 identify the Arctic sea ice and the Alpine glaciers as the most vulnerable sensitive elements for global warming. In the period 1979-2013, the sea ice cover in the Arctic area declined by 43,000 km^2 per year in the winter (measured in March when the sea ice covers up to approximately 15 million km^2) and by 95,000 km^2 per year in the summer (measured in September when the sea ice covers up to approximately 6 million km^2). The extent of the minimal sea ice cover during September 2012 broke all September records. A comparison with older observations suggests that the sea ice cover has been halved since the 1950s. The Arctic sea ice is also becoming increasingly thin and increasingly less ice survives the summer.

Most climate models underestimate the observed decrease in sea ice cover. Models that best represent the observed decrease in sea ice cover, project a significantly faster decrease for the future than do the other models. Recent studies that take this into account suggest that for the RCP8.5 scenario from the AR5 of the IPCC, a virtually ice-free Arctic Ocean in September is likely before the middle of this century.

A decline in the ice sea cover has a big impact on the Arctic ecosystems. Moreover, it leads to improved accessibility for potential sources of fossil fuels in Arctic areas, with ecological and geopolitical consequences. Possibly also the weather patterns in Europe are affected through the impact on the occurrence of extremely warm and cold periods.

In contrast to the Arctic areas (sea ice reacts quite differently than land ice: land ice does not react to winds, whereas sea ice does), the Antarctic sea ice is increasing, which is to be attributed to increasing circumpolar winds that push the sea ice inwards, thereby making it thicker and more stable.

5.1.3 Alpine glaciers

Glaciers are highly sensitive to minor changes in air temperature and precipitation, and are therefore excellent indicators for climate change. Over the last hundred years, the European glaciers have lost mass, mainly due to the increased summer temperatures. The ice volume of the glaciers in the Alps has been reduced from approximately 200 to 300 km^3 in 1850 to 90 ± 30 km^3 today. The mummy found in 1991 in the Ötztal Alps, is proof that the melting of the glaciers has exceeded the variability of the climate for many thousands of years. The mummy is in fact 5,300 years old and was only recently uncovered. Until the end of the 1990s the Norwegian glaciers had still been expanding, but since then they have also been retreating.

Alpine warming is proceeding at a rate almost twice the global average, which is also caused by the self-reinforcing effect of the ice-albedo feedback. Even a scenario with significant emissions reductions where the increase in the global average temperature remains below 2 °C, (which corresponds to +3 to +4 °C in the Alps), will lead to an almost total loss of the glaciers in the Alps within the coming decades (Figure 58).

Glaciers act as freshwater reservoirs, which is why a change in the ice mass of the glaciers will affect the water availability, especially in summer. This will impact on the seasonal dependence of the water discharge in rivers such as the Rhine. Various other sectors in Europe will be strongly affected, such as power production in hydroelectric plants and tourism. The loss of ice mass of the glaciers also contributes to the sea level rise and thus affects the freshwater supply, the river levels and the irrigation possibilities.

5.1.4 Arctic stratospheric ozone

Due to chemical reactions high up in the atmosphere, human emissions of CFCs greatly influence the ozone concentrations in the stratosphere (the atmospheric layer between approximately 12 km and 50 km altitude). The stratospheric ozone layer gives protection against skin disorders, cornea and DNA damage, skin cancer and suppression of the immune system, caused by ultraviolet solar radiation. In 1987, the Montreal Protocol drastically curbed CFC emissions and the downward trend in stratospheric ozone concentrations has ended since 1990.

Recent research shows, however, that humans also influence the ozone concentrations in the stratosphere through global warming. Greenhouse gases warm the earth's surface, but cool the stratosphere. In Arctic areas, this cooling will probably lead to an increased depletion of ozone. Low stratospheric temperatures lead to the formation of polar stratospheric clouds, which generally add to the depletion of the ozone layer through chemical reactions that take place at the surface of these clouds.

There is, however, great uncertainty about the transition of this sensitive element, because global warming may also lead to changes in the air currents in the stratosphere. Warm, ozone-rich air can thus probably be transported to the Arctic areas. The role of these changes in air currents is still unclear, so no estimates have been made for the transition potential of this sensitive element after 2060 (Figure 58). Until 2060 this sensitive element is unlikely to undergo a transition insofar as the treaties on reducing emissions of ozone-depleting substances are complied with.

5.1.5 Atlantic Ocean circulation

The Atlantic Thermohaline Circulation (THC) is part of a large-scale ocean circulation that contributes to milder winters in northern Europe when compared with regions at similar latitude in North America and northern Asia. A change in the THC is caused by changes in the distribution of salt in the North Atlantic Ocean. That is why this sensitive element is linked only indirectly to global warming, through melting of the Greenland ice sheet and changes in (Arctic) precipitation. The probability of collapse of this circulation is estimated to be low, even for high temperatures (Figure 58).

Without the heat transport of the Atlantic Ocean circulation, the North Sea would be approximately 2 to 3 °C cooler, and the ambient air in Flanders 1 to 2 °C cooler than is the case now. Europe would then have considerably more droughts and decreased precipitation. Moreover, the collapse of the THC would probably cause a(n) (additional) sea level rise in Flanders from 10 cm to 30 cm due to redistribution of the water masses. This regional contribution would come on top of the global sea level rise.

5.1.6 Indirect effects

In the preceding paragraphs we have discussed only the direct effect of transitions in sensitive elements. There are, however, also indirect effects of climate change with associated transitions in sensitive elements. Two forms can be distinguished:

1. The climate system is a coupled system, meaning that changes at the other end of the Earth may also affect us. For example, if the permafrost were to thaw, this could lead to the release of methane and carbon dioxide through biochemical processes. These are greenhouse gases that further add to global warming and therefore also affect Flanders.
2. The world, too, is a coupled system and socio-economic changes elsewhere may also affect us. For example, India, China and their neighbouring countries have a population of over two billion people who depend on the glaciers in the Himalayas for the water supply during the dry season. The ice-albedo feedback makes these glaciers highly vulnerable to global warming. Because we live in a globalised economy, regional disasters will also affect Flanders.

5.1.7 Sensitive elements and dangerous climate change

Sensitive elements and climate transitions have thus far only to a very limited extent been incorporated into integrated assessments of the consequences of climate change. This implies that the risk of climate change is perhaps still being underestimated. Incorporating these transitions into integrated assessments is compounded by the long-time scales on which these transitions occur. For example, there is more than a 50 % probability that the ice sheets will melt completely at a temperature increase of 4 °C, but the time scale on which complete, corresponding sea level rise will take place, is estimated to be on the order of millennia: +5 to 12 m over a period of 2,000 years. The speed of these changes is crucial for the extent to which humans are able to adapt to them. The palaeontological archive shows that typical speeds of sea level changes of 1 m per century over time scales of millennia were observed during the past glacial cycles (see also paragraph 2.5.1). Even in the short term, the present infrastructure is unable to deal with such sea level rises, but in the longer term such long sea level rises will be disastrous. What is also problematic is that once this process is under way, it will be difficult to stop it.

The need to avoid dangerous climate change was adopted as an objective in the UN Climate Change Convention in 1992. An assessment of these dangerous changes, especially the probability of the 'potential' of a transition of a sensitive element, is scientifically challenging: the natural variability of the climate even complicates the detection of those sensitive elements that are currently in transition. An assessment of these probabilities is, however, crucial for future social, political and economic decisions. Given the risks associated with the tipping points, the partly incomplete knowledge should nevertheless be used to gain an insight into the potential evolution of our climate system and the potential impact arising therefrom. Such an insight will, by definition, always be provisional, and the assessment will evolve further as new scientific knowledge becomes available.

5.2 Dealing with uncertainties and policy response

It is clear from the preceding chapters that the future climate evolutions are subject to great uncertainties. This means that the management cannot be based on precise, deterministic future evolutions. However, the great uncertainties in future climate change should not be a reason to postpone adaptation to the changing climate (climate adaptation).

More specifically, it is recommended to take the potential future climate change into account in new or updated policy or management plans or new infrastructure designs. To this end, the risk concept can be used. The technical 'risk' of certain events - meteorological events or climate evolutions in this case - is quantified as the convolution (multiplication of all possible combinations) of 'probability of occurrence' of the events with the 'potential effects' of these events. The risk may be great if either the probability or the effects, or both, are great.

In the case of climate scenarios, the exact probability of their occurrence is not known. It is also very difficult to estimate. We can, however, calculate the effects of the different climate scenarios. For this purpose, impact models as are currently available within the various policy areas, are used. For water management, for example, there are hydrological and hydrodynamic river and sewer models. For agriculture, there are crop growth models and models that quantify agricultural production under certain management and weather conditions. Models available to quantify the health effects of air pollution include air quality models. If the climate scenarios in these impact models (or in other impact assessment tools) are extrapolated, an assessment is obtained of the potential effects of the climate scenarios. If the effects of a certain scenario are great, it is important - in addition to pursuing a policy that is aimed at preventing the scenario from occurring - to take the potential scenario into account in policy and management. This builds on the precautionary principle. In the same way as we, as a “prudent man”, take out insurance to protect ourselves against high-risk events, even if the probability of their occurrence is small (*e.g.* fire, accidents). Only if the effects of a specific climate scenario are irrelevant can we dismiss that scenario.

If the effects of a given climate scenario are relevant, and the precautionary principle therefore has to be applied, the next question is how it should best be taken into account. The probability of occurrence is in fact not known. This can be done by making policy and management decisions, and the associated measures and technical designs, in such a way that they are ‘no regret’ and ‘climate proof’. Due to the high level of uncertainty, this can be done by making them flexible-adaptive and sustainable:

- flexible-adaptive: it should be possible to make adaptations later, preferably while keeping the cost as low as possible, if the climate is found to evolve towards a highly unfavourable climate scenario. The idea is to prevent that adaptations are made that would make further adjustments in the future impossible or prohibitively expensive. This requires the introduction of a great amount of flexibility into control measures and associated technical designs. Preferably, allowance should also be made for the future periods of the various climate scenarios in comparison with the life cycle of the adaptations (*e.g.* technical designs);
- sustainable: sustainable decisions are effective in each climate scenario as well as cost-efficient regardless of the exact development of the future climate (within the known bandwidth; high/medium/low climate scenarios). This also means that adaptations are sought that are not only advantageous in the context of climate change, but also offer benefits for other purposes. Climate scenarios often reveal weaknesses in the present management. By studying the effects of climate scenarios, and therefore representing the meteorological situation more extremely than it actually is, problems in the management - which are already present, but less visible - are more easily identified. Simple and small - but non-sustainable - solutions in the short term are then often not enough. Often, more intelligent, more advanced, more structurally effective solutions that are also sustainable in the long term, are needed. Another important aspect is awareness raising of the population (see also below).

To make these principles more specific, a number of examples from the flood management sector are given below. Flexible design means that we no longer work with fixed design rules (which on average produce the best designs in all circumstances), as was traditionally the case in civil engineering. Instead, more allowance is made for unknown time- and place-specific factors and we accept that our knowledge is imperfect and can/will change significantly in the near future. This process is known as ‘active learning’, and also implies that designs are no longer driven by engineers, but also supported by and based on the knowledge of all the stakeholders in society. In urban hydrology, which is very much dependent on place-dependent, local knowledge, this means, for example, that (representatives of) local communities become more involved in the decision-making process. Making designs adaptive means, in this context, that for upgrading or renovation, already-changed climatic conditions are taken into account and facilities are provided to allow subsequent measures to be implemented (at a limited cost), such as additional capture of rainwater, storage and pumping capacity.

Examples of sustainable measures are at-source measures (*e.g.* capture and retain rainwater more upstream, infiltration, prevent pollution). This requires structural modifications such as a thorough revision of urban planning legislation, better alignment between urban water management and spatial planning, town planning, land management, agriculture, green areas management, recreation and sports infrastructure management. It also requires a change in mentality among the population possibly induced by financial incentives, such as a rainwater tax, by no longer quickly discharging rainwater via a duct or pipe to the sewer, but having it infiltrate on-site into the ground wherever possible. Conventional, simpler, centralised end-of-pipe solutions (*e.g.* construction of buffer or retention basins, modification of barrages, by public services) are then no longer enough. At-source measures such as the upstream capture of rainwater discharge from the sewer and having this rainwater infiltrate as much as possible into public and private open spaces, also in the urban environment, are always cost efficient, regardless of climate change. They have a positive effect on water management and also address other problems that are associated with strong urbanisation (*e.g.* increasing sealing of surfaces). They not only reduce flood risks, but also counteract trends towards lower water availability for drinking water, agriculture and industry (problem of desiccation and decreasing groundwater levels) and provide multiple functions to open spaces (better management of scarce open space). At-source measures are therefore a good example of measures that are particularly useful in any case, regardless of climate change, as they address the adverse effects not only of climate change, but also of the other trends such as urbanisation.

It will be necessary to continuously monitor climate evolutions in the future and to adjust the climate projections in the event of significantly changing trends (and hopefully resulting in reduced uncertainties).

The climate scenarios, as described in Chapter 3, and the potential effects, as summarised in Chapter 4, cover a range that is expected to encompass the future reality with a high level of probability. There is, however, no absolute certainty. The climate scenarios are based on a number of greenhouse gas scenarios simulated in a series of climate models, but both future estimates of greenhouse gases and physical climate knowledge and therefore also the climate models, are subject to uncertainties. Furthermore, climate transitions with a far-reaching impact on Flanders are likely to occur with a definite, but unknown, probability (see paragraph 5.1). These far-reaching transitions have not been taken into account in the development of the climate scenarios. Such additional uncertainties cannot yet be explicitly taken into account in policy making. It is, however, important that we are aware of their existence. There is, in fact, a definite, but unknown (hopefully small probability) that the future is more extreme than suggested in the current climate scenarios.

Figure 59 indicates that there are different types of uncertainties. Statistical uncertainties are uncertainties that are statistically quantifiable. These allow probabilities to be assigned to estimates, *e.g.* because measurements are available to calculate these probabilities. However, because the future climate has not yet occurred, no measurements are available and the uncertainties regarding the future climate cannot be quantified statistically. Instead, we work with scenarios, *e.g.* climate scenarios. They can be used to estimate scenario uncertainties. These are less accurately quantified uncertainties, and are mainly indicative. The (climate) scenarios represent hypothetical future evolutions. The aim is, of course, to use hypotheses that are plausible, so that the whole range of scenarios provides an approximate, but realistic, insight into 'quantifiable' uncertainty.

Figure 59: *Gradations of uncertainty*

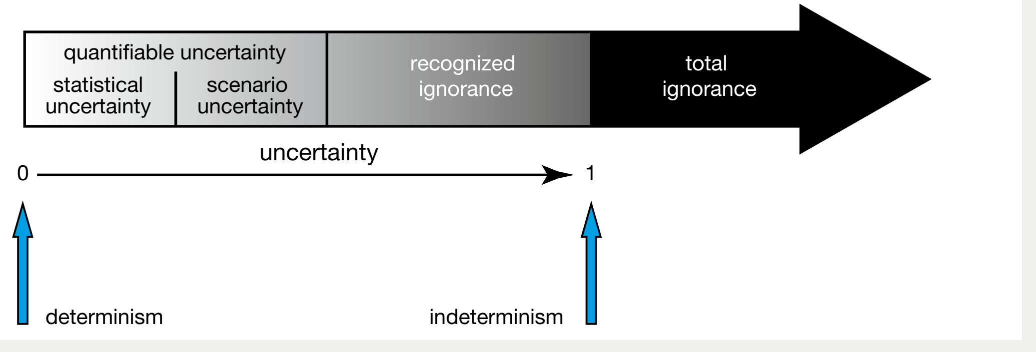


Illustration of the kinds of uncertainties from the ideal where everything is known (left) to complete unawareness (right).

Source: Willems (2012)

In addition to quantifiable uncertainty, there are other uncertainties that are not quantifiable, *e.g.* physical processes that have not yet occurred in the past, but that may occur in the future in an unpredictable manner *(e.g.* under changing climate conditions). There are some uncertainties of which we are aware, such as the potential processes and feedback mechanism enumerated in paragraph 5.1. While they cannot be explicitly taken into account in policy making, because they are totally unpredictable, it is nevertheless good that we are aware of their existence. There may even be uncertainties other than those referred to in paragraph 5.1, of which we are not yet aware (Figure 59). These uncertainties are of course much more dangerous, but because they are things (physical processes or mechanisms) of whose existence we have not been aware, we cannot formulate them either. We can only hope that they are non-existent or small.

In brief, the lack of knowledge about the future climate can be divided up into a quantifiable part and a non-quantifiable part. In the non-quantifiable part, we further distinguish between lack of knowledge of which we realise that it exists or, in other words, of which 'we know that we do not know', and other uncertainties of which 'we do not know that we do not know'.

Based on our climate knowledge and models, our knowledge of the (future) climate may vary from fully known or 'definite' to fully 'indefinite', cf. Figure 59. Regardless of our level of confidence, we may be right or wrong as the result of 'ignoring' certain things (*e.g.* process or feedback mechanisms). Such ignorance may even be more important than the quantifiable uncertainty. We do not have any idea of the latter, and - as already pointed out - it cannot be directly taken into account in policy making, but it is important to communicate about it, as we have done here in paragraph 5.1.

6 MORE INFORMATION AND SOURCES

MORE INFORMATION AND SOURCES

The MIRA Climate Report 2015 is designed as a compilation of texts from the following sources:

1. the description of the environmental theme of Climate Change and the associated indicator sheets on the website of Environment Report Flanders: http://www.milieurapport.be/nl/feitencijfers/milieuthemas/klimaatverandering/
2. a number of indicator sheets of the theme of Water Quantity, also available on the website of Environment Report Flanders: http://www.milieurapport.be/nl/feitencijfers/milieuthemas/waterkwantiteit/
3. the study report recently compiled by KU Leuven on behalf of MIRA: *van Lipzig N.P.M. & Willems P. (2015) Actualisatie en verfijning klimaatscenario's tot 2100 voor Vlaanderen, study commissioned by the Flanders Environment Agency, MIRA, MIRA/2015/01, KU Leuven in collaboration with RMI. Available at* www.milieurapport.be
4. a study report recently compiled by VITO and KU Leuven on behalf of MIRA: *De Ridder K., Maiheu B., Wouters H. & van Lipzig N. (2015) Indicatoren van het stedelijk hitte-eiland in Vlaanderen, study commissioned by the Flanders Environment Agency, MIRA, MIRA/2015/05, VITO and KU Leuven. Available at* www.milieurapport.be

The above sources also contain extensive reference lists with references to (other) source material used in their compilation.

In addition, the following information sources were used for the compilation of the MIRA Climate Report 2015:

- Brisson E., Demuzere M., van Lipzig N.P.M. (2015) A study on modelling strategies for performing convective permitting climate simulations using the COSMO-CLM over a mid-latitude coastal region. Met. Zeit. (in press).
- Brisson E., Demuzere M., Willems P., van Lipzig N. (2014) Assessment of natural climate variability using a weather generator. Climate Dynamics: doi:10.1007/s00382-014-2122-8.
- Brouwers J., Peeters B., Willems P., Deckers P., De Maeyer Ph., De Sutter R. and Vanneuville W. (2009) Chapter 11: Klimaatverandering en Waterhuishouding (pp. 283-304) in: Van Steertegem M. (red.), Environment Outlook 2030, Flanders Environment Agency, Aalst. Available at http://www.milieurapport.be/en/publications/outlook-reports/environment-outlook-2030/
- De Ridder K., Lauwaet D., Maiheu B. (2015) UrbClim – a fast urban boundary layer climate model. Urban Climate, 12, 21-48.
- De Troch R., Hamdi R., Van de Vyver H., Geleyn J.-F. and Termonia P. (2013) Multiscale performance of the ALARO-0 model for simulating extreme summer precipitation climatology in Belgium. Journal of Climate: 26, 8895-8915
- Deutsch F., Fierens F., Veldeman N., Vanpoucke Ch., Vancraeynest L., Bossuyt M., Janssen S. (2011) Air quality projections for Flanders up to 2030 using the year 2007 and 2003 meteorological conditions. Poster presented at the Air Quality and Climate Change: Interactions and Feedbacks, ACCENT-Plus Symposium, Urbino 13-16 September 2011.

- EEA (2004) Impacts of Europe's changing climate. EEA report no. 2/2004. Copenhagen: report (18.8.2004) + draft environmental issue report and fact sheets (18.2.2004).
- EEA (2010) Mapping the impacts of natural hazards and technological accidents in Europe – An overview of the last decade. EEA Technical report No 13/2010. doi:10.2800/62638
- EEA (2014) Europe's climate continues to change. http://www.eea.europa.eu/highlights/europe2019s-climate-continues-to-change
- EEA (2015) Atmospheric greenhouse gas concentrations - CSI 013/CLIM 052 http://www.eea.europa.eu/data-and-maps/indicators/atmospheric-greenhouse-gas-concentrations-4/assessment
- Flanders Hydraulics Research, Department of Mobility and Public Works, Flemish Administration (2015) Personal communication Toon Verwaest, July 2015.
- Global Carbon Project (2014) Global Carbon Budget 2014 by C. Le Quéré, R. Moriarty, R. M. Andrew, G. P. Peters, P. Ciais, P. Friedlingstein, S. D. Jones, S. Sitch, P. Tans, A. Arneth, T. A. Boden, L. Bopp, Y. Bozec, J. G. Canadell, F. Chevallier, C. E. Cosca, I. Harris, M. Hoppema, R. A. Houghton, J. I. House, T. Johannessen, E. Kato, A. K. Jain, R. F. Keeling, V. Kitidis, K. Klein Goldewijk, C. Koven, C. Landa, P. Landschützer, A. Lenton, I. Lima, G. Marland, J. T. Mathis, N. Metzl, Y. Nojiri, A. Olsen, W. Peters, T. Ono, B. Pfeil, B. Poulter, M. R. Raupach, P. Regnier, C. Rödenbeck, S. Saito, J. E. Salisbury, U. Schuster, J. Schwinger, R. Séférian, J. Segschneider, T. Steinhoff, B. D. Stocker, A. J. Sutton, T. Takahashi, B. Tilbrook, N. Viovy, Y.-P. Wang, R. Wanninkhof, G. Van der Werf, A. Wiltshire, and N. Zeng. Earth System Science Data Discussions, DOI:10.5194/essdd-7-521-2014, http://dx.doi.org/10.5194/essdd-7-521-2014, as released 21 September 2014 on http://www.globalcarbonproject.org/carbonbudget/
- Haylock M.R., Hofstra N., Klein Tank A.M.G, Klok E.J, Jones P.D., New M. (2008) A European daily high resolution gridded data set of surface temperature and precipitation for 1950-2006. Journal of Geophysical Research: 113, 1-12.
- Hooyberghs H., Lauwaet D., Lefebvre W., Maiheu B., De Ridder K., González-Aparicio I., Acero J.-A., Mendizabal M. (2015) Agglomeration-scale urban climate and air quality projections. Report D4.2, EU-FP7 RAMSES project. Available from www.ramses-cities.eu/resources/
- IPCC (2013) Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.
- IPCC (2014) Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland, 151 pp.
- RMI (2015a) Oog voor het klimaat 2015. RMI, Brussels, May 2015.
- RMI (2015b) Klimaatatlas, May 2015. Available at www.meteo.be/klimaatlas
- KNMI (2014) KNMI'14 climate scenarios for the Netherlands; A guide for professionals in climate adaptation, KNMI, De Bilt, The Netherlands, 34 pp. www.climate-scenarios.nl.
- Lauwaet D., Viaene P., Brisson E., van Lipzig N.P.M., van Noije T., Strunk A., Van Looy S., Veldeman N., Blyth L., De Ridder K. and Janssen S. (2014) The effect of climate change and emission scenarios on ozone concentrations over Belgium: a high-resolution model study for policy support. Atmos. Chem. Phys.: 14, 1–12, 2014

http://www.atmos-chem-phys.net/14/5893/2014/acp-14-5893-2014.html doi:10.5194/acp-14-1-2014
- Lauwaet D., Hooyberghs H., Maiheu B., Lefebvre W., Driesen G., Van Looy S. and De Ridder K. (2015) Detailed Urban Heat Island Projections for Cities Worldwide: Dynamical Downscaling CMIP5 Global Climate Models. Climate, 3, 391-415.
- Lenton T.M., Held H., Kriegler E., Hall J.W., Lucht W., Rahmstorf S. and Schellnhuber H.J. (2008) Tipping elements in the Earth's climate system. National Academy of Sciences: 105, 1786-1793.
- Levermann A., Bamber J., Drijfhout S., Ganopolski A., Haeberli W., Harris N.R.P., Huss M., Krüger K., Lenton T.M., Lindsay R.W., Notz D., Wadhams P., Weber S. (2012) Potential climatic transitions with profound impact on Europe: review of the current state of six 'tipping elements of the climate system'. Climatic Change: 110, pp. 845–878.
- Loulergue L., A. Schilt, R. Spahni, V. Masson-Delmotte, T. Blunier, B. Lemieux, J.-M. Barnola, D. Raynaud, T.F. Stocker and J. Chappellaz (2008) Orbital and millennial-scale features of atmospheric CH_4 over the past 800,000 years. Nature, Vol. 453, pp. 383-386, 15 May 2008. doi:10.1038/nature06950
- Lüthi D., M. Le Floch, B. Bereiter, T. Blunier, J.-M. Barnola, U. Siegenthaler, D. Raynaud, J. Jouzel, H. Fischer, K. Kawamura and T.F. Stocker (2008) High-resolution carbon dioxide concentration record 650,000-800,000 years before present. Nature, Vol. 453, pp. 379-382, 15 May 2008. doi:10.1038/nature06949

- McKee T.B., Doesken N.J. and Kleist J. (1993) The relationship of drought frequency and duration to time scales. Eighth Conference on Applied Climatology, 17-22 January 1993, Anaheim, California.
- NOAA (2014) The NOAA Annual Greenhouse Gas Index (AGGI). NOAA Earth System Research Laboratory, Boulder, USA. http://www.esrl.noaa.gov/gmd/aggi/index.html
- Photiadou C., van der Schrier G., van Oldenborgh G.J., Verver G., Klein Tank A., Plieger M., Mänchel H., Bissoli P., Rössner S. (2015) Climate Indicator Bulletin – update 19.1.2015. http://cib.knmi.nl/mediawiki/index.php/2014_warmest_year_on_record_in_Europe
- Rovers V., Bosch P., Albers R. (eindredactie) (2014) Eindrapport Climate Proof Cities 2010-2014. KvK report no.: 129/2014. http://www.knowledgeforclimate.nl/climateproofcities
- Schilt A., M. Baumgartner, T. Blunier, J. Schwander, R. Spahni, H. Fischer, T.F. Stocker. (2010) Glacial-Interglacial and Millennial Scale Variations in the Atmospheric Nitrous Oxide Concentration during the last 800,000 years. Quaternary Science Reviews, 29, 182-192.
- Tabari H., Taye M.T., Willems P. (2015a) Actualisatie en verfijning klimaatscenario's tot 2100 voor Vlaanderen – Nieuwe modelprojecties voor Ukkel op basis van globale klimaatmodellen (CMIP5), study commissioned by the Operational Water Management unit of the Flanders Environment Agency and MIRA, available at www.milieurapport.be, by KU Leuven – Department of Hydraulics, January 2015.
- Tabari H., Taye M.T., Willems P. (2015b) Water availability change in central Belgium for the late 21st century. Global and Planetary Change, 05/2015; DOI: 10.1016/j.gloplacha.2015.05.012
- van Vuuren D.P., Edmonds J., Kainuma M., Riahi K., Thomson A., Hibbard K., Hurtt G.C., Kram T., Krey V., Lamarque J.-F., Masui T., Meinshausen M., Nakicenovic N., Smith S.J. and Rose S.K. (2011) The representative concentration pathways: an overview. Climatic Change: 109, 5-31. DOI 10.1007/s10584-011-0148-z.

- Vicente-Serrano S.M., López-Moreno J.I., Beguería S., Lorenzo-Lacruz J., Azorin-Molina C. and Morán-Tejeda E. (2012) Accurate computation of a streamflow drought index. Journal of Hydrologic Engineering: 17, 318-332.
- VKP (2013) Vlaams Klimaatbeleidsplan 2013-2020, Deel Vlaams Adaptatieplan. http://www.lne.be/themas/klimaatverandering/klimaattips/klimaattips/wat-doet-de-vlaamse-overheid/vlaams-klimaatbeleidsplan
- VLIZ (2014) SeArch-tijdlijn. http://www.sea-arch.be/nl/tijdlijn
- VMM (2014a) Megatrends: far-reaching, but also out of reach? How do megatrends influence the environment in Flanders? MIRA Future Outlook Report 2014, Flanders Environment Agency (VMM), Aalst. Available via http://www.milieurapport.be/en/publications/outlook-reports/megatrends-report/
- VMM (2014b) Onderbouwing van het Overstromingsrisicobeheerplan van de onbevaarbare waterlopen. ORBP-analyse Basisrapport. Erembodegem, 116p.
- Scientific Institute of Public Health (2007) Mortality in Belgium in the summer of 2006. Department of Epidemiology, March 2007; Brussels (Belgium). WIV/EPI REPORTS N 2007-016. Depot number: D/2007/2505/16
- Willems P. (2012) Model uncertainty analysis by variance decomposition. Physics and Chemistry of the Earth, 42-44, 21-30.
- Willems P. (2013a) Multidecadal oscillatory behaviour of rainfall extremes in Europe. Climatic Change: 120(4), 931–944.
- Willems P. (2013b) Adjustment of extreme rainfall statistics accounting for multidecadal climate oscillations. Journal of Hydrology: 490, 126-133.
- Willems P. (2014) Actualisatie van de extreme-waarden-statistiek van stormvloeden aan de Belgische kust. KU Leuven - Department of Hydraulics, Rapport voor de Vlaamse overheid - Waterbouwkundig Laboratorium, oktober 2014, 29 p.
- WMO (2014a) Greenhouse Gas Bulletin No. 10, 6 November 2014 – The State of Greenhouse Gases in the Atmosphere Based on Global Observations through 2013. ISSN 2078-0796
- WMO (2014b) Atlas of mortality and economic losses from weather, climate and water extremes, United Nations Office for Disaster Risk Reduction, WMO-No. 1123, GENEVA, 11 July 2014. http://www.wmo.int/pages/prog/drr/transfer/2014.06.12-WMO1123_Atlas_120614.pdf
- WMO (2015) Warming trend continues in 2014, press release 2.2.2015.

GLOSSARY

Aerosol: gas in which solid particles or droplets are suspended.

Climate: average weather over a long period. Statistical description (in terms of averages and variability) of a number of relevant weather parameters such as temperature, precipitation and wind over a longer period (*e.g.* 30 years).

Climate change signal: change in the climate (also called climate sensitivity) under the influence of greenhouse gas scenarios.

Convective precipitation: precipitation as a result of convection, *i.e.* the phenomenon where heat propagates in a vertical direction (in the air, the ocean, etc.). Convective rainfall usually occurs on hot summer days. It is also referred to as a 'summer storm'.

Evapotranspiration: all losses of water from the soil, vegetation and their component parts to the atmosphere. This is all the precipitation that is not run off via the watercourse, but that goes into the atmosphere either by direct evaporation or absorption by plants and animals followed by evaporation. The 'potential evapotranspiration' is the maximum possible evapotranspiration that occurs if sufficient water is at all times available at the surface or in the soil. This is, however, not always the case. During dry summer periods, the actual evapotranspiration is less than the potential evapotranspiration.

Excess mortality: mortality rate above the modelled or expected level. The expected number of deaths for a given day is obtained by modelling the number of deaths observed during a reference period of five years that begins 5½ years before that day and ends six months before that same day. Not just the number of deaths recorded during the reference period are added together, but possible periods of extremely high mortality during the reference period are assigned a smaller weight in the reference figure to avoid overestimating the expected mortality. The excess (or shortage) of deaths is then calculated as the difference between the observed and expected number of deaths. The significance of this excess (or below-average) mortality is determined by means of the 95 % confidence interval (CI).

Flood plains: areas along a watercourse that may be flooded as a result of the flooding of the watercourse.

Grid (grid cell, grid size): regular grid of guide lines to facilitate the positioning and alignment of elements.

Heat stress: heat-related impact on human health during a period of extremely hot weather. When loss of moisture in the body due to excessive transpiration is not or insufficiently rehydrated, severe problems may arise. The body dehydrates and may even give rise to a heart attack or stroke. Elderly and sick people are the most vulnerable to heat stress.

Heat wave degree days: sum of exceedances of daily maximum and minimum temperatures above the threshold values of 29.6 °C and 18.2 °C respectively, for heat wave days (according to the definition of the FPS Public Health) in the period from April 1 to September 30.

Hydraulic: relating to water flow (*e.g.* along a river or sewer).

Hydrological: relating to hydrology, *i.e.* the behaviour, properties, movement and distribution of water in the atmosphere and on the earth's surface.

Level of petrification: the extent to which the soil surface is covered with paving (houses, roads, parking areas, etc.)

Model: a computer algorithm based on mathematical equations that describe/simulate a given physical reality.

Percentile: value below which a certain frequency or probability falls.

Perturbation: change (from the present to a future climate). The perturbation factor is a factor that quantifies this change; a perturbation factor of 1.2 means for example a 20 % increase. A climate perturbation tool is a calculation tool (computer algorithm) used to apply a perturbation to meteorological time series.

Precipitation run-off: run-off of rainwater, *e.g.* from a river basin to a watercourse or to a sewer.

Radiative forcing: indicator used to quantify the influence of various factors on the exchange of energy between the Earth and space. It stands for the difference between the radiative energy (heat) that is received by the climate system and the radiate energy that is radiated back into space. A positive radiative forcing is a net contribution to warming (more energy received than emitted), a negative value means a contribution to cooling (more energy lost than received).

Return period: average time between two consecutive exceedances.

Risk: combination of the probability of occurrence of a certain event and the associated effects. The flood risk is the risk as a result of floods.

Sigma plan: plan of the Flemish Government to better protect Flanders against floods from the Scheldt and its tributaries.

Standardized Precipitation Index (SPI): index that represents the standardised deviation of the precipitation over a number of months (including the month for which the index value is calculated) with respect to the precipitation during the same months in the reference period. The reference period used in this report is 1850-1899. The N preceding months are called the accumulation period, and the corresponding SPI is designated as SPI-N.

Storm surge: high water at the coast caused by a storm. Storm surges at the Belgian coast occur during storms from westerly to northerly directions. The wind creates an additional water surge, *i.e.* the wind forces the water up against the coast.

Storm surge (height): short rise of the sea level as a result of sea storms (wind forces).

Upper discharge: discharge along a watercourse originating from the precipitation run-off in the upstream river basin.

Urban heat island: phenomenon whereby the air temperature in cities is usually higher than in the surrounding rural areas, especially at night.

ABBREVIATIONS

ALARO: atmospheric model used by the RMI for making weather forecasts, and also for fine-mesh Belgian climate modelling

AR4: Fourth Assessment Report (IPCC)

AR5: Fifth Assessment Report (IPCC)

CCLM: climate model used by KU Leuven under the MACCBET project for fine-mesh Belgian climate modelling

CFC: chlorofluorocarbon

CMIP5: Coupled Model Intercomparison Project No. 5

COP: Conference of Parties,this is a meeting – and also the supreme governing body – of all parties to the United Nations Climate Change Convention.

CORDEX: Coordinated Regional Climate Downscaling Experiments

EEA: European Environment Agency

EU: European Union

EURO-CORDEX: Coordinated Regional Climate Downscaling Experiments for Europe

FPS: Federal Public Service

FRMP: flood risk management plan

GCM: General Circulation Model or Global Climate Model

HCFC: hydrogenated chlorofluorocarbon

IPCC: Intergovernmental Panel on Climate Change

KNMI: Royal Netherlands Meteorological Institute

KU Leuven: Catholic University Leuven

MIRA: Flanders Environment Report

ppb_v: parts per billion, volume unit

ppm_v: parts per million, volume unit

RCM: Regional Climate Model

RCP: Representative Concentration Pathway

RF: radiative forcing

RMI: Royal Meteorological Institute of Belgium

SAR: Second Assessment Report (IPCC)

SPI: Standardized Precipitation Index

SRES: Special Report on Emissions Scenarios (IPCC)

SUHI: surface urban heat island

TAR: Third Assessment Report (IPCC)

THC: Thermohaline Circulation

UHI: urban heat island

UNEP: United Nations Environment Programme

UNFCCC: United Nations Framework Convention on Climate Change

VITO: Flemish Institute for Technological Research

VMM: Flanders Environment Agency

WMO: World Meteorological Organisation

UNIT PREFIXES

10^{1}	= da	(deca)	10^{-1}	= d	(deci)
10^{2}	= h	(hecto)	10^{-2}	= c	(centi)
10^{3}	= k	(kilo)	10^{-3}	= m	(milli)
10^{6}	= M	(mega)	10^{-6}	= μ	(micro)
10^{9}	= G	(giga)	10^{-9}	= n	(nano)
10^{12}	= T	(tera)	10^{-12}	= p	(pico)
10^{15}	= P	(peta)	10^{-15}	= f	(femto)

INDEX

The **Flanders Environment Agency (VMM)** contributes to the realisation of the targets of the environmental policy by preventing, reducing and reversing harmful effects in water systems and the atmosphere. Moreover, it reports on the state of the environment and contributes to the realisation of the integral water policy. Further information on the Flanders Environment Agency at www.vmm.be.

The task determined by decree[9] of the **Environment Report Flanders (MIRA)** is threefold:

- a description, analysis and evaluation of the current state of the environment;
- an evaluation of the environmental policy conducted to date;
- a description of the expected environmental developments in case of an unchanged policy and a changed policy according to a number of scenarios that are thought relevant.

Moreover, broad publicity must be given to the environment reports. MIRA provides the scientific foundation for environmental policy planning in Flanders. More information about the Flanders environmental reporting and the MIRA publications at www.environmentflanders.be.

9 DABM, decree concerning general provisions on environment policy of 5 April 1995, BG 3 June 1995.

Colophon

MIRA Climate Report 2015, about observed and future climate changes in Flanders and Belgium is published by the Flanders Environment Agency (VMM) and compiled by the Environmental Reporting Unit (MIRA) of the Department Air, Environment and Communication (ALMC).

To quote

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You can download the publication at www.environmentflanders.be.
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FLANDERS ENVIRONMENT AGENCY

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‘To what extent is climate change already visible in Flanders and Belgium?’ and ‘What are the expectations for the future?’, these are the central questions in this MIRA Climate Report 2015.

An analysis of existing environmental indicators, supplemented with new indicators for drought and the urban heat island effect, provides the answer to the first question. Scenario analyses map out the bandwidth of the expectations for the future. They are based on the most recent scenarios of the Intergovernmental Panel on Climate Change of the United Nations (IPCC). Furthermore, the report for the first time examines potential spatial differences in climate change within Flanders and surroundings. Attention is also paid to the potential effects of climate change for public health and water management. Finally, this report dwells on the threat of tipping points in our climate system, and on how to deal with the uncertainties that are inherently associated with the climate scenarios.

With this report, MIRA again seeks to bridge the gap between science and policy. The report was developed by MIRA in collaboration with a diverse group of experts from the Katholieke Universiteit Leuven, the Flemish Institute for Technological Research, the Royal Meteorological Institute of Belgium, and the Flanders Environment Agency. They brought together the latest figures and insights in this report to facilitate their widespread dissemination and integration into policy-making.

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