SUMMARY

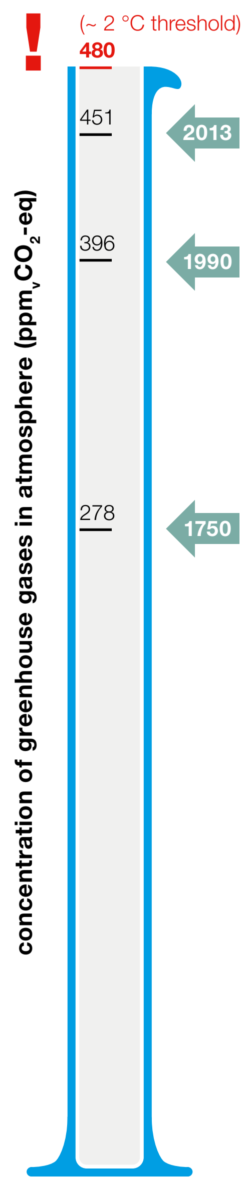
'To what extent is climate change already noticeable in Flanders and Belgium?' and 'What are the expectations for the future?', these are the central questions that this MIRA Climate Report 2015 seeks to address. The report begins with an explanation of the mechanism that is at the basis of global climate 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

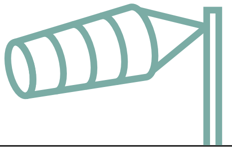


temperature

- 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.