Hessian Agency for Nature Conservation, Environment and Geology
Centre on Climate Change and Adaptation

HESSEN

Climate Change in the Future

Completely revised and updated: 2018

Climate change in Hesse

FACHZENTRUM KLIMAWANDEL UND ANPASSUNG

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Foreword

There has always been climate change. At no point in time have humans influenced the climate so dramatically and at such a pace as in recent decades. We can have a lasting effect on future climate change by living and conducting our business in a climate-friendly manner. However, we can no longer avoid it altogether. Currently, the global spread of climate-damaging gases is cause for concern, as this could lead to extremely pronounced warming in the future unless we manage to reverse the trend.

Many Hessian citizens are asking: How will climate change affect us? What can we still prevent? And what not? How do we even know what the future climate will look like? How reliable is the evidence?

In this brochure, we explain how we use climate projections to look into the future. We examine how reliable climate projection data is and give you an idea of what Hesse's future climate holds.

The Hessian Agency for Nature Conservation, Environment and Geology (HLNUG) provides further information on its website, and additional informational material and expert advice at its Centre on Climate Change and Adaptation.

Introduction

The more fossil fuels (that is, coal, oil and natural gas) we use, the more we heat up the atmosphere. Be it for energy production, transport or heating, we currently use large quantities of these fuels, thus emitting climate-relevant greenhouse gases, especially carbon dioxide (CO_2). There are other greenhouse gases that contribute to climate change apart from CO_2. These include methane and nitrous oxide, which are mostly produced in agriculture. And the more greenhouse gases we release today and in the future, the more we change our climate: our behaviour today will determine the future climate.

Even in Hesse, climate change has various consequences, affecting the water balance, agriculture, forestry and human health, to mention but a few. If you would like to learn more about the impacts of climate change in Hesse, you can obtain further brochures in the 'Climate change in Hesse' series online or by post from the HLNUG.

Future scenarios

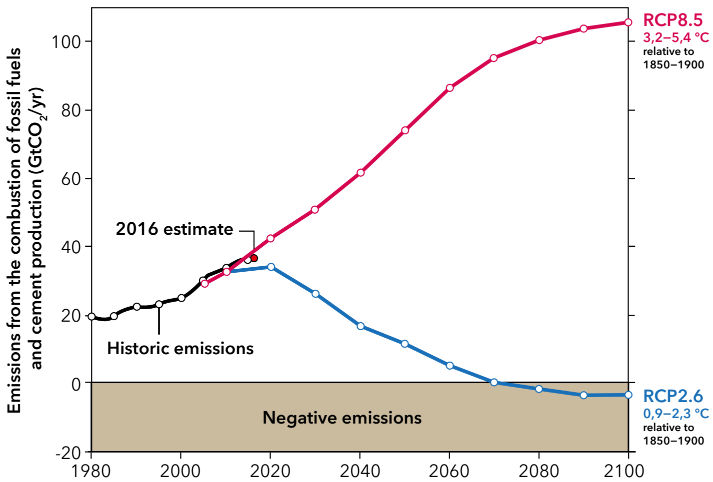
Economists and social scientists have developed possible **scenarios** to study the future climate. These consider global demographic trends, energy consumption and production, mobility, nutrition, transport and consumer behaviour among other things.

Until 2011, future scenarios were developed on the basis of greenhouse gas emissions. However, current scenarios use Representative Concentration Pathways (RCPs).

These scenarios are RCP2.6, RCP4.5, RCP6.0 and RCP8.5. The numbers refer to the severity of the climate impact at the end of this century: the higher the number, the more severe the effect on the climate system. In the case of RCP2.6, as a result of climate change, the sun will radiate an additional 2.6 W/m² onto the earth by the end of the century. This will reach 8.5 W/m² in RCP8.5.

If we carry on as usual, we can expect drastic climate change, roughly equivalent to the last scenario **(RCP8.5)**. This is why we will consistently refer to this scenario as the **'Business as Usual Scenario'** in this brochure.

At the World Climate Conference in Paris in December 2015, the global community set a target to limit the temperature increase this century to well below 2 °C above preindustrial levels (at around 1850). This would require industrialised countries (including Germany), to reduce greenhouse gas emissions by 90 % by 2050 (compared to 1990), and other countries to ensure that their greenhouse gas emissions do not increase too sharply. To meet the 2 °C target, we would have to adhere to the first scenario: the **RCP2.6** scenario. This is why we will consistently refer to this scenario as the **'Climate Protection Scenario'** in this brochure.



Own figure based on http://www.globalcarbonproject.org/carbonbudget/archive/2016/GCP_CarbonBudget_2016.pdf

Currently, greenhouse gas concentrations are heading towards the upper ranges of those proposed in the scenarios. So the Business as Usual Scenario is the more likely scenario at the moment.

Trends for the observed CO_2 emissions (black) and the two future scenarios 'Business as Usual' (red) and 'Climate Protection' (blue). The Climate Protection Scenario even requires that we eliminate greenhouse gases from the atmosphere (negative emissions) by the end of the century.

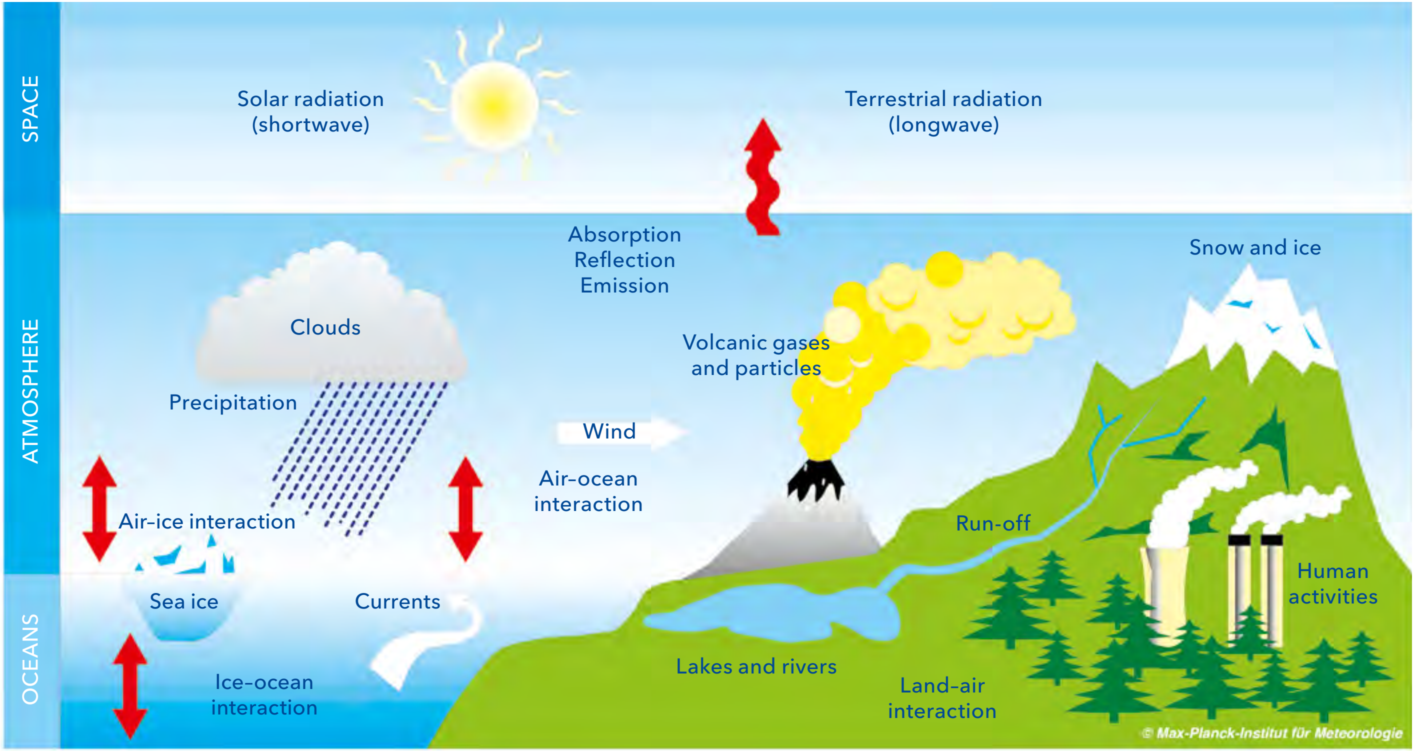
How do you determine the future climate?

In addition to the CO_2 content of the atmosphere, we take other greenhouse gases such as methane and nitrous oxide into account. To do this, their climate impact is converted into an equivalent CO_2 value and added to the CO_2 content. The resulting greenhouse gas concentration trend is then fed into the climate models.

A global climate model is a computer programme that describes the earth's climate system (that is, the atmosphere, land surface, oceans, ice, etc.) in terms of physics equations, simulating temperature, wind, sunshine and other climate properties. Processes that are too complex or small to be comprehensively simulated (such as individual clouds or rain) are approximated. The model then simulates changes in the above variables based on the increasing (or decreasing) greenhouse gas concentrations.

Of course, a computer programme is unable to provide an exact simulation of the climate system; hence, it simplifies many details. Still, these models generally manage to reproduce the present and past climate (for example, the last glacial and interglacial periods). So we can expect them to provide plausible projections for the future climate too.

The earth's climate system



Source: Hamburger Bildungsserver

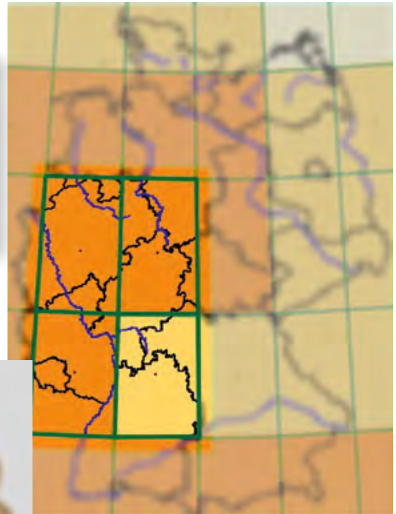
Max-Planck-Institut
für Meteorologie

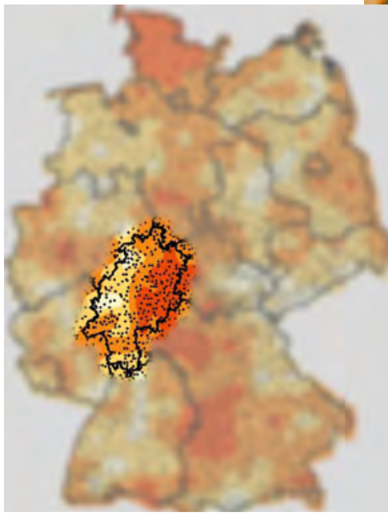
From global to local, in Hesse

The **global climate models** we described simulate the earth's climate in boxes on a grid, each with a length of 100 to 300 km. Of course, such a grid is far too coarse to determine Hesse's climate. This is why we use **regional climate models**. These determine how the climate will change in a specific part of the world, but with greater resolution.

Dynamic regional climate models use the same methodology as global models but apply it only to a section of the globe. **Statistical** regional climate models evaluate the statistical correlation between observations at weather or climate stations and the global atmospheric circulation. This correlation is extrapolated to the future, providing results for the areas where the observatories are located.

Resolution of a global climate model: each box on the grid has a single value which is the average value for the entire box (e.g. precipitation).

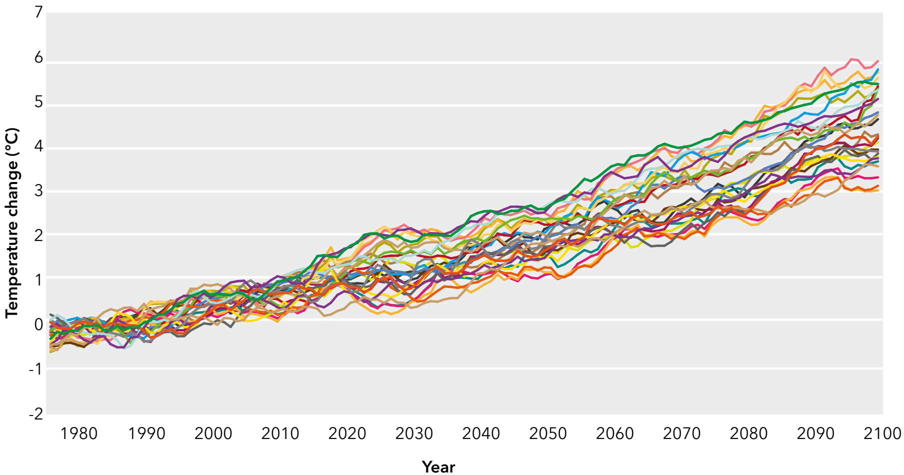




Resolution of a statistical regional climate model: each dot has a value (in this case precipitation); the area in between is interpolated.

Since neither the global nor the regional models are perfect, and each model has its own strengths and weaknesses, climate scientists usually use the results from as many different climate models as possible. This is called ensemble modelling. Models that plausibly determine the present and past climates are similarly expected to determine probable and possible future climate trends.

The figure shows the changes in annual average temperature for Hesse in the Business as Usual Scenario: the models project an average temperature increase of about 3.9 °C for the period 2071–2100 compared to the reference period (1971–2000). The breadth of warming in the individual models ranges from +2.6 °C to +5.1 °C.



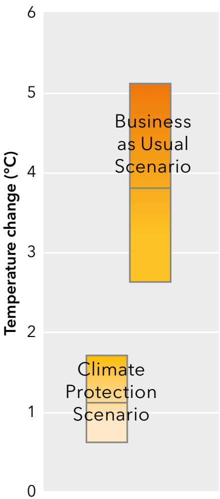
Source: Project ReKliEs-De, HLNUG

Change in annual average temperature (°C) in Hesse, using projections from 27 different combinations of global and regional climate models for the RCP8.5 scenario, with a moving average of 10 years.

Temperature change in Hesse

The average temperature in Hesse has already increased by 0.9 °C since preindustrial times (reference period 1971–2000).

The graph on the left shows the change in annual average temperature until the end of the century (2071–2100), compared to that at the end of last century (1971–2000).



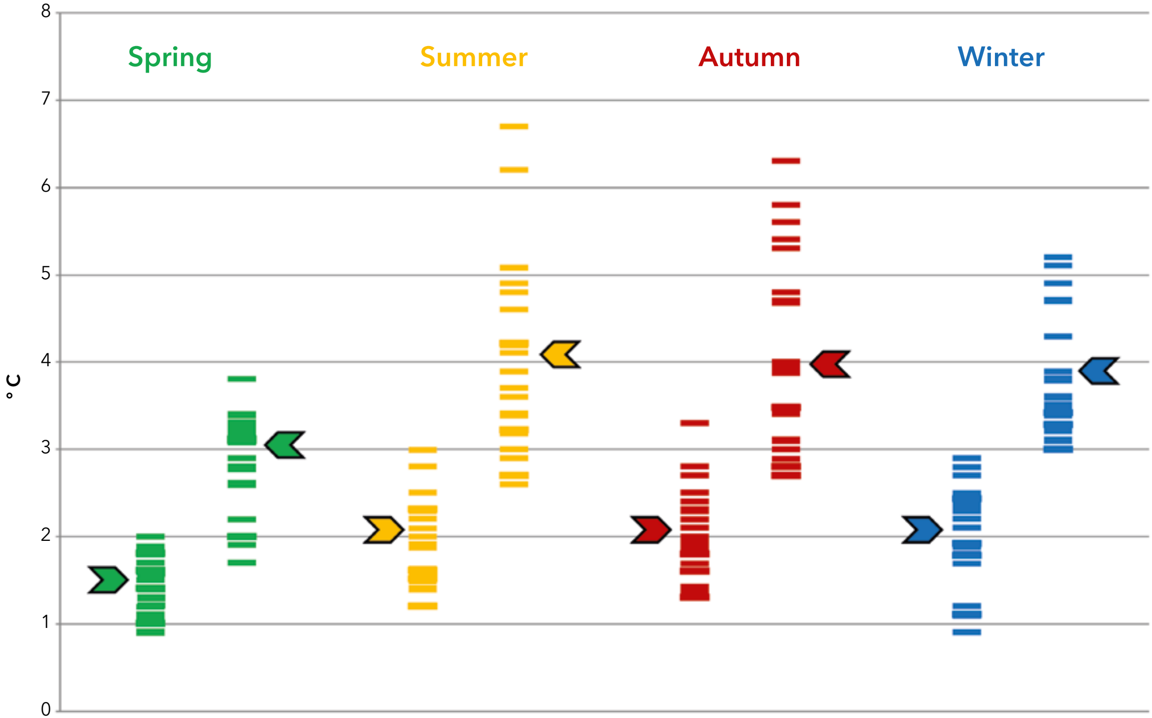
If we were to adhere to the global 2 °C target (Climate Protection Scenario), Hesse would have an annual average temperature increase of about 1.1 °C compared to the reference period 1971–2000

Projected annual average temperature change in °C by the end of the century (2071–2100) throughout Hesse compared to the period 1971–2000. Left: Climate Protection Scenario (12 model combinations). Right: Business as Usual Scenario (27 model combinations). The height of the vertical bars shows the breadth of the various model results, while the line shows the average value.

(breadth: 0.6 °C to 1.7 °C). In the case of the Business as Usual Scenario, the temperature increase would be about 3.9 °C (breadth: 2.6 °C to 5.1 °C) compared to the period 1971–2000.

Although the temperature increase varies by model, the bottom line is that the temperature will continue to increase, and the more greenhouse gases we emit, the more the temperature will increase.

The graph on the right shows seasonal temperature increases in the Business as Usual Scenario, both for the middle of the century (2031–2060) and the end (2071–2100), compared to the present day (reference period 1971–2000) for all 27 evaluated model combinations. In all seasons, the temperature increase at the end of the century is higher than that at the middle of the century. In addition, the lowest temperature increase is in spring, which indicates that future spring months could still be relatively cold and have late frosts.



Changes in the seasonal average temperature in Hesse (°C); 27 model combinations; Business as Usual Scenario; left: 2031–2060; right: 2071–2100; each compared to the period 1971–2000. Arrow: average value.

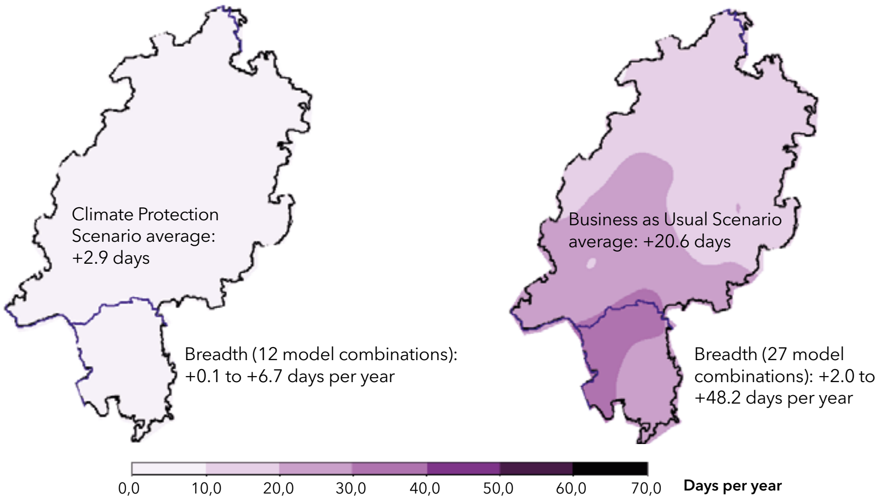
Increase in hot days, decrease in cold days

There was an annual average of 6.1 hot days (where the daily maximum temperature is 30 °C or above) in Hesse in the period 1971–2000. In the particularly hot summer of 2003, Hesse had 23 hot days, that is 17 days more than the average for the period 1971–2000.

Even the Climate Protection Scenario projects that about three additional hot days per year are to be expected by the end of the century (the breadth of the model simulations ranges between barely any change and twice the number of hot days as in the reference period 1971–2000).

In the case of the Business as Usual Scenario, at least 20 additional hot days per year are to be expected by 2071–2100. In the worst case, this figure could even increase to 48 additional hot days per year.

In the event of the Business as Usual Scenario, summers such as the one in 2003 would be normal or even perceived as relatively cool by the end of the century at the latest.



Increase in the number of hot days (daily maximum > 30°C) for the period 2071–2100 compared to 1971–2000.

As yet, we are unable to tell what a particularly hot summer would look like under such conditions. Our experiences of the extremely warm summers of 2003 and 2018 can only serve as an indication of what an average future summer would look like. We cannot even begin to imagine what it would look like in the worst case.

However, we can expect that the number of particularly cold days will decrease. The number of frost days (where the daily **minimum** temperature is below 0°C) and ice days (where the daily **maximum** temperature is below 0 °C) will decrease – by much more in the Business as Usual Scenario than in the Climate Protection Scenario. However, both scenarios also project occasional particularly cold autumns or winters, or springs with late frost until the end of the century.

Shift in precipitation from summer to winter

Precipitation can vary greatly from one place and one day to another. This is why models cannot project precipitation very realistically and the results of the various models (or combinations of global and regional models) sometimes differ considerably.

However, in the case of the **Climate Protection Scenario**, all models project a very small change of a maximum of ±15 % for both summer and winter. These changes are still within tolerance of the annual precipitation fluctuations we experience today. Hence, nature, agriculture and infrastructure can adapt.

Extremely dry summers, such as that in 2018, can even occur in the present climatic conditions. A drying old waterbody of the Rhine (Altrhein) near Lampertheim in summer 2018.

In the case of the **Business as Usual Scenario**, the projected changes are much more significant.

All model combinations project an increase in precipitation in winter, varying between less than 10 % and more than 40 %. Since precipitation is more likely to fall as rain than snow as a result of warming, there will be a greater risk of flooding in winter.

By contrast, most model combinations project a decrease in precipitation in summer. One model combination even projects a decrease in precipitation of more than half (-55 %) in the worst case. However, other model combinations even project a slight increase in precipitation of up to 15 %.

In winter, climate change causes an increase in precipitation.

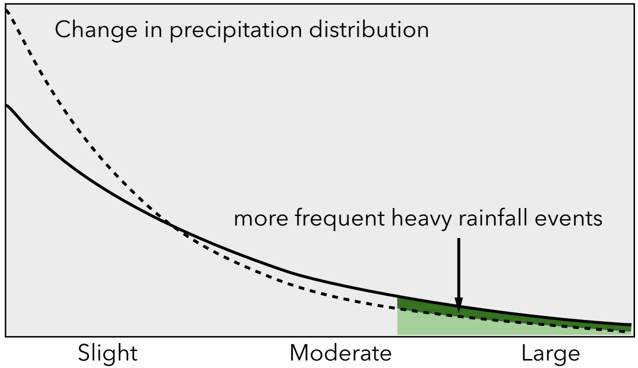
More days with heavy rainfall?

Rainfall events, some of which have more than 50 mm of precipitation per day, are very seldom and usually only occur at certain locations. But producing statistically significant results requires as much data as possible. Thus, days of heavy rainfall with a minimum of 20 mm of precipitation are also considered.

In the reference period 1971–2000, there was only an average of 4.3 such days per year throughout Hesse – somewhat more often in the Central Uplands than in the lowlands. However, such heavy rainfalls do not occur every year. Indeed, there may be years without a single heavy rainfall event, while there could be 10 such events in other years.

In the case of the **Business as Usual Scenario**, all 27 model combinations project an increase of an average of 1.7 days of heavy rainfall with a minimum of 20 mm of precipitation. The breadth of these results ranges from +0.6 to +3.4 additional days of heavy rainfall per year.

In the case of the **Climate Protection Scenario**, the 12 model combinations project a minimal increase of an average of +0.3 days of heavy rainfall per year with a breadth ranging from -0.1 to +1.0 days per year.



Own figure based on IPCC, 2013

Graph of change in precipitation: dashed line = present-day distribution; solid line = future distribution. Due to climate change, we can expect less mild and more extreme rainfall events.

Even though these changes seem minor, a single heavy rainfall event can in fact cause significant damage. Therefore, just a small increase in the days of heavy rainfall constitutes a problem.

Sun, wind and clouds

The various model combinations project different results with regard to the sun and cloud cover distribution. Some project a decrease in cloud cover and consequently an increase in sunshine duration, while others project an increase in cloud cover and thus a decrease in sunshine hours.

These changes are relatively small, even in the Business as Usual Scenario. Current year-on-year fluctuations between relatively sunny and relatively cloudy years are significantly greater than the projected changes due to climate change.

The average wind speed too only changes little and inconsistently in the projections of the various model combinations, and does not allow us to draw reliable conclusions about the frequency and severity of storms, which are particularly difficult to model.

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Uncertainty

All the mentioned climate changes are not to be understood as mere predictions but rather as possible consequences if the trends in greenhouse gas concentrations were to proceed in the manner assumed by the various scenarios.

The climate system reacts very slowly to changes in greenhouse gas concentrations in the atmosphere: it takes decades for all the resulting climate changes to fully take effect. The climate changes caused by the greenhouse gases emitted in the last few decades can no longer be avoided. However, should the global community opt for the Climate Protection Scenario, many of the outlined consequences could still be avoided. But the odds of this happening are shrinking rapidly. As of 2018, the world seems to tend towards the Business as Usual Scenario.

All climate models can only reproduce reality to a certain degree. In the case of temperature and precipitation, we are able to make fairly reliable projections of the expected climate change. In the case of storms, wind and clouds, any estimate is still unreliable.

Conclusion

In Hesse, we will need to adapt to increasing average temperatures in future. If we were to adhere to the Climate Protection Scenario, the average temperatures will only increase by about 1.1 °C. By contrast, in the case of the Business as Usual Scenario, the increase will be about 3.9 °C. An increase in the number of particularly hot days with temperatures above 30 °C is very likely. Nevertheless, there could still be occasional cold spells in winter and spring, as well as late frosts.

Precipitation will tend to shift from summer to winter and will be more likely to fall as rain than snow in winter.

Changes in average wind speed, sunshine and cloud cover are likely to be minor. However, this is still relatively uncertain and warrants further research.

Further information on climate change and its consequences in Hesse is available on our websites:

www.klimawandel.hlnug.de
and
www.atlas.umwelt.hessen.de
(only available in German)

The following information brochures in the
'Climate Change in Hesse' series have been published.

- Observed Climate Change
- Climate Change in the Future
- Extreme Weather Events in Hesse
- Climate Change and Water
- Impacts of Climate Change on Human Health
- Agriculture, Forestry and Climate Change
- Observing the Effects of Climate Change – Climate Impact Monitoring
- Hessian Soils under Climate Change

An information brochure for schoolchildren is available in German:

- Have you heard …? The Climate is changing!

Hessisches Landesamt für
Naturschutz, Umwelt und Geologie
Für eine lebenswerte Zukunft