

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

HESSEN



# Observed Climate Change

Climate change in Hesse



# Imprint

## **Series: Climate change in Hesse**

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## Foreword



*Prof. Dr. Thomas Schmid  
President of the Hessian  
Agency for Nature  
Conservation,  
Environment and  
Geology*

Climate change is real. Temperatures across the globe are increasing, the sea level is rising, precipitation is changing, glaciers are melting and, in many parts of the world, droughts and floods are occurring more frequently. Even here in Hesse, climate change is happening and we can already observe and document its impacts.

The human body does not have an organ that perceives the climate. We are able to perceive the weather and have distinct memories of last winter, but when we think back to our own childhood, we tend to only remember the pleasant times and forget the unpleasant. Our childhood memories consist of sledging every winter and swimming in a pool every summer. These memories may be happy, however, they do not concur with long-term observational data.

Weather observations in Hesse began as early as the 18th century. By evaluating such long time series, we are able to draw reliable conclusions with regard to climatic changes in Hesse during this period. This brochure gives an insight into climate changes that have been observed and recorded in Hesse to date.

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

# Introduction

The earth's climate has been in constant flux for millions of years, with alternating glacial and interglacial periods triggered by changes in the earth's orbit around the sun.

It has however remained relatively stable for several thousand years now, allowing the rise of highly developed civilisations. Since the onset of industrialisation, humankind has increasingly used coal, gas and oil as sources of energy. These materials were formed from forests and swamps many million years ago and store the carbon of prehistoric plants.

When we burn coal, gas and oil, we release this carbon into the atmosphere in the form of carbon dioxide ( $\text{CO}_2$ ). Thus, more  $\text{CO}_2$  is introduced into the atmosphere than plants, oceans and soil are able to reabsorb naturally. Consequently, the atmosphere's  $\text{CO}_2$  content increases, just like the water level in a bath where the tap is opened further but the water cannot drain out any faster.

This additional release of  $\text{CO}_2$  exacerbates our atmosphere's natural greenhouse effect. This is how we change our climate.

Climate is the term used to describe the 'average weather' in a region. Periods of 30 years are usually considered to avoid mistakenly interpreting climate variability from one year or decade to another as climate change.

However, the climate is not just the average values collected in the course of 30 years. It also includes natural fluctuations (such as warm or cold winters, and dry or wet summers) and the occurrence of extreme weather events (such as violent storms and extreme precipitation).

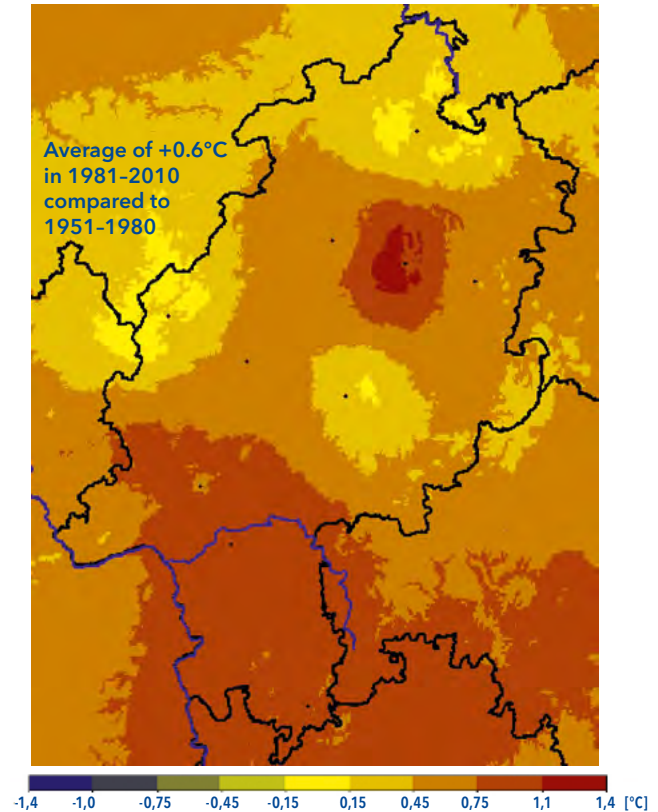
If there is a significant statistical difference in the average values, fluctuations or weather extremes between 30-year periods (that is, they are too high to be random), then we have climate change.

# Observed change in temperature in Hesse since 1900

On average, Hesse's river flats – particularly in the Rhine-Main region – are the warmest regions, while the higher altitudes of the Central Uplands are the coldest. Indeed, the coldest monitoring station in Hesse is on the Wasserkuppe and the warmest ones are in Geisenheim, Wiesbaden and Frankfurt am Main.

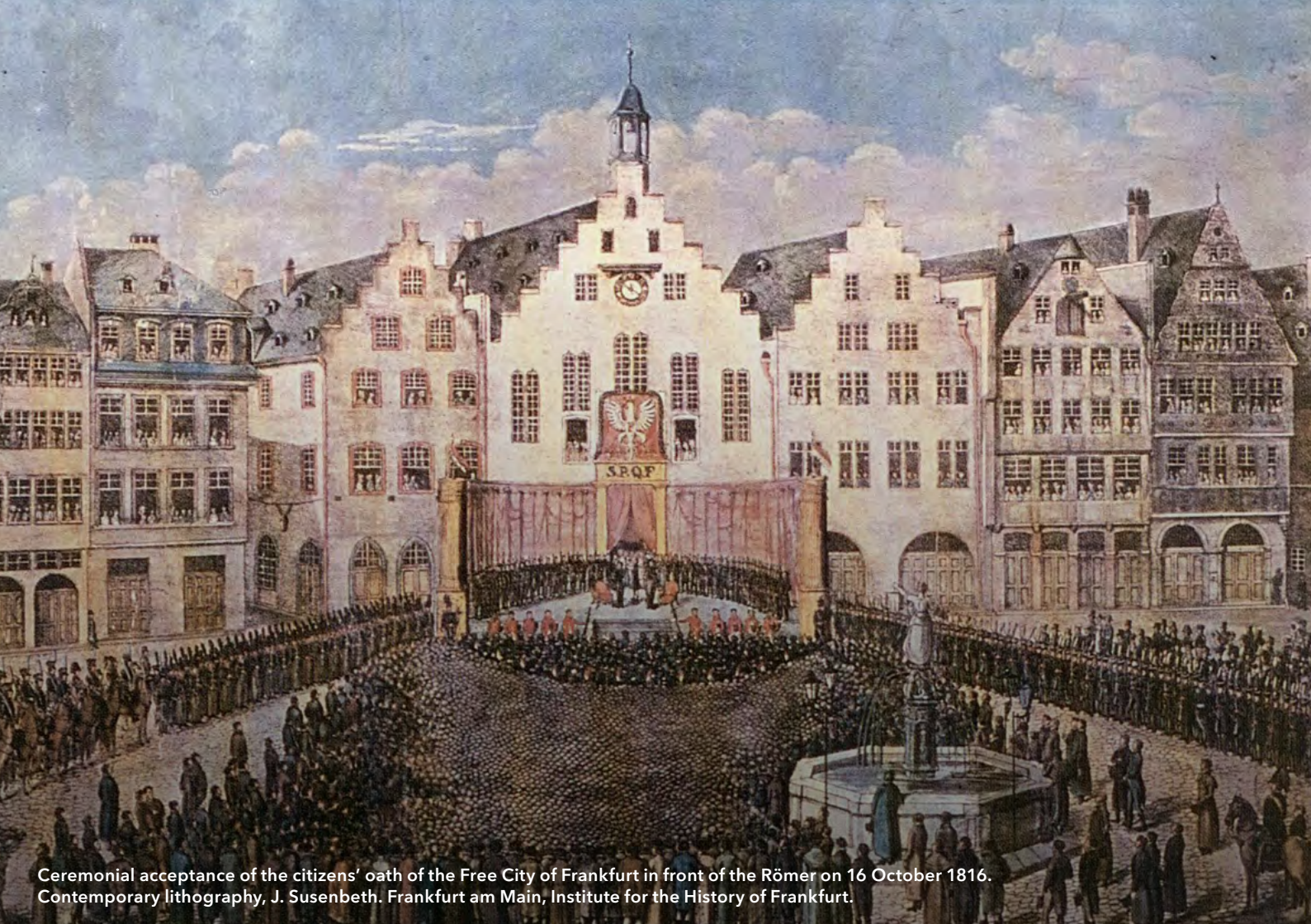
The air temperature in Hesse has been gradually increasing since the 19th century, reaching an average of 8.2 °C in the period 1951-1980. However, the temperature has increased significantly since the end of the 1980s: it had already reached 8.8 °C in the period 1981-2010 and has increased further since.

The highest temperature increases between these two periods were recorded in southern Hesse and the Knüllwald area, while the lowest temperature increases were in the areas around the Vogelsberg and Kassel, and in the Hessian foothills of the Westerwald.



Annual average temperature change in Hesse in 1981-2010 compared to 1951-1980. Data: (DWD).





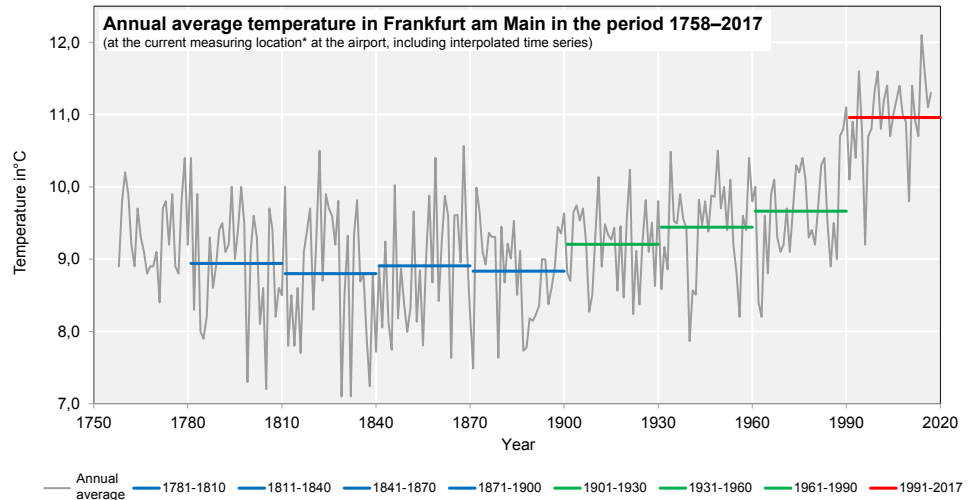
Ceremonial acceptance of the citizens' oath of the Free City of Frankfurt in front of the Römer on 16 October 1816.  
Contemporary lithography, J. Susenbeth. Frankfurt am Main, Institute for the History of Frankfurt.

# Long temperature measurement series with Frankfurt am Main as an example

The annual average temperature measurement series at the Frankfurt am Main station shows substantial year-on-year fluctuations in the period 1758–2017. The 30-year average values were around 9.0 °C until the end of the 19th century and gradually increased in the course of the 20th century. The average value for the period 1961–1990 was 9.7 °C.

Annual temperatures have been particularly warm since the end of the 1980s. Indeed, the average value of the period 1991–2017 was higher than the temperature of the single warmest year until 1987. Even a year that we considered cold (such as 2010 at 9.8 °C) would have been perceived as relatively warm in the past.

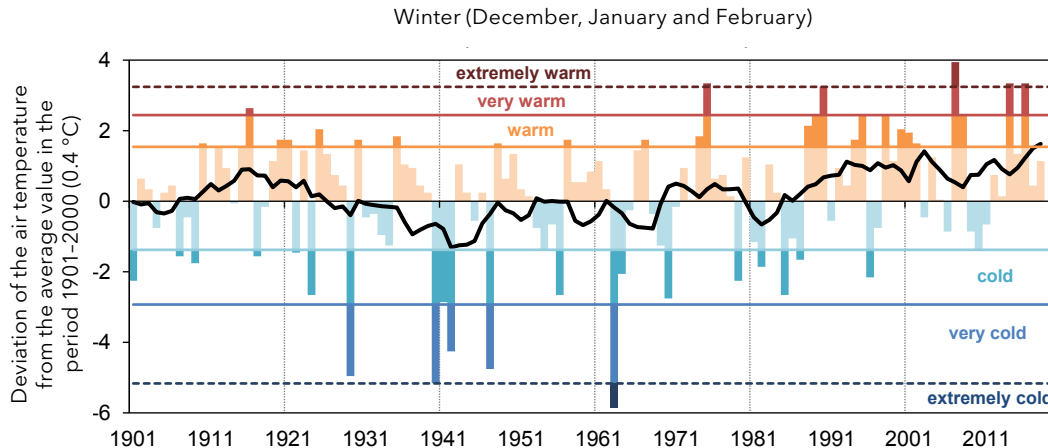
\* The Frankfurt am Main climate station is currently located at Frankfurt Airport to prevent the city's clearly increasing temperature from affecting the temperature time series. Since this was recorded in the present-day city centre until the mid 20th century, spatial interpolation was used to transpose the data to the current location.



# Seasonal change in temperature in Hesse

In Hesse, the average annual temperature increased from 8.1°C in the period 1901-1930 (30 years) to 9.2°C in the period 1991-2017 (27 years). The temperature has increased significantly in all seasons, especially in recent decades. A comparison of the periods 1961-1990 and 1991-2017 shows this very clearly (see table).

Season	Duration	Change	1961-1990 → 1991-2017
Winter	Dec.-Feb.	+1,0 °C	0,3 → 1,3 °C
Spring	Mar.-May	+1,2 °C	7,8 → 9,0 °C
Summer	Jun.-Aug.	+1,1 °C	16,2 → 17,3 °C
Autumn	Sept.-Nov.	+0,5 °C	8,6 → 9,1 °C



Average **winter temperature** deviations throughout Hesse from 1901 to 2018 in °C (coloured vertical bars: deviations in single years; black line: 11-year moving average)



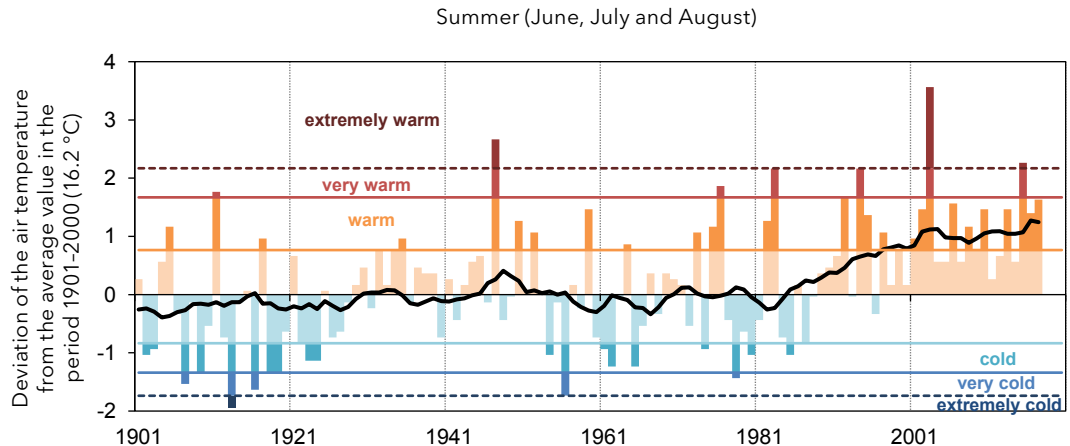
The figures show the average winter and summer temperature deviations in Hesse (coloured vertical bars) in relation to the average value in the 20th century and include the 11-year moving average (black line).

The period 1941–1970 was characterised by very cold winters. The five coldest winters by far were recorded between 1929 and 1963 (coldest winter: 1962/63). The five warmest winters were recorded from the 1970s onwards (warmest winter: 2006/07).

Cooler summers were mainly recorded before 1930 and in the period 1954–1987. Most subsequent summers were warmer than average, as indicated by the increase in the 11-year moving average (black line).

Summer 2003 was by far the warmest summer ever recorded in Hesse. It was 3.6 °C warmer than the average value for the period 1901–2000.

Average **summer temperature** deviations throughout Hesse from 1901 to 2017 in °C (coloured vertical bars: deviations in single years; black line: 11-year moving average)



## Particularly hot or cold days (threshold days)

**Threshold days** are days characterised by temperatures exceeding or falling below a certain threshold value.

On average, the number of **frost days** (where the minimum temperature is below 0 °C) and **ice days** (where the maximum temperature is below 0 °C) between the periods 1951–1980 and 1981–2010 decreased throughout Hesse (see figure on the right).

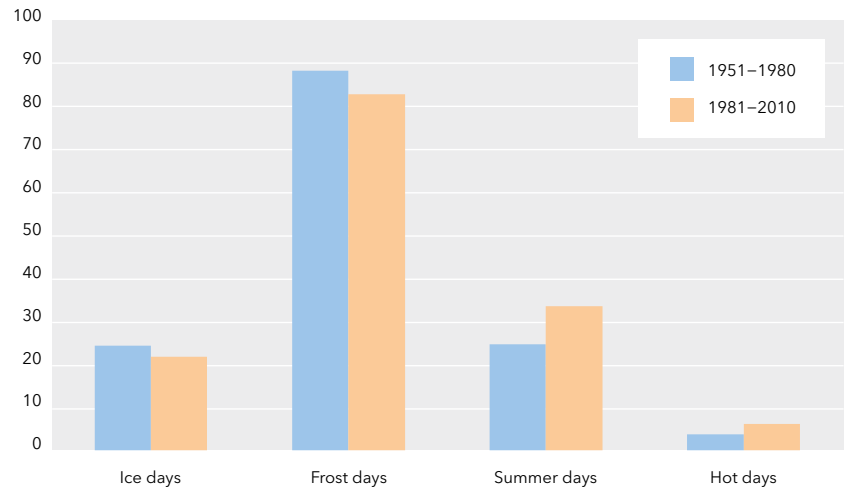


*Löwenburg in Kassel*



By contrast, the number of **summer days** (where the maximum temperature is above 25 °C) and **hot days** (where the maximum temperature is above 30 °C) between the two periods increased significantly on average throughout Hesse.

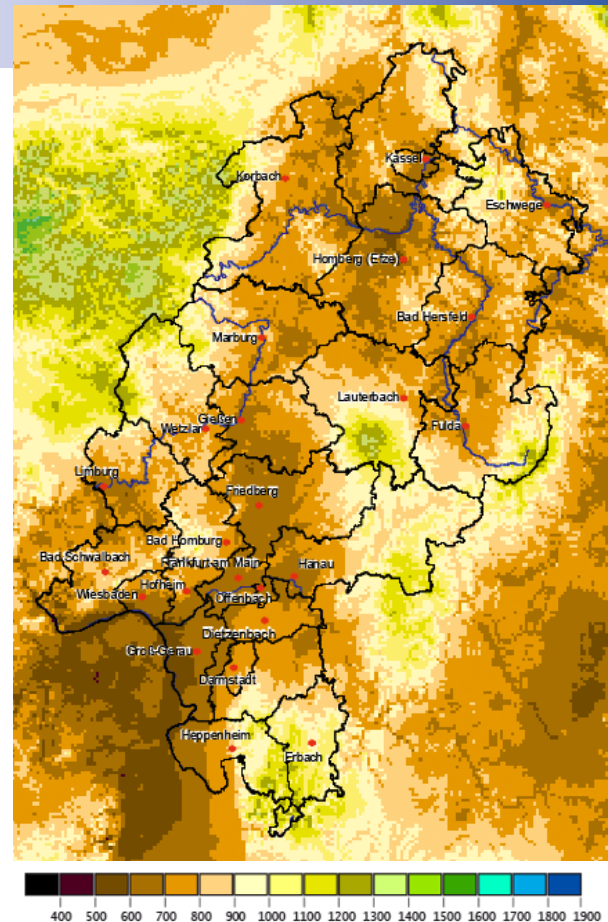
*Changes in the number of threshold days in Hesse in 1981–2010 in comparison to 1951–1980.*  
Data: DWD.



# Observed change in precipitation

Precipitation is highly variable, both spatially and temporally. In Hesse, the highest average precipitation occurs in the Vogelsberg, the Rhön Mountains and the Odenwald. There is significantly less precipitation on the river flats, the least being along the Rhine. Precipitation is highly variable from one year to another, and even fluctuates from one decade to another. Hence, it is all the more important to exercise caution in determining precipitation trends.

Hesse's average annual precipitation has slightly increased since precipitation started being recorded (mostly at the end of the 19th century). While it was relatively dry until the mid 20th century (1901-1930: 735 mm/year and 1931-1960: 748 mm/year), the subsequent periods were clearly wetter (1961-1990: 793 mm/year and 1981-2010: 807 mm/year).



Average annual precipitation in mm in the period 1981-2010.  
Data: DWD

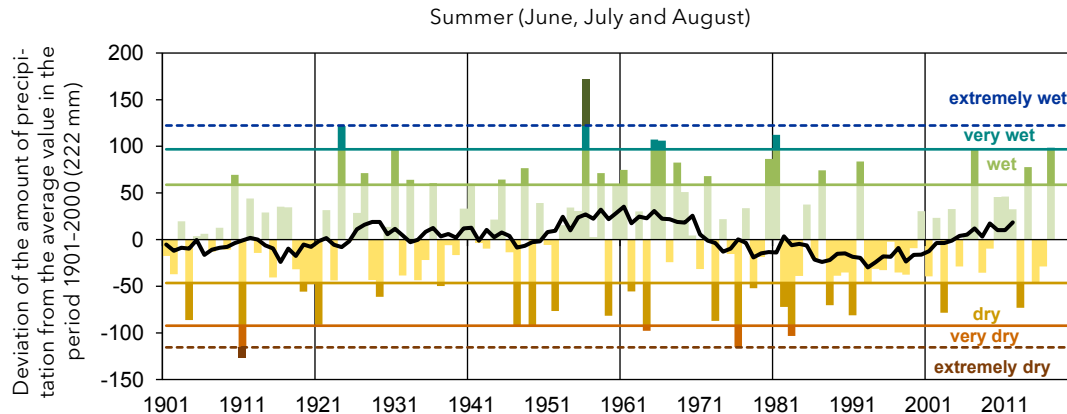




# Seasonal change in precipitation

Precipitation does not only fluctuate in the long term, but also in the course of a single year. Generally, the highest precipitation in Hesse occurs during summer (an average of 222 mm in the period 1901–2000), followed by autumn (187 mm) and winter (184 mm). Spring in Hesse is somewhat drier (169 mm).

The figures show the high variability in summer and winter in Hesse year-on-year. The summers in the period 1941–1970 were rather wet (an average of 240 mm throughout Hesse). By contrast, the **summers** in the period 1971–2000 were mostly drier (an average of 208 mm). Wet summers have been on the rise again since the turn of the millennium.

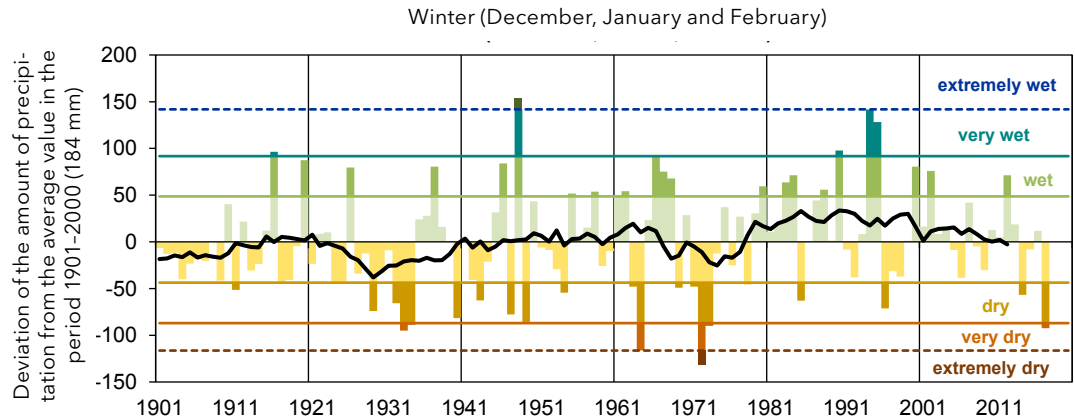


Average **summer precipitation** deviations throughout Hesse from 1901–2017 in mm (coloured vertical bars: deviations in single years; black line: 11-year moving average).

There was a spate of dry winters in the 1970s in particular: some winters had less than 100 mm of precipitation (for example, 1971/72 and 2016/17). However, there were quite a few wet winters in the 1980s and 1990s, occasionally with more than 300 mm of precipitation – most recently in the winters of 1993/94 and 1994/95, which included severe flooding.

Since 1901, the amount of precipitation in Hesse has somewhat increased in all seasons except summer. However, due to the very high variability of precipitation – both from one year or decade to another or even in the course of longer periods – all these developments in seasonal amounts of precipitation are not significant. Therefore, we cannot rule out the possibility that the trends are random.

Average **winter precipitation** deviations throughout Hesse from 1901-2017 in mm (coloured vertical bars: deviations in single years; black line: 11-year moving average).



# Combined effect of temperature and precipitation

The effects of the various weather elements often reinforce each other. In recent years, the spring and summer months have been increasingly dry and hot. The heatwaves of summer 2003 repeatedly made headlines across Europe because of the many people, the elderly in particular, that died as a result of the extraordinary heat stress. Studies have shown that the dry spring in 2003 significantly contributed to

the tremendous heat that summer. The desiccated soil warmed up much more than it would have after a wetter spring with comparable solar radiation.

Since the late 1980s, many other years have not only been particularly warm but also particularly dry, especially in summer.



*Edersee, September 2009: The low water level (due to lack of rain and drainage through the dam wall) exposed the ruins on the lake's bed that are otherwise submerged.*

*Near the village of Asel, a bridge that is normally submerged under a few metres of water can be crossed without getting your feet wet. Hesse's largest lake holds approximately 200 million m<sup>3</sup> of water. On 10 October 2009, it held merely 35 million m<sup>3</sup>.*

<https://www.op-marburg.de/Mehr/Hessen/Edersee-gibt-Schaetze-preis> (available only in German)



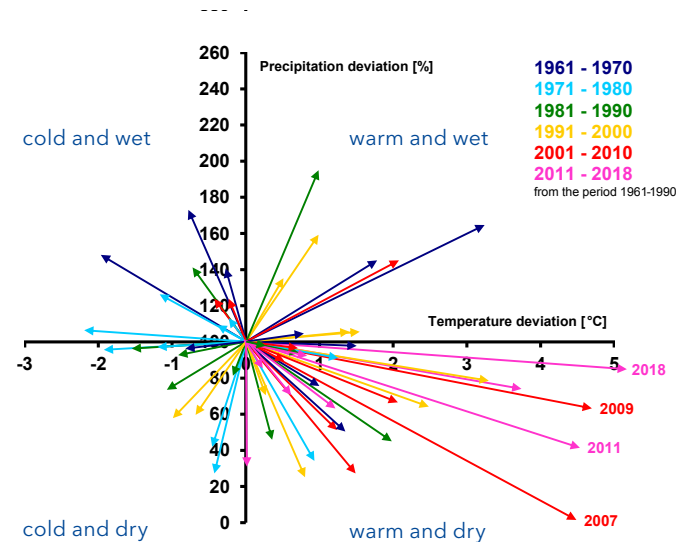
An example of particularly hot and dry spring months: the figure shows the deviation of the temperature (horizontal axis) and precipitation (vertical axis) in April from the average value for April in the period 1961-1990 in Hesse. Each arrow represents April's value for any single year and shows the deviation of this particular month from the long-term average value.

It is evident that April, particularly in recent years, has been increasingly significantly warmer and drier than all previous years.

The years 2007, 2009, 2011 and 2018 were particularly noticeable: in these four years, the average temperature in Hesse in April was 4.5-5.0 °C above the average for the reference period 1961-1990.

*Deviation of temperature and precipitation in Hesse in April in 1961-2018 from the average value in the period 1961-1990. The intersection of the two axes represents the average value for the period 1961-1990.*

To add insult to injury, there was only about half the usual amount of precipitation in April 2009 and 2011. In 2007, almost no precipitation was recorded throughout Hesse.



## Change in snow cover

Higher temperatures lead to more frequent rain than snow in winter, especially in the lowlands. While snow has rarely been seen in the mild Hessian river valleys, the decreasing snow cover in Hesse's Central Uplands is a real challenge for winter tourism.

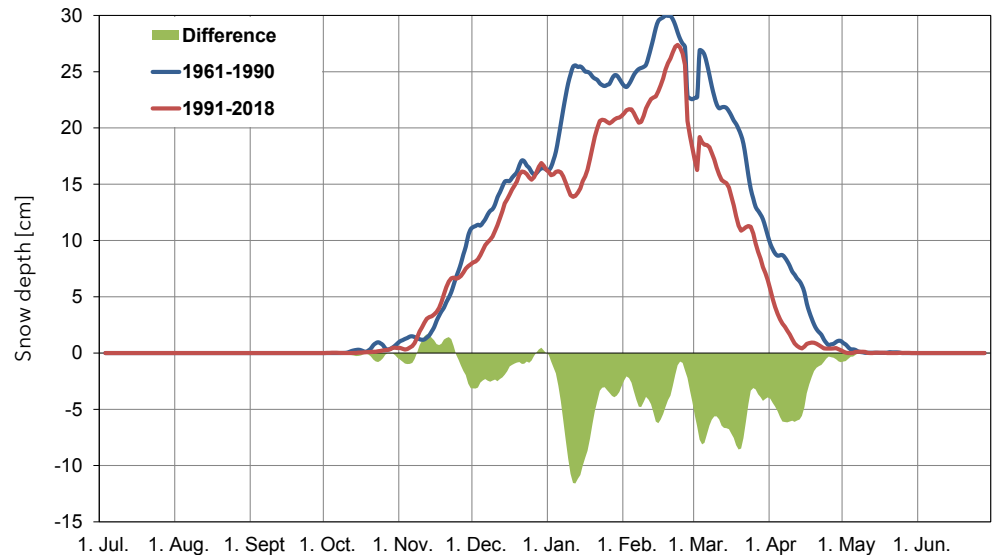
Larger ski resorts in particular are increasingly reliant on artificial snow, which, however, is not very sustainable as it requires water and energy. And still, the temperature for artificial snow must be below freezing. Consequently, the rising winter temperatures represent a hurdle.



*Snow on the Wasserkuppe*

The number of days with snow cover is highly variable from one winter to another. The winters of 2006/07 and 2013/14 in the Hessian lowlands were mostly free of snow. By contrast, it snowed on 41 days at Frankfurt Airport in the winters of 2009/10 and 2010/11 – just as frequently as on the Wasserkuppe in 2006/07.

Overall, the number of days with snow cover in Hesse has significantly decreased since the late 1980s. Simultaneously, the maximum snow depth at all altitudes has also decreased. The figure shows the difference in average snow depth on the Wasserkuppe in a comparison of the periods 1991–2018 and 1961–1990. While the difference in snow cover is rather small at



*Snow cover on the Wasserkuppe*

the beginning of winter, there is substantially less snow throughout the winter-sports season between January and March, which then melts earlier in spring.

# Extreme events

Extreme events are, by definition, so rare that drawing statistically reliable conclusions with regard to changes in the frequency and severity of extreme events is often impossible, even with

the help of very long measurement series. Still, we can employ the basic laws of physics when considering the occurrence of certain extreme events.



*Congested sewer system after heavy rainfall in Wiesbaden (27 May 2016)*

Climate change increases the probability of more extreme heavy rainfall events. Due to warming, the warmer air can absorb more water vapour than cooler air. Air that is saturated with water vapour forms cloud droplets, which in turn form raindrops, which eventually fall as rain. Thus, a cloud in warmer air contains more or larger cloud droplets than a cloud in cooler air.

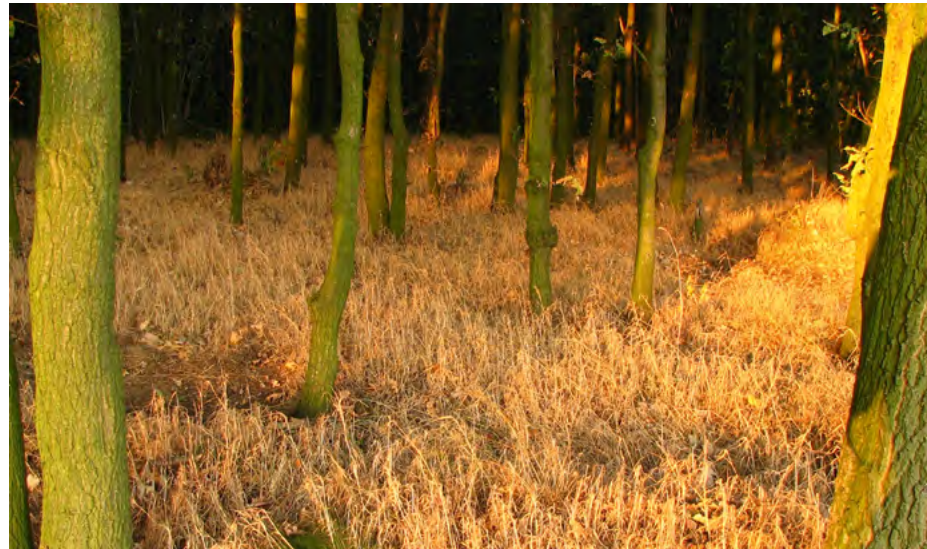
The HLNUG's 'KLIMPRAX - Starkregen' (Heavy Rainfall) project deals with the effects of heavy rainfall events on Hessian municipalities (<https://www.hlnug.de/?id=11199>).



Since the 1990s in particular, we have experienced increasingly more **summer droughts** in Hesse too. However, conclusions on trends are not yet statistically significant, since events are too rare to reliably establish that they are not random.

But, according to current knowledge, global warming intensifies global wind circulation and consequently increases subtropical high-pressure areas, among other things. Such high-pressure areas are responsible for the dry summer climate in the Mediterranean. An increase in the strength of these high-pressure areas would increase the probability that they extend further north and cause prolonged summer droughts in Hesse too.

In Central Europe, severe **winter storms** are responsible for the greatest damage caused by a weather event. However, it is currently not possible to draw any reliable conclusion with regard to future storm activity in Hesse.



*Impacts of summer drought*

# Conclusion

Climate change is real and we can already observe climatic changes in Hesse too.

The average annual temperature in Hesse increased by 1.1 °C between the periods 1901–1930 and 1991–2017, mostly in the last few decades.

The number of cold days (ice and frost days) has declined significantly since the 1960s, while the number of warm days (summer and hot days) has increased drastically.

Precipitation is highly variable from one year to another, and even in the longer term.

The annual average precipitation in Hesse has increased slightly since the turn of the 20th century. Winter, spring and autumn have become somewhat wetter, while summer remains virtually unchanged. Due to the very high variability of precipitation – both from one year or decade

to another or even in the course of longer periods – all these changes are not significant.

Thus far, the observed data provides insufficient evidence to determine reliable statistical trends for extreme events such as heavy precipitation, severe winter storms and summer droughts. However, employing the basic laws of physics leads us to presume that climate change could increase the likelihood of heavy precipitation and drought in future.

Further information on the climate in Hesse is available on our website:

- <http://klimawandel.hlnug.de>
- <http://atlas.umwelt.hessen.de> (Environmental Atlas of Hesse, available only in German)

Current measurement data is also available at:

- 'Witterungsbericht Hessen' (Report on Weather Conditions in Hesse, available only in German): <https://www.hlnug.de/?id=12741>
- 'Wetterextreme in Hessen' (Weather Extremes in Hesse, available only in German): <https://www.hlnug.de/?id=11522>

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

