

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

Extreme Weather Events in Hesse

Climate change in Hesse

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Conservation,
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Foreword

Extreme weather events such as hot and cold spells, droughts, floods and severe storms have always occurred and will continue to do so in Hesse. They cause major economic damage and, sadly, deaths time and again. This is why we need to know the types and frequency of extreme events that could occur, and whether climate change will make them occur more frequently.

Although not every event can be directly attributed to climate change, the changing average conditions (such as temperature and precipitation) make these extreme events even more likely. Climate change can even influence the severity of extreme events. Even though we are unable to predict exactly when and where the next extreme event will occur, we can investigate which types of extreme events will become more frequent or severe as a result of climate change. Therefore, we must prepare for extreme events to keep damage to a minimum should they indeed occur.

The Hessian Agency for Nature Conservation, Environment and Geology (HLNUG) provides further information on climate change in Hesse on its website, particularly through the interactive web applications 'Wetterextreme in Hessen' (Weather Extremes in Hesse) and 'Witterungsbericht Hessen' (Report on Weather Conditions in Hesse), both available only in German.

What is extreme?

Well, it depends on the context. In Hesse, for example, an average daily temperature of 20 °C is not exactly extremely high. In Greenland, it is. In this brochure, we define extreme events as very rare events in the time series we employ.

At least 10 German Meteorological Service (DWD) climate stations have been monitoring temperature, humidity, pressure, precipitation, wind speed and direction, for example, in Hesse since 1901. By 1960, there were more than 50. However, since 1990, the number of climate stations has decreased to around 40, since ground data is increasingly being replaced by radar or satellite data. Since precipitation has such small-scale variability, as opposed to temperature, for instance, there are additional precipitation monitoring stations. Measurement data has been collected from more than 150 such stations in Hesse since 1901.



*see: <https://www.hlnug.de/themen/wasser/niederschlag.html>
(available only in German)

This number increased to more than 350 stations by 1950, only to be reduced to 150 stations after 1990 due to the use of extensive radar data. The data we use was collected by the DWD. We also use precipitation data from 70 monitoring stations belonging to the Hessian state monitoring network.*

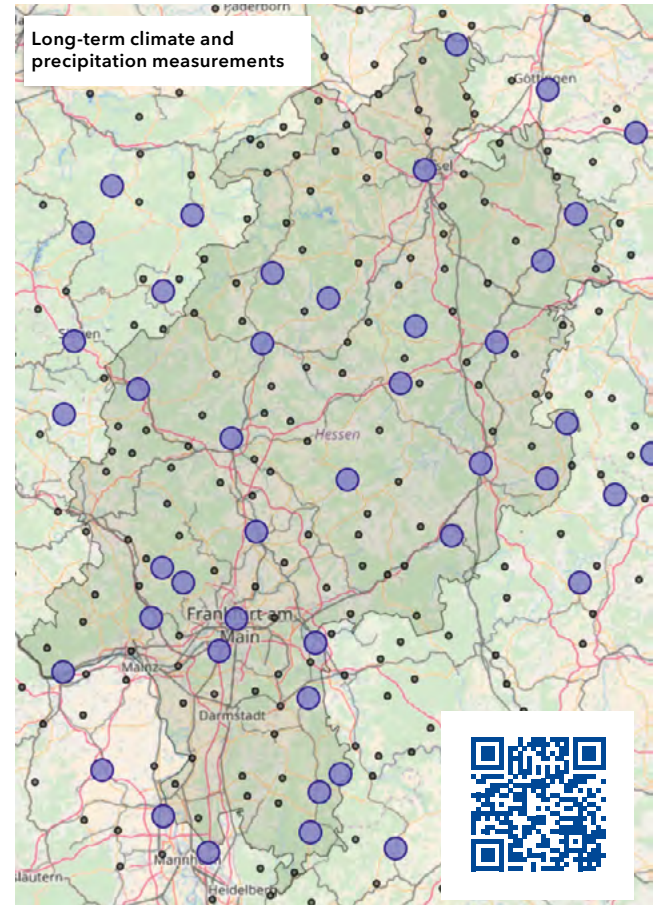


Offenbach's fire brigade deployed after storm damage.
© S. Danisch, Offenbach fire brigade

Only a few meteorological observatories have been monitoring the weather continuously from the same location over a very long period of time. Meanwhile, observation sites have been frequently changed and monitoring instruments replaced. Therefore, chronological gaps have appeared.

Most stations in Hesse have been monitoring the weather since the 1930s or 1940s. Initially, all measurements were recorded manually and entered into observation diaries. Much of this data has already been digitised for the purpose of climate analysis and now helps us interpret climate trends and extreme values.

The figure shows the location of climate stations (blue dots) and precipitation stations (black dots) in and around Hesse, which have recorded the weather for more than 30 years. Various analyses performed with data from these stations are available at 'Wetterextreme in Hessen' (<https://www.hlnug.de/?id=11522>). Graphs of the average values for Hesse are available at 'Witterungsbericht Hessen' (<https://www.hlnug.de/?id=12735>).

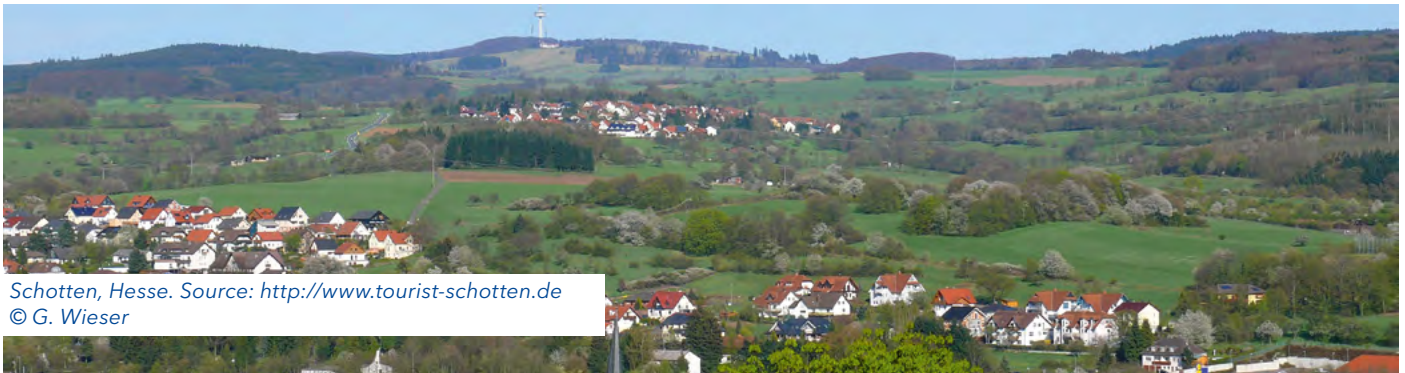


Temperature extremes

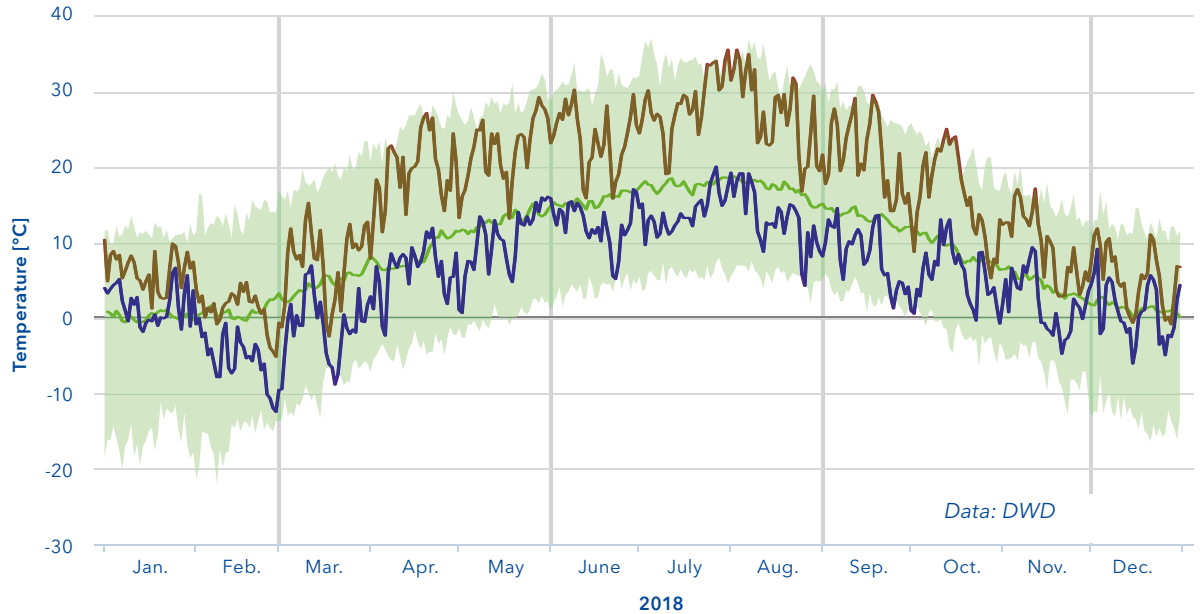
To determine whether a specific day in 2018 was extremely hot or cold, we need to compare the temperature with the normal value for that time of year.

The temperature statistics for the Schotten station (right) show the average value of the daily average temperature for the 30-year period 1981-2010 (**green line**) for every day of the year (for example, every 3 October). The green-shaded area shows the minimum and maximum temperatures from the most recent measurement period (1949-2017). The respective daily minimum (**blue**) and maximum (**brown**) temperatures for 2018 are also shown.

Indeed, 2018 was the warmest year in Schotten in the entire measurement series (since 1949): two new heat records were set as early as mid April and 17 consecutive hot days (where the daily maximum temperature is above 30 °C), interrupted only by one day at 29.3 °C, were recorded between the end of July and the beginning of August. New daily maximum temperatures of more than 35 °C were recorded on eight of these days. New heat records were also set in mid September and mid October.



Schotten, Hesse. Source: <http://www.tourist-schotten.de>
© G. Wieser



Source: Wetterextreme in Hessen

Overall, Schotten had 21 days with new record daily maximum temperatures and only five days with new record daily minimum temperatures in 2018.

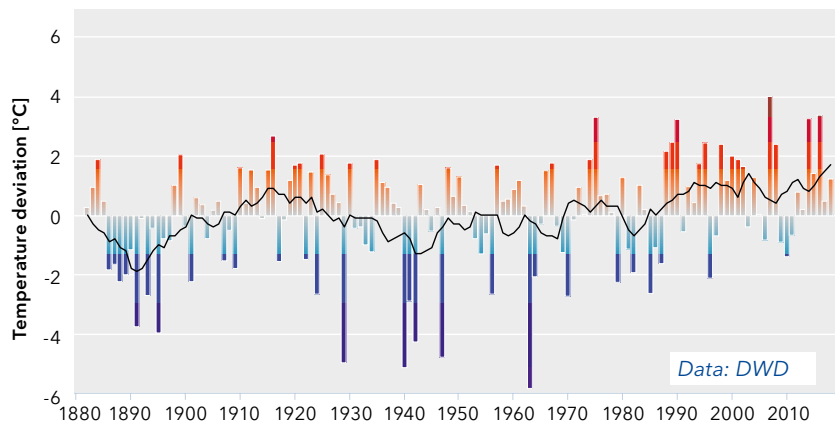
The figure was generated by the web application 'Wetterextreme in Hessen'.

Daily temperature in Schotten

- Average temperature for the period 1981-2010
- Daily minimum air temperature for 2018
- Daily maximum air temperature for 2018
- Daily records (min./max.) for the period 1949-2017

Was winter 2011/2012 particularly cold?

Many may recall the winter of 2012 (December 2011 to February 2012) as being particularly cold. But was it really? No! That winter was relatively warm, except for a very cold spell that lasted two weeks in February. In fact, it was actually slightly warmer than the average of $0.3\text{ }^{\circ}\text{C}$ for the period 1901–2000 (the zero line in the figure). The coldest winter in Hesse since 1881 was that of 1963, with a deviation from the long-term average of $-5.5\text{ }^{\circ}\text{C}$. The warmest was that



Some extreme values from February 2012:

- Kassel had 16 consecutive ice days (where the daily maximum temperature is below $0\text{ }^{\circ}\text{C}$)
- Minimum temperature on the Wasserkuppe: $-18.9\text{ }^{\circ}\text{C}$
- Minimum temperature in Sontra and Schlüchtern: $-20.2\text{ }^{\circ}\text{C}$

of 2007, with a deviation of $+4.4\text{ }^{\circ}\text{C}$. The 11-year moving average (black line) has increased, mainly since the mid 1980s. A winter that seems cold to us today would have been normal in the past. Apart from that, warm winters are on the increase and very cold winters hardly ever occur.

Deviation of winter temperature (December to February) from Hesse's 20th-century average value for the period 1881–2018 in $^{\circ}\text{C}$. Coloured vertical bars: average winter temperature; black line: 11-year moving average. (Source: Witterungsbericht Hessen)



There was also a very cold spell in March 2013, which resulted in the formation of huge icicles in the Taunus

Late frost

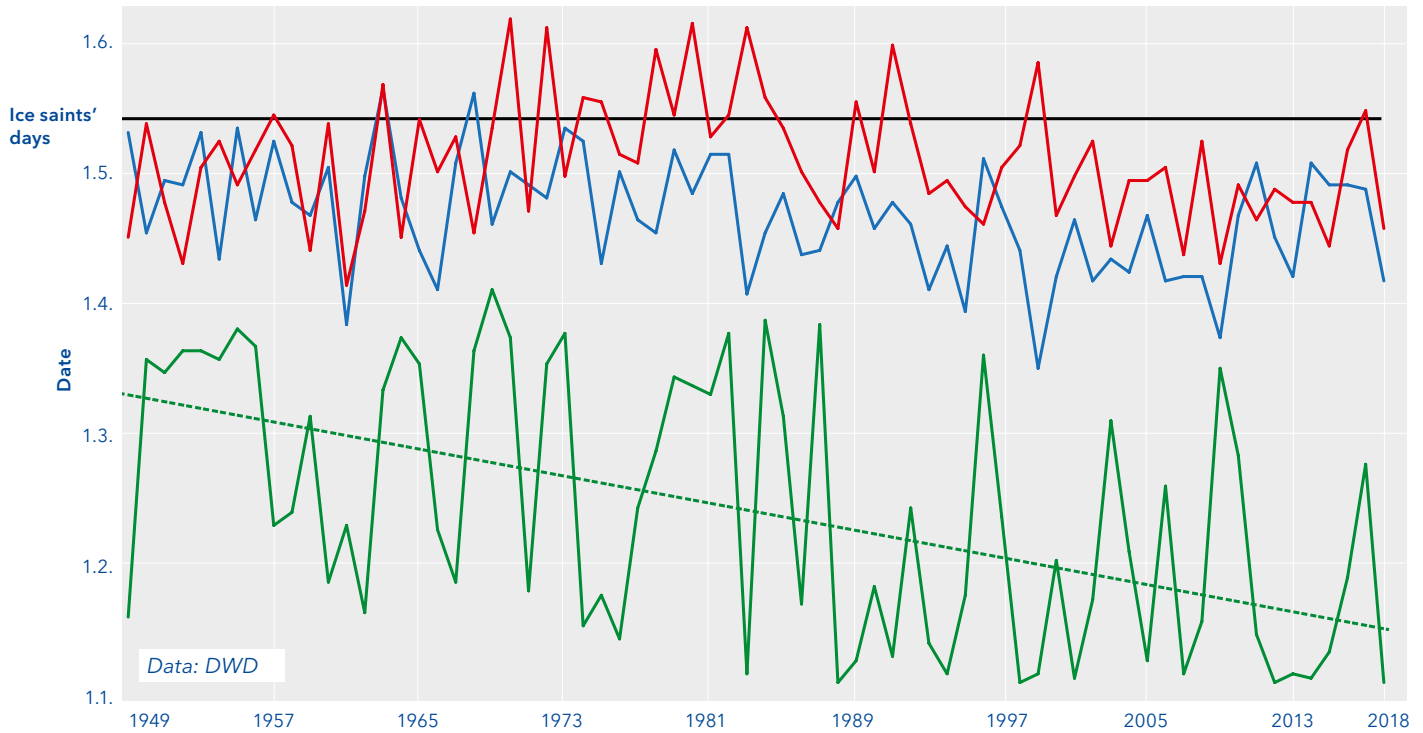
Late frost can still occur in these parts until mid May (ice saints' days). Plants that have not fully developed at this point can survive the frost without any damage. But if they are already in full bloom, the frost can severely damage them, causing considerable crop failure.

The adjacent figure shows the date of the (theoretical) beginning of the growing season in Frankfurt am Main (defined as five consecutive days where the average daily temperature is at least 5 °C; **green** line). However, this definition of the beginning of the growing season does not take wintry days that occur after this date into account. In the last few decades, the growing season began significantly earlier, consistently before the last frost day of the year (where the minimum temperature is below 0 °C; **blue** line). The earlier the growing season begins, the greater the threat of damage due to late frost.



Damage to cherry blossoms due to late frost. © Giessen University

The **red** line shows the first summer day of the year (where the maximum temperature is above 25 °C), which occasionally even occurred before the last frost day, most recently in 2011, 2014 and 2015.



In 2017, March was already very warm. The late frost in a number of localities in April and May caused considerable damage to wine- and fruit growers.

Threat of late frost in Frankfurt am Main, 1949-2018

- first summer day of the year
- last frost day of the year
- beginning of the growing season
- - - growing season trend
- ice saints' days

Record hot summers

It is hot days with a maximum above 30 °C and tropical nights in which temperatures do not drop below 20 °C that are a strain. Summer 2003 was particularly hot throughout Europe. This resulted in many heat-related deaths, especially in France. According to estimates by the Hessian State Health Office (HLPUG), there were about 1,000 more deaths than usual in Hesse in summer 2003. New heat records for Hesse were set in the summers of 2015 and 2018. Heatwaves such as those in 2003, 2015 and 2018 will occur much more frequently in future due to climate change.

Some extreme values from the summers of 2003, 2015 and 2018:

- *New record temperature for Hesse on 7 August 2015: 39.6 °C, Frankfurt am Main city centre*
- *Summer 2003: 98 summer days (51 of which were consecutive) ≥ 25 °C in Gernsheim*
- *Summer 2018: 42 hot days ≥ 30 °C and 13 tropical nights ≥ 20 °C, Frankfurt am Main city centre*



Whoever can go swimming in the heat can consider themselves lucky. Swimming in the Hattensteinweiher.

Great heat is often accompanied by drought. The driest summer (June to August) recorded in Hesse was that in 2018, where there was only 40 % of the usual average rainfall (for the period 1901-2000).

Dry soil gets much warmer much faster than wet soil. Consequently, drought increases heat. In the case of agriculture, the combination of heat and drought causes crop failure.

Hours of sunshine, April to September (averages for the period 1981-2010 and 2018)		
Station	1981-2010	2018
Schotten	1 092	1 485
Bad Hersfeld	1 066	1 459
Kassel	1 096	1 473
Wasserkuppe	1 112	1 458
Gießen-Wettenberg	1 181	1 459
Geisenheim	1 200	1 561
Frankfurt a. M.	1 215	1 561



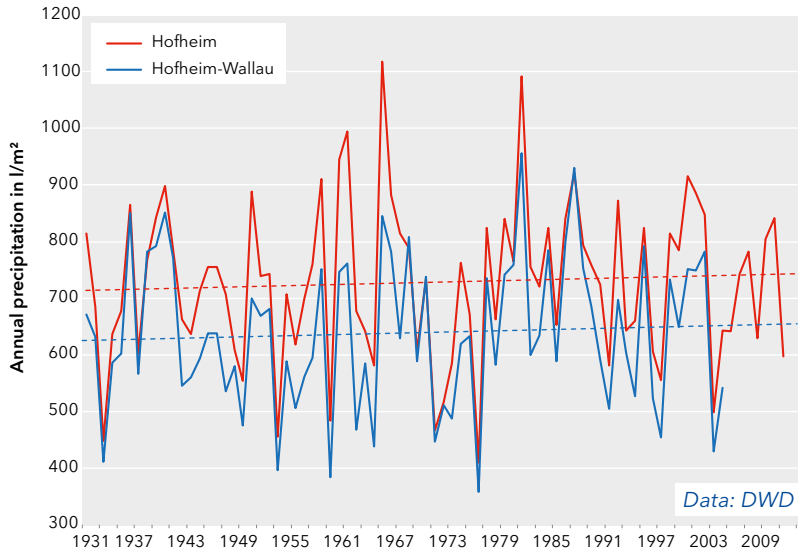
Parched soil in a strawberry field in the Hessian Ried in May 2011

However, other areas are also affected by prolonged drought. In the case of forestry, the dry and hot summer of 2003 led to a decrease in tree growth and heavy pest infestation. Since, unlike many other plants, trees do not respond immediately, the damage only became apparent in the following year (2004).

Precipitation

Precipitation is highly variable spatially. The figure shows the average annual precipitation at two stations only 5 km apart. Although the two lines may show a similar trend,

Hofheim mostly has far more precipitation than Hofheim-Wallau. The average difference is of almost 100 l/m² per year, which may even reach 300 l/m² per year, as in 1965.



Total annual precipitation in l/m² at the Hofheim and Hofheim-Wallau stations



Heavy rain and hail in Hofheim, 27 May 2016. © Maik Reuss

Extremely wet years in Hesse:

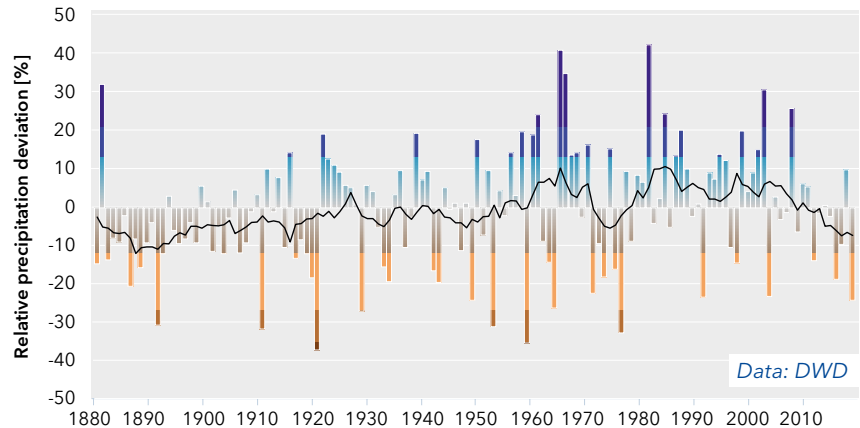
- **1965:** Average total annual precipitation of 1,074 l/m² throughout Hesse; the highest value was 1,823 l/m², recorded at a DWD station in Grebenhain-Herchenhain
- **1981:** Average total annual precipitation of 1,085 l/m² throughout Hesse

Extremely dry years in Hesse:

- **1959:** Average total annual precipitation of 492 l/m² throughout Hesse; the longest drought was in Greifenstein and lasted 69 days, from August to October
- **1959 and 1976:** Only 297 l/m² precipitation fell in Volkmarsen (1959) and Lich (1976)

The figure shows which years were drier or wetter than the 20th-century (1901–2000) average precipitation, which was 761 l/m² (the zero line in the figure).

Summer and autumn 2018 were extremely dry. However, based on the annual average, 2018 was only one of the 10 driest years. Rather than changing the average annual precipitation, climate change is expected to shift precipitation from summer to winter.



Deviation of the annual precipitation from the 20th-century average in Hesse for the period 1881–2018 in per cent. Coloured vertical bars: precipitation; black line: 11-year moving average (source: Witterungsbericht Hessen)

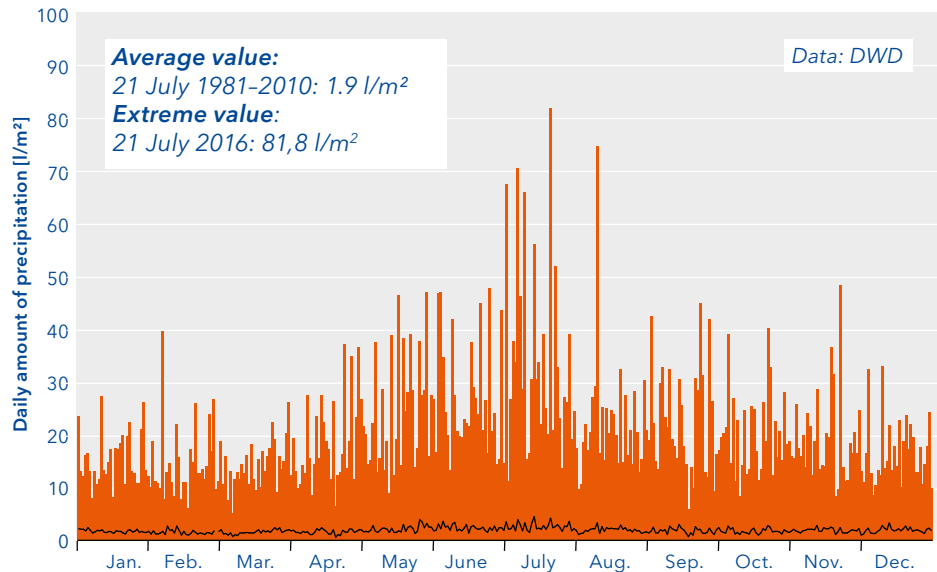
Heavy rainfall

The occurrence of heavy rainfall resulting in floods and other damage is increasing, particularly in summer. While the 30-year average daily precipitation (blue) in Bad Hersfeld is between 0.6 and 4.5 l/m², individual occurrences of extreme events (orange) exceed these values by far. Although there are about 150 precipitation monitoring stations belonging to the DWD and an additional 70 monitoring stations belonging to the Hessian state monitoring network, not every occurrence of heavy rainfall can be recorded. Occasionally, the

heaviest rainfall occurs right next to the monitoring station. Meanwhile, radar is used to record precipitation throughout Hesse. This also records any heavy rainfall that cannot be recorded by the monitoring stations.

Daily precipitation (l/m²) in Bad Hersfeld

Average precipitation per calendar day for the period 1981–2010 (blue) and maximum precipitation per calendar day ever recorded for the period 1951–2018 (orange).



The table shows the maximum total daily precipitation recorded at various stations in Hesse. The same amount of rain can fall in one day of heavy rainfall as in an entire month of normal precipitation.

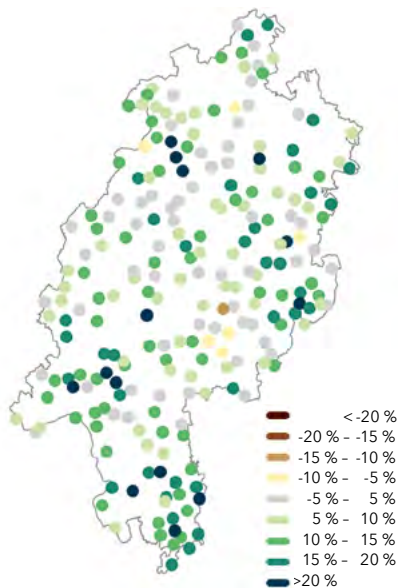


Maximum total daily precipitation at selected stations (DWD and state monitoring network)

l/m ²	Date	Monitoring station
168,0	18.07.1994	Wächtersbach
162,3	03.11.1940	Lautertal-Eichelhain
161,0	17.09.2006	Haiger
156,0	15.07.1965	Diemelstadt-Rhoden
155,5	18.07.1994	Sinntal-Weiperz
151,2	17.09.2006	Angelburg-Frechenhausen
150,0	20.06.1992	Bad Soden-Salmünster
149,5	13.07.1941	Weilrod-Gemünden
140,4	07.08.2018	Kirchhain

Studies by Giessen University have shown that in the winter months (December, January and February) of the period 1961–2000, most monitoring stations recorded an increase in total precipitation for the heaviest rainfall per month respectively (green dots in figure on the left). By contrast, in the summer months (June,

July and August), the maximum daily precipitation per month decreased at most stations (brown dots in figure on the right). Some stations recorded no significant change in heavy rainfall during the study period (grey dots).



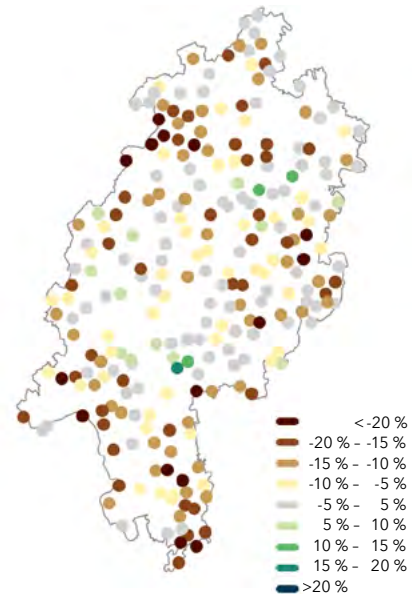
Winter

Trends in observed extreme rainfall

1961–2000 in per cent
(100 % = average value for the period 1961–1990).

Source: Giessen University, 2013.

Currently, researchers are investigating whether the recent heavy rainfall events (since 2001) would change this.

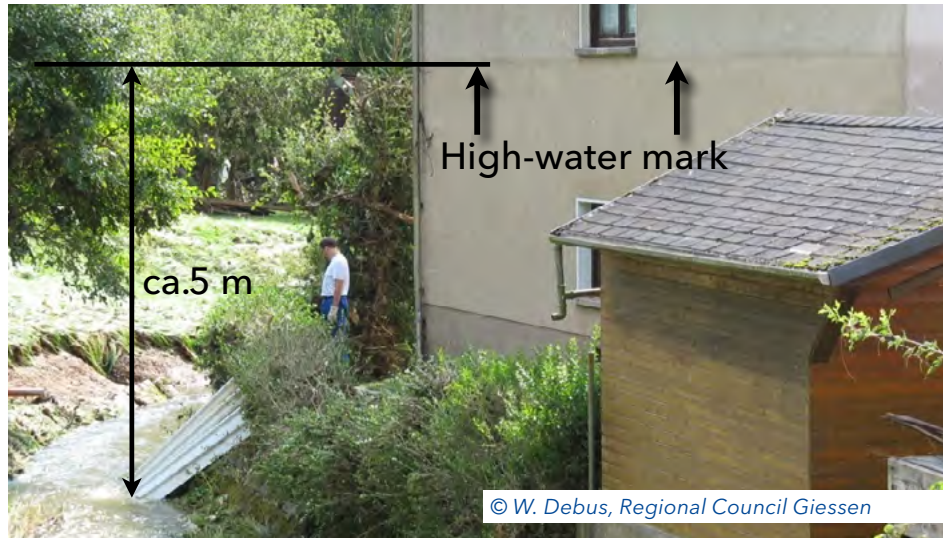


Summer

Local, very heavy rainfall events can trigger extreme run-off, especially in smaller water-courses. This often causes damage to buildings and infrastructure (such as roads, railways and power lines) and, in the worst case, even death. In addition, heavy rainfall events often erode soil, causing considerable damage, particularly to agriculture. The warmer the air, the more precipitation falls during an extreme event. This is why more heavy rainfall is to be expected with climate change.

The HLNUG's 'KLIMPRAX - Starkregen und Katastrophenschutz in Kommunen' (Climate Change in Practice: Heavy Rainfall) project helps municipalities take precautions for heavy rainfall events (<https://www.hlnug.de/?id=11199>).

Extreme precipitation and run-off following a heavy rainfall event in Kuhbach, Haiger-Sechshelden, on 17 September 2006. The Haiger station, which is part of the state monitoring network, recorded 161 l/m² of precipitation, 150 l/m² of which fell in just four hours. Several other stations also recorded more than 100 l/m² within a few hours. A detailed account of the event is available in the 2006 HLNUG annual report.



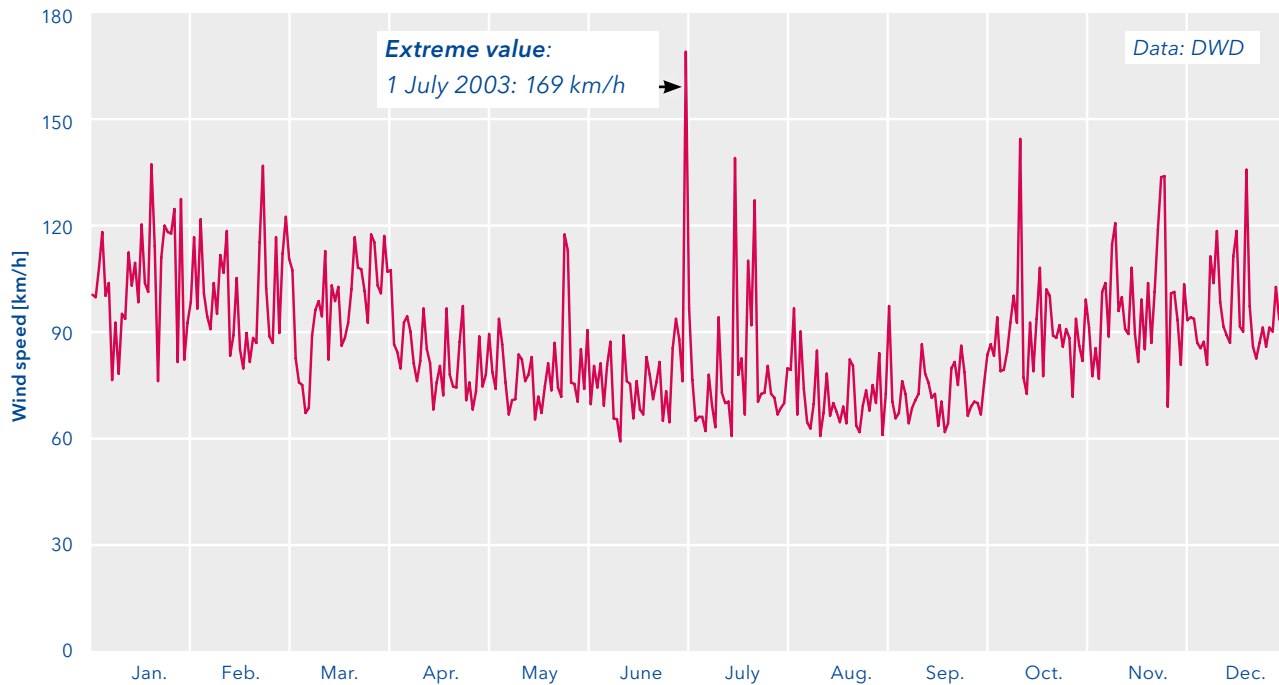
Wind and storms



An uprooted tree after a storm front moved across Wiesbaden, 21 June 2013

Strong winds and storms can also cause significant damage. Although winter storms such as Cyclone Kyrill (18 January 2007) and Cyclone Friederike (18 January 2018) featured extensively in the national press, they caused less damage in Hesse than in other German states. However, gusts are not just a winter phenomenon. They can also arise during summer thunderstorms, such as that on the Hallgarter Zange in the Rheingau-Taunus district, on the night of 1 August 2017.

The adjacent graph shows the daily maximum wind speed (gusts) on the Kleiner Feldberg (Taunus) for every day of the year. This station has recorded numerous gale-force winds during autumn and winter storms, such as a wind speed of 144 km/h on 11 October 1981. But the highest wind speed ever recorded on the Kleiner Feldberg was during a summer thunderstorm on 1 July 2003.



Wind speed on the Kleiner Feldberg, Taunus (1966-2017)

— Daily maximum wind speed (gusts)

Extreme weather events in Hesse: Conclusion

There have always been and will continue to be extreme events. In all likelihood, certain extreme events will become more frequent or severe due to climate change.

Temperature extremes

Even today, there are occasionally very cold phases in winter (such as February 2012 and March 2013). But on average, winters are becoming increasingly milder.

The warmest summer (June, July and August) in Hesse was in 2003. But new heat records were also set in the summers of 2015 and 2018, including the Hessian record temperature of 39.6 °C on 7 August 2015 and 42 hot days (where the maximum temperature is above 30 °C) in 2018, both in Frankfurt am Main.

We can expect more heat extremes in Hesse in future, due to climate change. Cold extremes are becoming less frequent, but could still occur occasionally.

Precipitation extremes

Precipitation has high small-scale variability. In most regions of Hesse, it rains more in summer than in winter. Maximum total daily precipitations are also recorded in summer, usually during heavy thunderstorms. We can expect more heavy rainfall events in future as a result of climate change.

Wind extremes

Autumn and winter storms are often the cause of great damage, as they affect relatively large areas and involve strong winds that last several hours. However, the strongest gusts of wind can also arise during summer thunderstorms. So far, we are uncertain as to whether storms and strong winds will increase due to climate change.

Further information on weather extremes in climate change in Hesse is available on our website:

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

'Witterungsbericht Hessen' (Report on Weather Conditions in Hesse, available only in German):
<https://www.hlnug.de/?id=12735>

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

