Deutscher Wetterdienst
Wetter und Klima aus einer Hand

# Yearbook 2022

## of the Deutscher Wetterdienst

## The Reference for Meteorology is the Deutscher Wetterdienst

Virtually everyone is interested in the weather and virtually every area of our lives is affected by weather and climate. As the reference for meteorology in Germany, the Deutscher Wetterdienst (DWD) is the prime point of contact for all questions related to these areas. The range of duties is many and varied. The DWD records, analyses and monitors the physical and chemical processes in our atmosphere. It holds information on all types of meteorological events, offers a diverse range of services both for the general public and for special user groups and operates the national climate archive.

In its role as a national meteorological service, the DWD is also a provider of scientific and technical services and a competent and reliable partner for public and private partners in the field of meteorology and climatology. Its customers' increasing demands on quality not only oblige the DWD to supply high-quality products and services, but also are a continuous incentive to improve product quality, customer orientation and economic efficiency.

The DWD, which was founded in 1952, is, as the national meteorological service of the Federal Republic of Germany, responsible for providing services for the protection of life and property in the form of weather and climate information. This is its core task. Established as an executive agency of the Federal Ministry for Digital and Transport (BMDV), the DWD provides meteorological information to ensure the safety of aviation and maritime shipping, traffic routes and vital infrastructures, in particular those needed for energy supply and communication systems. It also issues warnings of meteorological events that could become a danger to public safety and order and have a high potential to cause damage. The DWD, however, also has other important tasks, such as serving the needs of the Federation, the federal states, the local governments and institutions of justice; monitoring the climate; analysing and projecting climate change and climate change impacts; providing climate and environment consultancy services; and ensuring the fulfilment of the international commitments entered into by the Federal Republic of Germany. The DWD thus coordinates the meteorological interests of Germany on a national level in close agreement with the Federal Government and represents the Government in intergovernmental and international organisations such as, for example, the World Meteorological Organization (WMO). These duties are embodied in the Deutscher Wetterdienst Act of 10 September 1998 (Federal Law Gazette I, p. 2871), last amended by Article 1 of the Act of 17 July 2017 (Federal Law Gazette I, p. 2642).

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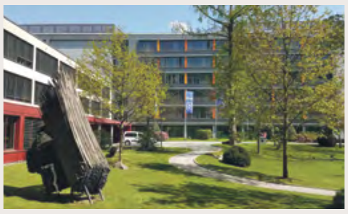

01

02

03

04

**01–04**
DWD headquarters in Offenbach, photo taken by DWD staff member Michael Kügler from the same place in spring (01), summer (02), autumn (03) and winter (04). The picture on the front cover is a composition of these four photos.

### Photo series in the Yearbook 2022

The pictures for the special photo series in the yearbook were taken by DWD staff. Over 160 photographs were submitted to an internal photo competition entitled ‘Four Seasons in the Context of Weather and Climate’. A jury selected the best 36 from the submissions, and these are now presented here in the yearbook.

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# Foreword

Dear readers,

**2022** – a year of immense changes, particularly in the global political situation because of the Ukraine war, which has also had a direct impact on the Deutscher Wetterdienst (DWD): In addition to its extended consultations with the Federal Network Agency (BNetzA) on weather developments during the heating season, the DWD also intensified its legally mandated work on measuring radioactivity in the air and precipitation. Both topics are covered in depth in Chapter 3 ‘The year in review’ of our Yearbook, to which I welcome you warmly.

**2022** – a year in which human-induced climate change continued unabated. It was the sunniest and, together with 2018, warmest year in Germany since systematic weather records began, with a significant deficiency of rainfall. The mean annual temperature in five of the past nine years, including 2022, was higher than 10 °C. Temperatures this high had never been reached in Germany prior to 2014. These are the key climatological findings for the past year. Chapter 2 of the Yearbook, ‘Weather and climate’, reviews the year 2022 in a detailed and broader climatological context. The year also was one of the warmest years in both Europe and globally.

**top**
Prof. Dr Gerhard Adrian, President of the Deutscher Wetterdienst

**2022** was also the year in which the DWD could look back on 70 years since its foundation. As Federal Minister Dr Volker Wissing made clear in his speech at the DWD Annual Reception last November, a great deal has changed over this time in terms of weather and climate. Nevertheless, the Minister concluded, the DWD is as important as ever for Germany, particularly to provide warnings of dangerous weather events. I am therefore extremely glad that Minister Wissing was available to give an interview for this yearbook. In addition, the photo series in this publication is the outcome of our activities within the framework of ’70 Years of DWD’: DWD employees were invited to submit their photos of ‘Four Seasons in the Context of Weather & Climate’ to an internal photo competition. Some of these photos now adorn the pages of the Yearbook.

**2022** – a year in which projects were completed and new ones kicked off. Chapter 3 ‘The year in review’ delves into some of these projects in greater depth. Among these is the full automation of the measuring and observation network – a process that took a good 20 years – was completed in 2022. Furthermore, it is estimated that noise protection embankments along federal trunk roads could generate a potential yield of around 1,200 gigawatt hours (GWh) of electricity annually if 50 per cent of their surface area were covered with photovoltaic systems. This would provide 450,000 households with electricity. These are the findings of a study carried out by the DWD and the Federal Highway Research Institute (BASt) within the framework of the Network of Experts established by the Federal Ministry for Digital and Transport (BMDV). The DWD delivers weather information to Lufthansa cockpits almost in real time and, with partners, has begun developing the Integrated Greenhouse Gas Monitoring System (ITMS) for Germany.

You can read about these and other topics in this Yearbook. I am confident it will give you many interesting insights into the world of weather and climate! Finally, I would like to thank you for your confidence in the DWD and say goodbye. After almost 24 years with the DWD, 13 of them as President, I am retiring on 1 August. I wish you all the best for the future, and above all good health. Please remain loyal to the DWD and to my successor, Professor Dr Sarah Jones.

Yours sincerely,

Gerhard Adrian

Gerhard Adrian

# Prelude

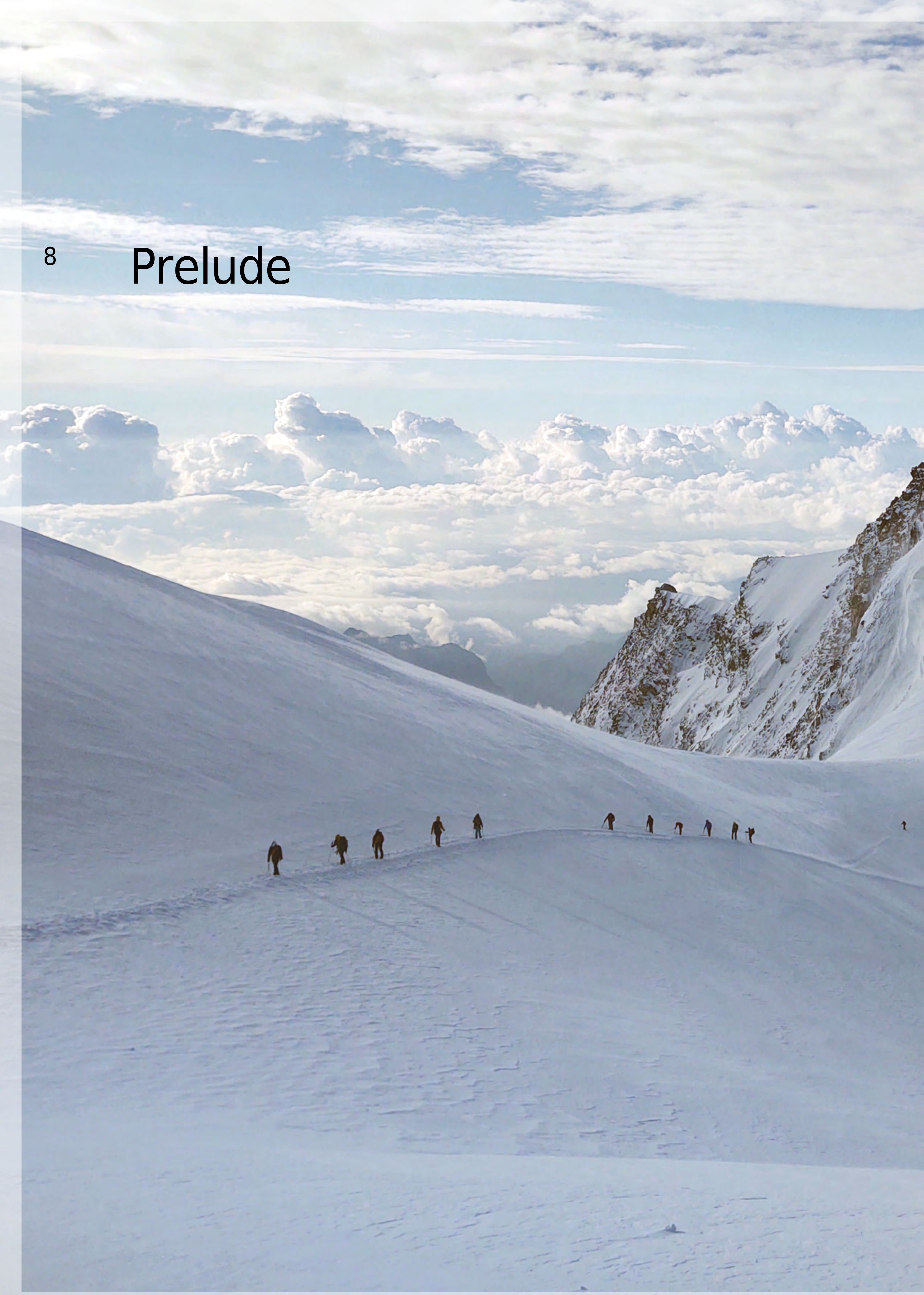


**Image**
Snow hikers on their way from the Vincent Pyramid (in the background) to the Ludwigshöhe. Photo taken in the Monte Rosa massif.

# A journey through the 70-year history of the Deutscher Wetterdienst

The Deutscher Wetterdienst (DWD) celebrated its 70th anniversary in 2022.

Key milestones in the history of the DWD include technical and digital progress, baptisms of fire and the international exchange of data. Society has to deal with ever new challenges, and the DWD's areas of responsibility have grown, too, in response. A key driver in this process has been the DWD employees themselves. Read here a brief journey back through time.

01
Prof. Dr Ludwig Weickmann, first president of the DWD.

## The beginning

The journey through time begins on 11 November 1952, the day on which the Act on the Deutscher Wetterdienst was passed by the Bundestag. The DWD was created from the meteorological services of the three western occupation zones: the Meteorological Office for North-West Germany (Meteorologisches Amt für Nordwestdeutschland, MANWD) in the British sector, the Meteorological Service for the US Zone (Deutscher Wetterdienst in der US-Zone) and the three regional meteorological services in the French zone. The Meteorological Service of the former GDR (Meteorologischer Dienst, MD), headquartered in Potsdam, had already begun operations two years earlier, on 1 January 1950. For the first five years, the DWD was based in Bad Kissingen, before it moved to its newly-built premises in Offenbach in 1957/58. The founding of the two German Republics also saw the establishment of two meteorological services within today's German territory – two separate institutions that shared the same principal task, however: forecasting the weather.

## Meteorology as manual work

The DWD broadcast its first weather report on television in 1952. But what exactly did weather forecasting involve at that time? Meteorology was still in its infancy and was regarded as 'manual scientific work'. Manual work because the weather forecasts were basically put together by hand – a far cry from today's technical methods. Meteorological data were encoded by weather observers using a globally standardised system. The 'synoptic' system comprised 100 symbols that were used to depict the current weather conditions. These synoptic symbols were transmitted via teleprinter from the weather stations to the headquarters in Offenbach or Potsdam every three hours. There they were decoded, entered by hand onto meteorological maps and distributed worldwide. The meteorologists then prepared the weather forecast for the following day based on their knowledge of the atmosphere, the physical relationships and the meteorological maps.

02

03

**02**
‘Alfred-Wegener-Haus’ on the Telegrafenberg in Potsdam (1952), first headquarters of the Meteorological Service of the former GDR (MD) from its foundation in 1950.

**03**
The headquarters of the DWD have been located in Offenbach since 1957. The picture here shows the previous building at the site of today’s premises.

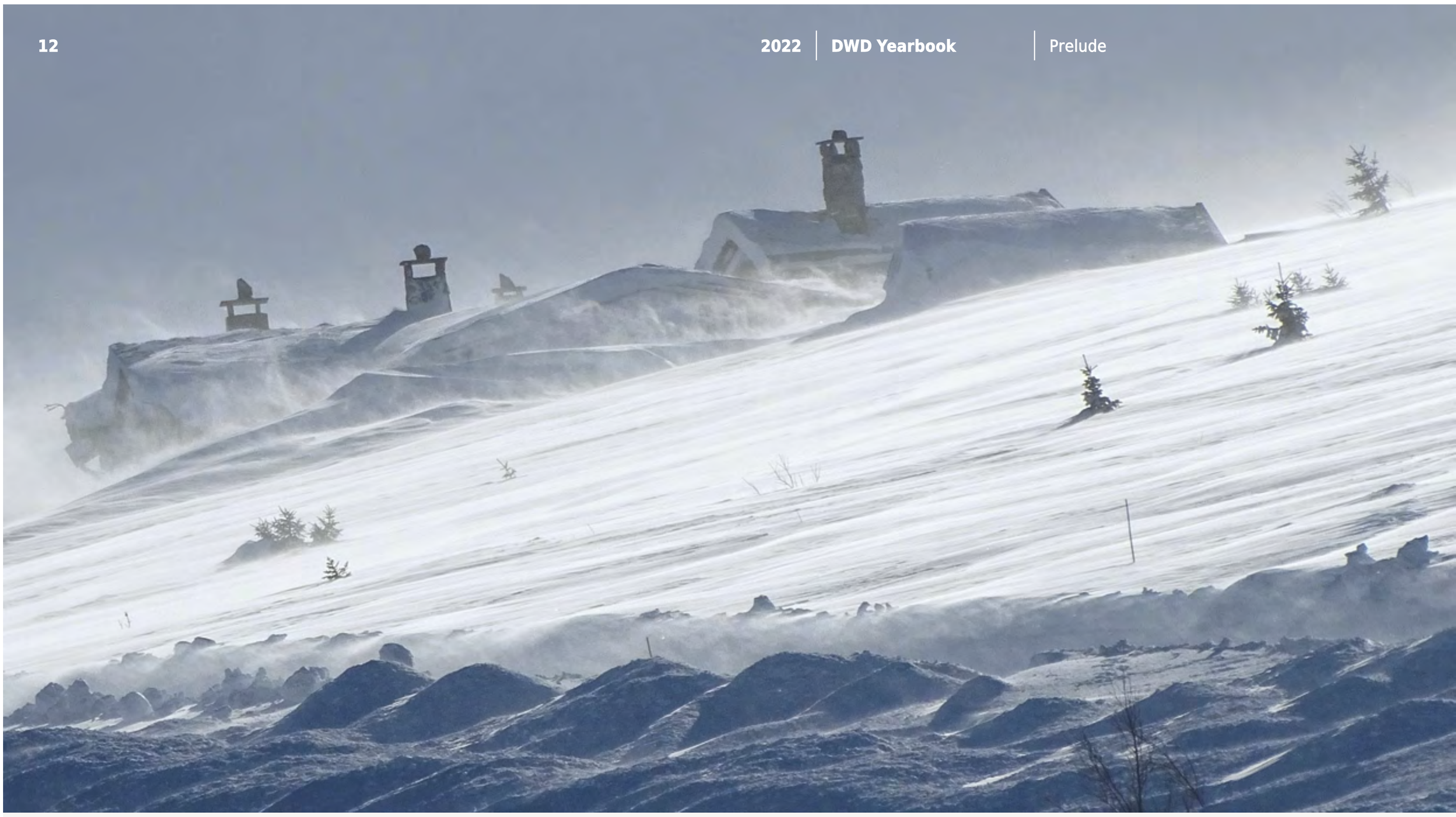
## The foundation stone of modern weather forecasting

In the 1960s, a number of technical milestones laid the foundation for modern weather forecasting. The DWD developed its first numerical weather prediction model, for example. The first supercomputer went into operational use. It calculated the mathematical equations of the forecast model in just a few hours, simulating the physical changes in the atmosphere. The age of data processing began. For the first time, the DWD and MD were able to receive and process data from meteorological satellites and use them for weather forecasting. And the era of wide-area precipitation radar coverage started. Weather forecasts up to three days in advance were now possible.

*A brief detour to the present: Meteorological satellites and precipitation radar created the basis for wide-area and high-resolution weather observation.*

Radar devices detect precipitation in the atmosphere. Today, the constantly rotating antennas of the DWD radar network emit electromagnetic waves both vertically and horizontally. This is known in technical terms as dual polarisation. Raindrops, snowflakes or hailstones reflect these waves. Their different forms generate different radar echoes. The distance can be determined from the time taken for the echo signal to return. The strength of the echo, also called reflectivity, provides an indication of the amount of precipitation. The differences in the backscatter of the vertical and horizontal waves make it possible to deduce the type of precipitation.

The satellites are used to observe weather conditions from space. Previously, weather data were only collected from specific weather stations, but radar and satellite mean that weather information is now available at full spatial coverage. The DWD uses 15 different meteorological satellites today. These include both polar-orbiting and geostationary satellites.



**top**
Snowstorm in Gomobu, Norway.

**04**
Radar system in Warnemünde 1983.

## Back to the 1970s and 1980s

The remit of the DWD was expanded in the 1970s. There were now twelve further branch offices in Germany in addition to the headquarters in Offenbach. The demand for weather information for the maritime and aviation sectors as well as for agriculture increased steadily. The forecast models were gradually refined. The performance of the mainframe computers increased many times over and the radar network was expanded nationwide. The first automatic temperature sensors were installed in the weather stations.

Political tensions grew during the period of the Iron Curtain. The international exchange of data, organised by the World Meteorological Organization (WMO), functioned smoothly. Everyone realised that weather was not bound by national borders. The intergovernmental organisation EUMETSAT was founded in 1986. Its tasks included the development and operation of meteorological satellites. As a founding member, the Federal Republic of Germany, represented by the DWD, not only made use of the data from the meteorological satellites but it also took an active role in shaping the programmes.

In 1986, the DWD passed its ‘baptism of fire’ by measuring radioactivity in the air and precipitation. The DWD had already been legally mandated with this task in 1955. After the reactor accident in Chernobyl, the DWD was given responsibility for conducting detailed atmospheric dispersion calculations. To this day, the DWD is still responsible for performing this task and for the daily checking of radioactive elements in the atmosphere.

**top**
Tree covered in snow and ice. Photo taken near mount Kreuzberg (Rhön).

### The 1990s: Reunification and the digitalisation boom

The fall of the Berlin Wall in 1989/90 resulted in much of the MD being integrated into the DWD – a change which brought its own special challenges. The number of employees grew by 1,050 overnight. It was important to ensure that uniform standards were applied with regard to the technology of the two meteorological services. Some good came of this too, however: In the following ten years, the DWD built up a comprehensive new radar network, the first of its kind in Europe based on uniform technology. In addition to the observatory already run at Hohenpeissenberg, the DWD expanded its observatory in Lindenberg, with research on mount Hoher Peissenberg dedicated to chemical composition of the atmosphere, and the focus in Lindenberg on the physical state of the atmosphere and radiation. Both observatories also began to participate in national and international research projects and joined numerous research networks.

Two international institutions – the Global Precipitation Climatology Centre (GPCC) under the auspices of the World Climate Research Programme as well as the EUMETSAT Satellite Application Facility on Climate Monitoring (CM SAF) – were brought under the roof of the DWD.

Further automatic sensors were put into operation at the weather stations: air pressure, humidity and wind could now be measured automatically. Technological progress led to more frequent weather observations, and weather forecasters could draw from a large pool of data. Data from aircraft, ships, buoys, the precipitation radar network and the meteorological satellites were now available alongside those from the weather stations. All these could be processed by the supercomputer in Offenbach in only 45 minutes instead of the two hours previously required. The DWD developed its NinJo meteorological work station system together with international partners and the Bundeswehr. This digital programme made it possible to process all meteorological data and forecasts currently available and to display them for the meteorologists.

### Key partner: Bundeswehr

Since 1958, there has been close cooperation with the Bundeswehr Geophysical Service (GeophysBD). The partnership was put onto a firmer legal footing by the Bundestag in 1998. This intensified the collaboration in various areas, such as the German Meteorological Computing Centre (DMRZ) and the training of meteorologists. The DWD head office in Offenbach also became one of the headquarters of the Bundeswehr Geoinformation Service.

## 2010s: Broadening of responsibilities

The Hans Ertel Centre for Weather Research (HErZ) was founded to improve cooperation with universities and other research institutions.

Global climate change put new demands on the federal states, towns and cities and local communities as a consequence of the rising probability of extreme weather events with high damage potential. It was expected that Germany, too, would see higher average temperatures and an increase in the risk of weather-related damage. In order to provide optimum support to the federal states in the development of adaptation strategies, the DWD concluded administrative agreements with all 16 federal states as part of preventive protection measures against disasters.

In addition, the DWD set up a strategic alliance of authorities with the Federal Office of Civil Protection and Disaster Assistance (BBK), the Federal Agency for Technical Relief (THW) and the Federal Environment Agency (UBA) with the aim of joining forces to answer questions about climate change and to define corresponding adaptation measures. The DWD joined the German Climate Consortium (DKK), established for the exchange of climate research information on the significance of climate change for disaster forecasting and to represent the interests of research. In addition to the Climate Atlas, which was now available online, the DWD began to offer numerous climate services, such as the Soil Moisture Viewer and the Urban Climate Analysis.

In 2011, the DWD launched its own social media channels, which significantly extended the reach of its weather warnings. The DWD's warning system was also adapted to reflect the challenges of climate change. This was the start of warnings about heat or UV radiation, for example. 2015 saw the DWD WarnWetter app go online as a modern means of warning the general population directly. Only one year later, the DWD changed its warning system: instead of district ('Landkreis') level, warnings of severe weather were now issued at the local ('Gemeinde') level. FEWIS, a dedicated information system for the fire brigades, went online, allowing the individual units to obtain specific weather data for their operations.

**below**
Reflected dewbow. Photo taken near Neustadt (Coburg).

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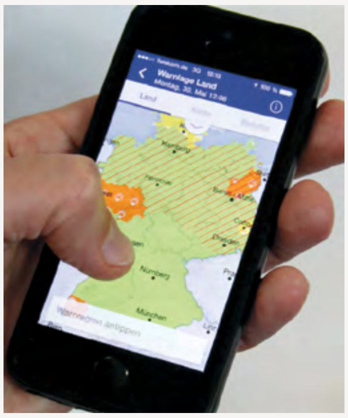
**05**
New HPC 2020.

**06**
The DWD's app for weather warning, DWD WarnWetter, was launched in 2015.



06

### New model system, open data policy and a glimpse into the future

The ICON model system, the ninth generation of a weather forecast model, was introduced at the DWD in 2015/16, representing a further milestone. ICON has made it possible to take even better account of local conditions, such as mountain elevations. Instead of just one layer, as was still the case in 1966, 120 layers of the atmosphere could now be observed. The mesh spacing in the German model grid, which spans the globe like a virtual net, was now down to 2 km, instead of 381 km as it was over 50 years ago. Using this model, the predictions for the coming week have thus become as accurate as they had been 50 years ago for the coming day.

The amendment of the DWD Act in 2017 marked the start of the open data policy. This opened up access to extensive DWD databases, now made available free of charge. Further new areas of responsibility were added, such as climate change analysis and projection. In 2019, DWD President Prof. Dr Gerhard Adrian was the first German to be elected President of the WMO – a novelty in the history of the Federal Republic. Since 2022, the DWD's measurement and observation network has functioned fully automatically, with some of the data being updated every minute. The DWD now produces climate forecasts on all time scales: from three-month forecasts through to decadal predictions up to the end of the 21st century. The DWD provides advice to political, administrative, business and economic bodies on all matters concerning climate change. It does so for the benefit of society and for the good of the people.

*The pictures for the special photo series in the yearbook were taken by DWD staff. Over 160 photographs were submitted to the internal 'Four Seasons in the Context of Weather and Climate' photo competition. A jury selected the best 36 from the submissions, and these are now presented here in the yearbook.*

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# Weather and climate in 2022

**right**
Little plum tree in April. Photo taken near Langenselbold.

# Sunniest and, together with 2018, warmest year ever

The year 2022 was the sunniest and, along with 2018, the warmest year in Germany since the beginning of systematic weather records. Moreover, it was characterised by a significant precipitation deficit.

Five out of the past nine years, including 2022, featured a mean annual temperature greater than 10 °C, a level that had never been reached in Germany before 2014. Again, like in 2018, 2019 and 2020, the consequences were heatwaves and very dry conditions in the summer months with serious impacts on agriculture and forestry in particular, as well as an extremely warm turn of the year 2022/23 with multiple new monthly records.

Across Europe, 2022 was the second warmest year on record, with regionally intense periods of heat and drought. Globally, the past eight years have been the warmest since records began.

| Year | °C |
|---|---|
| 2022 | 10.5 |
| 2018 | 10.5 |
| 2020 | 10.4 |
| 2014 | 10.3 |
| 2019 | 10.3 |
| 2000 | 9.9 |
| 2007 | 9.9 |
| 2015 | 9.9 |
| 1994 | 9.7 |
| 2002 | 9.6 |

**Table 1**
The ten warmest years in Germany since 1881.

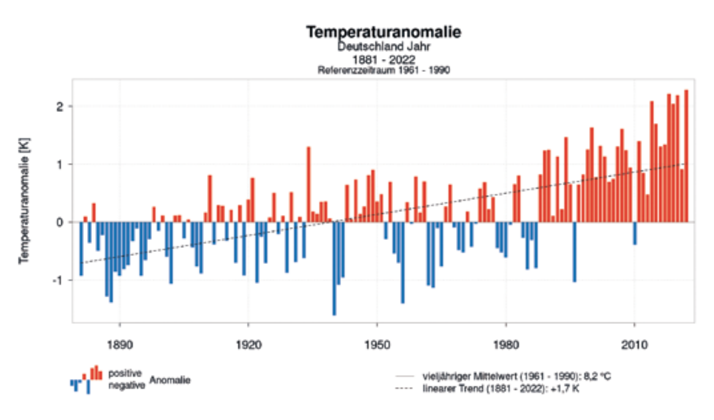

**Figure 1**

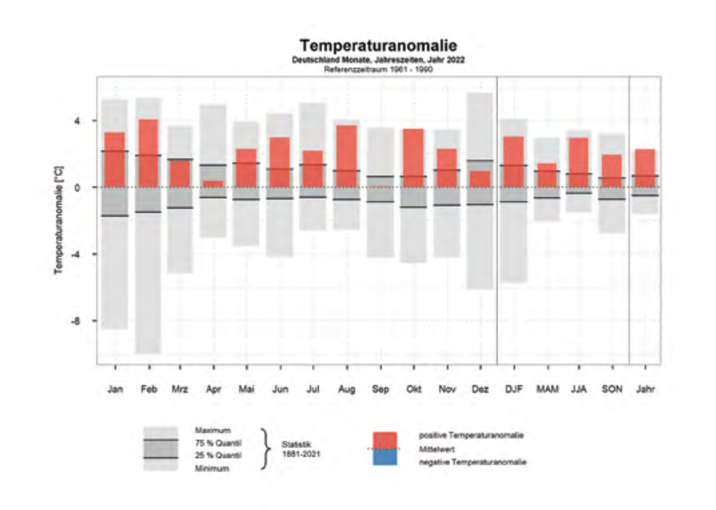

**Figure 2**

**Figure 1**
Deviation of mean annual temperatures for Germany (1881–2022) from the long-term mean for 1961–1990.

**Figure 2**
Long-term statistical comparison of Germany-wide temperature anomalies. The chart shows the figures for 2022 (red/blue) relative to the 1881–2021 period (grey).

## Nationwide temperatures

With a mean annual temperature of 10.5 °C, 2022 was the warmest year in Germany since 1881, along with 2018 and narrowly ahead of 2020 (10.4 °C), 2019 and 2014 (10.3 °C each) (Figure 1). Compared to the reference period 1961–1990, the year was 2.3 Kelvin (K) too warm[1]. Accordingly, nine of the ten warmest years in Germany have occurred in the 21st century (Table 1). 2014 was the first year in Germany with a mean annual temperature above 10 °C. Since then, such a high average has been recorded five times in total.

In 2022, all months (with September just making the mark) and seasons were warmer than their respective long-term mean for 1961–1990 (Figure 2). The anomaly in the months of January, February, August and October was more than 3 K. An anomaly of more than 3 K was also observed in the winter of 2021/22. The warmest month was August (20.2 °C) while February saw the largest anomaly from the long-term mean (+4.1 K). The coldest month of the year was December (1.8 °C). Based on this, the temperature increase observed in Germany for the period 1881 to 2022 is now at 1.7 °C (linear trend).

[1] For areal-average ranking, figures are rounded to one decimal place. We consider this necessary due to the length of the times series, the fact that the number of stations varies over the observation period, and the accuracy of temperature measurements and associated uncertainties. With its nationwide mean temperature of 10.5 °C, the year 2022 therefore came top of the rankings, together with 2018. To visualise the time series graphically, however, we also round to two decimal places.

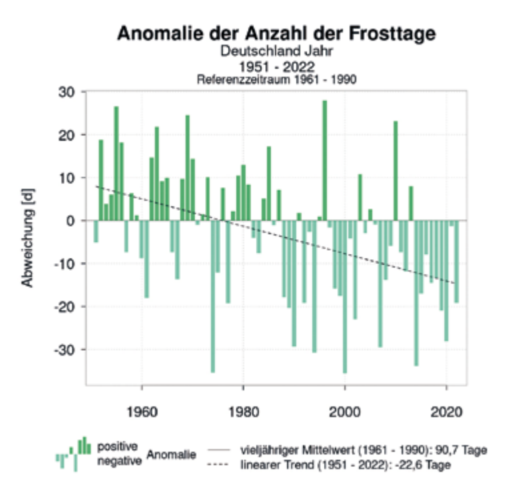

**Figure 3.1**

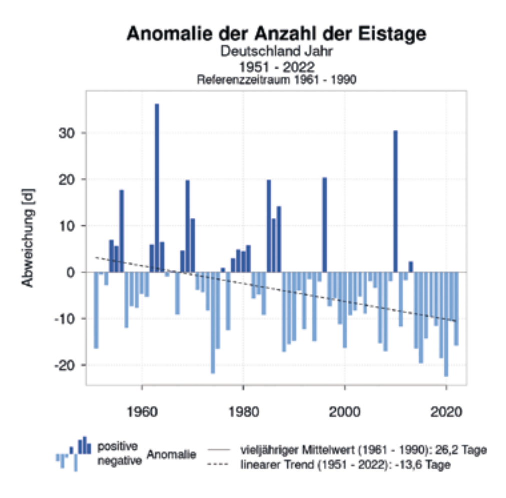

**Figure 3.2**

**Figures 3.1–3.4**
Temperature-related indicator days 1951–2022: frost days (3.1), ice days (3.2), summer days (3.3), hot days (3.4).

Although March was extremely sunny, the first ‘summer day’ (Tmax ≥ 25 °C) was not recorded until 12 April. The first ‘hot day’ of the year occurred on 11 May, the last hot day on 7 September. The last summer day was recorded on 31 October. Averaged over Germany, 2022 had nearly 59 summer days, which is double the long-term mean for 1961–1990. It is also the third highest number of summer days after 2018 and 2003 (Figure 3.3). The daily maximum temperature rose to 30 °C or higher on more than 17 days. After 2018, 2003 and 2015, this is the fourth highest number of hot days since 1951, with an excess of +300 % compared to 1961–1990.

The total number of ‘frost days’ (Tmin < 0 °C) registered during the whole year amounted to 71.4, the total number of ‘ice days’ (Tmax < 0 °C) to 10.4. The number of frost days was roughly 20 % lower, while there were 60 % fewer ice days compared to the long-term mean for 1961–1990. The most frost days occurred in March. Little cloud cover led to large fluctuations between daytime temperatures and the corresponding strong nocturnal cooling. By far the highest number of ice days occurred in December. The very cold spell of weather from 6 December onwards was the coldest period during the whole year. The highest number of summer days, hot days and ‘tropical nights’ (Tmin ≥ 20 °C between 18 UTC and 06 UTC) was recorded in August.

Overall, the year 2022 accounts for the third highest number of summer days (after 2018 and 2003), the fourth highest number of hot days (after 2018, 2003 and 2015) as well as for the twelfth lowest number of frost days and eleventh lowest number of ice days since 1951.

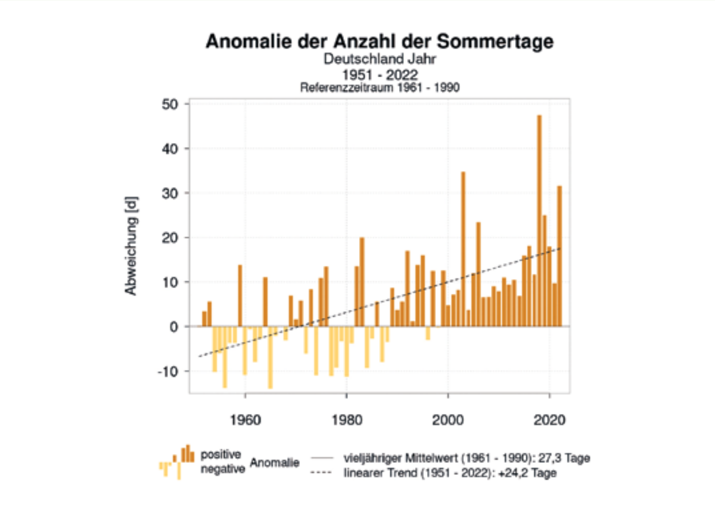

Figure 3.3

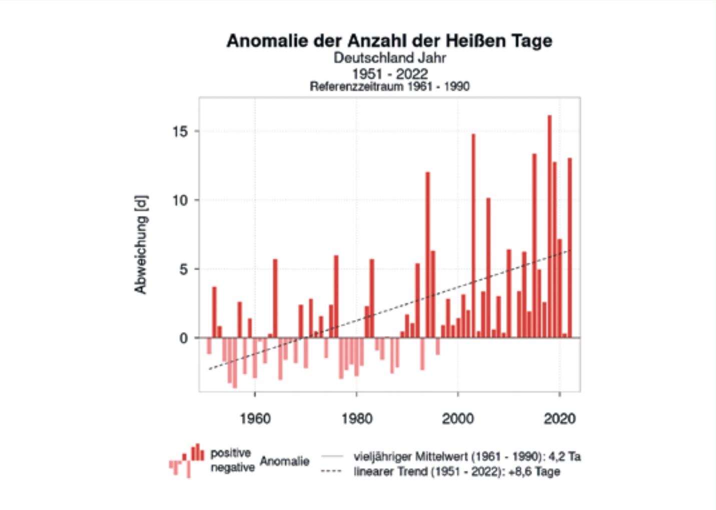

Figure 3.4

## Areal mean temperatures in the federal states

When looking at the areal mean temperatures across Germany, it appears that several German federal states, especially those in the south and west, recorded their warmest ever year or matched previous records whereas the north and east reported their third and fourth warmest year, respectively (Table 2).

**Table 2**
Mean annual temperatures for 2022 in the federal states including ranking.

| Federal states | Mean annual temperature °C | Ranking | Matches previous record of |
|---|---|---|---|
| Brandenburg/Berlin | 10.8 | 3 | 2018 |
| Baden-Württemberg | 10.6 | 1 | – |
| Bavaria | 9.9 | 1 | 2018 |
| Hesse | 10.6 | 1 | – |
| Mecklenburg-Western Pomerania | 10.2 | 3 | 2014, 2018 |
| Lower Saxony/Hamburg/Bremen | 10.8 | 2 | 2014 |
| North Rhine-Westphalia | 11.2 | 1 | – |
| Rhineland-Palatinate/Saarland | 11.2 | 1 | – |
| Schleswig-Holstein | 10.2 | 3 | – |
| Saxony | 10.2 | 4 | – |
| Saxony-Anhalt | 10.8 | 4 | – |
| Thuringia | 10.0 | 1 | – |

Table 2

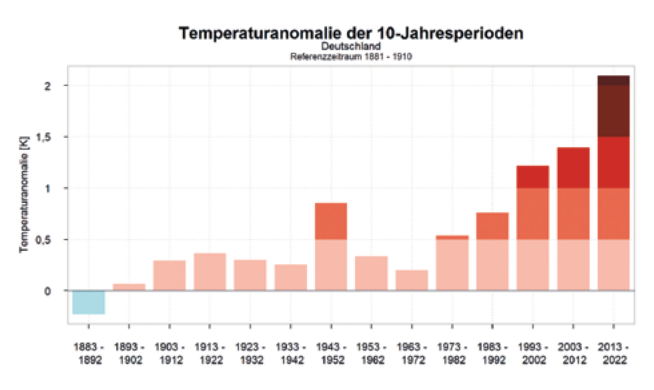

**Figure 4**

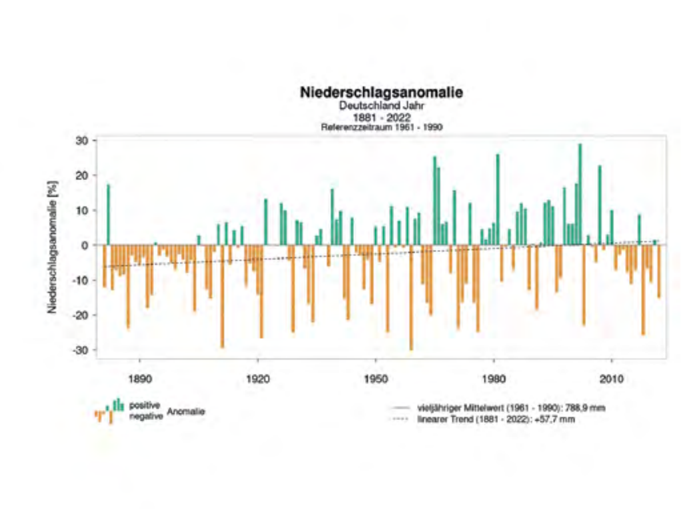

**Figure 5**

**Figure 4**
Deviation of the 10-year averaging periods 1883–1892 to 2013–2022 from the long-term mean temperature 1881–1910.

**Figure 5**
Deviation of annual precipitation totals 1881–2022 for Germany from the long-term mean 1961–1990.

### Long-term temperature trend in Germany

Since the 1960s, every decade in Germany has been warmer than the previous one. The years 2013–2022 were 2.1 K warmer than the first thirty years (1881–1910) of the evaluation period, which makes them the warmest decade since records began in 1881 (Figure 4).

### Precipitation

In summary, 2022 was a very dry year. At around 670 mm, total precipitation was 15 % below the long-term annual figures for the reference period 1961–1990, which means a deficit of approx. 120 mm (or l/m²) and rank No. 24, i. e. in the ‘very dry’ range, of the temperature series since 1881 (Figure 5). Only the north-west and the Bavarian Forest saw precipitation totals slightly above normal values. Central and eastern parts of the country registered deficits of more than 15 %, in some areas even more than 25 %.

Looking at the individual months and the seasons reveals large differences (Figure 6). All in all, two months were wetter and ten months drier than normal compared to the long-term mean for the international climatological reference period 1961–1990. February 2022 saw very large amounts of precipitation. The spring and summer months, except April, were all very dry. September finally brought considerable precipitation and thus ended the long period of drought. The following months (October, November and December) also remained below the long-term mean. At 100 mm, the highest amount of precipitation occurred in September (+63.6 % compared to the climatological reference period 1961–1990). The driest month was March, with only 15 mm of precipitation (73.5 % compared to the climatological reference period 1961–1990).

While winter crops benefited from the wet conditions in February and had good yields, the summer crops suffered from the prolonged drought, which caused considerable shortfalls in the yields. The forests also suffered from the drought. Large forest fires occurred in particular in Saxony and Brandenburg.

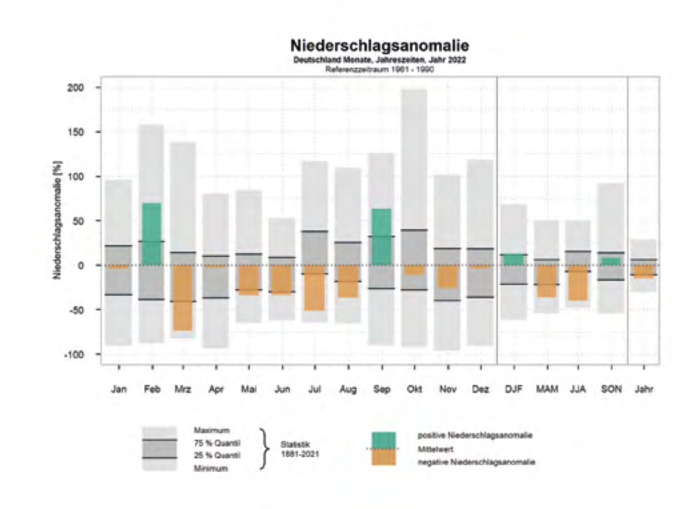

**Figure 6**

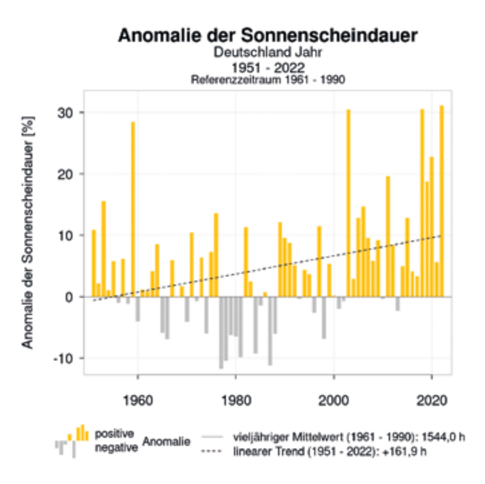

**Figure 7**

## Sunshine duration

Overall, the year 2022 saw an average of 2024.1 hours of sunshine. Compared to the international climatological reference period 1961–1990, there was an excess of 480.1 h (or +31.1 %). This made 2022 the sunniest year ever, displacing 2018 (2015.4 h) from its top position (Figure 7).

Only January remained below the long-term average. Sunshine durations in September and December were slightly above the long-term average. At 278.8 h, June saw the highest number of sunshine hours, with an excess of sunshine of around 37 % (compared to the climatological reference period 1961–1990). August (272.8 h) and July (265.8 h) saw only slightly less sunshine. The highest deviation from the long-term mean 1961–1990 was recorded in March, which saw an excess of +111.4 % (235.2 h) (Figure 8). January and December received only 41.2 h and 38.8 h of sunshine, respectively.

**Figure 6**
Long-term statistical comparison of Germany-wide precipitation anomalies. The chart shows the figures for 2022 (green/brown) relative to the 1881–2021 period (grey).

**Figure 7**
Deviation of annual sunshine duration 1951–2022 for Germany from the long-term mean 1961–1990.

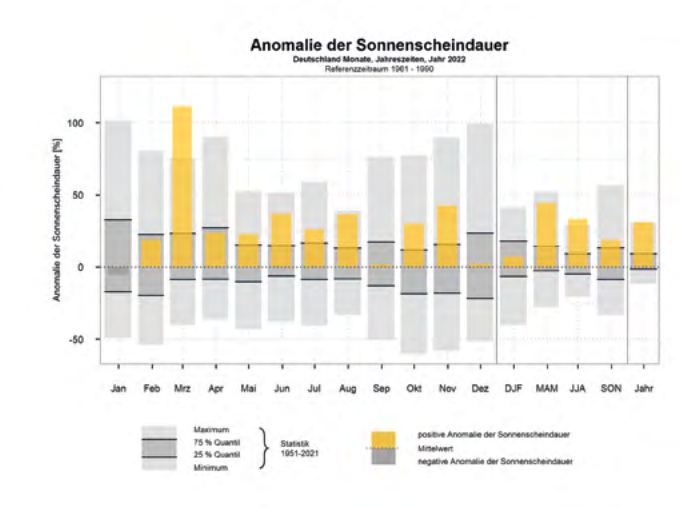

**Figure 8**

**Figure 8**
Long-term statistical comparison of sunshine anomalies for Germany. The chart shows the figures for 2022 relative to the 1951–2021 period.

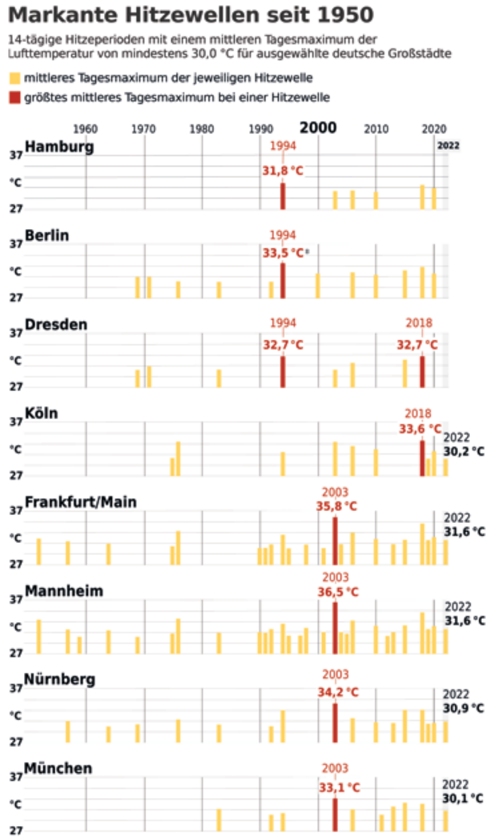

**Figure 9**

**Figure 9**
Significant heatwaves in eight Germany cities between 1951 and 2022.

## Intense heat and drought periods in summer 2022

Under frequent high-pressure influence, the summer of 2022 in Germany and large parts of western and southern Europe was characterised by exceptionally high temperatures, below-average precipitation and exceptionally high levels of sunshine with a series of intense heatwaves[1].

The first intense heatwave hit Germany and central Europe on 18 and 19 June. Subtropical air masses arriving from the south-west caused the temperatures to rise above 35 °C in widespread parts of the country. Saxony even recorded temperatures up to 39 °C. The middle third of June brought not only extremely high maximum temperatures, this heatwave also yielded very high daily mean temperatures.

From mid-July, another intense heatwave developed over Germany and central Europe. At its peak, temperatures of 35 to 40 °C were recorded over large areas. On 20 July, a total of 437 of the DWD's stations reported a 'hot day' (Tmax ≥ 30,0 °C), 274 DWD stations a 'very hot day' (Tmax ≥ 35,0 °C). 87 DWD stations measured daily maximum temperatures of 38.0 °C or higher and four DWD stations recorded temperatures of 40 °C or higher. Since systematic records first began in 1881, this was only the tenth day ever on which temperatures above 40 °C were registered in Germany. A highly extraordinary development was that the temperature at Hamburg-Neuwiedenthal climbed beyond the 40 °C threshold: It was the first time ever that a temperature value above 40 °C occurred in central Europe at a location north of the 53rd latitude.

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[1] https://www.dwd.de/DE/leistungen/besondereereignisse/temperatur/20220921_bericht_sommer2022.pdf

Summer 2022 is thus the latest in a series of summers with notable heatwaves. Figure 9 provides an overview of 14-day heatwaves with a mean daily maximum air temperature of at least 30 °C in eight German cities since 1951. Before 1980, marked heatwaves by this definition were rare in southern Germany and very rare in northern Germany. In Hamburg, for example, such an event was registered for the first time in 1994. The frequency of heatwaves of such significance has been increasing throughout Germany since the beginning of the 21st century.
In summer 2022, too, five out of the eight cities shown experienced such marked heat periods.

In the Alps, observations reveal a very sharp decline of the glaciers. In addition to very high temperatures, another reason for the melting of glaciers is the small amount of fresh fallen snow. The highly reflective snow cover melted away rapidly. As glaciers have a lower albedo, there was more energy available for the melting process. The melting of snow and glaciers was increased even further by Saharan dust transport events into the Alps in spring, as the dust reduces the reflection of incoming solar radiation. In September, Germany's Southern Schneeferner officially lost its glacier status and is now considered as dead-ice. This means that Germany now has only four glaciers.

## Exceptionally mild turn of the year 2022/23

Driven by a very lively south-westerly flow on the leading edge of a low-pressure area over Great Britain and Scandinavia, warm sub-tropical air arrived in central Europe for the turn of the year 2022/23. It gave rise to record temperatures since 1881, with unusually high daily maximum temperatures as well as minimum temperatures at New Year's Eve not below 15 degrees in some cases – such as may occur in high summer.

On 31.12.2022, temperatures of 20 °C and higher were reached at four DWD stations, 14 other DWD stations reported maximum temperatures between 19.0 and 19.9 °C. Altogether 340 stations registered levels of 15.0 °C and higher (Figure 10). No DWD station registered daytime temperatures below freezing. The Zugspitze station reported 1.9 °C, Feldberg in the Black Forest 10.8 °C. As many as 295 DWD stations (with time series of different time lengths) reported new station records for December.

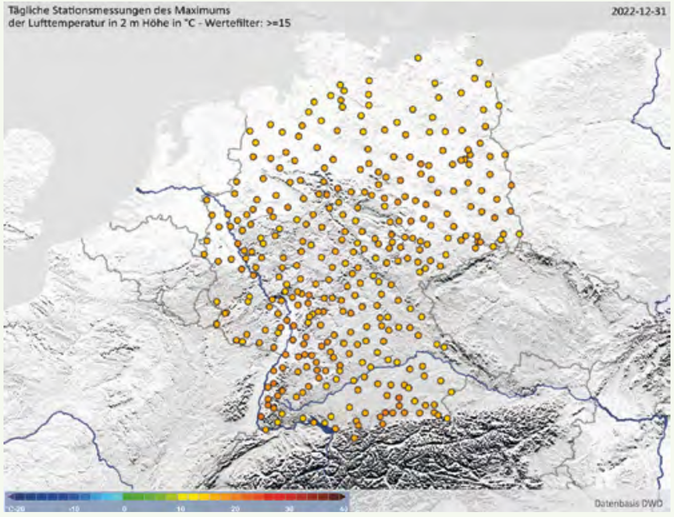


**Figure 10**

**Figure 10**
DWD stations that registered a maximum temperature of 15 °C or more on 31.12.2022.

| **31.12.2022 Tmin** | **°C** |
|---|---|
| Bad Neuenahr-Ahrweiler | 15.3 |
| Baden-Baden-Geroldsau | 15.2 |
| Weilerswist-Lommersum | 14.3 |
| Schaafheim-Schlierbach | 14.0 |
| Freudenberg/Main-Boxtal | 13.9 |
| Königswinter-Heiderhof | 13.9 |
| Rheinstetten | 13.9 |
| Lahr | 13.8 |
| Heinsberg-Schleiden | 13.7 |
| Rheinau-Memprechtshofen | 13.5 |
| Neunkirchen-Seelscheid-Krawinkel | 13.2 |
| Aachen-Orsbach | 13.2 |
| Tönisvorst | 13.1 |
| Köln-Bonn | 13.1 |
| Duisburg-Baerl | 13.0 |
| Düsseldorf | 13.0 |
| Nideggen-Schmidt | 13.0 |
| Obersulm-Willsbach | 13.0 |

**Table 3**
DWD stations that registered a minimum temperature of 13 °C or more in the night 31.12.2022/1.1.2023.

Maximum temperatures above 20 °C were once again reached in the Upper Rhine area on 01.01.2023, and as many as 313 DWD stations reported a new January temperature record.

Both 31.12.2022 and 1.1.2023 brought exceptionally high daily mean and daily minimum temperatures. In many places, the temperature during the night of New Year's Eve 2022/23 did not fall below 13 °C. Bad Neuenahr-Ahrweiler and Baden-Baden even recorded minimum temperatures above 15 °C (Table 3).

### Agro- and forest meteorological assessment of 2022

The prolonged very warm and very dry conditions in spring and summer 2022 had serious consequences in Germany and across many regions of central and southern Europe, in particular for agriculture, the risk of forest fires and the water levels in many rivers.

**Figure 11**
Mean soil moisture under grass (based on regional soil profiles, depth: 0 to 60 cm) for Germany in summer from 1961 to 2022.

**Figure 12**
All-year mean soil moisture under grass (based on regional soil profiles, depth: 0 to 60 cm) for Germany from 1961 to 2022.

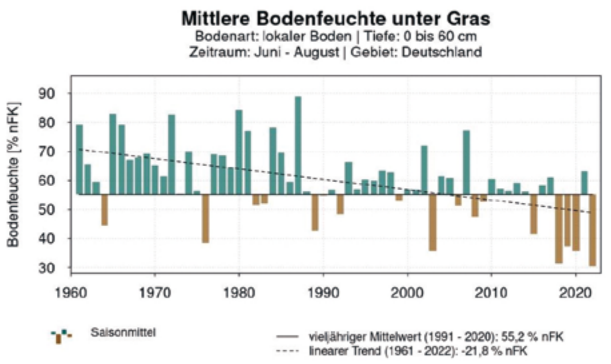


**Figure 11**

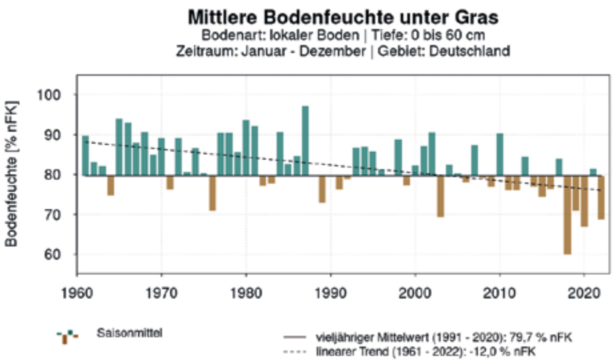


**Figure 12**

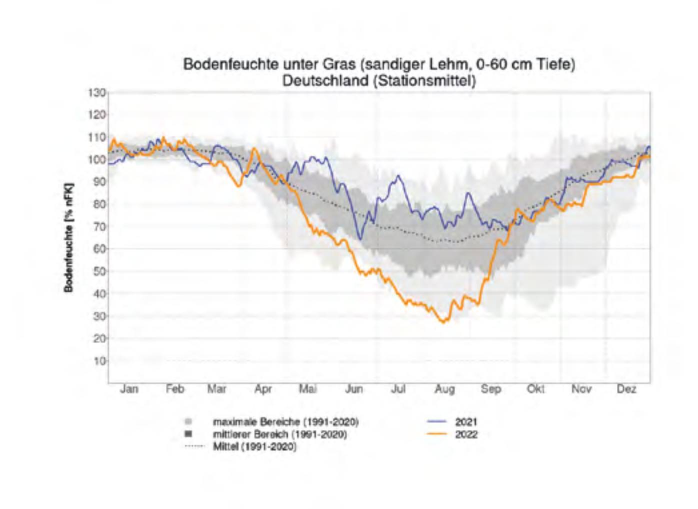


**Figure 13**

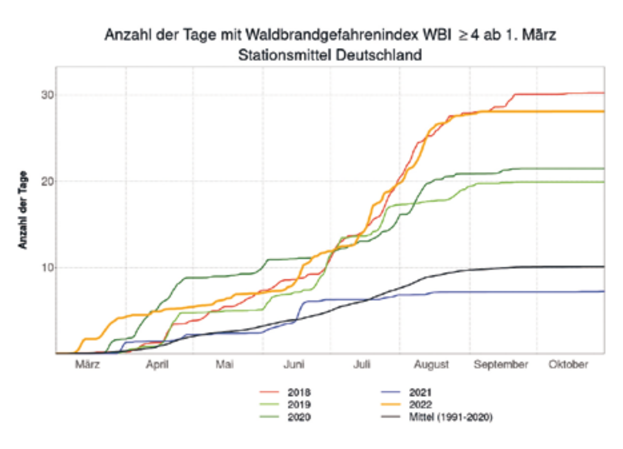


**Figure 14**

**Figure 13**
Mean soil moisture under grass (depth: 0 to 60 cm, model soil: sandy clay) for Germany in 2021 and 2022 compared to the 1991–2020 average.

**Figure 14**
Number of days with a forest fire risk index (WBI) of ≥ 4 after 1 March (years 2018 to 2022 and 1991–2020 average).

The soil moisture under grass calculated for summer 2022 (averaged over the whole of Germany) was at its lowest level since 1961 (Figure 11). The annual mean of soil moisture in 2022 comes third in the rankings (behind 2018 and 2020), thus qualifying the year as very dry.

Figure 13 shows the development of mean soil moisture (sandy clay under grass) for Germany in 2022 and 2021 in comparison with the long-term mean 1991–2020. Following on from average levels of soil moisture during the winter months (due to copious amounts of rainfall in February), there was a strong decline in mean soil moisture starting in May 2022. By July and August, some areas were at their lowest level since 1991. Only when intense precipitation arrived everywhere over Germany in September did the mean soil moisture values recover and then vary around the average.

Crops sown in autumn 2021 (e. g. winter cereals and rapeseed) often still benefited from sufficient soil moisture from the abundant rainfalls in February 2022, allowing good yields to be achieved. However, some areas accounted for significant shortfalls in the yield of summer cereals. Major losses were also suffered for potatoes, sugar beet and, above all, maize. Grassland and pastures turned increasingly brown during the summer, making second cuts impossible in certain areas. In some cases, animals kept on dried grazing grounds had to be fed with winter fodder. Another consequence of the high temperatures and large amounts of sunshine in the summer was that many fruit crops, for example apples, suffered from sunburn.

The very dry and warm summer once again facilitated the rapid spread of bark beetle, and more trees which had been weakened by the drought succumbed to the beetle. This is likely to lead to an even higher degree of infestation in the coming year.

The year 2022 was also marked by an extremely high risk of forest fires. March already saw the highest ever number of days with a forest fire risk index (Waldbrandindex, WBI) of at least 4. The situation was similar in May (Figure 14). The result was a high number of forest fires, in particular in Brandenburg, Saxony-Anhalt and Saxony.

According to the German Association of Towns and Municipalities, nearly 4300 hectares (ha) of forest had been destroyed in large fires (fires of over 30 ha) in Germany by August 2022. The burned area in 2022 was thus five times the annual average (nearly 776 ha, since 1991). This tops the previous record year 2019 when 2711 ha of forest burned away.

# Seven tornadoes in one day

On 20 May 2022, large parts of Germany experienced the heaviest series of thunderstorms of the 2022 season up to that point.

Summary reports on the weather and severe weather situation had been issued well in advance via social media. There were fears that the thunderstorms would also bring hurricane-force gusts (which, however, showed their full severity only later over the Czech Republic). In addition, warnings of the increased potential for developing tornadoes were also repeatedly issued and it came as no real surprise when these did in fact occur.

### A look into the statistics

Data on all tornado events are stored in the severe weather database of the European Severe Storms Laboratory (ESSL). Robust figures on statistical studies of tornado events in Germany are only available from about the year 2000 onwards. Drawing on the data from 2001 to 2020, an annual average of 32 tornadoes and just under 17 waterspouts were recorded. The numbers fluctuate from year to year, and it can be assumed that not all weak tornadoes find their way into the statistics.

The intensity of tornadoes is rated using the Fujita scale from F0 to F5. Strong tornadoes are those with an intensity of at least F2. Around five strong tornadoes per year occur on average (4x F2, 1x F3). Tornadoes stronger than these are much less frequent. In recent years, the number of strong tornadoes has been somewhat below-average (2019: 1x F2, 1x F3, 2020: none, 2021: 1x F2). Statistically speaking, it therefore was ‘about time’ that some strong tornadoes appeared again. However, it is important to emphasise once again that the tornado statistics currently show no trend with regard to the number and intensity of tornadoes in Germany. Tornadoes therefore do not lend themselves as arguments in relation to climate change.

### Tornado outbreak on 20 May 2022

A total of seven tornadoes were recorded in central Europe in connection with the severe weather situation on 20 May 2022. One of these was in the Netherlands near the border to Germany, the other six were in Germany. A large number of tornadoes such as this is referred to as a tornado outbreak. Three of these tornadoes were strong events (Merxhausen, Lippstadt and Paderborn; each F2).

## Parameters that favour the formation of tornadoes

DWD meteorologists work with the so-called ingredients method. This involves keeping an eye out for the ingredients that need to come together for thunderstorms and tornadoes to form. Thunderstorms require moisture and temperatures that decrease rapidly with altitude (instability). Both ingredients together form the available energy for thunderstorms. This energy was significantly elevated for some regions over the centre and in the south on 20 May 2022.
A further element is also required: lifting, as this causes the air to cool during the process and eventually form thunderclouds. On 20 May 2022, a strengthening low-pressure system that, as the day progressed, moved from Benelux to northern Germany provided sufficient lifting from its remnants.

But for thunderstorms to turn into severe weather, one more crucial ingredient is needed: wind shear. This refers to the variation in wind speed and direction with height. Specifically in the case of tornadoes, the wind change between the ground and about 1 km altitude is important. This was also significantly elevated on 20 May. A tornado is also more likely to form if the base of the thundercloud is as low as possible from the ground. This was also the case over the western centre in particular. It was therefore apparent by just looking at the ingredients that a tornado might possibly form on the Friday in question.

## No spatially accurate prediction possible

It is impossible, however, to say in advance where tornadoes will actually occur. What is possible, on the other hand, is a so-called potential assessment. The information on the potential risk of tornadoes occurring was shared in the weather watch issued on the previous day, 19 May 2022. As soon as the potential tornado was then recognised with the help of weather radars and incoming reports, the related phenomena also appeared in the acute warnings.

A study of strong tornadoes in Germany from 2013 to 2020 identified certain typical conditions associated with tornado occurrences. One interesting aspect was that precipitation often occurs in the run-up to tornado events, which can, among other things, provoke moistening and thus lowering of the cloud base. This was the case in 12 out of 17 events investigated. In eight cases, the tornado was immediately preceded by showers or thunderstorms, and this was also the case on 20 May 2022. It was also found that one and the same thunderstorm can produce tornadoes repeatedly. On eight out of ten days on which there was more than one tornado, a thunderstorm produced at least two tornadoes. This was also observed on 20 May 2022. The thunderstorm cell that resulted in the Paderborn tornado has been shown to have produced at least four tornadoes (Lippstadt, Paderborn, Lütmarsen and Merxhausen) and three of them were strong. In summary, the situation on 20 May 2022 can be classified as a classic tornado weather situation.

More information on this subject:
European Severe Weather Database
https://www.eswd.eu/

# Weather in Germany 2022

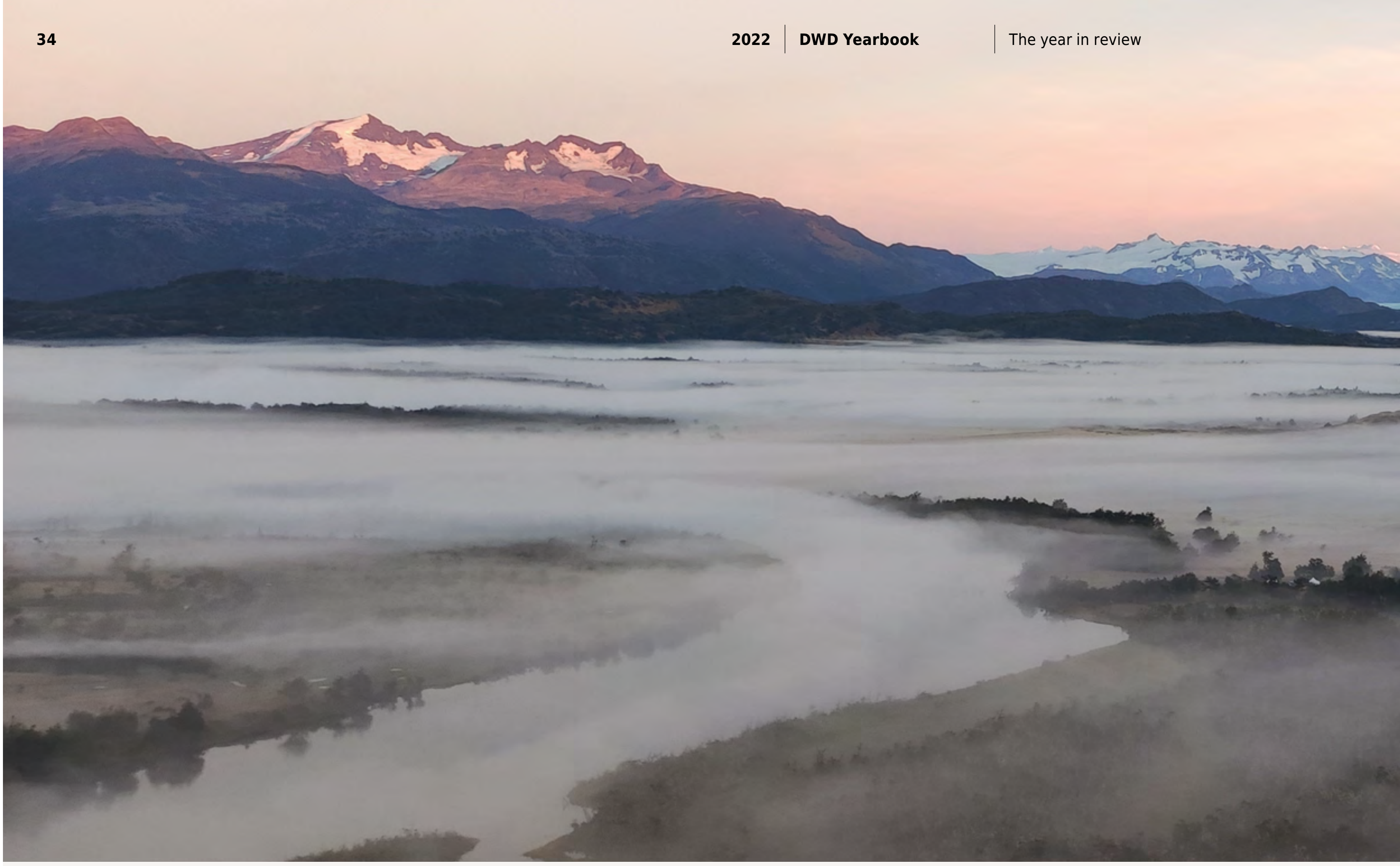
| | Average temperature in °C | Highest temperature in °C | Lowest temperature in °C |
|---|---|---|---|
| **January** | **2.8 (-0.5)** | **18.2**<br>in Rheinfelden on the 4th | **-20.2**<br>on the Zugspitze on the 21st |
| **February** | **4.5 (0.4)** | **17.3**<br>in Metzingen on the 18th | **-18.3**<br>on the Zugspitze on the 11th |
| **March** | **5.1 (3.5)** | **23.0**<br>in Regensburg on the 28th | **-16.9**<br>on the Zugspitze on the 4th |
| **April** | **7.8 (7.4)** | **26.0**<br>in Wolfach on the 13th | **-18.4**<br>on the Zugspitze on the 2nd |
| **May** | **14.4 (12.1)** | **33.7**<br>in Ohlsbach on the 20th | **-18.4**<br>on the Zugspitze on the 3rd |
| **June** | **18.3 (15.4)** | **39.2**<br>in Cottbus and Dresden-Strehlen on the 19th | **-9.1**<br>on the Zugspitze on the 30th |
| **July** | **19.1 (16.9)** | **40.1**<br>in Hamburg-Neuwiedenthal on the 20th | **-3.9**<br>on the Zugspitze on the 11th |
| **August** | **20.2 (16.5)** | **39.6**<br>in Bad Kreuznach on the 4th | **-4.8**<br>on the Zugspitze on the 8th |
| **September** | **13.4 (13.3)** | **32.3**<br>in Kleve on the 5th | **-0.8**<br>on the Zugspitze on the 22nd |
| **October** | **12.5 (9.0)** | **28.7**<br>in Müllheim on the 13th | **-9.9**<br>on the Zugspitze on the 21st |
| **November** | **6.4 (4.0)** | **20.5**<br>20.5 in Müllheim on the 8th | **-7.0**<br>on the Zugspitze on the 3rd |
| **December** | **1.8 (0.8)** | **20.8**<br>in Wielenbach on the 31st | **-13.6**<br>on the Zugspitze on the 22nd |
| **Spring** | **9.1 (7.7)** | **33.7**<br>in Ohlsbach on the 20th of May | **-18.4**<br>on the Zugspitze on the 2nd of April and 3rd of May |
| **Summer** | **19.2 (16.3)** | **40.1**<br>in Hamburg-Neuwiedenthal on the 20th of July | **-9.1**<br>on the Zugspitze on the 30th of May |
| **Autumn** | **10.7 (8.8)** | **32.3**<br>in Kleve on the 5th of September | **-9.9**<br>on the Zugspitze on the 21st of October |
| **Winter 2021/22** | **3.3 (0.2)** | **18.2**<br>in Rheinfelden on the 4th of January | **-20.2**<br>on the Zugspitze on the 21st of January |
| **Year** | **10.5 (8.2)** | **40.1**<br>in Hamburg-Neuwiedenthal on the 20th of July | **-20.2**<br>on the Zugspitze on the 21st of January |

The figures in parenthesis indicate the long-term mean values according to the internationally agreed 1961 to 1990 reference period.

| Precipitation in l/m² | Sunshine duration in hours | Memorable facts |
|---|---|---|
| 58.2 (60.8) | 41.2 (43.6) | Very mild start to the year; storm in northern and eastern parts of Germany and storm surge on the North Sea coast at the end of the month |
| 83.7 (49.4) | 85.0 (71.5) | Series of storms (Ylenia, Zeynep, Antonia) from 16 to 21 February; very high amounts of precipitation |
| 15.0 (56.5) | 235.2 (111.2) | Extremely sunny (more than 200 hours of sunshine), very dry |
| 56.5 (58.2) | 190.4 (153.7) | Still snow at the beginning, first summer days in the middle of the month |
| 47.0 (71.1) | 247.7 (201.6) | Very warm and dry month with much sunshine; first ‘hot day’ |
| 56.2 (84.6) | 278.8 (203.3) | Many ‘summer days’, a couple of ‘hot days’ and first heatwave of the year after mid-month |
| 37.8 (77.6) | 265.8 (210.7) | On 20 July, tenth day with temperatures of 40 °C and higher since records began |
| 48.9 (77.2) | 272.8 (199.5) | Continuing drought with consequences for the vegetation and river levels; twelfth month in succession that was too warm |
| 100.0 (61.1) | 152.3 (149.6) | High amounts of precipitation put an end to the drought; summer weather at the beginning of the month; first snowfalls in the Alps at the end of the month |
| 49.7 (55.8) | 141.1 (108.5) | Extremely mild month and, together with 2001, warmest October on record; summer temperatures from the middle of the month |
| 48.9 (66.3) | 75.3 (52.8) | Very mild month with much sunshine and below-average precipitation |
| 67.5 (70.2) | 38.8 (38.0) | Very cold conditions until after mid-month; coldest spell for the whole year; extremely mild end of the month |
| 118.5 (185.9) | 673.2 (466.6) | Dry and very sunny spring |
| 142.9 (239.4) | 817.3 (613.5) | Very warm and dry summer, with large amounts of sunshine and several heatwaves with temperatures above 40 °C; extreme drought |
| 198.7 (183.3) | 368.6 (310.9) | Very mild autumn with a last ‘summer day’ at the end of October |
| 203.3 (180.7) | 164.0 (152.9) | Almost no winter in lowland areas, little snow in the low mountain ranges and in the Alps |
| 669.5 (788.9) | 2024.1 (1544) | Together with 2018 warmest year ever since records began in 1881 |

# The year in review

**right**
Virga in sunset sky at the rear of a thunderstorm. Photo taken at the federal-state border between Thuringia and Bavaria.

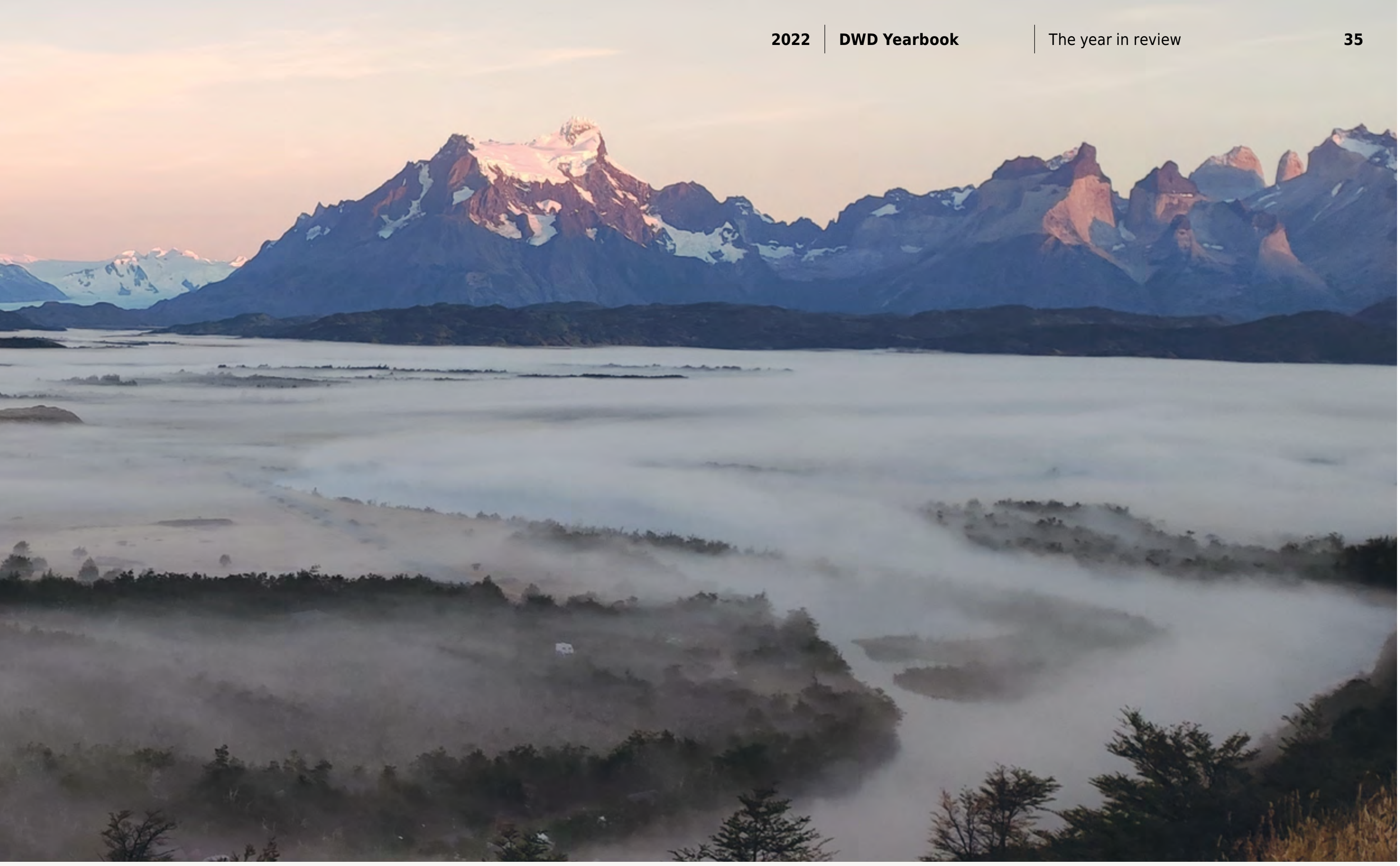


# The year in review Winter 2022/23: Cooperation with the Federal Network Agency and gas network operators

Ordinary people, business, industry and politicians all had grave fears that there might be gas shortages in Germany over the winter of 2022/23. Gas consumption depends on a wide range of influences, including meteorological variables: air temperature, humidity and sunshine duration all play a role. It was therefore all the more important to consult the DWD’s seasonal climate prediction as well as the daily weather reports in autumn 2022.

Entirely unnoticed by the public, the DWD has been cooperating with gas network operators for many years and, since last winter, with the Federal Network Agency (BNetzA) in particular. With a view to meeting acute gas demand, gas network operators focus on the weather forecast for the next three days. For this purpose, they use the so-called target temperature, a variable that is calculated from measured daily mean temperatures and gas consumption per day in specific network areas.

For these purposes, the DWD has developed the ‘gas prediction temperature’ in a project of the German Association of Energy and Water Industries (BDEW). This is a calculated daily mean temperature optimised for customer consumption in the network area of the gas network operator, which refers to the so-called ‘gas day’ (6 a.m. previous day to 6 a.m. current day). The DWD provides the gas forecast temperature for every gas grid area in Germany. After the target temperatures have been supplied, further improved forecasts for grid operators’ areas can also be made available.



**top**
After a clear cold night, ground fog formed as the sun began to climb, creating this fascinating impression. Photo taken in the Torres del Paine National Park (Chile).

For the BNetzA, on the other hand, forecasts up to 90 days into the future are relevant. As a rule, the BNetzA uses models to calculate consumption. These calculations were previously based on historical daily mean temperatures and gas consumption. For this purpose, ‘rough’ measurement data, such as the daily mean temperature for the whole of Germany, are adequate. In view of the unusual situation last year due to the war in Ukraine, the BNetzA wished to optimise its simulations and it stepped up its cooperation with the DWD for this purpose.

The DWD provided air temperature data for the previous day from all its measuring stations so that the BNetzA could promptly complete its own archive of measured values and apply the data. In addition, the DWD also supplied the BNetzA with forecast daily mean temperatures for almost 500 DWD stations up to the ninth day in the future. In order to improve forecasts for gas consumption, the BNetzA successively converted the daily average for Germany to the daily averages of the stations. While data sets for individual forecasts are usually produced in a second, it took up to 60 seconds to produce the point and time-specific forecasts, including the provision of the measurement data for the BNetzA.

The DWD also provided information on seasonal and subseasonal climate predictions for the coming weeks and months in Germany to meet the BNetzA’s request for longer-term weather forecasts. The temperature data in the predictions for the coming six-week averages and for different regions of Germany were provided every week. This involved taking account of the 51 prediction simulations as well as statistical evaluations, such as mean values, probabilities or skill scores. In addition, documents on the current subseasonal and seasonal climate predictions for the coming weeks and months were sent to the BNetzA. These documents describe in text and images the probability of warm, normal or cold conditions and how the climate predictions were calculated.

# Contribution to climate protection: Potential savings of 1 million tonnes of $CO_2$ each year

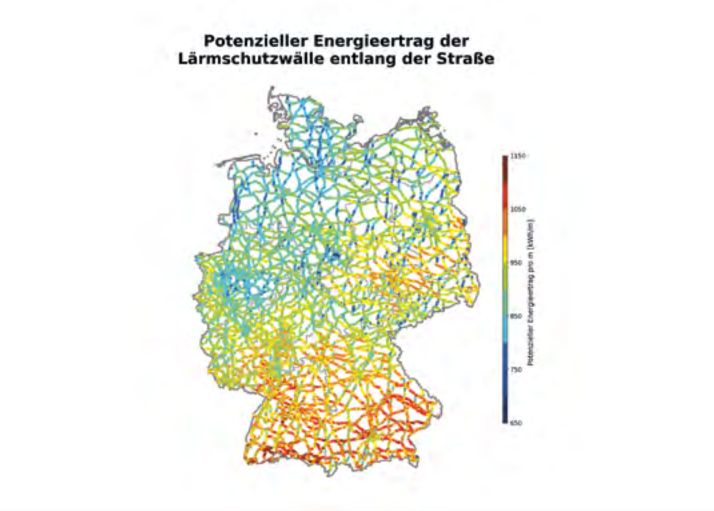
The growing use of photovoltaic (PV) panels on public surfaces also offers opportunities to protect the climate. The potential offered by noise protection structures is revealed by an analysis carried out by the Deutscher Wetterdienst (DWD) in cooperation with the Federal Railway Authority (EBA) and the Federal Highway Research Institute (BASt) as part of the Network of Experts of the Federal Ministry for Digital and Transport (BMDV). Federal Minister Dr Volker Wissing summarises the result: “If we attach photovoltaic modules to suitable noise protection walls and embankments along German motorways and railway tracks, we could save up to 1 million tonnes of $CO_2$ per year. This would allow us to make a substantial contribution to the national climate protection goals.”

## Electricity for 450,000 households

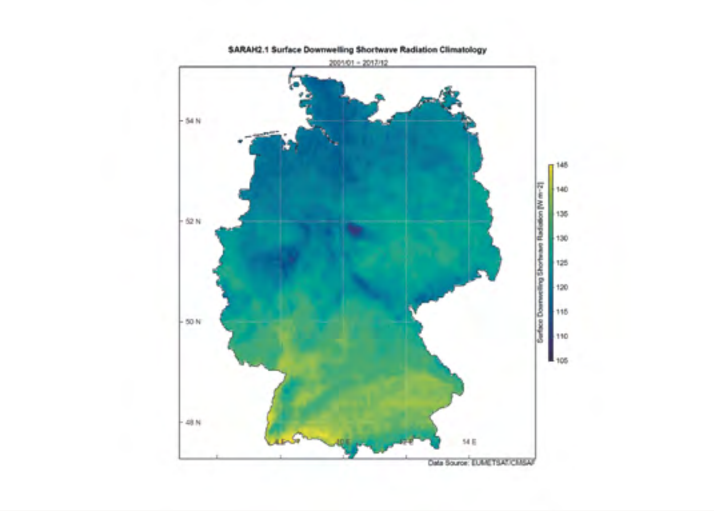
There are roughly 5,800 km of noise protection structures along railway lines, motorways and federal trunk roads in total. More than 1,800 km of noise protection structures exist along railway lines[1] and almost 4,000 km are located alongside motorways and trunk roads[2]. The DWD has used satellite data to calculate the potential electricity yield that photovoltaic modules fitted to such structures could deliver: around 1,500 gigawatt hours (GWh) of electricity, depending on the orientation and angle of inclination of the noise protection structures. This energy could cover the annual consumption of roughly 450,000 households in Germany.[3]

**01**
Example of potential yield estimates for noise protection structures along trunk roads.

**02**
Irradiation data for Germany during the analysis period 2001–2017. The satellite-based data set was produced by the DWD as part of its contribution to the EUMETSAT Climate Monitoring Satellite Application Facility.



**01**



**02**

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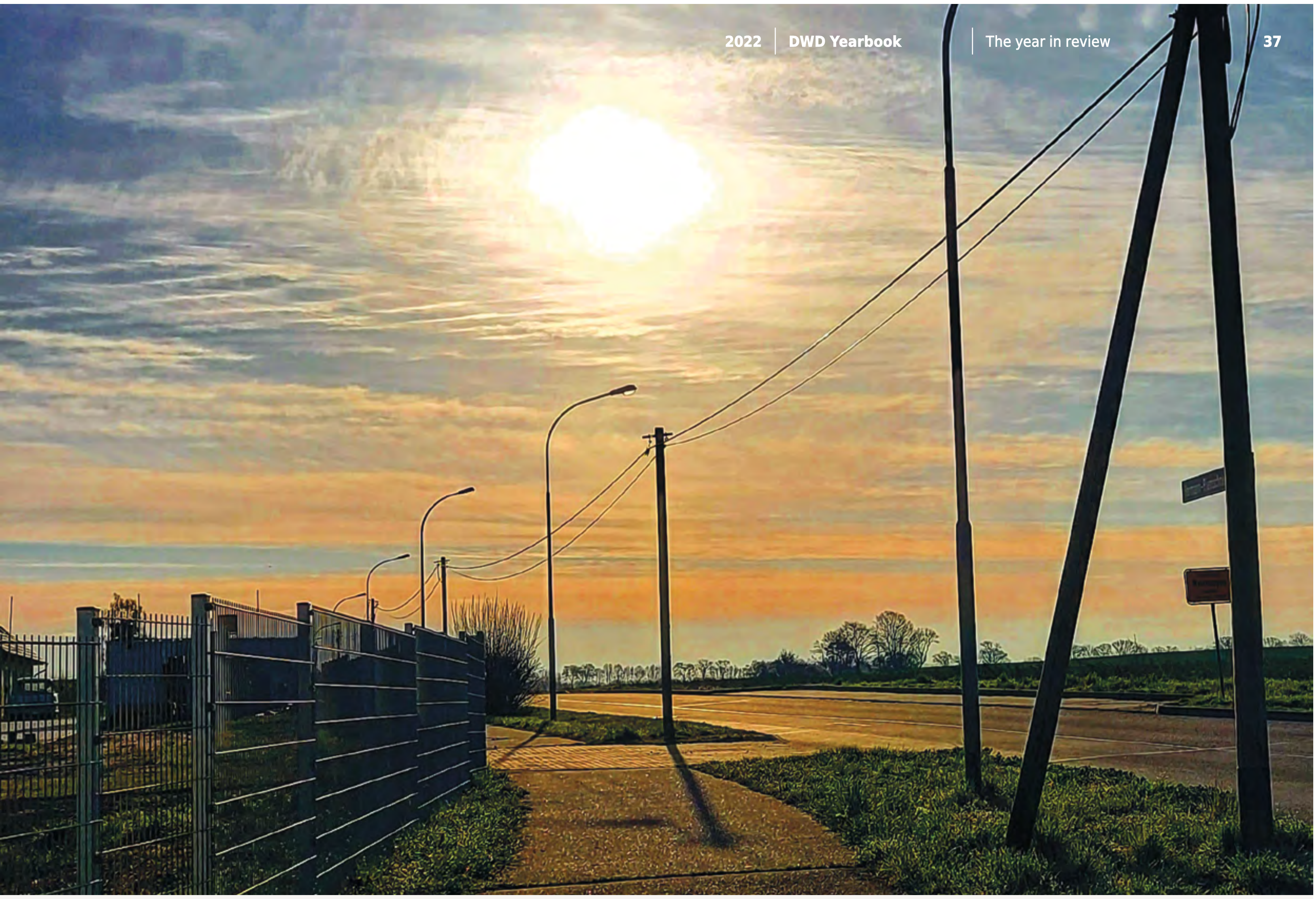
[1] Data basis: Third noise mapping, conducted in 2017, EBA 2017
[2] Data basis: Statistik des Lärmschutzes an Bundesfernstraßen 2017 – 2018 – 2019 (Statistics on noise protection on federal trunk roads 2017 – 2018 – 2019), BMDV 2021
[3] Data basis: Federal Statistical Office. Average electricity consumption per household in 2019 was 3,106 kWh.



**top**
Sunshine through a cloudy sky. Photo taken during a morning walk in Neuruppin.

### Noise protection embankments along motorways hold the greatest potential

There are different types of noise barriers along federal trunk roads. About 80 km of these are made up of steep embankments, consisting of metal frames filled with stones. There are roughly 2,500 km of noise protection walls. Experts have estimated that PV systems could be attached to around ten per cent of these. Much greater potential is offered by the noise protection embankments, which typically have a 30-degree angle of inclination. There are roughly 1,300 km of such embankments along the motorways. They are often covered with grass and resemble dikes. The noise protection embankments have a calculated annual yield potential of around 1,200 GWh, assuming that 50 per cent of their area is covered with PV systems. If the proportion of photovoltaic module coverage is increased to 60 per cent, the yield is around 1,400 GWh; at 70 per cent, the figure rises to 1,695 GWh.

### Noise and nature protection – an important contribution to the energy transition

The experts involved stated how important it is that any efforts to exploit the potential of the structures should not compromise their noise-related and operational properties. Landscaped noise protection structures are often also covered under nature protection laws.

### About the BMDV Network of Experts

The BMDV Network of Experts forms a key element of departmental research. In 2016, seven departmental research institutions and specialised authorities of the BMDV joined forces under the banner of ‘Knowledge – Ability – Action’ to form a network of experts. The aims are to provide a broader common foundation for the competences of the participating authorities, to encourage them to liaise more intensively with each other and thus to facilitate the publication of application-oriented research results for practical use.

# Weather forecasts and dispersion calculations for the war zone

**top**
Dispersion calculation using the 'RODOS' representation.

The DWD's statutory tasks include measuring radioactivity in the air and in precipitation, and performing dispersion calculations in the event of a possible nuclear incident. For this purpose, the DWD operates a network of 48 stations in total that measure radioactivity. Right at the outset of the Russian war against Ukraine on 24 February 2022, the Federal Office for Radiation Protection (BfS) and the DWD agreed to provide weather reports and dispersion calculations for the area affected by the war.

Russian troops captured the former Chernobyl nuclear power plant at an early stage in the war. Radioactively contaminated soil was stirred up by the attacks, and elevated radiation levels were measured around Chernobyl. However, the DWD's dispersion calculations quickly showed that there was no danger to German territory. No elevated levels were measured by the DWD's radioactivity monitoring network throughout the last year.

However, the ongoing fighting means that there is a risk of damage to Ukrainian nuclear power plants and of a release of radioactive material. As the war progressed, Russian forces seized the entire Chernobyl facilities as well as the Zaporizhzhya power plant. There were also critical situations at the Kharkiv Institute of Physics and Technology (NSC KIPT) in eastern Ukraine, a research institute that also works with radioactive materials. The power supply line was repeatedly damaged at the Zaporizhzhya site, Europe's largest nuclear power plant.

The agreement with the BfS required the DWD to provide a separate daily weather report for the Ukraine area. The DWD feeds these weather reports continuously into the federal emergency system and distributes them to a selected group of users. The DWD directly informs not only the BfS but also the Bundeswehr, the Federal Office of Civil Protection and Disaster Assistance (BBK) and the Federal Ministry of the Interior and Community (BMI).

In addition, from the beginning of the war, the BfS requested that dispersion calculations be drawn up four times a day for all operational Ukrainian nuclear power plants and the 'nuclear ruin' of Chernobyl. These dispersion calculations are distributed via the information and decision support systems of the Federal Government and the federal states and form part of the BfS's daily report on the radiological situation in Ukraine.

The threat posed by the war in Ukraine led the DWD to develop a so-called OIL (Operational Intervention Level) flight procedure. This procedure can be used in the aftermath of a nuclear accident to predict the location of radioactively contaminated air spaces and to identify which areas are definitely unaffected. The aim here is to safeguard air traffic. The DWD itself is kept continuously informed about the situation in the war zone via various platforms and contacts.

## Weather forecasts delivered directly to the cockpit

Alongside turbulence and icing, thunderstorms are a further weather phenomenon in aviation that constitutes a major threat to aircraft, especially en-route. It is therefore all the more important that up-to-date weather forecasts are always available in the cockpit. Since 2022, the Deutscher Wetterdienst (DWD) has been supplying Lufthansa pilots every 15 minutes with current thunderstorm forecasts during their flights. The forecasts are delivered by the DWD's internally-developed NowCastSAT-Aviation (NCS-A) global short-term forecast system directly to the cockpit. This enables the pilots to rapidly assess the meteorological situation along their flight route and decide, based on the information from their on-board radar, whether to fly around a dangerous thunderstorm.

### Second DWD component for Lufthansa pilots while in the air

No aircraft takes off in Germany without the cockpit crew having received a meteorological briefing beforehand. This comes from the DWD, whose legal tasks include providing meteorological information and services to ensure the safety of aviation. Accordingly, Lufthansa has for some time been using the DWD's turbulence forecast EDP, which is also delivered directly to the pilot crew.

The global thunderstorm forecast NCS-A represents the second DWD cockpit assistance component. Via an interface to the DWD spatial data server, Lufthansa's IT provider integrates the forecasts directly into the airline's own systems. From there, they are distributed in near real time to around 340 aircraft. The DWD uses the data from as many as five geostationary satellites, global lightning data from an external service provider and data from the global model of the DWD weather forecasting system ICON to produce these thunderstorm forecasts. NowCastSAT-Aviation then prepares convection information at three severity levels and makes this available together with cloud top data. Based on this interplay of available weather information, state-of-the-art methods make it possible to deduce the displacement of thunderstorm cells and thus support the pilots in assessing the meteorological situation. Due to the high quality of the data, the false alarm rate can be significantly reduced, thus increasing overall aviation safety.

However, this is by no means the end of the DWD's work as a certified aeronautical meteorological service provider. Further developments, such as the European version of the thunderstorm forecast for the cockpit, are close to becoming operational.

**right**
The cockpit of a Lufthansa aircraft: the screen on the left displays the on-board radar, the screen on the right is for en-route detection and nowcasting (forecasts for up to two hours in advance) of thunderstorms.

# Summit weather – behind the scenes

Around 100 km south of Munich, an idyllic valley in the heart of the Wetterstein mountains, above the village of Klais at an altitude of around 1,000 m – it was here, in Schloss Elmau, that the heads of state and government of the G7 countries met for their annual summit from 26 to 28 June 2022. The G7 Summit was hosted here because the presidency in 2022 was held by the Federal Republic of Germany.

The meeting not only kept politicians and numerous security agencies busy, the DWD, too, had its hands full with its responsibility for providing the meteorological information and services to ensure the safety of the summit. The DWD began preparing for the summit in January. The Federal Police had previously sent a corresponding request to the DWD's MET Advisory Centre at Munich Airport. The task was to provide reliable weather forecasts and weather briefings for around 18,000 operational forces and the flights of about 45 helicopters.

01
View into the DWD's MET Advisory Centre at Munich Airport.

## Mixed operation

The MET Advisory Centre usually focuses on aeronautical meteorology. But this time, forecasts and briefings relating to the weather on the ground (surface weather) were also requested. This was completely uncharted territory for the advisory centre. The DWD developed a comprehensive package of services and products to meet the requirements for a 'mixed' operation of surface and air forecasting.

This included a set of maps that was made available on a protected page in the DWD's Heliportal to the command and control staff of the Berlin and Munich Federal Police and all crews. The map set was supplemented with further data, such as temperature forecasts for forecast points at different altitudes, astronomical data as well as a forecast text. Three flight routes were generated and colour-coded according to weather conditions to enable flights between Elmau and Munich Airport to be planned as vividly as possible. This meant that non-pilots too were able to use the tried and tested traffic light system to estimate whether VIPs and operational forces could be flown by helicopter in the next twelve hours or whether land transport would have to be used instead.

### Large number of consultations

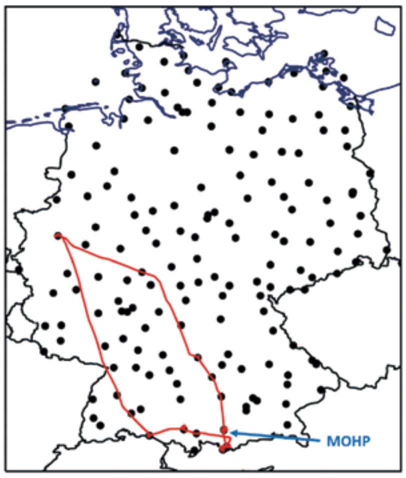
Official G7 operations began for colleagues at the DWD’s Munich MET Advisory Centre on 13 June. Relatively few telephone conferences were held initially, but the number increased as the summit approached. At the beginning of the official G7 operation, products were also sent to the White House Military Office (WHMO). The pilots of Marine Corps Helicopter Squadron One and the head of Presidential Weather Operations of the WHMO made extensive use of the DWD products. They also took the opportunity to consult regularly by telephone.

From a meteorological point of view, the weather up to the summit Sunday was calm and all the planned flights were able to take place. On Monday and Tuesday, 27 and 28 June, the weather changed with numerous thunderstorms forming in the unstable hot air. Several supercells developed and there were several heavy hail events. To the east of the summit location, images of hailstones six to eight centimetres large were published in the DWD weather warning app. Schloss Elmau and the nearest staging area for the helicopter squadrons at the Ohlstadt-Pömetsried airfield were spared from the hail, however. The DWD extended the ‘G7 shift’ into the evening owing to the complex weather and the large number of consultations over the two days. On Tuesday, it was time to fly the state guests back to Munich airport. Once the helicopter units had taken off for home on Wednesday (29 June), the DWD was able to discontinue its supplementary forecasts.

**below**
Mood after summer thunderstorm.
Photo taken in Saxon Switzerland.

# An exceptionally strong Saharan dust event

Saharan dust was transported from the Algerian desert to central Europe in mid-March. In Germany, too, the dust in the air produced orange, reddish or brownish skies and spectacular sunrises and sunsets. These phenomena indicated a particularly high concentration of Saharan dust. This is confirmed by measurements by the DWD and Düsseldorf University of Applied Sciences (HSD). According to a vertical profile of particle mass concentration measured from an aircraft above the DWD's Hohenpeissenberg Meteorological Observatory (MOHp), the highest concentration during this Saharan dust event was over 2200 µg/m³ (or 2.2 mg/m³) at an altitude of two kilometres above sea level. This means that the concentration of dust in the air at this altitude was 200 times higher than normal values. The long-term average of surface concentrations at Hohenpeissenberg has decreased from approximately 12 to 6 µg/m³ over the past 25 years. However, 170 µg/m³ were measured there briefly in March, almost as much as during the strongest event in the measurement series to date in May/June 2008, when up to 250 µg/m³ were recorded.



**01**
Flight route (red line) and ceilometer sites (black dots).

On Thursday, 17 March 2022, the DWD, in cooperation with the Department of Physics and Environmental Measurement Technology at the HSD, was able to investigate the Saharan dust event in more detail using laser remote sensing and aircraft measurements. For this purpose, a research aircraft flew from Essen/Mülheim airport to the Zugspitze and back. The flight route also took account of the positions of DWD measuring stations, at each of which a ceilometer is operated for the active remote sensing of the atmosphere.

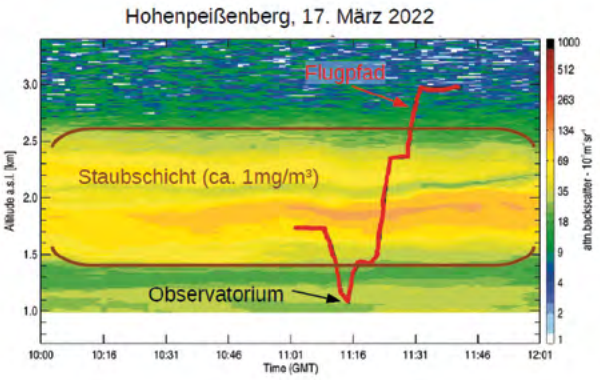
Ceilometers are instruments for automatically measuring cloud height or the cloud base. They are also suitable for the qualitative and quantitative detection of particles in the air, such as dust or volcanic ash. However, this is only possible if additional measurement data are available for dust and volcanic ash or assumptions are made about the dust properties, such as density and backscattering capacity.

Desert dust from the Sahara can be observed on an average of 50–60 days per year in southern Germany and on 30 days per year in northern Germany. In most cases, it is not possible to see from the ground whether there is a layer of dust some kilometres up in the air or not. But it is possible to use ceilometers to detect these dust events, provided they are not too faint or clouds obscure the sky.

The data obtained are also used in the 'PermaStrom' project. The aim of PermaStrom is to make the prediction of photovoltaic energy production more precise by, for example, improving the predictions of occurrence and transport of desert dust. Sahara sand is a big problem for photovoltaic systems. When the sand darkens the sky, electricity generation drops by 10 to 20 per cent, as shown by the predecessor research project 'PerduS', in which the DWD, the Karlsruhe Institute of Technology (KIT) and the company meteocontrol GmbH were involved. Even in the days following a Saharan dust event, output drops wherever systems have been directly covered by the dust. It is therefore very important for energy producers to be aware of these analyses and forecast data so that they can make reliable yield forecasts during Saharan dust events.

**02**
Ceilometer system.

**02**



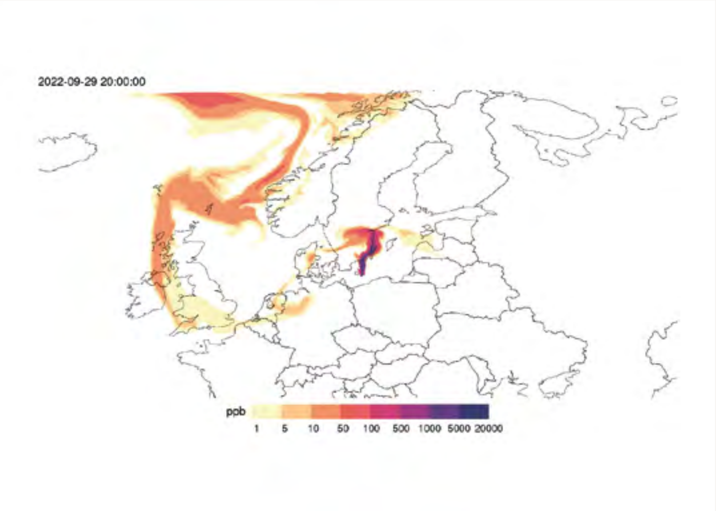
**03**
The highest dust concentration is found in the layer between 1.5 and 2.5 km of altitude. The bold red line shows the position of the aircraft.

## On the trail of greenhouse gases

The sources (emissions) and sinks (uptake) of greenhouse gases in Germany must be better recorded and monitored in future. This is the goal of the Integrated Greenhouse Gas Monitoring System (ITMS) for Germany, which was officially launched in October 2022 at the Max Planck Institute for Biogeochemistry (MPI-BGC) in Jena. The ITMS is funded by the Federal Ministry of Education and Research (BMBF) with the aim of providing the German government and the public with reliable information on the status and development of greenhouse gas fluxes.

The lead partners include the MPI-BGC, the DWD, the Institute for Environmental Physics (IUP) at the University of Bremen, the Institute of Meteorology and Climate Research – Institute of Atmospheric Environment Research (IMK-IFU) at the Karlsruhe Institute of Technology (KIT) and the Institute for Atmospheric Physics at the German Aerospace Center (DLR). Furthermore, the German Environment Agency (UBA) and the Thünen Institute of Climate-Smart Agriculture also play a central role in national reporting on international climate change treaties.

**below**
Thunderstorm cell. Photo taken near Langstadt (Hesse).



**01**

**01**
ICON-ART modelled methane plume from the leak in the Nordstream pipes. Such methane clouds can also be detected using ITMS.

A new feature of the ITMS is that the sources and sinks of greenhouse gases can be determined independently on the basis of observations. Highly reliable new calculations can be made based on measured concentrations in the atmosphere and by applying current models of source and sink processes as well as meteorological transport. It is precisely such trustworthy data that are of particular relevance for a fact-based policy to curb climate change, to manage trading in $CO_2$ certificates and to move towards a climate-neutral economy (NetZero).

## Inverse modelling finds sources and sinks

Sources and sinks of greenhouse gases and their origin on the Earth's surface can be determined with the help of 'inverse modelling'. This method uses real observational data on atmospheric greenhouse gas concentrations; with the help of a model, it can then be used to infer the spatial distribution and strength of sources and sinks. Together with a research group at the MPI-BGC, the DWD will develop inverse greenhouse gas modelling for Germany and transfer it to operational use.

Just how important real measurements are was demonstrated by the Nordstream 1 and 2 leaks, which released large amounts of methane ($CH_4$) into the atmosphere. Greenhouse gases are not visible but are detected by ground-based systems included at the measuring stations of the Integrated Carbon Observation System (ICOS) and by satellites. The DWD was able to follow the course of the methane plume with the help of the atmospheric transport model ICON-ART, which is based on the DWD weather forecasting system ICON.

## Satellite data provide important information

One of the most important advances made by the ITMS is the improvement of data flows from the various observation systems, which include measurements on the ground, from aircraft and from satellites. New satellite data in particular will make important contributions in this context. High-resolution satellite measurements of atmospheric concentration allow the emission strength of local $CO_2$ and $CH_4$ sources to be quantified from space. In future, it will be possible to use simulation models in combination with estimates of emissions from transport and industry to distinguish between the sources of emissions, for instance fossil sources, agriculture and forestry, and natural sources (such as wetlands).

# An intercomparison of radiosondes

From 16 August 2022 to 13 September 2022, radiosoundings were performed at the Meteorological Observatory Lindenberg – Richard Assmann Observatory (MOL-RAO) of the DWD on behalf of the World Meteorological Organization (WMO) for the international radiosonde comparison campaign ‘Upper-Air Instrument Intercomparison 2022’ (UAII2022). Colleagues from the MOL-RAO and the Swiss Observatory in Payerne had prepared the campaign several years in advance. The objective was to obtain an independent comparison of the commercially available radiosonde systems used in the global operational observing network. Such a comparison helps national meteorological services to decide which systems best meet their requirements. At the same time, it provides manufacturers with incentives to improve the quality and cost efficiency of their systems.

The campaign consisted of an in-situ and a laboratory measurement campaign in which a total of ten radiosonde manufacturers participated with their instruments. The manufacturers set up their rigs one week before the start of the campaign and trained operators appointed by the WMO on how to handle them. The manufacturers then had to leave the observatory. The operators’ task was to prepare the radiosondes, carry out independent and honest data collection and evaluate the user-friendliness of the systems.

**01**
Manufacturer training of operators in Lindenberg’s balloon hangar.

**02**
Shortly before the launch of a radiosonde train.

01

02

**top**
Limestone cliffs of Cirque de Gavarnie (France) in the Pyrenees National Park.

During the in-situ campaign, 40 day and 40 night flights were carried out. The soundings began at 10 a.m., 3 p.m., 9 p.m. and 1 a.m. (all local time). They were all performed independently of the four routine radiosonde ascents that take place daily in Lindenberg. Up to ten radiosondes were launched mounted on one payload rig into the atmosphere. After each sounding was completed, the atmospheric profiles collected were handed over to the data management team for initial analysis.

The laboratory campaign took place between February 2022 and January 2023 in seven two-week periods before and after the in-situ campaign. The quality of the measurements was tested under laboratory conditions. This not only enabled in-situ results to be interpreted but also provided the manufacturers with approaches to improving or optimising measurement sensors and correction algorithms.

## Into the future. Most important findings

The final WMO report included information on the quality of the training materials, the usability of the software and the quality of the evaluation software. The focus of both the evaluation and the WMO report, however, was on assessing individual sensing systems. In the process, measurement errors as well as uncertainties were determined by comparison for each flight. The statistical analysis of this data set was then interpreted and presented in line with a predefined catalogue of criteria. In this way, each radiosounding system is evaluated to determine whether it meets the requirements for specific areas of application, such as aviation weather, numerical weather prediction or climate research.

# Drifting buoys – revisited

**right**
Poppy flowers in a field of rapeseed. Photo taken near Frankfurt.

**01**
Release of the refurbished drifting buoy from the DAGMAR AAEN back into the sea.

Drifting buoys are generally used in marine research to gather ocean data (such as water temperatures, in particular sea surface temperature, and salinity) as well as meteorological data (for example air pressure and air temperature). Today's drifting buoys transmit the collected data by satellite.

There are different sizes and types of drifting buoys, depending on their purpose and the area where they are deployed. For instance, buoys that are designed to follow an ocean current as closely as possible are equipped with a sea anchor in order to minimise the distorting effects from wind and waves. Modern drifting buoys can also be fitted with receivers for global satellite navigation systems (e.g. GNSS, GPS or Galileo). This allows very exact linking of the measured data to the buoy's respective position. If a buoy is placed in trafficked waters, the measurements can also be used for shipping warnings.

The DWD, represented by its Marine Observation Network Group, supports the network of European meteorological services, EUMETNET, in deploying drifting buoys in areas where only few measurement data are available, for example, the Arctic Ocean, the Greenland Sea, the Barents Sea and the European North Sea. The data from there are important for weather forecasting and are also used for climate change research.

The DWD's Marine Observation Network Group also seeks collaboration with relevant research institutions. In September 2022, for instance, polar researcher Arved Fuchs deployed a drifting buoy made available by EUMETNET from his expedition sailing ship DAGMAR AAEN in the waters between Iceland and the Faroes.

What was special about this buoy was that Arved Fuchs had released the same buoy a year before off the eastern coast of Greenland. From there, the buoy floated southwards on the ocean currents and drifted in an arc first in an easterly, later in a northerly direction towards Iceland. Following the loss of its anchor, it stranded there on the south coast north of the island of Vestmannaeyjabær. The buoy was rescued and handed over to the DWD for a general overhaul. After that, it was returned to the expedition ship DAGMAR AAEN. This is the first-ever case of a buoy being released, rescued and released again by the same ship – a success story that generated great international interest.

**top**
Photo showing a more gentle (if not deceptively harmless) side to the weather: a few cumulus clouds in the sky, a little fog in the valley. In fact, the picture was taken after several thunderstorms with hailstones up to 5 cm large had crossed the area the night before. Photo taken in the Néouvielle National Park in the French Central Pyrenees.

## Cross-border, interdisciplinary cooperation

The Deutscher Wetterdienst (DWD), together with the German Meteorological Society (DMG), the Hans Ertel Centre for Weather Research (HErZ) and the University of Bonn, hosted the Annual Meeting of the European Meteorological Society (EMS) in Bonn from 5 to 9 September 2022. Close to 800 participants registered for the conference, staged for the first time again as a face-to-face event since 2019.

The meeting featured an extensive and wide-ranging programme dedicated to ‘Connecting communities to deliver seamless weather and climate science and services’. The central theme of the conference was on how can meteorologists and climatologists be more effective in communicating their research results to the general public, how can they achieve better awareness levels and consensus with regard to climate change? Repeatedly emphasised here were the importance of interdisciplinary cooperation in meeting the enormous challenge of climate change and of breaking down barriers not only at the national and international levels but also between the political, business and research communities and society at large. The DWD took the opportunity to shine a spotlight on the results of its cooperation-based research with universities and research centres under the umbrella of the Hans Ertel Centre. Over its twelve-year period of funding, the HErZ has established itself as an integral part of the international weather and climate research landscape, applying its motto of ‘Connecting communities’ to both its research and teaching activities.

The programme included a range of tried-and-tested formats such as workshops, excursions, poster presentations, expert lectures and panel discussions. However, a new format was introduced in the form of the ‘Café Météorologique’. This involved talks being given in eleven cafés and museums in Bonn during the congress in which weather and climate topics were explained and elucidated to a lay audience in easily understandable ways.

The EMS 2022 kicked off with a press conference given by Prof. Dr Gerhard Adrian (DWD and WMO President), Prof. Dr Clemens Simmer (DMG President), Prof. Dr Celeste Saulo (WMO Vice-President and future WMO Secretary-General from 1 January 2024) and Bert Holtslag (EMS President). In their statements, they each underlined the importance of cooperation between the different scientific disciplines. The increase in weather events of major socio-economic impact – such as heavy rainfall, storm surges, extreme heat and drought – means that meteorological findings, products and services are now in greater demand than ever.

A final note: In the spirit of sustainability, several DWD employees cycled the 200 km from Offenbach to Bonn.

All information on EMS 2022 can be found on the EMS webpage at www.ems2022.eu.

Further information on the HErZ is available at www.hans-ertel-zentrum.de/.

**01**
Opening press conference of the EMS Annual Meeting 2022.

**02**
EMS opening event at Bonn University.

**01**

**02**

# High-performance computing system: Next stage of extension complete

The year 2022 saw a further successful extension of the DWD's NEC SX-Aurora TSUBASA high-performance computing system (HPC). Measured in terms of numerical weather prediction models, this upgrade, which is referred to as 'phase 2a' and is based on identical technology, increased the computing power by a good 36 per cent compared to the previous phase 1.

Implementation took place during ongoing operation and, as the required infrastructure had already been put in place at the time of the initial installation of the HPC, it was possible to carry out the installations at both sites, Offenbach and Ludwigshafen, without any major interruption. Readiness for service was demonstrated in August 2022, thereby allowing the system to be put into operation.

With a peak performance of 8.41 PFLOPS (= quadrillions of floating-point operations per second), the system hosted at Ludwigshafen ranked No. 89 in the TOP500 list of the fastest supercomputers in the world, published in November 2022. The HPC at Offenbach, slightly less powerful at 6.54 PFLOPS, followed at number 114.

The systems are particularly energy-efficient due to their direct hot-water cooling with an inlet temperature of 35 °C, which permits 'free cooling' on most days without any additional cooling energy required. This is also reflected in their high rankings in the Green500 list published simultaneously, where they occupy places 69 and 71, respectively.

Further improvement of the HPC systems is scheduled for 2023, when a new generation of NEC vector processors will be installed. This measure is aimed at achieving a further increase in performance of around 47 per cent, doubling the overall computing power compared to phase 1.

**right**
High-performance computing system at the DWD.

# How the DWD is helping to strengthen social resilience

Socio-economic aspects are playing an increasingly important role within the DWD's work. This is because they reinforce the interactivity between weather and climate services and society at large. Germany, too, has suffered from a rise in extreme events, highlighting the vulnerability of our society. The consequences of climate change are increasingly putting people, their livelihoods and Germany's socio-economic and cultural assets in danger. Strengthening the resilience of society as a whole is therefore set to become a core task for politicians in the future.

This also involves strategically-based disaster management, including impact-oriented weather and climate services.
In performing its statutory tasks, the DWD uses socio-economic methods and findings to identify strategies for mitigating and managing climate change, as well as for optimising protection of the population and critical infrastructure systems.

**How can socio-economics help?**

Socio-economic methods and findings are already being incorporated into the DWD's advisory and productive operations. Mirroring national and international developments, interdisciplinary cooperation on socio-economic matters has been steadily growing in importance over the last ten years or more. Cognitive and behavioural psychology, for example, have shown us in which ways information must be communicated in order to induce people to act. If this is applied to the handling of risks, it can raise the effectiveness of weather and climate services.

**Socio-economic action areas within the DWD**

The areas in which the DWD should actually use socio-economic methods in its work – which is already happening order to foster good decision-making and induce changes in behaviour. It is important here to conduct retrospective evaluations of the communication strategy asking: Were the warnings heeded, were they understood and did the users actually behave as expected?

The DWD considers the impact of its services and products in its Social Benefit action area. Here it is important to measure any social benefit against quantitative as well as qualitative indicators and to include positive changes in behaviour as a metric in the evaluations.

Taken together, these three action areas give us a comprehensive picture of the DWD's interactivity with society and enable us to optimise the impact and social benefit of weather and climate services.

## World Meteorological Organization

The World Meteorological Organization (WMO) began preparing the ground for its WMO Congress 2023 as early as in 2022. The June 2022 session of the Executive Council (EC) was to have been its last before the Congress. However, in view of the many open questions still to be resolved, it was decided that the Executive Council should convene an extraordinary session at the end of February 2023. A new board was established: the Consortium of WMO Education and Training Collaborating Partners (CONECT), which reports to the Capacity Development Panel and has the aim of bringing together existing training initiatives and facilities. The consortium is open to all members. Another pre-Congress task was to prepare the WMO's Strategic Plan for 2024–2027. This required updating the current Strategic Plan, regional priorities and the aims of the Focus areas.

The year saw also the launch of two new initiatives: firstly, the Early Warnings for All initiative announced by the UN Secretary-General in March and which the WMO coordinates on behalf of the participating UN organisations. It was decided that the WMO Commission for Services should lead the development of an implementation plan. The corresponding Executive Action Plan was presented by the WMO Secretary-General at the United Nations Climate Change Conference COP27 in November 2022. Secondly, the Global Greenhouse Gas Watch (GGGW) was established, aimed at coordinating the various existing regional initiatives. The mission is to ensure global availability of high-resolution data on greenhouse gas fluxes.

Coinciding with the EC, the WMO published its second Open Consultative Platform White Paper on the Future of National Meteorological or Hydrological Services. The lead author of the paper was Professor Gerhard Adrian, President of WMO and DWD.

The sessions of two WMO Technical Commissions, i.e. the Commission for Services (SERCOM) and the Commission for Infrastructure (INFCOM), took place in October 2022. The discussions were about global standards and requirements, and their possible implementation. The results will be presented to Congress next year for adoption. Great interest was taken in the implementation plan for the WMO's Information System 2.0 (WIS 2.0), which in the longer term aims to replace the WMO Global Telecommunication System (GTS).

The implementation plan for the pilot phase of the GCOS Surface Reference Network (GSRN) was adopted, with the China Meteorological Administration (CMA) as the Lead Centre. The Global Data Processing and Forecasting System (GDPFS) was renamed 'WMO Integrated Processing and Prediction System' (WIPPS), and the Common Alerting Protocol (CAP) was determined as the standard format for the exchange of warnings.

**left**
Summer evening on the river Elbe.

# European Centre for Medium-Range Weather Forecasts

01

02

**01**
Dr Axel Andersson (1st from left) shows historical ship logbooks to the guests.

**02**
Group photo of the participants to the bilateral meeting between the ECMWF Directorate and the directors of the DWD’s Executive Board at the Marine Meteorological Office in Hamburg.

September 2022 marked one year since the opening of the new site of the European Centre for Medium-Range Weather Forecasts (ECMWF) in Bonn. More than 100 ECMWF staff members were now working there.

The corresponding ‘Hosting Agreement’, which governs the legal status of the ECMWF in the host country of Germany, was formally signed in Berlin on 9 December on behalf of the ECMWF by Director-General Florence Rabier and on behalf of the German hosts at State Secretary level by the Federal Foreign Office (AA) and the Federal Ministry of Digital Affairs and Transport (BMDV). To enter into force within Germany, the consent of the Bundesrat and publication in the Federal Law Gazette are still required. This is expected in the first half of 2023.

ECMWF and the Center for Earth System Observation and Computational analysis (CESOC), which is the network of the two neighbouring universities of Bonn and Cologne and the Forschungszentrum Jülich, have agreed to work very closely together in future. Key aspects here include joint cutting-edge research projects, joint training pathways and publication of joint research results. A formal Memorandum of Understanding on this was concluded in October 2022.

At the beginning of December, the ECMWF hosted the kick-off meeting of ‘WarmWorld’. Funded by the German Federal Ministry of Education and Research (BMBF), the project explores the scalable development and the application of climate information systems. The project is led by the Max Planck Institute for Meteorology (MPI), the German Climate Computing Centre (DKRZ) and the Alfred Wegener Institute (AWI). It brings together partners from the Max Planck Society, the Helmholtz Association as well as the DWD and ECMWF.

On 15 and 16 November, the ECMWF Directorate and the directors of the DWD’s Executive Board met in Hamburg at the Marine Meteorological Office of the DWD for their annual bilateral meeting. In addition to reviewing the activities of the two organisations over the past twelve months, the talks focused on possibilities for further intensification of the cooperation.

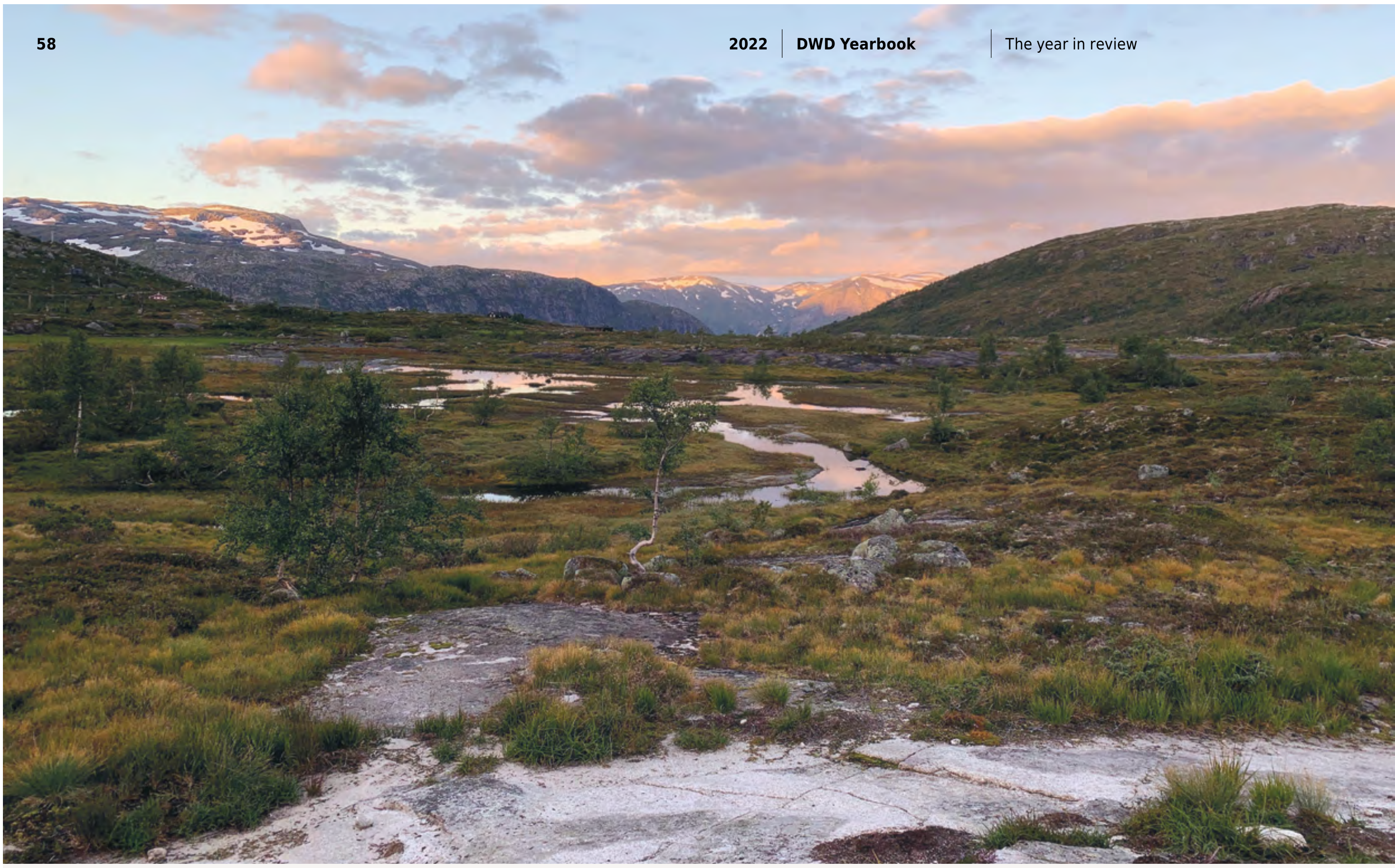
### Further milestones achieved in 2022

In March, the European Commission held a public online information event, jointly organised with the ECMWF, ESA and EUMETSAT, to inaugurate its Destination Earth (DestinE) initiative. Based in Bonn, the ECMWF’s DestinE team will develop a multi-stage partnership programme in collaboration with the project partners ESA and EUMETSAT and several other institutions across Europe.

The ECMWFs new supercomputer in Bologna went into operation. The final handover of the data centre took place on 29 April 2022, operational forecasting was successfully switched to Bologna on 18 October 2022.

The first operational medium-range ensemble forecasts were introduced at ECMWF in 1992, bringing a considerable improvement to weather forecasting. In 2022, the EZMW could look back on 30 years of ensemble forecasting.

**below**
Hohenpeissenberg Meteorological Observatory encircled by a layer of fog up to the mountain top.



## European Union

**top**
Hike to Norway's famous Trolltunga. Photo taken near Tyssedal, Norway.

At the end of 2022, the regulation laying down the definition of the so-called high-value datasets, including those of the thematic data category 'meteorology', was adopted. As an annex to the 'Directive (EU) 2019/1024 of 20 June 2019 on open data and the re-use of public sector information', it determines the conditions for re-using high-value datasets, in particular the minimum requirements for disseminating meteorological and climatological data via application programming interfaces (APIs). In the years prior to this, DWD experts had assessed related studies and consistently advocated opening up the treasure trove of meteorological data to the widest possible extent.

In the context of the EU's Copernicus programme, the DWD continues to make significant contributions to the Climate Change and Atmosphere Monitoring services (C3S and CAMS) as well as to the early flood warning component of the Emergency Management Service (CEMS).

The DWD participates under the EU's Destination Earth (DestinE) initiative in the development of the Climate Adaptation Twin. Operated together with the partners, the DWD's ICON weather forecasting system serves as a basis for creating a digital twin of the atmosphere to investigate the effects of climate change.

At the same time, the DWD and its partners in Italy and Switzerland are working together on a highly resolved regional structure for climate models, for which a novel computer infrastructure is required. The work is taking place in close collaboration with the EU's DestinE programme.

## EUMETSAT/ESA

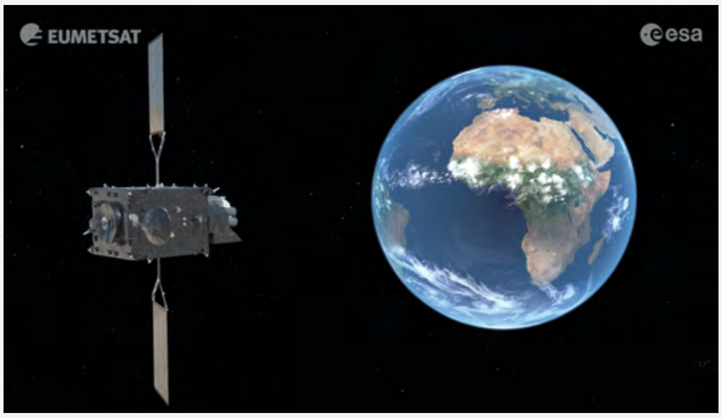
For EUMETSAT, the end of 2022 brought about a new beginning: the successful launch of its newest satellite Meteosat Third Generation – Imager 1 (MTG-I1) marked the start of the commissioning of a new generation of space-based meteorological and climatological observations in geostationary orbit. The DWD’s weather forecasting system processes around five million observations per day, about 85 per cent of which come from satellites. MTG will supply a data stream 50 times larger than the preceding Second Generation mission.

### Overview of launches in the near future

| **Programmes** | **Scheduled launch** |
|---|---|
| MTG (Meteosat Third Generation) | MTG-I 1: successful launch on 14 December 2022 |
| | MTG-S1: Q1 2024 |
| EPS-SG (EUMETSAT-Polar System Second Generation) | Metop-SG A1: Q1 2024 |
| | Metop-SG B1: Q1 2025 |

In November 2022, the Council of Ministers of the European Space Agency (ESA) agreed to invest 400 million euros in the development of the EPS-Aeolus programme. This is intended to ensure the operational continuation of a Doppler wind lidar mission for global wind profiling; the experimental testing of the mission was launched in 1999 under ESA’s Earth Explorer Mission Aeolus.

The purchase of commercial radio-occultation data reached the end of the pilot phase. The continuous discussions between EUMETSAT and the US National Oceanic and Atmospheric Administration (NOAA) made it possible to preserve the principle of global data exchange. The data were subjected to detailed quality studies and the benefits were confirmed by model prediction experiments. From the DWD’s point of view, this gave the green light for future commercial procurement of this type of satellite data by EUMETSAT.



01

**01**
Graphical illustration of the new MTG satellite scanning the Earth from space.

# Development cooperation activities at the DWD

The DWD has joined the World Meteorological Organization's Systematic Observations Financing Facility (SOFF) as a 'Peer Advisor'. This financing initiative is based on the requirements adopted by the WMO within the framework of the Global Basic Observing Network (GBON) for ground-based observation stations and radiosounding stations worldwide. SOFF aims to provide sustained technical and financial support for the establishment of meteorological observation structures in developing countries. Peer Advisors play a key role in the implementation of SOFF.

SOFF Peer Advisors are national meteorological or hydrological services (NMHSs) that provide technical assistance within the framework of SOFF in the respective development countries. They have substantial expertise in the relevant areas of advisory services and a track record in partnering and supporting other NMHSs. A major milestone in the preparatory work was a hybrid-format workshop held in Vienna in autumn 2022, bringing together 84 participants from 35 organisations, including all eight SOFF Implementing Entities and 24 of the 26 SOFF Peer Advisors.

The DWD's first partner is Madagascar's national meteorological service Direction Générale de la Météorologie (DGM), which is to be provided with advisory support from April 2023. The cooperation between DGM and DWD began a few years ago with a very successful partnership in an agrometeorological project, led together with Germany's agency for international cooperation, the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH.

Guests from Central America visited the DWD to learn more about its services in the field of warning management and climate risk prevention regarding heavy rainfall and heat in cities. They were accompanied by representatives of the GIZ.

Furthermore, the DWD is involved in the Water Security in Africa (WASA) project, which is funded by the Federal Ministry of Education and Research (BMBF) and led by the Karlsruhe Institute of Technology (KIT). Another project to which the DWD is contributing is the Co-design of a hydrometeorological information system for sustainable water resources management in southern Africa (CO-HYDIM-SA). The project aims to improve fresh and wastewater services in Africa on a sustainable basis. It is part of the BMBF's Research for Sustainability – FONA strategy. The kick-off meeting took place in February 2022, with the main goal of discussing all relevant steps required for successful submission of the proposal for the first main phase of the WASA programme.

# EUMETNET

**top**
Group photo of the participants to the General Assemblies of both EUMETNET and ECOMET in Karlsruhe.

Founded in 2009, the Network of European Meteorological Services, EUMETNET, is an Economic Interest Grouping under Belgian law. This form of organisation, however, was abolished in Belgium as part of a reform of company law, and all economic interest groups, including EUMETNET, which existed before that date must now be switched to a new legal form by the end of 2023. In 2022, representatives of EUMETNET's members, including the DWD, drafted an amendment agreement for the new legal form of a General Partnership (Société en Nom collective, SNC), which is due to enter into force in 2024.

In May 2022, for the first time since the start of the COVID19 pandemic, the EUMETNET General Assembly was held again in person. The DWD hosted the meeting, during which important decisions were taken regarding

- preparations for the new EUMETNET programme phase 2024–2028
- integration of data policy tasks from the previous economic interest group ECOMET in EUMETNET
- submission of a bid by a consortium of individual European meteorological services and EUMETNET for an EU project regarding the free provision of high-quality meteorological data sets in compliance with the EU's Open Data Directive.

## Bilateral cooperation

01

02

**01**
Dr Peter Binder, Director of MeteoSwiss (2nd from left) thanking the team for the good cooperation during the WMO radiosonde intercomparison campaign.

**02**
DWD president Prof. Dr Gerhard Adrian (4th from right) welcoming the representatives of MeteoSwiss for the bilateral director's meeting at Lindenberg.

The DWD maintains close cooperation with other European meteorological services and uses regular coordination meetings to exchange information on the latest developments in the respective services and to discuss strategic and political views on the work in international organisations.

Of key importance here are the meetings with the two large services Météo-France and the UK Met Office, as well as the annual trilateral D-A-CH meetings with the directors of MeteoSwiss and the Austrian Central Institute for Meteorology and Geodynamics (ZAMG)/Geosphere Austria. In addition to strategic questions about WMO, ECMWF, EUMETSAT and EUMETNET, the talks deal with EU projects for the provision of free high-quality data sets, such as Destination Earth and the Digital Europe Programme (DEP). Other topics currently being discussed include the use of modern technologies and data types (for example cloud services offered by private service providers), cloud infrastructures (for example the European Weather Cloud), artificial intelligence and crowd-sourcing for the services' development processes and routine operations.

Joint projects with MeteoSwiss are often initiated at the regular bilateral meetings of the directors. The Directors' Meeting of MeteoSwiss and DWD in 2022, for instance, took place in Lindenberg during the operational phase of the WMO radiosonde intercomparison campaign at the Meteorological Observatory Lindenberg – Richard Assmann Observatory (MOL-RAO), as both services had jointly organised the campaign. During the meeting, both partners reaffirmed their mutual interest in continuing the close cooperation on numerical weather prediction and modernisation of their warning systems. Further meetings at the directors' level were held again for the first time since the beginning of the pandemic with the meteorological services of the Netherlands (KNMI) and the Czech Republic (CHMI).

## International human resources policy

Despite the pandemic, eight DWD staff members were able to travel to different meteorological services, universities and international organisations, including the UK Met Office, the European Centre for Medium-Range Weather Forecasts (ECMWF), the Swiss Federal Institute of Technology (ETH Zurich) and the universities of Lund (Sweden), Wageningen (Netherlands) and Virginia (USA), funded by the DWD's expert knowledge programme 'Expand your knowledge going abroad for DWD'. This programme gives highly motivated and qualified staff the opportunity to gain work experience in an international environment for a few weeks on a temporary assignment. It is offered in recognition of the significance of international cooperation within the DWD's range of tasks.

In addition, close to 20 DWD employees were temporarily seconded to different areas of the WMO and to EUMETSAT.

**below**
Lost rest area in the Spessart hills.

## Aboard the frigate BAYERN

01

02

**01**
Frigate F 217 BAYERN.

**02**
Bundeswehr students aboard the frigate BAYEREN (left to right: Gerald Schmied (trainer), Johanna Stöhr, Niklas Leßmann, Yannick Seeliger, Hardy Werner (course HS 40)).

The Meteorological Service department of the Federal University of Applied Administrative Sciences (HS Bund) is composed of staff from the Deutscher Wetterdienst (DWD) and the Bundeswehr Geoinformation Service. Both services select the candidates they need for higher intermediate meteorological service training, a programme which is completed as part of the three-year meteorological study course at the HS Bund.

The study programme includes two weeks of work experience abroad. In May 2022, four Bundeswehr students were given the opportunity to complete their work experience aboard the Bundeswehr's frigate BAYERN, which set sail from Wilhelmshaven. During the two weeks, the students gained experience in weather observation and weather briefing at sea. Here the conditions are much more difficult than on land as far fewer data are available for the production of weather forecasts.

Observation and forecasting activities must meet the specific requirements, which is why it is important for the students to acquire knowledge of the planning and execution of military operations. Preparatory training was therefore carried out, including in the area of radio geophysics (for example calculation methods for radar wave propagation in different weather conditions).

During the four students’ stay on board, a so-called Individual Ship Exercise (ISEX) was carried out. The focus of this exercise is on teaching or consolidating basic skills in preparation for emergencies, for example by practising ‘man overboard’ manoeuvres. The ship’s entire crew and all the other staff on board are involved.

During the two-week tour, helicopters took off and landed several times. Helicopter procedures on the ship, including approaches, landings and take-offs, were trained. Exercises such as these are important for pilots and on-board staff alike. The ship serves as a fully equipped airfield – weather forecasts are essential!

In addition to the observations that are relevant for flights, the students carried out numerous other observations, for example of the state of sea. To make this information available to other vessels, the data were disseminated. During their first week aboard, the students compiled weather briefings and practised presenting them. Weather briefings are short descriptions of the current weather situation and the conditions to be expected, especially for the parameters temperature, present weather, wind, cloud, visibility and sea state. In the second week, the students produced briefings for commanders and presented their results to the captain. This type of briefing takes account of the possible effects of the weather on planned operations or missions, and helps the ship management with decision-making.

**below**
The legendary dragon monster of Ehrwald stretches out its fire tongue towards Zugspitze weather station, but can’t reach beyond the barrier of Schneefernerkopf …

## DWD and BKG join forces on apprenticeships

The Deutscher Wetterdienst (DWD) and the Federal Agency for Cartography and Geodesy (BKG) entered into a partnership regarding the training of geomatics technicians from the 2022 training year. In future, each BKG apprentice will complete a six-week practical training period at the DWD.

As higher federal authorities, the BKG and the DWD are each legally mandated to gather, process and disseminate geoinformation. Another similarity is the proximity of their respective headquarters in Frankfurt and Offenbach – which means that both operate within the highly competitive labour market of the Rhine-Main region, where they need to present themselves as attractive employers. This includes offering promising career prospects to motivated and suitably qualified candidates. In April 2022, the two authorities agreed to enter into a partnership for this purpose.

The BKG has been running a successful apprenticeship programme for geomatics technicians for some time. An attractive and proven structure is therefore already in place, but this is now to be expanded through forward-looking cooperation with the DWD. The BKG's apprenticeship programme is of great interest to the DWD, as it offers an alternative route for potential candidates to take up work in the scientific-technical areas of the DWD. In future, the BKG plans to incorporate one to two DWD apprentices per year into its training programme for geomatics technicians. The DWD will then be able to assume the first BKG alumni into its own ranks in three years' time.

In return, all BKG apprentices will in future be offered a six-week period of practical training at the DWD. They will be deployed in the DWD's Business Areas for two-week periods at a time. In addition to the six-week practical training, a five-day DWD online seminar entitled 'Introduction to Meteorology' is planned for the BKG apprentices. This will acquaint them with the basics of the most important meteorological parameters and processes and familiarise them with the recording, representation and numerical simulation of these.

Both authorities benefit from the partnership. It represents an opportunity for the DWD to establish contact with the BKG's apprentices from the outset, to offer them attractive prospects for the future and, if appropriate, to recruit them.

**left**
Foggy autumn weather: air humidity has accumulated on the plants. Photo taken near Weiterstadt (southern Hesse).

# Interview

**right**
Autumn mood at the Ostersee
(Upper Bavaria).

# “The very highest technical level”

## Interview with Dr Volker Wissing, Federal Minister for Digital and Transport (BMDV)

**DWD:**
Minister Wissing, you first visited the DWD in Offenbach last November when you came to celebrate the DWD’s 70th anniversary. Looking back on this visit, what is the first thing that springs to mind?

**Dr Volker Wissing:**
The DWD operates at the very highest technical level. Weather forecasts are accurate down to a small scale, and they are getting better all the time. One of the most powerful supercomputers in Germany makes all of this possible. When the DWD was founded 70 years ago, it was still necessary to read off the measuring instruments used for the weather forecasts manually. The technical developments since then are impressive. I am pleased that these achievements are receiving a lot of public attention. This shows an important level of appreciation for the employees who carry out their work with conviction and enthusiasm.

**DWD:**
How important is the national meteorological service for the people here in Germany and in their daily lives?

**Dr Volker Wissing:**
There are probably few authorities which enjoy such widespread recognition as the DWD. The work of the DWD is of great significance in our everyday lives. It all starts with the daily weather reports. Before we leave the house in the morning, we all check what the weather will be like in order to decide what to wear. The medium-term weather forecast is of great significance in guaranteeing the security of our energy and other basic supplies. Not to forget, long-term observations provide us with important information on how the climate is changing and on how important it is to adapt to the changing conditions.

**DWD:**
How important is the DWD within your ministry?

**Dr Volker Wissing:**
The DWD has close links with all departments in the BMDV. Weather and climate information is of great importance for all forms of transport and infrastructure. In addition, the DWD is an important digital player – as a provider of open data, for instance. And that is why the DWD has been a key part of today’s BMDV since its inception. Its work helps ensure that we can all travel safely. The road and motorway maintenance authorities, for example, base their gritting decisions on information provided by the DWD. It is imperative that the captains of ships and aircraft check the current weather situation before setting off. The number of autonomous vehicles is likely to grow in the future, and these will need up-to-the-minute weather data in order to make automatic adjustments to driving styles for black ice or rain, for example.

**DWD:**
Disaster protection is the responsibility of the individual federal states, whereas the DWD is an overarching federal authority. Thinking back to the flood disaster of 2021 in particular, do you see any scope for improving cooperation among the federal government, the governments of the federal states and the municipalities at the local level with regard to disaster management?

**Dr Volker Wissing:**
The federal states can rely on the DWD to provide them with weather information and severe weather warnings, as was the case during the flood disaster. The DWD liaises closely with federal states. We want to expand this cooperation and optimise it even further. And that is why, at the request of the federal states, we are setting up a natural hazards portal which will be operated by the DWD. This will help us ensure that DWD weather warnings reach the right audience and allow us to share relevant information from other authorities – on possible flooding, for example – from a central point. The flood disaster in the summer of 2021 showed how important it is to bundle weather watches and warnings, recommendations for preventive action as well as situation reports and updates on the weather situation and make all these readily accessible. The relevant actors at both federal and federal-state level are liaising on the development and design of this portal. We will also be amending the DWD Act accordingly. This will be an important and useful addition to the warning structures existing at federal and federal-state level.

**left**
Marking the DWD's 70th Anniversary at the annual reception (left to right): Prof. Dr Gerhard Adrian, Dr Volker Wissing (Federal Minister for Digital and Transport), Dr Felix Schwenke (Mayor of the City of Offenbach)

**DWD:**
Are there any areas where you think the DWD should improve or expand its responsibilities or services?

**Dr Volker Wissing:**
Basically, constant further development is required to ensure that the DWD products are scientifically and technologically state-of-the-art. The DWD provides valuable and reliable basic data that can be used in many areas and to create new products and services. I see great potential in making DWD information available in special data spaces and linking them with other data. This is precisely why the principle of open data is fundamental to who we are and what we do. The DWD's climate and weather data have been public since 2017, meaning that they are freely accessible and can be used by everyone – quickly, easily and free of charge. The other authorities in our sector also make large quantities of their administrative data accessible. They can be found in the BMDV's new 'Mobilithek', which is not only our open data portal but also the national access point for mobility data such as traffic and travel information. The services can be accessed and used by all interested parties. Enterprises can use the data to develop innovative offerings and new business models.

**DWD:**
The DWD conducts much of its data acquisition and data processing – and also the production and distribution of its products – digitally. Where do you see potential for becoming even more digital?

**Dr Volker Wissing:**
We can develop even more innovative products and services, and intelligently link previously stand-alone applications. Weather data – perfectly customised to our needs – help us to make our personal mobility more efficient, sustainable and convenient. In order to achieve this, it is important to link together weather and mobility data. Special apps could be used, for instance, to suggest the best means of transport for particular traffic and weather conditions. Take the following example: If there is a traffic jam, it might make more sense to use a bicycle rather than the car – provided it doesn't rain, of course. In that case, the train would not only get you there quickly but also dry. The DWD itself, as well as the other federal authorities, have a whole treasure trove of data at their disposal. And that is something we have to make good use of.

**DWD:**
Let's talk about climate change. You come from Rhineland-Palatinate. Your position there was Minister of Economics, Transport, Agriculture and Viticulture. How did you view the issue of climate change, especially with regard to agriculture and wine-growing?

**Dr Volker Wissing:**
Climate change affects us all. And agriculture, of course, is directly and profoundly affected by climate change. And that is why I welcome the close and intensive collaboration of the BMDV and the DWD with the Federal Ministry of Food and Agriculture and its various subordinate authorities. As the authoritative body for climate data and climate knowledge in Germany, the DWD supplies all authorities at the federal, federal-state and municipal level with the relevant information. The data on decreasing precipitation and more frequent heavy rainfall events, for instance, can also be used to develop adaptation strategies for viticulture.

**DWD:**
And a slightly more personal question to finish with. Do you use a weather app? If not, why not? If so, which one and why?

**Dr Volker Wissing:**
Of course, I have weather apps on my smartphone, including the ones from the DWD. I can't imagine life without these digital aids any more. And I'm looking forward to seeing what other innovative services the DWD will develop in the future.

# Finale

**right**
Gellen beacon on Hiddensee island.

## Annual productivity and performance figures

Around 180,000 manual forecasts, of which around 90,000 were standard-type

Around 177,000 manual weather warnings, plus around 8,000 warnings for severe and extremely severe weather (district level)

8,760 automated winter road forecasts for around 1,500 road weather stations and with some 250 million page views on the SWIS winter services portal

Around 1.4 billion page views on the FeWIS disaster management portal; provision of more than 37 terabytes of data for disaster situation assessment

Distribution of around 1.4 billion push warning messages through the DWD WarnWetter app

Around 1.2 million weather observations received from users of the DWD WarnWetter app for use by the forecasting service

Around 540,000 manual forecasts and warnings for aviation

Around 24,500 telephone briefings for aviation

Provision of self-briefing systems for civil aviation, aerodromes/airports and air services providers (around 62 million retrievals and around 3 million accesses through the DWD's air sport web pages)

Around 6.4 million accesses to aeronautical meteorological information through the DWD FlugWetter app

Around 240,000 reports, warnings and advisory statements for marine shipping, coastal protection and offshore projects

Overall 29 terabytes of data on the DWD's open data server, with around 47 billion accesses over the year (i.e. around 130 million accesses per day)

Over 400,000 reports uploaded by users during the 2022 summer season via the crowd-sourcing function in the DWD WarnWetter app

## DWD sites in Germany

**Headquarters** in Offenbach am Main

**6** major branch offices: Hamburg, Potsdam, Leipzig, Essen, Stuttgart, Munich (partly with more than 100 staff members)

**5** sites with regional climate and environment consultancy offices

**2** meteorological observatories

**1** Aeronautical Meteorological Centre (Frankfurt)

**4** MET advisory centres

**3** agrometeorological advisory offices

**1** marine meteorological consultancy centre

**181** main automatic weather stations (of which **15** are aeronautical meteorological stations at international airports)

Aeronautical meteorological observation at **42** regional airports

**1,722** secondary weather and precipitation stations (of which **832** are online stations reporting every half-hour)

**1,104** phenological observation sites

Around **1,730** road weather stations in partner networks (with automated quality assurance every 15 minutes)

**2** staffed main weather stations aboard research ships

**490** ships at sea participating in the voluntary observing programme (of which **141** are equipped with automatic shipboard weather stations)

**6** moored buoys in the North and Baltic Seas

**10** automated shipboard aerological stations

**18** weather radar sites in Germany

**10** upper-air stations with around 7,500 radiosonde launches per year

**48** stations where radioactivity is measured

Mobile measuring unit at **3** sites

**9** automatic greenhouse gas measuring stations at high towers

**1** special air mission unit for radioactivity and volcanic ash measurements

# Budget figures

### DWD costs each citizen 3.82 euros per year

The DWD’s budget in 2022 amounted to around 361 million euros, which was largely over 26 million euros less than in the previous year. The actual requirement for public funds, however, was much lower than that due to the fact that 10.7 % of the overall budget were indirectly covered by revenues. Compared to the previous year, the DWD’s requirement for public funds decreased in 2022 by over 48.6 million euros. This means that every citizen[1] had to pay 3.82 euros for public or statutory tasks such as weather forecasting, severe weather warnings and climate monitoring. The main reasons for the reduced requirement for public funds was the overall decline in the subsidies for international organisations (around 15.6 million and 5.9 million euros less for EUMETSAT and ESA, respectively, as opposed to around 1.3 million euros more for ECMWF). In addition, the DWD’s expenditure on investment fell by around 9.7 million euros (around 5.1 million less for information technology, around 2.3 million euros less for buildings and property and around 1.9 million euros less for investments for material). At the same time, the DWD’s revenues, which are not ascribed to the DWD but to the federal budget, increased by as much as 21.9 million euros.

**The DWD’s total budget amounted to:**

| 2022 | 2021 | 2020 | 2019 |
|---|---|---|---|
| around 361 million € | around 388 million € | around 379 million € | around 370 million € |

**Every citizen of Germany thus paid:**

| 2022 | 2021 | 2020 | 2019 |
|---|---|---|---|
| 3.82 € | 4.46 € | 4.30 € | 4.12 € |

**In 2022, the DWD’s expenditure was distributed as follows:**

| Appropriations/Subsidies: | Investments: | Expenditure on material: | Personnel: |
|---|---|---|---|
| 147.961 million € | 39.039 million € | 50.821 million € | 123.385 million € |

**In 2022, appropriations and subsidies went to the following organisations (external funds included):**

| EUMETSAT: | ESA: | ECMWF: | EUMETNET, WMO, others: |
|---|---|---|---|
| 79.733 million € | 49.964 million € | 12.277 million € | 17.608 million € |

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[1] Number of inhabitants at the end of December 2022: 84.3 million (Source: Federal Statistical Office)

## Staffing figures

**Number of established posts:**

| 2022 | 2021 | 2020 | 2019 |
|---|---|---|---|
| 2,149.5 | 2,143.0 | 2,156.5 | 2,171.0 |

**Number of staff members[2]:**

| 2022 | | 2021 | | 2020 | | 2019 | |
|---|---|---|---|---|---|---|---|
| 2,133 | | 2,157 | | 2,187 | | 2,216 | |
| Men: | Women: | Men: | Women: | Men: | Women: | Men: | Women: |
| 1.316 | 817 | 1.339 | 818 | 1.363 | 824 | 1.384 | 832 |

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[2] The difference between the number of established posts and the total number of staff members is partly due to temporary or part-time employment.

## Last but not least

# Hunga Tonga Volcano: DWD measuring instruments detect shock wave

The Hunga Tonga volcano (Kingdom of Tonga, South Pacific) erupted at around 04:00 UTC on Saturday, 15 January 2022. The eruption can be seen on numerous satellite images. Initial reports stated that ash, steam and gas rose to a height of around 57 km and that a tsunami warning had been issued for large areas of the Pacific region.

The shock wave of the main explosion could also be observed over Germany, recorded by DWD meteorological measuring instruments. The wave was first registered in the north (Helgoland, 19:24 UTC) and later in the south (Hohenpeissenberg, 20:02 UTC). The shortest distance on a spherical surface (the direct distance across the North Pole from Hunga Tonga volcano to Helgoland: is ~16,200 km and to Hohenpeissenberg ~16,900 km) can be used to describe the propagation of the shock wave and then to estimate its speed. This is about 1,050 km/h. For comparison: An intercontinental airliner flies at around 900–1,000 km/h. Under standard conditions, the speed of sound is about 1,235 km/h.

The following figure shows the normalised air pressure over time. The data shown were measured at the DWD’s highly sensitive stations of the Integrated Carbon Observation System (ICOS), which record numerous meteorological parameters for the ICOS project. The passage of the first shock wave at each station is clearly visible as well as the overall movement from north to south through Germany.

The difference between the maxima and minima is about 3 hPa, which corresponds to a wave amplitude of about 1.5 hPa. The duration between maximum and minimum was from 21 to 28 minutes, depending on the station.

The second shock wave travelled in the opposite direction to the first wave on a longer route across the South Pole to Germany. Applying a figure of 40,000 km for the Earth's circumference, the distances from the volcano are about 23,100 km to Hohenpeissenberg and about 23,800 km to Helgoland. The amplitude of the second shock wave was only about a third as large (+/- 0.5 hPa) as that of the first wave, making it more difficult to identify it in the data. This time, the shock wave passed through Germany from south to north, arriving at Hohenpeissenberg at 01:12 UTC and at Helgoland at 01:52 UTC on 16 January 2022. The shock wave therefore travelled at a slightly higher speed of approximately 1,090 km/h. This small deviation is within the range of uncertainties included in the estimation.

The following graph again shows the passage of the normalised air pressure over time. A low value (bias) has been added for each station for clarity of presentation and to differentiate the lines. The graph now shows the change in air pressure at each station for the second shock wave and the passage of the wave from south to north.

The DWD operates a volcanic ash advisory centre at the Hohenpeissenberg Meteorological Observatory. The highly sensitive measuring instruments used there, such as ceilometers or lidars, can identify volcanic ash particles in the atmosphere. Due to the geographical location and knowledge about the exchange of air masses in the atmosphere, it would have taken weeks, if not months, for the measuring instruments at the Hohenpeissenberg Meteorological Observatory to detect volcanic ash particles – but this was not the case.

**Figure 1**
The figure shows the normalised air pressure over time. The data were collected at ICOS stations. The passage of the shock wave at each station is clearly visible as well as the overall movement from north to south through Germany.

**Figure 2**
This graphic again shows the passage of the normalised air pressure over time, but here with a low value (bias) added for each station to better visualize the change in air pressure at each station for the second shock wave and the passage of the wave from south to north.

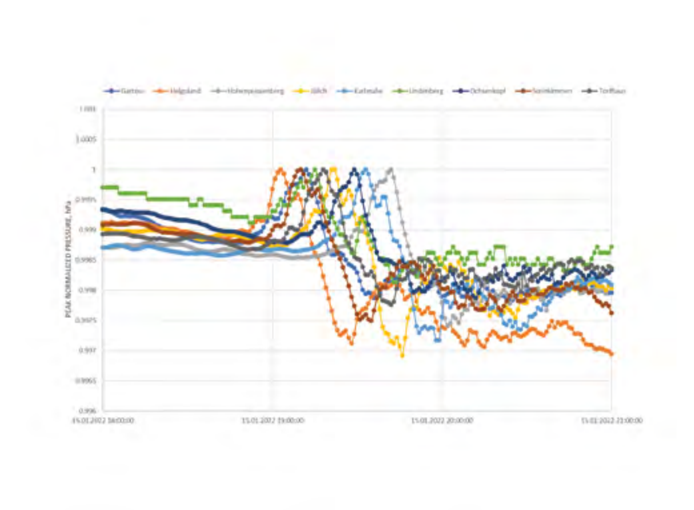

Figure 1

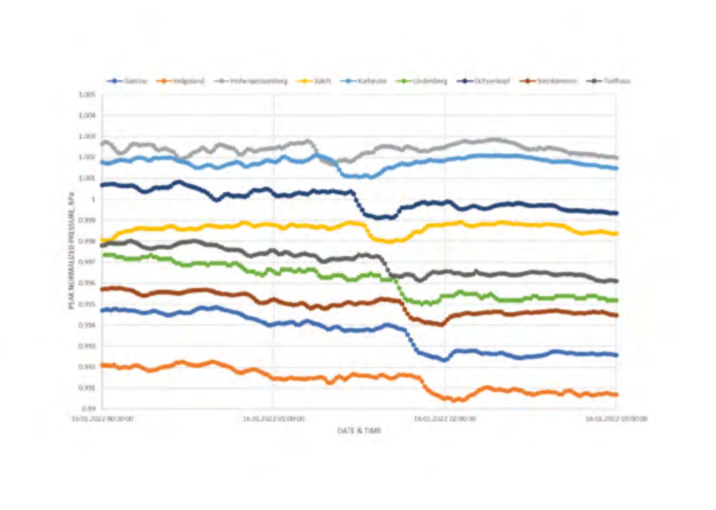

Figure 2

# Contact, publishing details and source references

**Image**
Life in Leipzig before the weather changed from almost 20 °C to 20 °C within one week.

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Telephone +49 18 02 91 39 13

When calling the weather hotline you will automatically be connected with the closest DWD Branch Office.

**Further telephone and service numbers**
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[1] Availability and costs depending on foreign telephone provider

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**Cover**
The headquarters of the Deutscher Wetterdienst in Offenbach over the course of the seasons – a composition of four photos, all taken by DWD staff member Michael Kügler always from the same place.

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