Adv. Sci. Res., 10, 99–106, 2013
www.adv-sci-res.net/10/99/2013/
doi:10.5194/asr-10-99-2013

Advances in Science & Research
Open Access Proceedings

12th EMS Annual Meeting and 9th European Conference on Applied Climatology (ECAC) 2012

Monitoring of climate change in Germany – data, products and services of Germany's National Climate Data Centre

F. Kaspar, G. Müller-Westermeier, E. Penda, H. Mächel, K. Zimmermann, A. Kaiser-Weiss, and T. Deutschländer

Deutscher Wetterdienst, Frankfurter Str. 135, 63067 Offenbach, Germany

Correspondence to: F. Kaspar (frank.kaspar@dwd.de)

Received: 7 February 2013 – Revised: 24 June 2013 – Accepted: 4 July 2013 – Published: 23 August 2013

Abstract. Germany's national meteorological service (Deutscher Wetterdienst, DWD) is the responsible authority for monitoring climate change in Germany. To fulfill this task it operates the National Climate Data Centre ("Nationales KlimaDatenZentrum, NKDZ"). The historical and current instrumental measurements and visual observations of DWD's station network are archived, quality-controlled and used to provide aggregated products, as for example daily and monthly means or climate normals. Gridded data are generated and used to derive time series of national and regional averages. Phenological observations and radiosonde data are also part of the data base.
In recent years, additional historical data have been digitized to expand the data base. The products are used for informing the public, e.g. as an element of the German climate atlas (http://www.deutscher-klimaatlas.de). One major recent activity was the provision of information for the new climatological reference interval 1981–2010 and an updated climatological analysis based on the newly digitized data.

1 Introduction

Climate is the synthesis of weather conditions in a given area, characterized by long-term statistics (mean values, variances, probability of extreme values, etc.) of the meteorological elements in that area (World Meteorological Organisation, 1992). Climate shows great variability in space and time and the knowledge about observed variability and trends is an important information for several societal sectors. To characterize long-term climate change, especially in extremes, observations over many decades are required.

Ground-based meteorological observations have been performed by National Meteorological and Hydrological Services and their predecessors for more than a century and therefore provide the basis for long-term analysis of regional climate change. However, over this interval several changes have been applied to the observing systems. Therefore the data need to be accurately documented.

Deutscher Wetterdienst (DWD) operates a dense measurement and observation network[1] for Germany. The data from this network is the basis for Germany's National Climate Data Centre (Nationales KlimaDatenZentrum, NKDZ). In the following, we give a short overview of the historic development of the German observation network and the NKDZ. We also describe typical derived products and how they are used to inform the public about the status of German climate.

[1]The term "measurement" refers to determining the value of a quantity, typically based on an instrument; whereas the term "observation" is used in a more general sense and does not necessarily involve the use of a measurement instrument (i.e. in the case of cloud cover observations of human observers or phenological observations).

Table 1. The primary network of Deutscher Wetterdienst (as of 8 December 2012).

Type of station	Number of stations
main meteorological watch offices and automatic weather stations,	179
… manned around the clock	38
… manned part-time	28
… fully automatic weather stations	113
main upper-air stations	9
… fully automatic stations (auto launcher)	5
… integrate ozone soundings	2
stations for measuring radiation	119
… with measurements of global radiation	119
… with measurements of diffuse illumination	117
… with measurements of atmospheric thermal radiation	9
stations measuring radioactivity	48
weather radar sites	17
surface weather stations run by the Bundeswehr Geoinformation Service (as part of the joint network)	35

2 The development of the measurement and observation networks in Germany

In the year 1847 the Prussian Meteorological Institute was established (the predecessor of DWD), the first national meteorological service in the northern part of Germany that collected, analyzed and archived the meteorological observations of the voluntary observers. These data were published in an annual book together with a standard observer instruction. An additional, denser precipitation network was built up in the 1880s where only precipitation was measured by volunteers once a day.

Over the years further 8 national meteorological services were founded in other parts of Germany which had their own instruments and instructions. After the establishment of the International Meteorological Organization (IMO) in 1873 the different standards were continuously adjusted to this specification. In 1934 these different services were united and had the same instrumentation and observer instruction (see Wege, 2002 for a detailed description of the development of meteorological services in Germany).

After World War II, in the divided Germany, different instrumentation and observation practices have been developed with different observational times. After the reunification in 1990 these practices were again harmonized.

At the beginning in 1848 the climate network included about 24 stations and increased up to 200 stations in 1900 and about 400 stations during World War II. The peak was reached in the 1980s with about 600 stations. With the beginning of the automatization of the network the number of stations decreased (Fig. 1). On the other hand, the automatic stations provided measurements at higher temporal resolution.

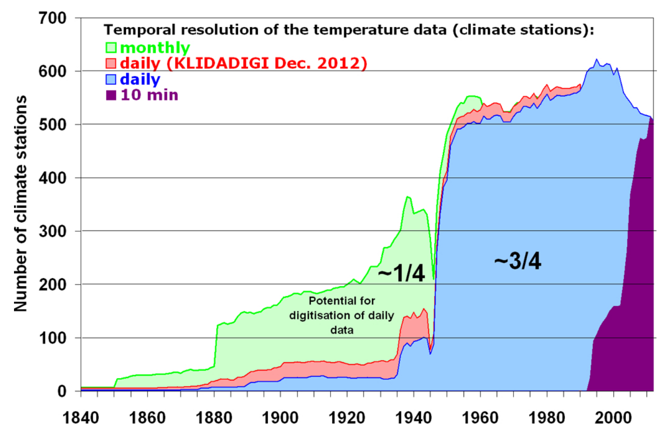

Figure 1. Number of temperature stations in the data base with specific temporal resolution in the database. The blue area indicates the amount of data that was already digitally available at daily resolution prior to the recent digitization efforts. The red area indicates the data that have already been digitized at daily resolution within the KLIDADIGI project. The green area indicates the amount of data with monthly resolution. This data can potentially be completed with daily resolution by digitizing further original documents.

The precipitation network increased rapidly to more than 1400 station in the year 1901 and reached the peak in the 1980s with about 4500 stations.

The current network (as of 8 December 2012) of DWD is based on a so-called “primary network”, which has mainly been planned for the needs of daily weather forecasting. The components of that network are summarized in Table 1.

Table 2. Number of stations of the total network of DWD (the 35 stations of the Bundeswehr Geoinformation Service included) measuring specific parameters.

Parameter	Number of stations
Temperature and humidity	507
Air pressure	212
Precipitation	1925
Wind	297 (68 as part of the storm warning network)
Sunshine duration	302

As for spatial climatological investigations a higher density is desirable, a secondary "climatological" network is supported. It consists of 1787 stations run by voluntary weather observers. The densest network exists for precipitation, as this parameters shows an especially large spatial variability. Table 2 shows the total number of stations measuring selected parameters.

In addition, DWD operates a phenological network which consists of 1304 secondary phenological observation sites, largely based on voluntary observers.

Selected stations are operated as so-called "climate reference stations". For these stations long time series are already available and manual observations will be continued with automatic weather stations in parallel. This will allow a long-term comparison of both techniques and thereby also supports the homogenization for those stations where the old technique is not continued.

The climate reference stations are: Helgoland, Hamburg, Schleswig, Potsdam, Görlitz, Lindenberg, Brocken, Aachen, Fichtelberg, Frankfurt (Main) and Hohenpeißenberg.

An up-to-date description of the components of the German climate observing system can be found in Deutscher Wetterdienst (2013).

3 Data base of Germany's National Climate Data Centre (NKDZ)

The data base of NKDZ mainly comprises "conventional" in situ observations that are made within the station network of DWD. The archive contains historical German climate data and current data are continuously added. In addition to the classical meteorological data taken near the Earth's surface, the archive also comprises data from the free atmosphere and the soil, as well as phenological data and data on the classification of weather conditions. The number of stations available has varied in the course of time and depends on the parameter. The longest time series goes back to the 18th century (Hohenpeißenberg, since 1781 with measurements of temperature, pressure and precipitation), but many do not start before ∼ 1945.

The main aim of the NKDZ is the sustained development of a comprehensive data base of high quality, which is available to applied climatology and climate research. A major focus of the activity is to guarantee a defined data quality by means of validation and correction of the data (or at least a description of errors), as well as a detailed description of the data base, including provision of detailed records of station metadata, as e.g. change of instrumentation (see Table 3 for an example), location or observer instructions.

4 Quality assurance

Continuous quality assurance and documentation is necessary to provide a high quality data base for research purposes. Quality assurance of NKDZ comprises the identification and correction or description of errors in the historical data. Documentation comprises the description of the historical time series, including the changes in the coding and observation regulations.

Data from the current observation network of DWD pass through several steps of quality control. The first step is a quality control directly at the automatic stations. As this is an automatic test, rather broad limits are applied. It includes tests for completeness, thresholds, temporal and internal consistency. Based on these tests, a quality flag is assigned to the data. The data are then transferred to the data base. At this stage, a second test (with thresholds of the data base) is applied. Based on the values in the data base, a third level of quality control is performed with smaller limits than during the first step. It is based on a software (QualiMet, see Spengler, 2002) that tests for completeness and climatological, temporal, spatial and internal consistency. Doubtful values are manually examined and the quality flag is adapted. A final step of quality control is applied after all data of a month is available, with focus on the aggregated values. The quality flags are stored in the data base and are also provided to the users, e.g. when providing the data in the internet.

The introduction of near real-time automatic quality control in the current observation network allowed shifting the focus of the NKDZ to the quality control of previously insufficiently verified historical data. Original quality control was only subjectively and undocumented. There has not been a complete, systematic and well documented quality assurance of the data that was observed before the introduction of the computer-based verification methods (i.e. prior to 1979). For the quality control of these historical data, suitable procedures have been developed and are currently applied to the data. The focus is on daily values. In general, the quality of these values can be considered as reasonably good, but there are still doubtful values, especially in data prior to 1979 (in the order of about 0.1–1 %).

It is important for the user to note that data might be affected by certain none-climatic effects, e.g. changes in instrumentation or observation time. Except for a few exceptions,

Table 3. An example for the provision of supplementary metadata on station/instrumentation history: instruments used to measure precipitation at station Bremen. Further metadata, e.g. observation times, are provided in additional tables (table is shown as provided with the data, i.e. in German language).

ID	Stations-name	Geo. Länge [Grad]	Geo. Breite [Grad]	Stations-höhe [m]	Von Datum	Bis Datum	Gerätetyp Name	Messverfahren
691	Bremen	8.79	53.05	3	01.02.1949	31.05.1978	Niederschlagsmesser	Niederschlagsmessung, Hellmann
691	Bremen	8.79	53.05	3	01.01.1961	31.05.1978	Niederschlagsschreiber (beheizt)	Niederschlagsmessung, Hellmann
691	Bremen	8.8	53.05	4	01.06.1978	31.08.1990	Niederschlagsmesser	Niederschlagsmessung, Hellmann
691	Bremen	8.8	53.05	4	01.06.1978	30.10.2008	Niederschlagsschreiber (beheizt)	Niederschlagsmessung, Hellmann
691	Bremen	8.8	53.05	4	20.06.1991	30.10.2008	Ombrometer Lambrecht 1518H3	Niederschlagsmessung, Hellmann, elektr.
691	Bremen	8.8	53.05	4	14.10.2008		PLUVIO-OTT	Niederschlagsmessung, Hellmann, elektr.
691	Bremen	8.8	53.05	4	19.06.1991		Niederschlagsgeber Kroneis	Niederschlagsmessung, elektr.

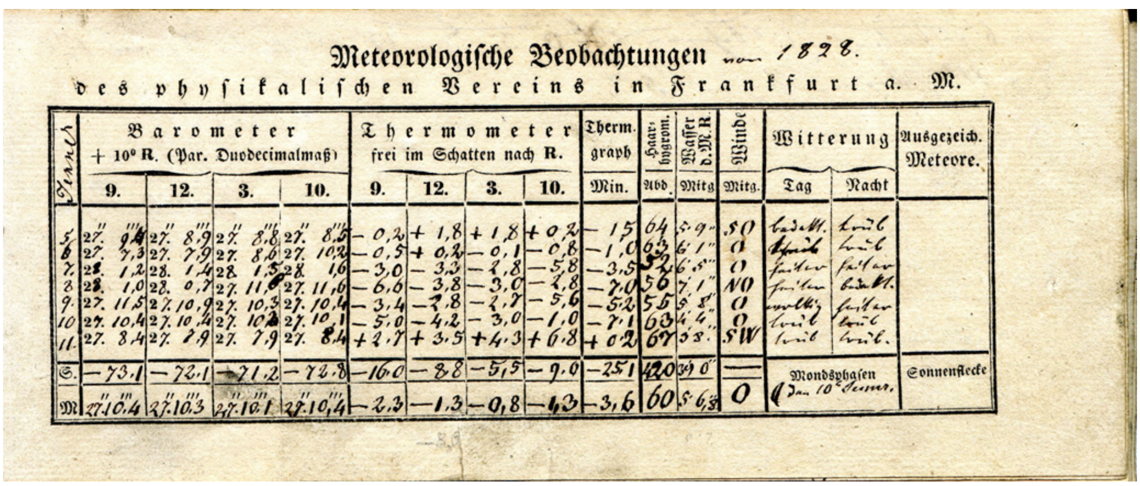

Figure 2. An example of handwritten historical documents with weather observations: Frankfurt, 1828 (5 to 11 January).

data are provided "as observed", e.g. no homogenization procedure has been applied. Information on these changes is therefore provided together with the data. A homogenization procedure has only been applied to selected parameters at monthly resolution (Herzog and Müller-Westermeier, 1998). These monthly data are available as an alternative version, but are not continuously updated.

A systematic verification of the upper-air and phenological data has also not yet been carried out.

5 Digitisation of historical climate data

Apart from the integration of current data, the data base is also expanded by adding additional historical time series. Such data are still available as hand-written documents (Fig. 2 shows an example). Therefore the digitization can only be done manually and is a time-consuming and costly process, which can only be carried out as a long-term activity on a best effort basis.

In particular for the time prior to 1951 (in the new federal states prior to 1969) the availability of daily data (or data of a higher temporal resolution) is still insufficient. A comparison of the number of monthly values in the data base to the daily data illustrates the missing information in the data base at that temporal resolution (see Fig. 1).

The project KLIDADIGI was initiated to digitize additional data, but also to rescue the original documents, esp. by taking photographs of the paper documents. A focus is the expansion and completion of data for stations with long time series (Mächel and Kapala, 2013).

During the last 7 yr, daily records from 97 climate stations or 2932 station-years (about 12.7 % of the total potential) were digitized (Fig. 1). Records from 514 precipitation stations were digitized which equals to 19 300 station-years or 11.7 % of the total potential. 492 000 photos of paper documents have been taken.

The greatest deficiencies exist in East Germany before 1969, where only 50 % of the precipitation stations are digitally available. The filling of these gaps and digitizing all available precipitation stations back to the end of World War II have the highest priority in the next few years.

6 Climate analysis

The NKDZ data base can be used to describe the climate in Germany over a period of more than 130 yr. For the provision of aggregated information the following two steps are performed: (a) calculation of gridded fields and (b) aggregation of regional averages based on these gridded data.

Gridded data at a resolution of 1 km × 1 km are produced for the monthly mean of temperature, monthly sums of precipitation and sunshine duration, grass reference evaporation, aridity index and the climatic water balance.

The calculation of the gridded fields is done in three steps: first, the monthly values at the station locations are reduced to a reference level (sea level). Due to the high station density, linear regression between topographic height and climatological parameter is sufficient within a specific region. For precipitation and other parameters with a very dense network, the regression is calculated within regions of $1^\circ \times 1^\circ$. For other parameters, 10 larger regions are used (for details see Müller-Westermeier, 1995). The regression coefficients are interpolated between the center locations of the regions and are calculated for each of the 12 months, based on the period 1961–1990. With the interpolated coefficients (covering the whole area), the climatological values at each individual station are reduced to sea level.

In the second step, the values at reference level are horizontally interpolated (inverse squared-distance weighted).

In the third step, the values are transferred from the reference level to the real height of the grid point. A grid with 1 km resolution is used (Gauss-Krüger projection with central meridian at 9° E; EPSG-code: 31467). The grids are produced for each month. More details can be found in Müller-Westermeier et al. (2005). Gridded fields for reference intervals (e.g. 1961–1990) are produced with the same methodology based on the station-based mean values for the respective interval. Grids for the new reference interval 1981–2010 have recently been calculated.

The monthly climate monitoring products are produced within a few days after the end of a month in order to provide near real time information on the status of German climate. At that stage, not all steps of the quality control procedures have been applied to the data. Therefore, the gridded data are reproduced once again after a few months. Figure 3 shows an example.

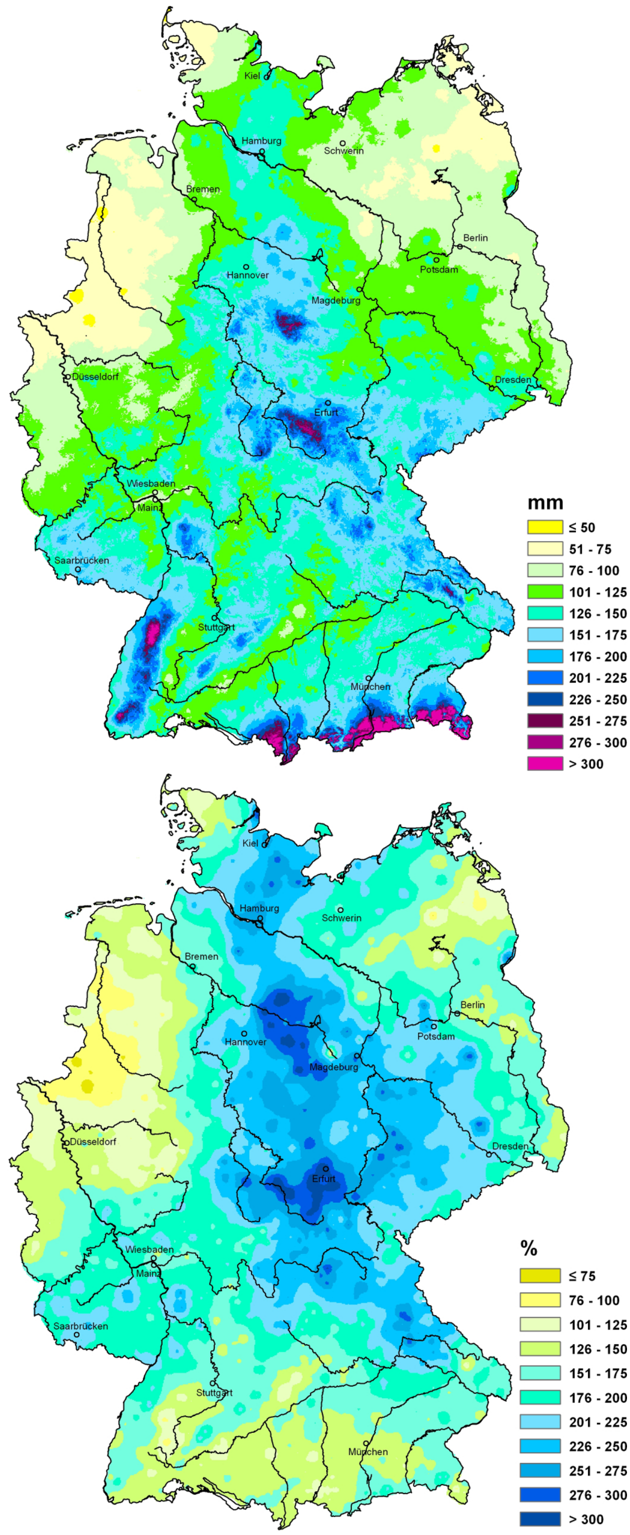

Figure 3. An example for the gridded products: precipitation in May 2013, which was the 2nd wettest May in Germany since 1881; (top): absolute values in mm. (bottom): in percent of the long-term mean 1961–1990.

Table 4. Trend of the annual mean temperature in Germany's federal states from 1881 to 2012 (i.e. change in areal mean temperature). For small states values are combined.

Region	Trend in degree Celsius from 1881 to 2012
Schleswig-Holstein	1.1
Lower Saxony (Niedersachsen), Hamburg, Bremen	1.3
North Rhine-Westphalia (Nordrhein-Westfalen)	1.3
Rhineland Palatinate (Rheinland-Pfalz), Saarland	1.4
Baden-Württemberg	1.2
Hesse (Hessen)	1.2
Bavaria (Bayern)	1.3
Mecklenburg-Vorpommern	1.1
Brandenburg, Berlin	1.0
Saxony (Sachsen)	1.1
Saxony-Anhalt (Sachsen-Anhalt), Thuringia (Thüringen)	1.2
Germany (Deutschland)	1.2

The gridded data are used to calculate means for administrative areas (esp. for Germany and the federal states) which are then combined to make time series. The gridding procedure considers location and height of the stations. It can therefore be assumed that the time series of the spatial means are less affected by such changes in the measurement network than the time series of the individual stations.

In 2012, the gridded temperature fields have been reprocessed for the full interval 1881–2011 based on the updated and completed data base, including the newly digitized data. To improve the interpolation, also data from neighboring countries have been included (stations within a distance of ~ 50 km to the border; taken from the HISTALP, CRU and GHCN data collections as they are available from the archive of the International Surface Temperature Initiative). Especially in the north-east of Germany, the station density has been significantly improved. Compared to previous results, the north-eastern federal states are now slightly more consistent. Table 4 shows the updated trends for the federal states for the interval 1881–2012.

The interpolation method has been verified and compared with other (GIS-based) interpolation methods (Maier and Müller-Westermeier, 2010) and it was shown that other standard interpolation procedures do not lead to better results.

For climatological reference periods (so-called "climate normals"), mean values of temperature, precipitation amount and sunshine duration are provided at station locations. These products are now also available for the period 1981–2010.

7 The German climate atlas

The monthly maps are one element of the German climate atlas (Deutscher Klimaatlas; http://www.deutscher-klimaatlas.de). The German climate atlas is an interactive online tool to provide comprehensive information about past, current and projected future climate in Germany, together with sector-specific information (currently agriculture, forestry, soil). The atlas offers a combined view on observation-based information from the past (back to 1881) and results of regional climate model projections (until 2100). The scenario information is based on an multi-model ensemble (from the EU-project ENSEMBLES and additional sources). The maps are visualized in combination with time series of the national mean. This allows a direct visual comparison of observed to projected data. Figure 4 shows an example of the atlas.

8 Data access

Relevant parts of the data are accessible via internet-based access tools. The Climate Data Centre (CDC) of DWD provides an entry point to all access tools (http://www.dwd.de/cdc). Due to legal restrictions only a selection of the data can be provided free of restrictions. Additional data are available for science, research and education, but registration is required. The set of free data currently comprises the time series from 78 selected stations, the long-term average values for all stations, grid fields for the climatological (30 yr) reference periods and the phenological data. The data can be found on the internet pages of NKDZ (http://www.dwd.de/nkdz, http://www.dwd.de/phaenologie). The time series of the stations are provided with metadata that describes the history of the station, including all relevant modifications in the instrumentation. General information on the status of climate in Germany is also provided at http://www.dwd.de/klimamonitoring. Data from all German stations and monthly grid fields are available for science, research and education after registration via the *Web-based Weather Request and Distribution System* (WebWerdis; http://www.dwd.de/webwerdis). The phenological data are also provided to the PEP725-project (Pan-European Phenology; http://www.pep725.eu) and to the plant-phenological

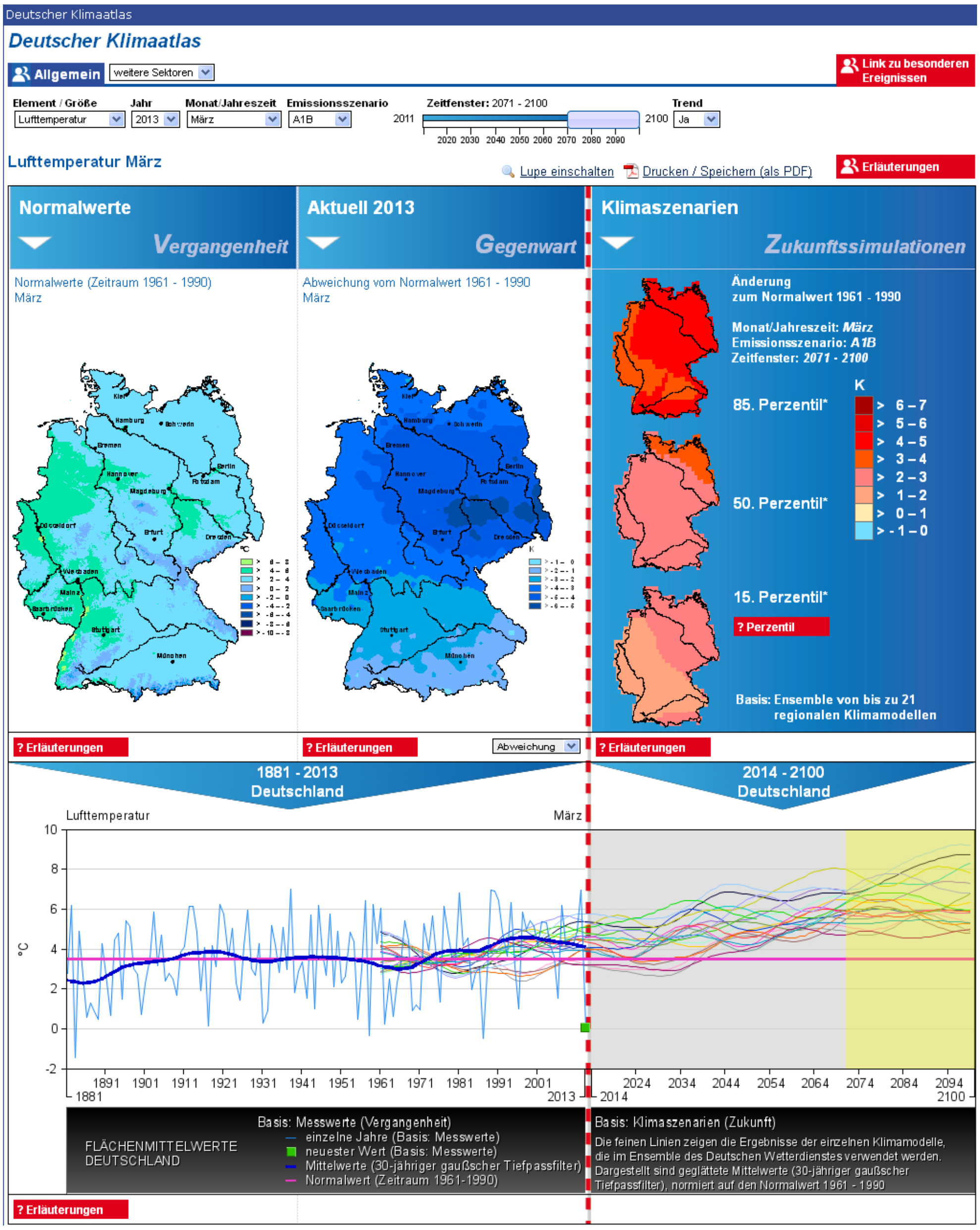

Figure 4. The German climate atlas provides a comprehensive overview of climate in Germany. Here, the parameter "temperature" of "March 2013" is selected (which was the 5th coldest since 1881). The left map shows the average values for March during the reference period 1961–1990. The middle map shows the anomaly in March 2013. The right maps show results of regional climate models (also for March; interval 2071–2100 is selected). At the bottom, the time series of March temperatures is shown. The observation-based information (black and pale blue; left part) can directly be compared with the climate projections (assorted colours; right).

online database (PPODB; www.ppodb.de) and are accessible at these portals. The aim of PEP725 is to establish a pan European open access database with plant phenology data sets for science, research and education. PPODB also contains phenological data from additional sources and supplements the DWD-data especially for periods prior to 1951.

Edited by: M. Brunet-India
Reviewed by: O. Bulygina and one anonymous referee

References

Deutscher Wetterdienst: Die deutschen Klimabeobachtungssysteme. Inventarbericht zum Global Climate Observing System (GCOS), Selbstverlag des Deutschen Wetterdienstes, Offenbach am Main, 130 pp., http://www.gcos.de/inventarbericht, 2013.

Herzog, J. and Müller-Westermeier, G.: Homogenitätsprüfung und Homogenisierung klimatologischer Messreihen im Deutschen Wetterdienst, Berichte des Deutschen Wetterdienstes 202, Selbstverlag des Deutschen Wetterdienstes, Offenbach am Main, 1998.

Mächel, H. and Kapala, A.: Multivariate testing of spatio-temporal consistence of daily precipitation records, Adv. Sci. Res., 10, 85–90, doi:10.5194/asr-10-85-2013, 2013.

Maier, U. und Müller-Westermeier, G.: Verifikation klimatologischer Rasterfelder. Berichte des Deutschen Wetterdienstes 235, Selbstverlag des Deutschen Wetterdienstes, Offenbach am Main, 2010.

Müller-Westermeier, G.: Numerisches Verfahren zu Erstellung klimatologischer Karten. Berichte des Deutschen Wetterdienstes 193, Selbstverlag des Deutschen Wetterdienstes, Offenbach am Main, 1995.

Müller-Westermeier, G., Walter, A., and Dittmann, E.: Klimaatlas Bundesrepublik Deutschland, Teil 1–4, Selbstverlag des Deutschen Wetterdienstes, Offenbach am Main, 2005.

Spengler, R.: The new Quality Control- and Monitoring System of the Deutscher Wetterdienst. Proceedings of the WMO Technical Conference on Meteorological and Environmental Instruments and Methods of Observation, Bratislava, 2002.

Wege, K.: Die Entwicklung der meteorologischen Dienste in Deutschland. Geschichte der Meteorologie in Deutschland – Band 5. Selbstverlag des Deutschen Wetterdienstes, Offenbach am Main, 2002.

World Meteorological Organisation: International Meteorological Vocabulary, 2nd Edn., WMO No. 182, 1992.