04.08 Long-term Mean Precipitation Distribution 1991-2020

Introduction

The mean precipitation distribution provides key information on the development of precipitation in an area. In individual events, however, the precipitation distribution may deviate greatly from the mean precipitation distribution. This applies in particular to heavy rainfalls, as they are usually confined to smaller areas and not evenly distributed (cf. Spektrum.de online 2016, only in German). They occur during the summer months as a result of convective air flows reinforcing themselves. Although physiographic characteristics may contribute to the development of heavy rain cells, their formation is highly coincidental.

Heavy rainfalls can thus contribute to small-scale changes in the annual or semi-annual means. Considering the long-term period of 30 years, however, the impact of individual events is rather insignificant, as heavy rainfalls are quite rare and random in their distribution.

The weather conditions in an area are greatly influenced by its **topography** (surface structure of the earth). Mountain ranges, smaller hill chains, and even lower ridges already have an impact on the amount of precipitation. Other influencing factors include forests, lakes, fields and such (cf. Flohn 1954, only in German). Furthermore, cities with their agglomerations of buildings influence the quantity and distribution of precipitation once they reach a certain size.

Increased precipitation within a confined area, due to, for example, relief rainfalls are mainly caused by the influence of soil friction, i.e. the surface roughness parameter. Soil friction slows down the lower air layers, causing subsequent air masses to accumulate and rise. Adiabatic cooling may effect the formation of clouds and precipitation. Additionally, aerosols tend to accumulate above urban areas more often. As condensation nuclei, they influence the formation of clouds and precipitation. In addition, the heat emanating from urban areas may contribute to convective precipitation, if additional constraints come into play.

The present evaluations are based on grid data provided by Germany's Meteorological Service (DWD). The DWD's REGNIE data was used to analyse the reference period between 1981 and 2010. This data set, however, has been discontinued and will no longer be updated. The current update was therefore based on the precipitation data of the HYRAS-DE-PRE data set (only in German). The DWD's scientifically improved HYDRAS-DE-PRE data set succeeds and replaces REGNIE entirely.

As the data base changed, the Environmental Atlas' results of the long-term mean precipitation distribution from 1981-2010 may only be compared to those of the current period to a limited extent.

Effects of precipitation

Precipitation is an essential component of nature. Animals, plants, and indeed us humans cannot survive without it. To analyse the effects of precipitation, however, a differentiated approach is needed. On the one hand, precipitation causes a cleaning process of the air. On the other hand, highly impervious surfaces and how they are used cause precipitation to flush out a variety of pollutants. The latter are then able to enter rainwater drains and combined sewerage systems and eventually make their way into our bodies of water, too.

A lack of precipitation affects animals and plants alike, which may lead to permanent damage. This is especially true if dry periods occur increasingly, as has been the case in recent years. The simultaneous increase in heavy rainfalls, however, does not compensate for the lack of precipitation in the water balance. Soils, especially when dry, cannot absorb these copious amounts of precipitation, or only to a small extent. The precipitation therefore largely runs off superficially and does not contribute to the regeneration of the soil water store. What is more, heavy rain may also cause soil erosion. Flash floods resulting from heavy rain also pose a danger to people, animals and property.

Regional Classification of Precipitation Conditions in Berlin

Berlin is located in an area of transition, where the climate shifts from continental to predominantly oceanic. This is reflected in Berlin's precipitation conditions on a regional scale. Berlin is one of the drier regions compared to the rest of Germany. Incidentally, the annual mean precipitation for Germany was 782 mm per square metre for the international standard reference period from 1991 to 2020, whereas it was 579 mm per square metre for Berlin for the same period (long-term mean of the calendar years, cf. Fig. 1).

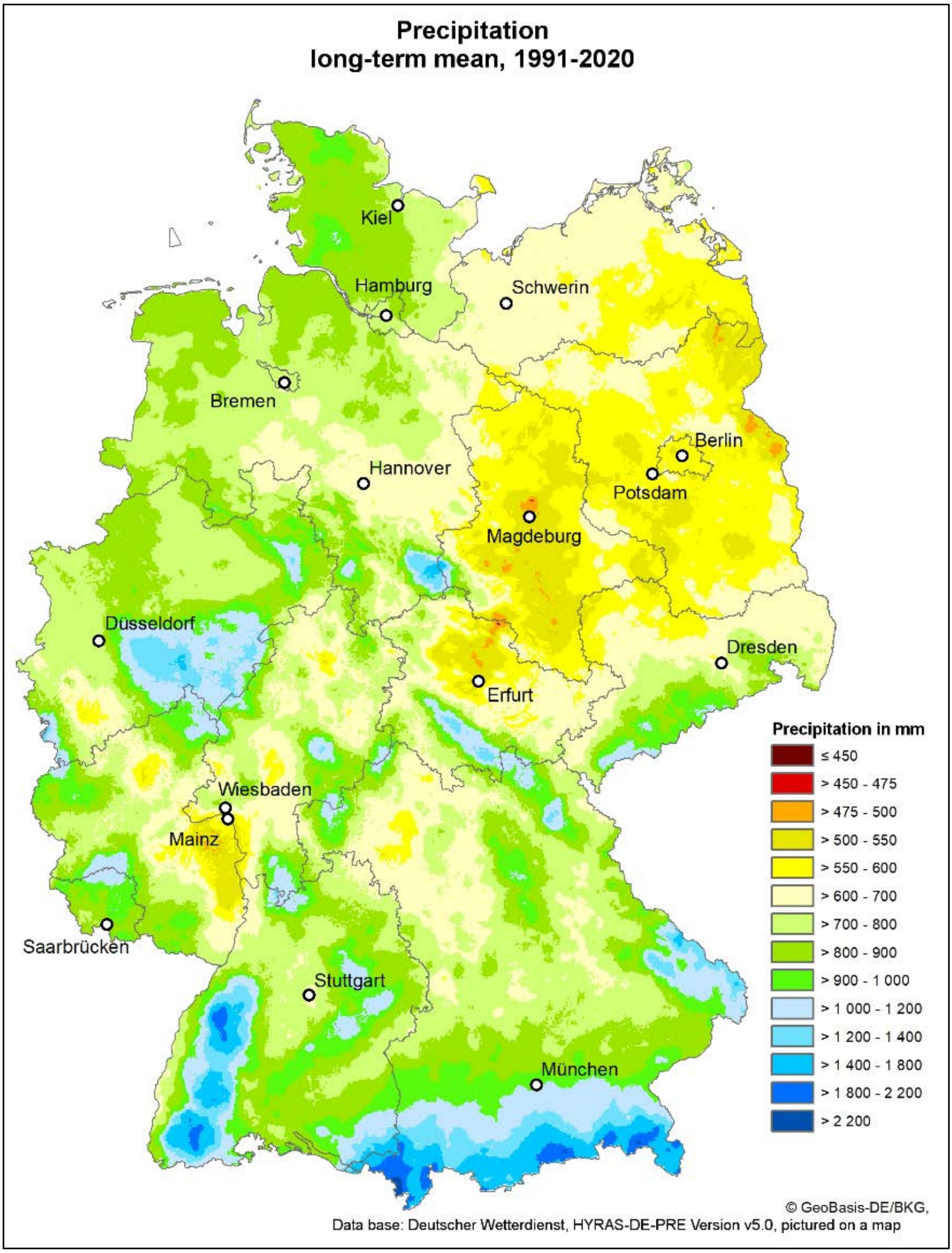

Fig. 1: Distribution of the amount of precipitation per year in Germany – long-term mean, 1991-2020 (GeoBasis-DE/BKG, data basis: DWD, HYRAS-DE-PRE, version v5.0, illustrated)

In addition to the above-mentioned factors, the **global climate change** is also expected to influence our regional water supply more and more in the future. Over the past 10,000 years, changes in climate have altered the geographical distribution of precipitation dramatically. Forecasts of potential developments largely depend on future greenhouse gas emissions and are being studied by authorities such as the DWD (cf. DWD 2020a, only in German). According to the DWD, the annual precipitation is predicted to increase slightly (+6%) in Germany by the end of the century. The winter months and the transitional seasons are expected to see an increase in precipitation. For the summer, precipitation predictions range from slight increases to decreases, depending on the scenario.

Statistical Base

The **HYRAS-DE-PRE grids of the 30-year mean precipitation** for Germany covering the period from 1991 to 2020 formed the statistical base (version v5.0, retrieved on December 2, 2022). The DWD provides these as part of a freely accessible data set via the Climate Data Center (CDC) (DWD 2022b). The HYRAS-PRE-DE data is embedded in a 1 km x 1 km grid based on a Lambert conformal conic projection.

Precipitation data is available for multiple reference periods (1961-1990, 1971-2000, 1981-2010 and 1991-2020). It reflects the 30-year mean amount of precipitation (in millimetres) for each calendar month, the four meteorological seasons, water management periods of 6 months and the entire year per reference period.

The DWD has ensured that the precipitation data used is complete and consistent and has corrected the data where necessary. The HYRAS-DE-PRE grids **do not correct for systematic precipitation losses** due to wetting, evaporation and wind effects, however. Measurement errors are influenced by many factors, including the station type, installation site, precipitation pattern and precipitation type. For conventional precipitation gauges (Hellmann) across the *Nordostdeutsches Tiefland* (Northeast German Plain), the precipitation measurement error in the annual mean ranges between 8.6 and 16.6 %, depending on wind exposure (cf. Richter 1995, only in German). In the methodology presented in Rauthe et. al. 2013, the DWD mentions that the true precipitation is underestimated by at least 10 %.

The regionalisation method is essentially based on the interpolation of anomalies in relation to long-term means. For this purpose, background fields are determined for precipitation distributions. Based on these, the amount of precipitation is then calculated. Background fields are calculated by multiple linear regression taking into account geographical location, altitude, slope and direction of slope that may influence the amount of precipitation and its distribution. As a next step, the measured station precipitation and the background fields are interpolated to calculate regionalised precipitation. If a grid point coincides with a station, the value of that station is used.

The regionalisation method is described in detail in Rauthe et. al. 2013. See DWD 2022b (only in German) for a condensed methodology and a description of the data set.

The analysis of the long-term mean precipitation **between 1981 and 2010**, which is also available in the Environmental Atlas, was based on REGNIE grids. However, REGNIE was discontinued as a data set. It was succeeded and replaced by HYRAS-PRE-DE on January 1, 2022. The DWD's process for generating precipitation grids has generally remained the same. It was developed further scientifically, however, to rectify known weaknesses and implement technical adjustments. The main changes include:

- an updated reference period for the background field. The field is now based on the period from 1971 to 2000 instead of 1961 to 1990. According to the DWD's assessment, the impact of this change is negligible, as the 30-year means differ only slightly,
- an adjustment in the calculation of the background fields, correcting orographic effects that were previously overemphasised. According to the DWD, this results in changes mainly in the *Mittelgebirge* (low mountain ranges) and the Alps,
- the generation of data in a projected grid (Lambert conformal conic projection), rather than a geographical grid,
- water management periods of six months that were added to the evaluation periods, and
- the provision of results in netCDF files.

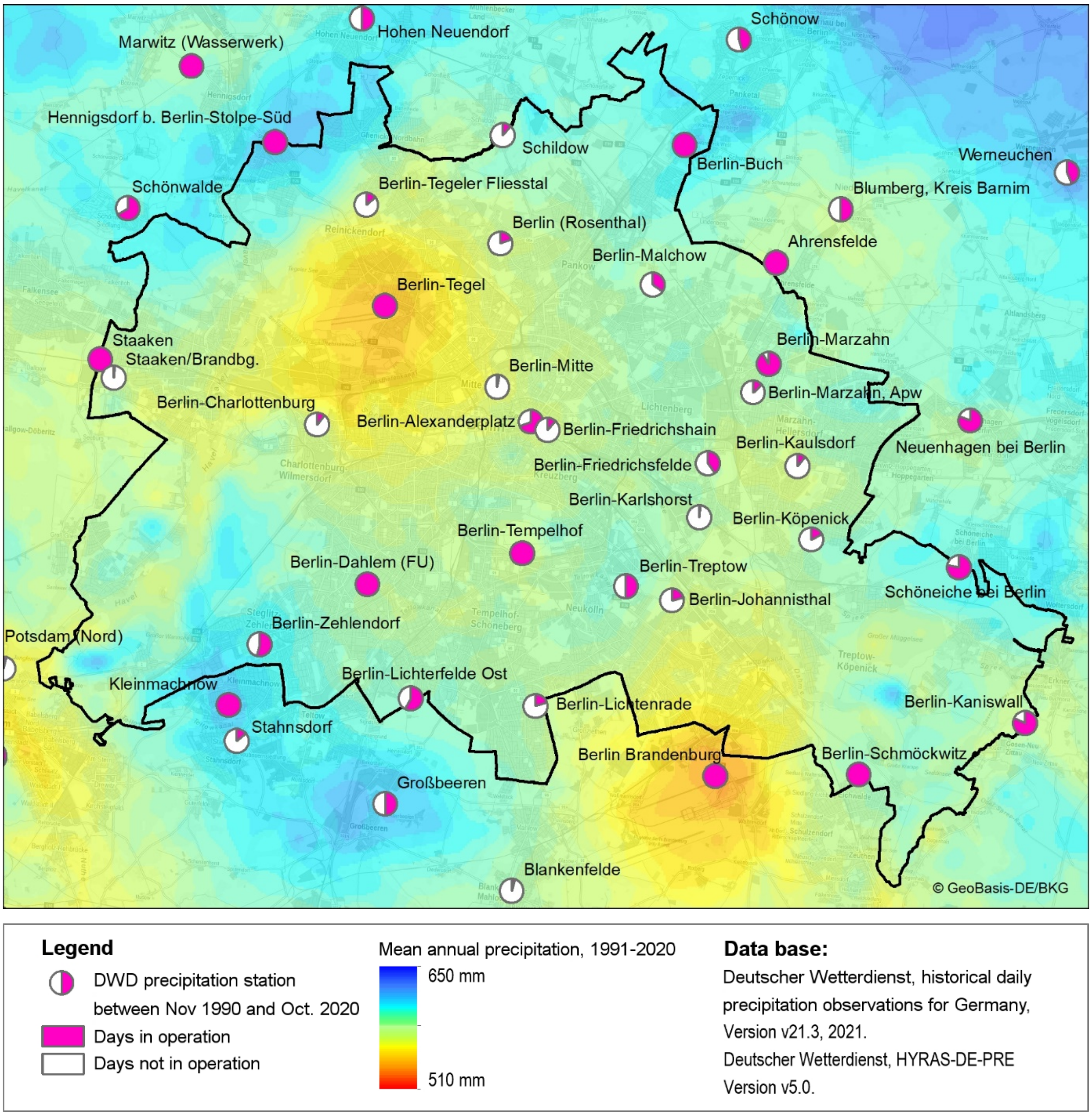

Fig. 2: Active precipitation stations of the DWD in the period between November 1990 and October 2020 (ProAqua using DWD Climate Data Center (CDC): Historical daily station observations for Germany, Version v21.3, 2021 and DWD 2022b)

The DWD uses an extensive data base of precipitation measurements recorded at ground stations to develop its HYRAS-DE-PRE precipitation grids. Different combinations of stations are used in each step of the regionalisation process (e.g. development of the background field, regionalisation of the station data) for scientific reasons. In addition, the station network has been subject to frequent changes, due to new installations, closures, transfers, outages or modernisations. It is therefore impossible to develop a simple and accurate representation of the combinations of time series and precipitation stations that were used to develop the precipitation grids, which is also not provided by the DWD.

To gain some insight into the density of the station network behind the grid data, Figure 2 presents all precipitation stations that were in operation during the evaluation period between 1991 and 2020 (i.e. November 1990 to October 2020). Each station's pie chart indicates to what extent the station was in operation during the period in question. A fully coloured pie chart means that the station was in operation for the entire period (incl. potential short outages). A 50/50 pie chart indicates, for example, that the station was active only for 15 years of the 30-year period. The figure does not show which stations (if any) were actually used to develop the HYRAS-DE-PRE grid.

Methodology

The following steps were taken to evaluate the precipitation distributions for the Environmental Atlas' purposes (cf. Figure 3):

- converting and transforming the HYRAS-DE-PRE source data,
- increasing the spatial resolution of the precipitation distribution by using a suitable interpolation procedure,
- deriving a **mode of presentation suitable for the map based on isolines and isosurfaces**, and
- aggregating the results based on the block, block segment and road areas of the spatial reference of the Urban and Environmental Information System (ISU5).

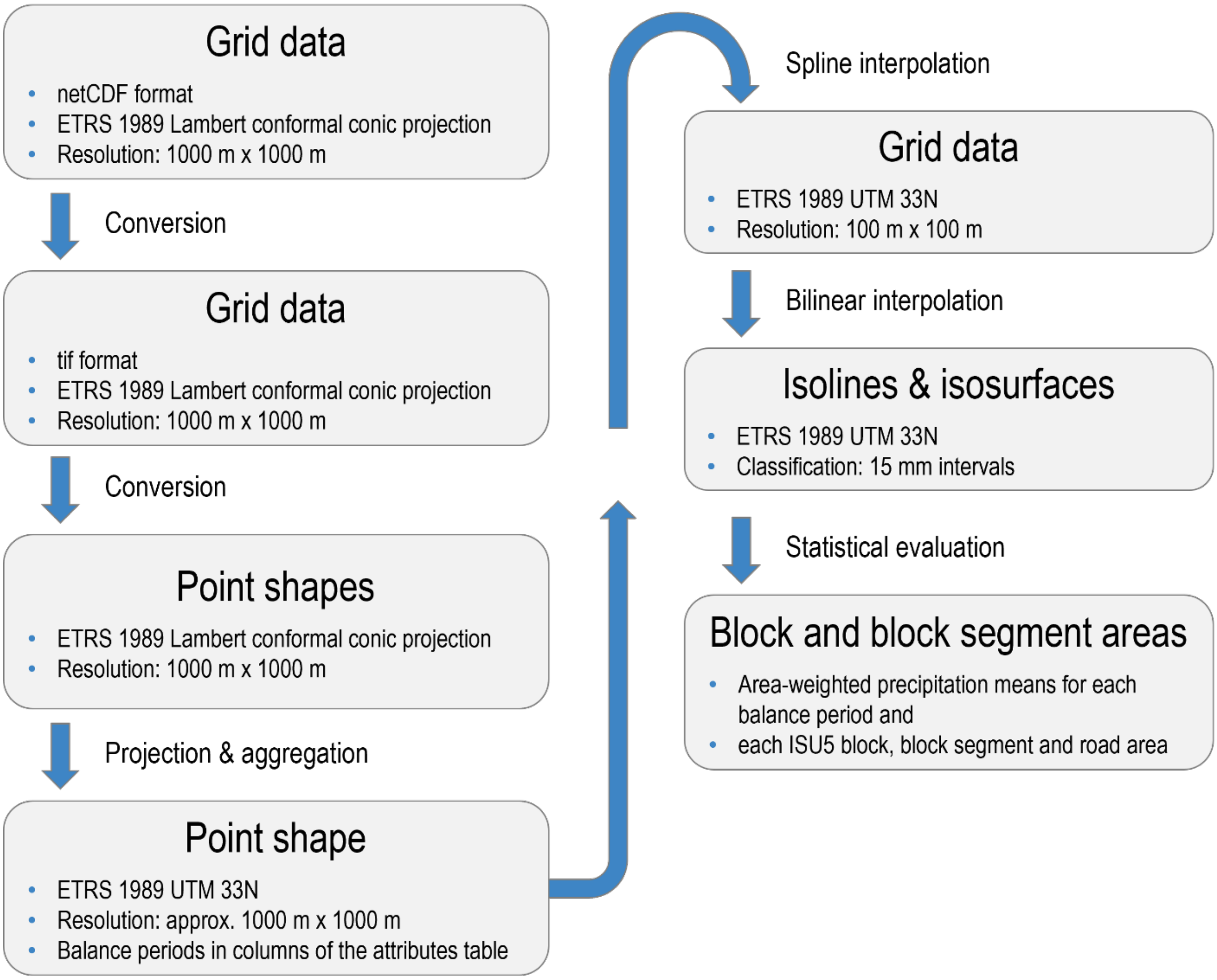

Fig. 3: Diagram of how the multi-annual mean precipitation grids are processed for Berlin, 1991-2020 (ProAqua using statistical base from DWD 2022b).

The source data was available in netCDF format (version 4), an open standard binary file format. The data format is self-describing and contains information on the data structure, which is stored in one- or multi-dimensional arrays within a data set. Many programmes support netCDF files. The data was converted into another grid format (tif) here.

The HYRAS-DE-PRE data on long-term precipitation means is available as a two-dimensional data set (x, y, excl. time) for each reference period (one year, six months, one month, ...) in the projected coordinate system 'ETRS 1989 Lambert conformal conic projection'. Precipitation data serves as an important base for water balance analyses. The latter is usually balanced according to the water year (discharge year, hydrological year), starting on November 1 and ending on October 31 of the following year. This classification is used as late autumn and early winter precipitation is stored as snow or ice and does not run off until the following spring. With the release of HYRAS-DE-PRE version v5.0 in December 2022, the DWD has extended the available data sets. They now also include water balance periods (water year, winter half of the year, summer half of the year), which means that this data may be used directly.

Technically, the HYRAS-DE-PRE data is grid data. According to DWD documentation, however, the precipitation data should be considered point data, which refers to the centre of each grid cell (grid point). Precipitation is a physiographic process. Its distribution is continuous and steady. Therefore, the transitions between the different precipitation data points in the individual grid cells should also be gradual. To this end, the source data (1 km x 1 km resolution) was interpolated to a resolution that is ten times higher, i.e. 100 m x 100 m. A Spline interpolation of the type “Tension” with a weight of 1 and a search radius of 4 points was chosen as the interpolation method (cf. ESRI 2019a). This method is a good compromise between smoothing values on the one hand and representing the original values in the grid points as accurately as possible on the other.

Isolines and isosurfaces were generated from the interpolated 100 m x 100 m grid data using bilinear interpolation (cf. ESRI 2019b). Isolines are lines that connect points of equal value. In relation to precipitation, these lines are also referred to as isohyets, i.e. they connect points of the same precipitation. Isosurfaces comprise the areas between two isolines and thus indicate areas with precipitation within a specific range of values.

Finally, the precipitation for each evaluation period was summed and averaged by area for each block, block segment and road area of the Urban and Environmental Information System (ISU5).

Map Description

The maps present the total precipitation averaged over the period from 1991 to 2020 according to water years (hydrological years, discharge years). A water year ends in October of the year in its title; it begins, however, in November of the year prior to that. The evaluations for the water years from 1991 to 2020 thus refer to the period from November 1, 1990 to October 31, 2020.

In addition, the totals for the winter and summer halves of the water year are also presented. Table 1 displays the evaluation periods.

Tab. 1: Evaluation periods for the long-term mean precipitation distribution, 1991-2020

Map	Evaluation period	Months	Period
04.08.1	Annual precipitation	November – October	November 1990 – October 2020
04.08.2	Summer half	May – October	May 1991 – October 2020
04.08.3	Winter half	November – May	November 1990 – May 2020

Tab. 1: Evaluation periods for the long-term mean precipitation distribution, 1991-2020

Berlin’s **mean annual precipitation totals** for the period from 1991 to 2020 range between 539 mm and 618 mm, depending on the location, the mean of which is 581 mm (cf. Table 2). The annual precipitation is generally distributed homogeneously across the city with only a few deviations. Areas around the former Berlin-Tegel Airport and Berlin Brandenburg Airport stand out in particular for being considerably drier. Both locations contain DWD precipitation stations. Here, the long-term mean precipitation is distinctly lower compared to other stations nearby (e.g. Berlin-Tempelhof). For example, the mean long-term precipitation for the period from 1991 to 2020 (calendar years) is 540 mm at the Berlin-Tegel station, 534 mm at the Berlin Brandenburg station and 572 mm at the Berlin-Tempelhof station (cf. Figure 4). Due to the regionalisation procedure, the local station measurements impact a larger area (cf. Figure 2). A meteorological or technical reason for the deviating precipitation totals could not be identified.

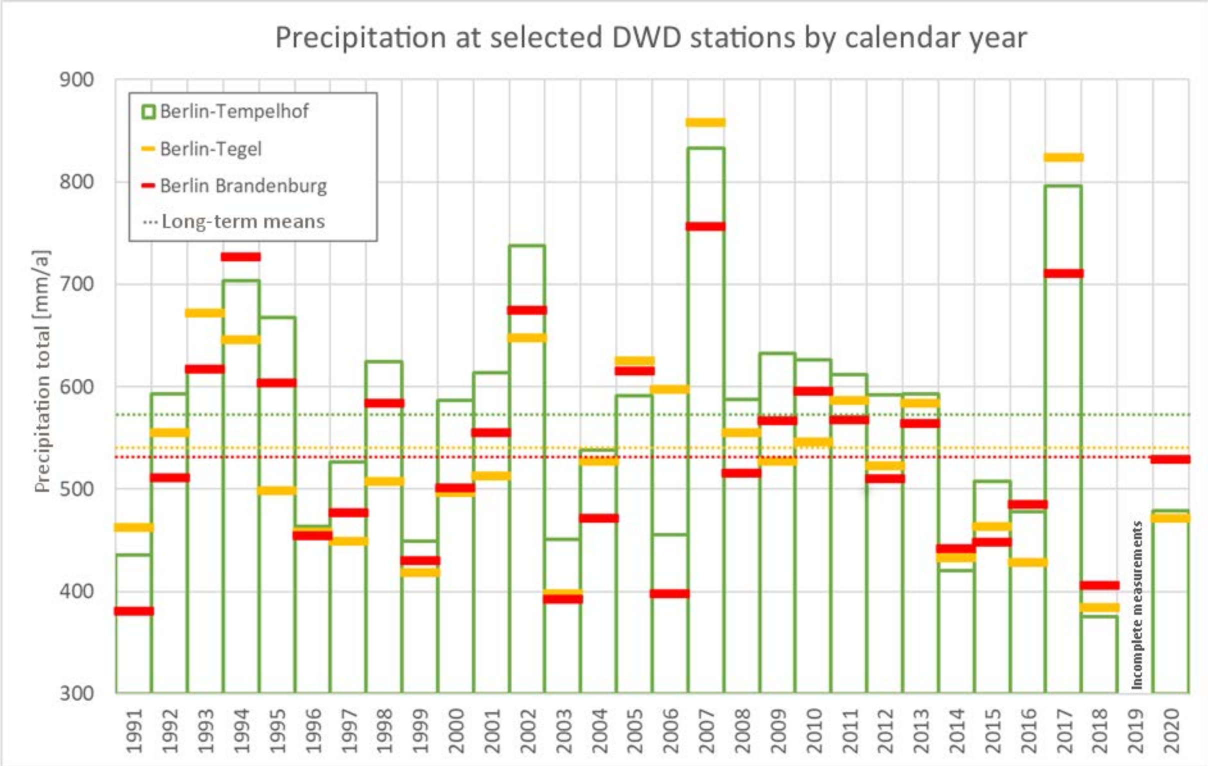

Fig. 4: Annual precipitation totals at the DWD stations Berlin-Tempelhof, Berlin-Tegel and Berlin Brandenburg between 1991 and 2020. (ProAqua using DWD Climate Data Center (CDC): Annual precipitation total (in mm) of station measurements in Germany, version v21.3, retrieved on December 21, 2022)

At some of Berlin's elevations, the mean precipitation is higher than the national mean due to orographic effects. This is the case, for example, at the *Großer Müggelberg* mountain (115 m) in the southeast, the *Schäferberg* mountain (103.5 m) in the southwest and on the Barnim Plateau northeast of Berlin. Overall, the orographic effect has decreased noticeably, however, since the earlier evaluation of the **period from 1981 to 2010**, which was based on REGNIE data. The area of the *Grunewald* forest up to *Diedersdorfer Heide* (heath in Brandenburg) south of Berlin as well as the forest between Henningsdorf (Brandenburg) and Berlin-Frohnau also measured precipitation totals above the mean. (Map 4.08.1, cf. Figure 6).

Overall, similar characteristics have been observed for the **summer half** (Map 04.08.2) and the **winter half** (Map 04.08.3) of the year. In the summer half, with an average of 335 mm, the mean precipitation is distinctly higher than in the winter half with an average of 246 mm.

A correlation between the prevailing **wind direction distribution** for the Berlin area and the influence of the city's **topography** may be derived both for the distribution for the year as a whole and in relation to the two halves of the year.

Figure 5 (SenUVK 2019) presents the mean wind direction distribution at the DWD station in Berlin-Tempelhof for all four seasons, differentiated by wind speed. Westerly winds of maritime and sometimes humid air occur frequently throughout the year. During winter months, the influence of continental, often dry currents moving from the south to the east increases.

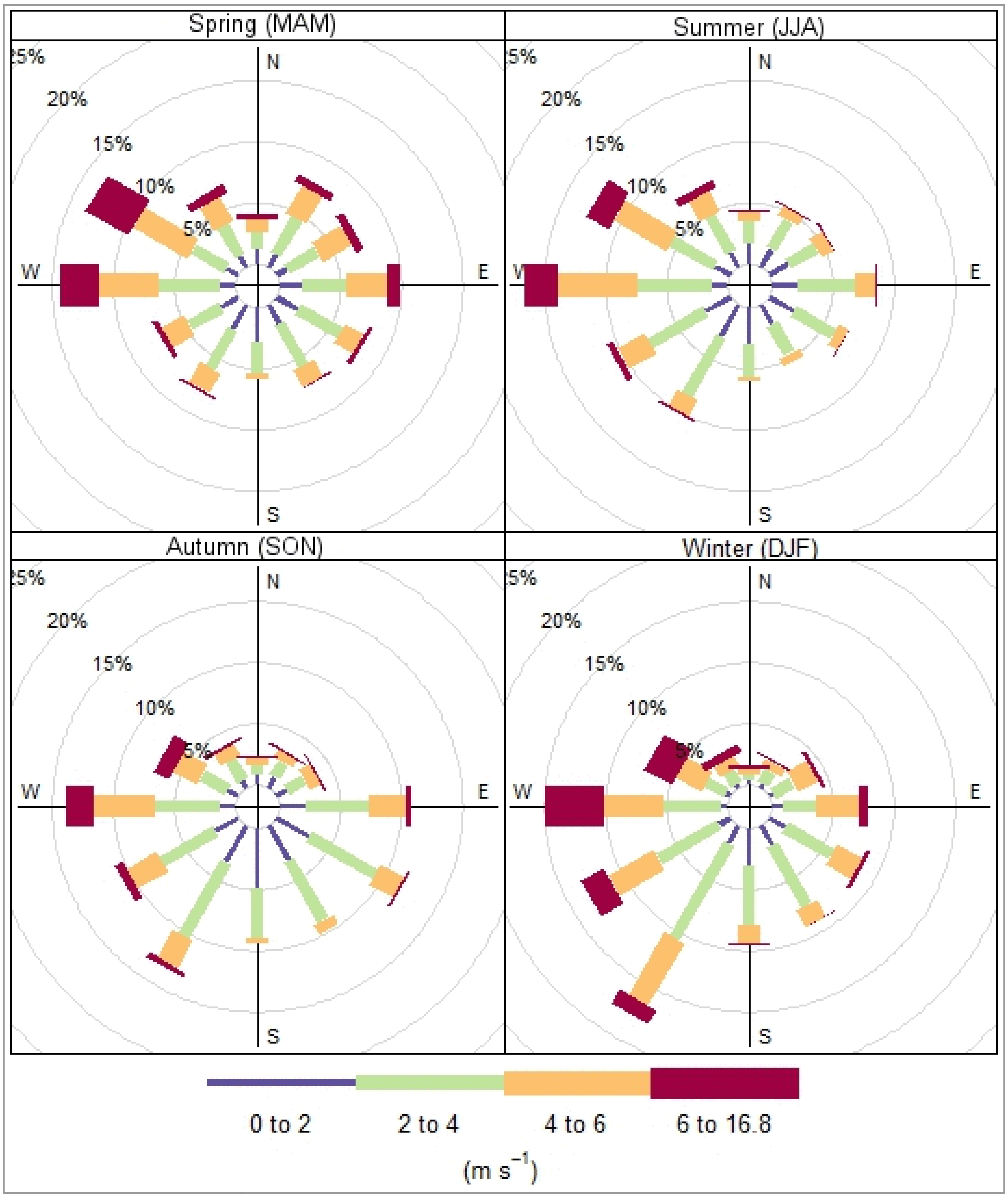

Fig. 5: Mean wind direction distribution at the Berlin-Tempelhof DWD station for all four seasons from 2011 to 2017, differentiated by wind speed (SenUVK 2019)

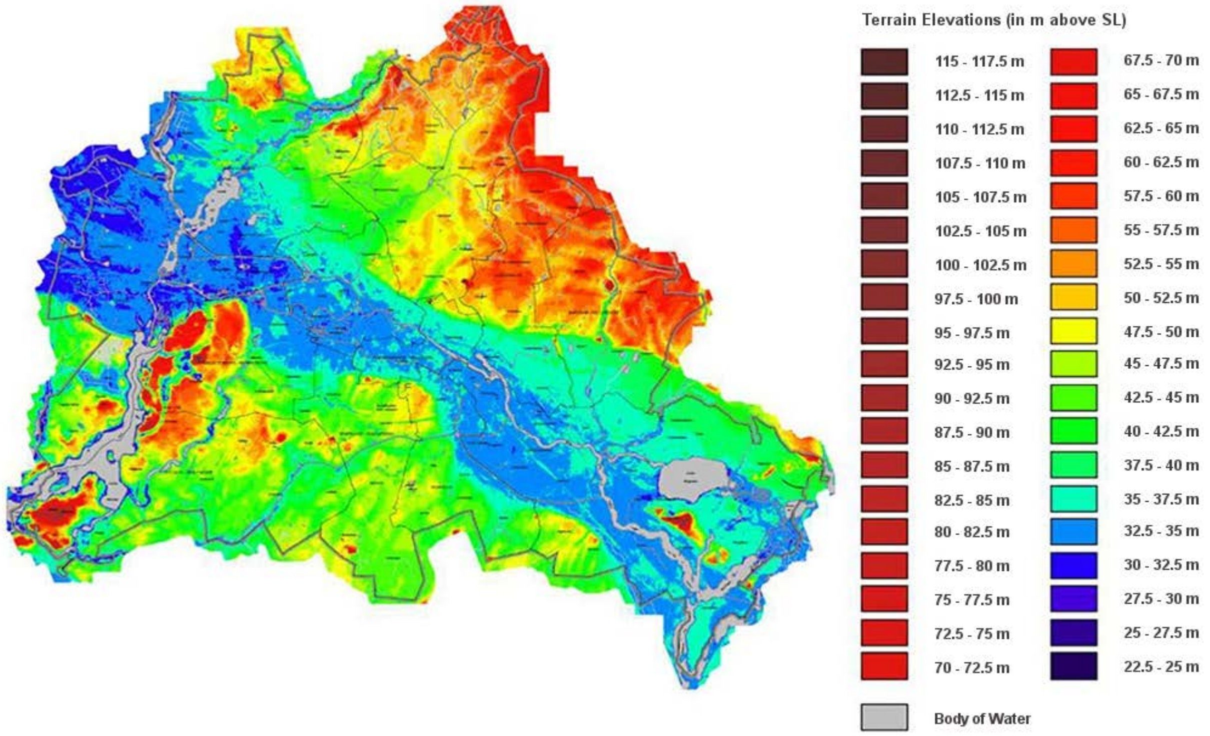

Fig. 6: Terrain elevations, Berlin (SenStadtUm 2010)

The map characteristics do not provide any evidence that urban development impacts upon the precipitation distribution, as has been indicated by studies (cf. Introduction). Berlin's development is still rather homogeneous in regard to height. This means that, on the one hand, there have been no artificial alterations of the soil roughness locally, alterations that could cause relief rainfalls. If the latter do occur, however, these are locally confined and rather spontaneous events that appear to be negligible regarding the long-term mean.

Table 2 presents a selection of statistic characteristic values for the long-term precipitation distribution from 1991 to 2020 for the evaluation periods indicated. The evaluations refer to the area of Berlin excluding surrounding areas.

Tab. 2: Statistic characteristic values for the long-term precipitation distribution in Berlin, 1991-2020

	Annual precipitation	Summer half	Winter half
Minimum [mm/a]	539	320	217
Maximum [mm/a]	618	352	270
Mean [mm/a]	581.3	335.0	246.3
Standard deviation [mm/a]	13.4	5.3	9.0

Tab. 2: Statistic characteristic values for the long-term precipitation distribution in Berlin, 1991-2020

Comparing the evaluations for the years from 1991 to 2020 with the evaluations for the **period from 1981 to 2010**, all maps display clear differences in their precipitation distributions (cf. Figure 7). However, the statistical characteristic values for the mean annual precipitation remain almost the same. Regarding the two hydrological halves of the year, it is evident that the summer half of the year is wetter on average (approx. +14 mm), while the winter half appears to be drier on average (approx. -16 mm) in the current evaluation period (1991-2020) compared to the previous one (1981-2010). For the period between 1991 and 2020, the spatial variance of the mean precipitation decreases, i.e. is more homogenous, in the summer half of the year, while it increases in the winter half.

The question of whether these statistical differences are a result of a change in data processing due to HYRAS-DE-PRE (1991-2020) as compared to REGNIE (1981-2010), or, whether they are due to climatic differences that occurred in the more recent reference period was not investigated as part of this data evaluation.

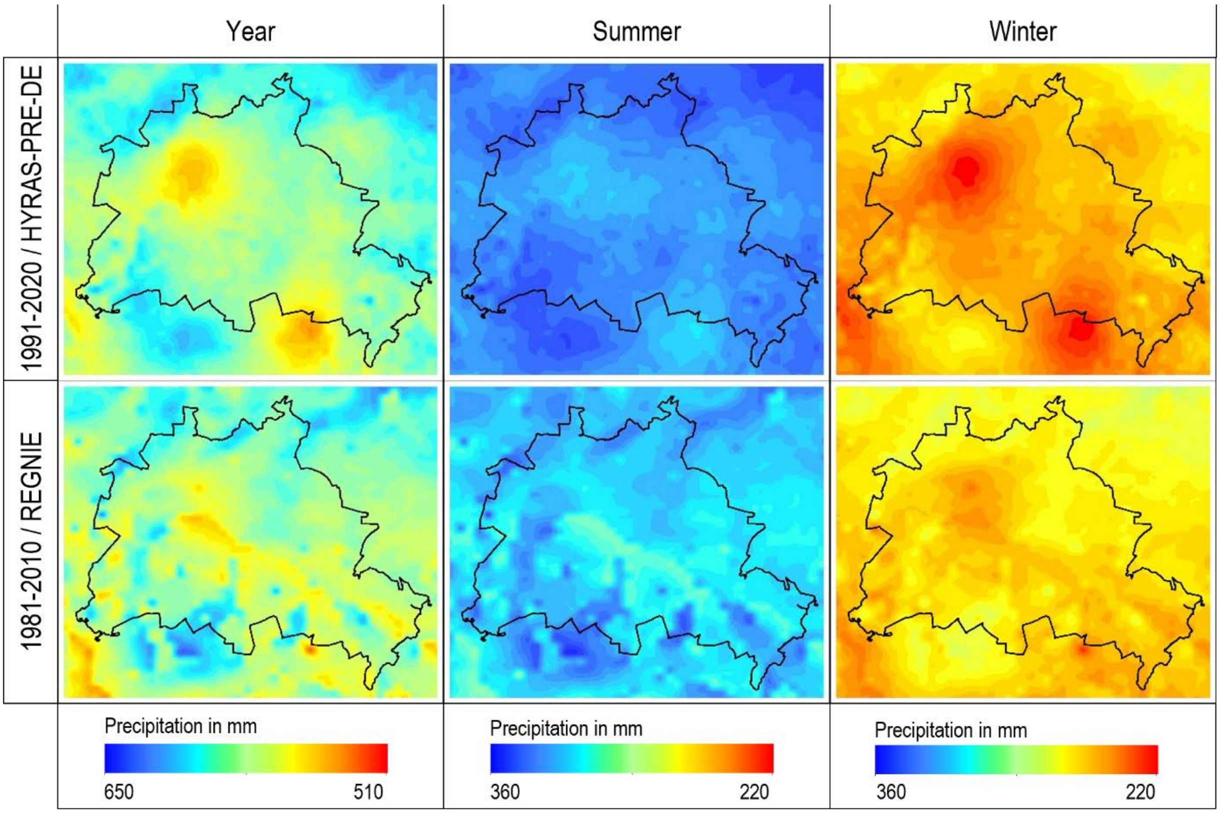

Fig. 7: Comparison of precipitation distributions for the evaluation period between 1991 and 2020 based on HYRAS-DE-PRE, and between 1981 and 2010 based on REGNIE. (ProAqua using the statistical base from DWD 2022b and DWD 2018).

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