2.1 Network of Climate and Precipitation Stations

The *Deutscher Wetterdienst* (*DWD, German Meteorological Service*) operates several networks of observation stations in Germany to acquire the data needed for describing weather and climate. The most important climate elements that are regularly measured are precipitation, air temperature, air humidity, air pressure, duration of sunshine and global radiation. These are also the basic data needed for many hydrological studies, for example the preservation of water resources, the protection against extreme hydrometeorological events at all time scales or water quality studies.

A particular meteorological parameter cannot be determined at each station with the same temporal and observational density. Depending on equipment and modes of operation, the DWD stations are grouped in different network categories. The three most important ones are the *synoptic network*, the *climate network* and the *precipitation network*. Map 2.1 shows the local distribution of these three major networks in Germany. The illustration is supplemented by the sites of the radar network which complements the direct measurements of the ground precipitation networks by indirect measurements of precipitation by radar.

The map of the climate and precipitation stations is placed in the Atlas before the hydrometeorological maps to enable a better appraisal of the information value of spatial presentations, areal values of parameters or of derived information. The density and distribution of the networks are decisive for the observation of the spatial variability of parameters. The precondition is that the measurements and observations are carried out at the stations on a regular basis, over many years and according to standardised guidelines.

Besides these networks other networks exist which are not shown on the Map 2.1. These include, for instance, the wind measuring network which supplements the wind measurements and observations at synoptic and climate stations, the aerological network, which records the meteorological conditions in the free atmosphere, a radiation network and a network for monitoring radioactivity.

On the historical development of meteorological networks

First precipitation measurements were reported from China, India and Palestine as early as from the 3rd to the 2nd millennium B.C. The Greek philosopher Aristotle gave a systematic description of meteorology in his "Meteorologica" in the 4th century B.C. The records of weather observations, which are based on this work, constitute important historical sources, and they can serve as proof of the occurrence of outstanding climatic and weather events. The development of meteorological instruments in the 17th and 18th centuries provided the basis for spatially comparable measurements in meteorology. The first observation network with unified organisation and equipment was established in 1781 by the Pfälzer Meteorologische Gesellschaft (Palatinate Meteorological Society) in Mannheim. The publication of meteorological yearbooks originated from this. The foundation of the International Meteorological Organisation in 1873, a predecessor of today's World Meteorological Organisation (WMO), intensified the efforts for the creation of international standardised measuring and observation networks. The systematic development of the station networks in Germany followed, and it lasted until the end of the 19th century. The oldest digitalised precipitation time series in the DWD's archives dates back to the year 1825.

The networks operated today by the DWD for the acquisition of meteorological data are products of a historical development; their establishment was repeatedly marked by compromises between the scientific-technological requirements and economic and other constraints. Observation stations are usually sited at locations where they can be representative of the climatic conditions of a larger area. Depending on the parameters to be measured, a sufficient spatial and temporal density of observations is needed. To satisfy the comprehensive need for data, the DWD has in addition to its professional network of synoptic stations with DWD staff secondary networks as well that are run by volunteers.

Evaluation of long time series

For the interpretation of the statistical distribution of climatological parameters in a certain area the following requirements must be fulfilled:

- sufficiently long series of observation data (dependent on the parameter)
- a standardised evaluation period (reference period)
- largely unchanged surroundings at the station during the reference period
- regular measurements at one place at fixed times
- standardised rules for instruments and observations

Following a recommendation of the WMO, climatological studies are based on a 30-year reference period to ensure statistical stability and allow international comparisons. Currently, the time series 1961-1990 is the reference period.

Secondary stations operated by volunteers often exist only for 15 to 20 years. High requirements are placed on the honorary observers regarding the precise timing of the observations and their exactness, so that the staff fluctuation at these stations is relatively high. Standardisation and comparability of measurements must also be ensured after the replacement of measuring equipment or its substitution as a result of new developments. However, even if observation series are free of gaps, the climatological conditions in the vicinity of a station may change in the course of time, for instance because of new buildings or growing trees, so that the series lose their temporal representativeness. Shorter data series and inhomogeneous sub-series are converted to the reference period by means of statistical-climatological methods. In this case one speaks of "reduced" series.

All stations of the DWD apply unified guidelines concerning the measuring times, the installation of measuring equipment, technical facilities and other boundary conditions. These rules are also laid down in international guides (WMO 1983, 1994). In order to acquaint the operators of other precipitation networks with these general principles as well, Germany established a "precipitation guideline" of nation-wide validity that is regularly updated (ATV et al. 1985, 1989, 1993, 1994). Since the raingauge according to Hellmann (Fig. 1) has remained unchanged since 1886, it has high relevance as the national reference instrument and ensures the comparability of long precipitation data series. It is still in use for daily precipitation measurements.

Map Structures

Map 2.1 shows the stations that were used in the study period 1961-1990. It can be seen at first glance that the three major networks together are relatively evenly distributed over the whole territory of Germany. The synoptic stations are simultaneously operated as climate stations and these again as precipitation stations. This means that precipitation is recorded at all measuring stations. To visualise these relations and to convey an impression of the network density, all stations are marked by a circle.

The table on Map 2.1 compares the measuring programmes of the three network categories and gives information on the number of stations, the mean distance between them and the timing of observations. A differentiation is made between the distribution of the stations in currently operating networks (status December 1996) and the distribution of stations which provided the basis for the interpretation of the hydrometeorological maps (reduced time series 1961-1990).

Fig. 1 Raingauge according to Hellmann

The collected precipitation (collecting surface 200 cm²) can be read from the measuring cylinder in mm

The synoptic network

In meteorology "synoptic" means an approach which determines the physical (sometimes also chemical) status of the atmosphere – i.e. the weather situation – and leads to weather forecasts. The meteorological parameters, which are observed and exchanged all over the world simultaneously in synoptic networks, describe the momentary weather. The German Meteorological Service operates such a synoptic network which is characterised by a comprehensive measuring and observation programme, high quality of observations, high temporal density of observations and availability of data in real-time. Since the data from these stations are also available for climatic studies, it is common to speak of synoptic-climatological stations. These are also constituents of the climate network.

The climate network

Climate is understood as a summary of weather phenomena over many years which characterises the mean condition of the atmosphere and is represented by the statistical parameters of a reference period. In the recent past, studies on extreme weather events and processes have gained more and more importance. To determine the climate over the whole area of Germany, the DWD operates a climate network in addition to the synoptic network. The stations of this network also have standardised technical equipment. The central part of a climate station is the screen with sensors for the dry and wet air temperatures as well as thermograph and hygrograph, mounted two metres above the ground (Fig. 2). The DWD's climate stations are usually run by voluntary observers. The climate station network is spatially denser than the synoptic one. However, the times of measurements and the measuring programmes are considerably reduced (see the table on Map 2.1). It can be seen on Map 2.1 that the climate stations are not evenly distributed over the territory. Many climatological parameters are more or less dependent on orography. The climate network is adapted accordingly: in orographically strongly structured areas, such as mountainous or alpine regions, the number of climate stations is higher than in the north German lowland.

Fig. 2 Screen of a DWD climate station

Measuring equipment: Thermometer for wet and dry air temperatures, thermograph and hygrograph

The precipitation network

In contrast to other climatic factors, precipitation shows a particularly high spatial and temporal variability. This necessitates a high density of precipitation stations and long observation periods so that mean precipitation depths can be shown in their spatial distribution. For this reason, the DWD operates additionally a precipitation network that is also run by volunteers. Together with the synoptic and climate stations the network comprises about 4,450 (current) or 4,750 (reduced) stations where precipitation is recorded (for the sum of the stations see the table on Map 2.1). The reference instrument at all stations is the raingauge according to Hellmann shown in Figure 1. Its surface of 200 cm² is one metre above the ground.

Fig. 3 Ombrometer

Automatic raingauge

Practical Information

Modernisation of networks

Especially because of the delayed availability of conventional climatological measurements, automatic measuring stations were established some time ago. The DWD began in 1996 to build an automated volunteer-operated precipitation network which uses an automatic instrument, the ombrometer (Fig. 3). However, experience has shown that observers are not redundant. Advantages of automatic stations consist in the possibility of acquiring meteorological data with high temporal density and without the subjective bias of the observer. The data are available in real-time and may be used additionally for weather warnings or forecasts. A disadvantage lies in the fact that the instrumental equipment of an automatic station differs from the equipment used in conventional stations. With a view to the discussions about possible climate changes, this should not be allowed to influence the existing long homogeneous time series. To ensure comparability, conventional measurements are made for reference. Moreover, the use of remote-sensing data (from radar or satellite) for climatological studies is gaining in significance. However, for the initial calibration of the remotely sensed data, observations of ground stations remain necessary. It can be assumed that the automation of networks and the integration of indirect methods in the coming years and decades will lead to a number of changes in the networks for climate and precipitation.

Additional information

Additional information on the measuring networks of the DWD may be found in the publications of the Deutscher Wetterdienst, such as the list of national/international weather stations (1992), the measuring and observation networks in the Federal Republic of Germany (1992) and in the updated lists and maps of the networks. Moreover, the DWD issues periodic publications of numerous measured data and derived parameters. These are mainly the Deutsche Meteorologische Jahrbuch (German Meteorological Yearbook), the Europäischer Wetterbericht (European Weather Report), the Jahreszeitenbericht (Seasonal Report), the Klimatologische Werte (Climatological Data), the Klima-Eilinformation (Climate Quick Information), the Monatlicher Witterungsbericht (Monthly Weather Report), the Tägliche Wetterdaten Deutschland (Daily Weather Data of Germany), the Großwetterlagen Europas (Synoptic Situation of Europe).