# The Century Flood of the River Elbe in August 2002: Synoptic Weather Development and Climatological Aspects

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## 1 An event of the century

The meteorological cause of the catastrophic floods along the Danube and - in particular – the Elbe rivers in August 2002 was an extraordinary weather situation, with various meteorological factors leading to such extreme precipitation as has never been recorded before in Germany. In parts of the Erzgebirge (mountain range between Germany/Saxony and Czech Republic) more than 300 mm fell in one day. On 12 August the record precipitation total of 352.7 mm was measured in the period from 5:00 Central European Summer Time (CEST) up to the same time at the following day at the meteorological station Zinnwald-Georgenfeld. Also in the region north of this low mountain range more than 150 mm fell over a widespread area in 24 hours, and even in the Berlin area approximately 100 mm were recorded. The above-mentioned data are extreme values, which – statistically evaluated according to previous observations - would be expected to occur less than once in 100 years.

The extreme precipitation was followed by a very quick rise in the water levels of the Elbe tributaries, in particular the rivers, which drain the Erzgebirge to the north. The water level of the Elbe subsequently reached a maximum mark, which had not been recorded for centuries. The total economic damages resulting from the August flood (the Czech Republic: € 3 billion, Austria: € 3 billion; Germany: € 9.2 billion) represent a new European record for flood damages. Floods never have merely one single cause, therefore it is important from the point of view of climatological research to examine more closely the individual meteorological factors leading to the flood. Only in comparison with the climatic temporal-spatial precipitation distribution can it be assessed how extraordinary and extreme the meteorological conditions for this event really were.

Figure 1: The flooding of the Elbe near Elster (left) and the flooded streets of Meissen (right), photos by M. Zebisch, TU Berlin.

# 2 Synoptic description of the weather situation

## 2.1 Synoptic development

An essential cause of the catastrophe was in the transport of cold maritime air from the Icelandic-Greenland area to the western Mediterranean Sea days before, where on 10 August a well-defined upper-air trough was formed. Dynamic lifting processes led to a rapid fall in air pressure in front of this low over Upper Italy, so that in the night of 11 August over the northern Adriatic Sea a so-called Vb-low was formed (core isobar 1000 hPa). The low included extremely moist and warm Mediterranean air into its circulation, a process that was decisive for the precipitation potential that later existed over Central Europe (Figure 2).

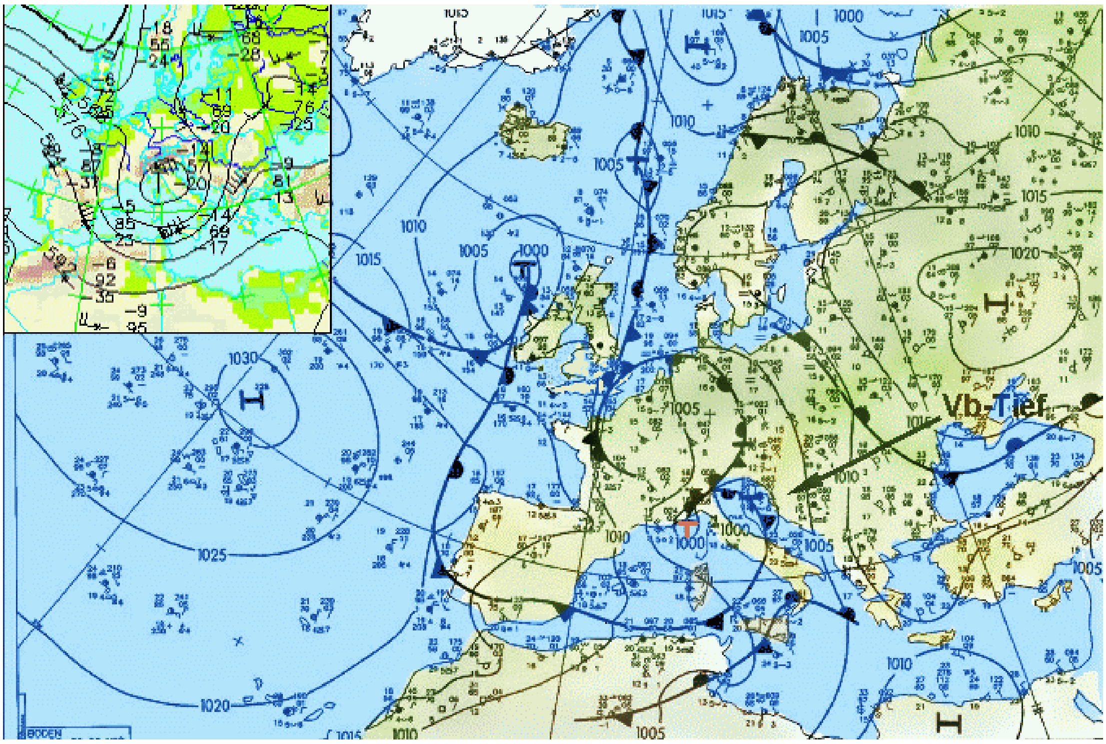


Figure 2: DWD surface weather chart dated 11 August 2002, 00 UTC (large picture) and absolute topography 500 hPa dated 11 August 2002, 12 UTC (small picture).

The low subsequently moved on "a Vb-track" north-eastwards (Figure 3), whereby its cloud structure was increasingly transformed into a vortex. At this time high-reaching frontal cloud bands with heavy rainfall, which also included thunderstorm cells, were already lying over the southern side of the Alps and over the Alps themselves. By 12 August the low had moved towards the Czech Republic, strengthening all the time, and later reaching Saxony. On the northern and western side of the low an expanded and strong lifting was connected to a divergent upper current (Figure 4), whereby persisting and abundant large-scale precipitation was initiated. Due to stable high pressure areas over eastern and western Europe the low finally became almost stationary and pivoted itself to a certain extent exactly over the eastern part of Germany. The atmosphere here was supplied again and again with warm and very moist, unstably layered air (advection from the Mediterranean and Black Sea), which experienced a large-scale lifting, condensation and immediate raining out.

The situation was intensified by the fact that on 12.08.2002, in the region of the Erzgebirge, due to the fall in pressure in the east and the increase in pressure in the west a strong pressure gradient developed, which resulted in a freshening, stormy north-west wind in this mountainous area. As a consequence, the air mass saturated by water vapor was orographically lifted in the north of the Erzgebirge, which led to extraordinary heavy precipitations.

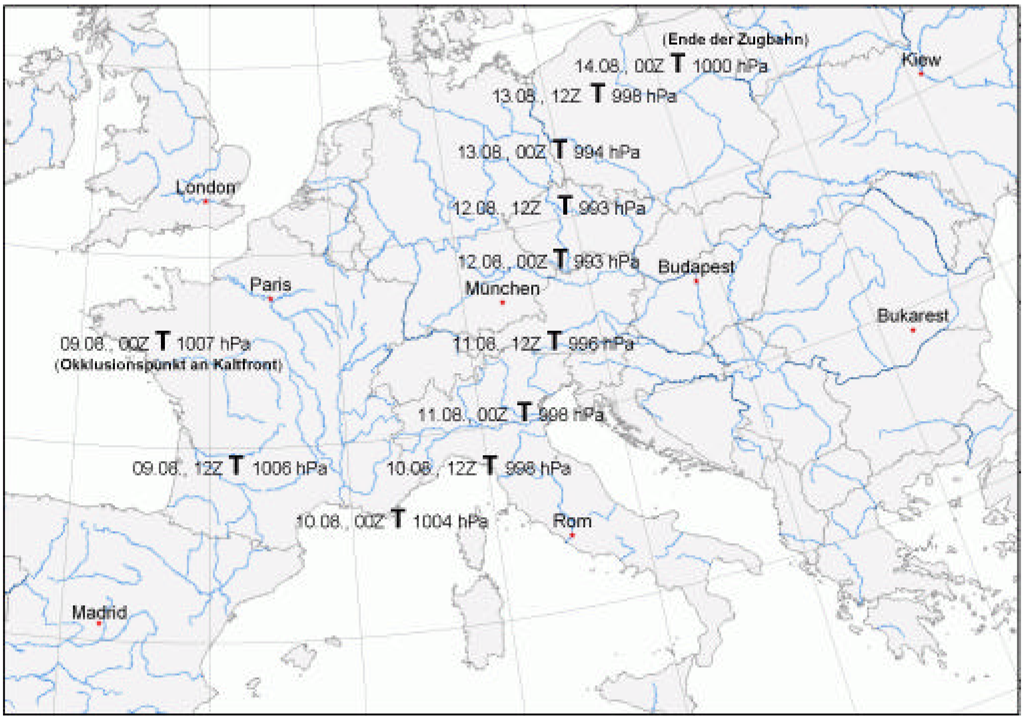


Figure 3: Track of the "Vb-low" with indication of the core pressure (map by M. Neumann, DWD).

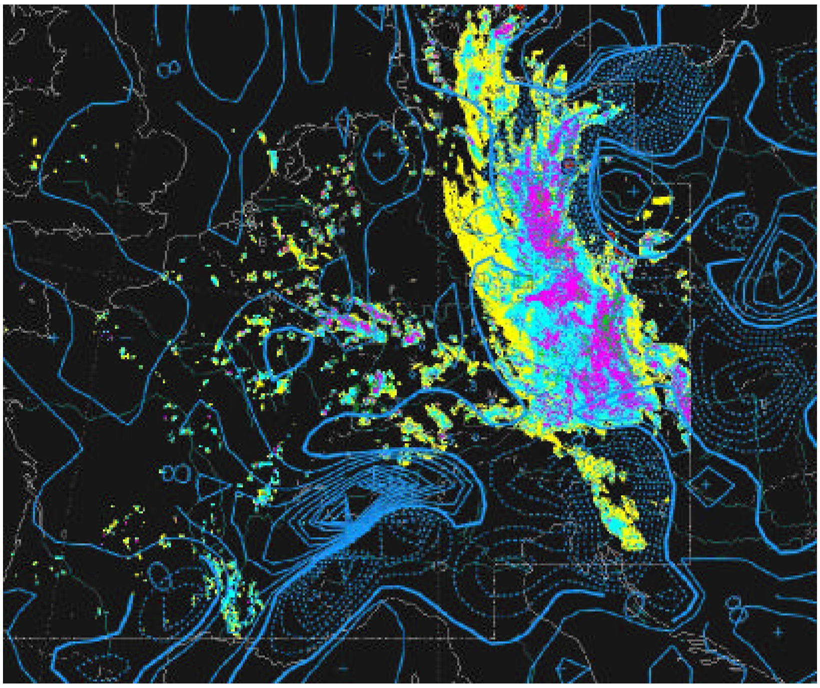

Figure 4: Radar image and omega field (broken line showing lifting in 500 hPa) for 12 August 2002, 12UTC.

## 2.2 Meteorological causes

The introductory paragraphs have already explained how the impact of various meteorological factors upon one another led to the catastrophic flood:

**The large-scale, strong and quasi-stationary lifting area**

was connected with the development of the Vb-low (Figures 2 to 4) and is to be classified as essential synoptic precondition of the heavy precipitation. The large-scale constellation of pressure and airflow over Central Europe changed only very slowly. Warm and very moist air was guided from the Mediterranean and Black Sea via the typical Vb-track, water vapor saturated and with an extended

**very high liquid water content,**

a necessary condition for record precipitation, which is naturally fulfilled much better in the summer than in the winter.

**Convective precipitation processes (showers, thunderstorms)**

in the moist-unstable air mass further east constituted a considerable additional effect locally. Essentially more significant, however, was the

**additional orographic lifting**

windward of the Erzgebirge due to a reinforcement of the pressure gradient at the rear of the low. Finally the

**already deeply water saturated ground and the relatively high water level**

of many rivers due to the heavy rainfall in the weeks before was responsible for the explosive nature of the Elbe flood, particularly since this river drains - contrary to most of the other rivers - the whole mountain range and not only one side.

On the basis of a synopsis and an interpretation of the observation material available (total precipitation measured at stations, other weather observations, radar and satellite images, lightning echoes etc.), the following estimation of the causal proportions of the various precipitation mechanisms can be made:

- Stratiform (scaled) precipitation 2 thirds
- Convective precipitation (showers, thunderstorms) 1 third

- Orographic intensification along the mountains doubling of the quantities

The extremely high diurnal precipitation and the devastating flash floods caused by it, which affected the places in and close to the Erzgebirge, resulted thus above all from the stemming at the northern edge of the mountains. Over all, the precarious flood situation along the Elbe and its larger tributaries with flooding in many places and towns was due to the combination of the five causes described above.

## 3 Measured data and comparison with forecasts

The extreme dimension of the flood disaster was thus based, as shown in chapter 2, also on the soil moisture saturation resulting from the rainy weather before. Figure 5 shows first on the left the precipitation totals for the period 6 - 8 August. The rainfall first centred on Upper Austria with amounts of more than 100 mm (which led to heavy flooding along the Danube), but it also rained considerably (20 to 30 mm) in the Erzgebirge. Some days later (Figure 5 on the right) the heavy rainfall expanded northwards to include the Czech Republic, Saxony and Brandenburg. In the period 10 -13 August, 100 mm were exceeded over widespread areas, with many places in the Erzgebirge reaching the 200 mm threshold. Zinnwald-Georgenfeld even reported 380 mm of rain. 312 mm fell on one day alone (06 to 06 UTC the following day), or even 353 mm if the reference interval is shifted by three hours (03 to 03 UTC). Table 1 shows further impressive individual values of the total precipitation measured. For example, in Dresden, 158 mm fell in 24 hours. The record precipitation also led to unusually high monthly values, which in the areas concerned varied mostly between 150 and 300 mm, which constitutes 200 to 350% of the rain which normally falls in the month of August (reference period 1961-1990).

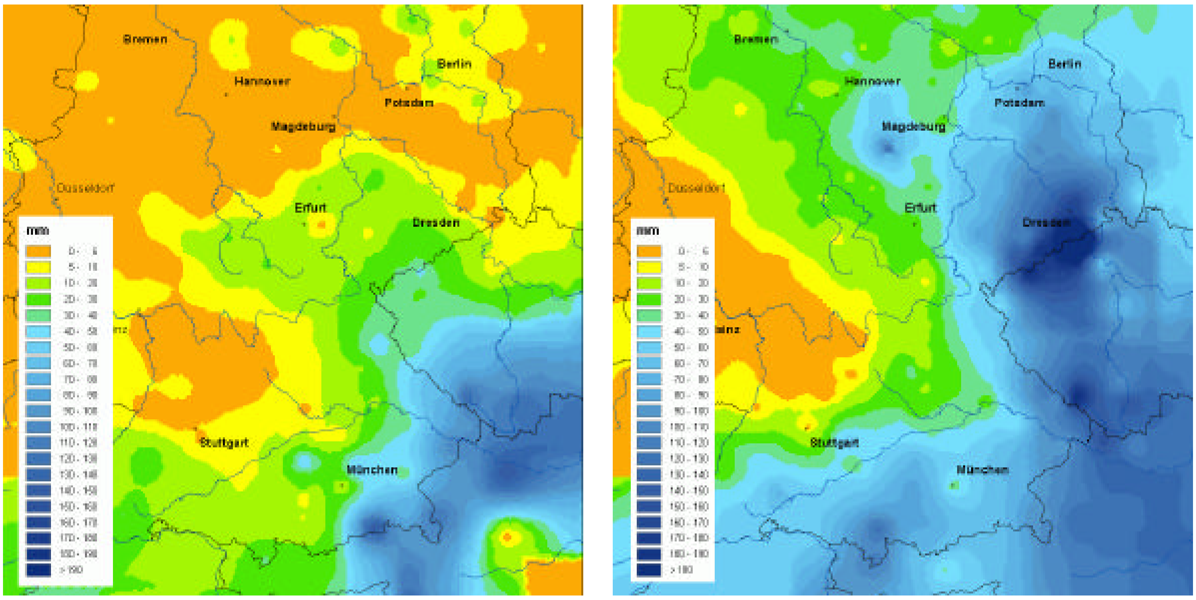


Figure 5: Precipitation totals of the periods 6 - 8 August (left) and 10 - 13 August, 2002 (right) in each case from 08 to 08 CEST (06 to o6 UTC).

The exact temporal course of events on 12 and 13 August is shown in Figure 6. The severe rainfall began in the early hours of 12 August and persisted, but with high fluctuations, until the late morning of the following day. On the first day extreme hourly precipitation totals of up to 30 mm were measured in the Erzgebirge (Zinnwald-Georgenfeld). Even in the northerly foreland (Dresden) 15 mm or more fell repeatedly. By 13 August the rain intensity had decreased to around 5 mm/hour in the mountains and 2 to 3 mm/hour in the lowlands.

Table 1: Measured precipitation totals for various periods in August 2002 in comparison to data and mean values observed earlier.
*) one observational day is counted from 6 UTC to 6 UTC the following day.

| Station name | Station height ab. msl (m) | 1d-maximum of August 2002 | Date of maximum of August 2002*) | 3d-totals 10.-12. of August 2002*) | August totals 2002 | August normals average 1961-90 | relation of August 2002 to 1961-90 |
|---|---|---|---|---|---|---|---|
| Kempten | 705 | 62.2 | 10.08. | 126.0 | 360.8 | 156 | 231% |
| Oberstdorf | 810 | 67.1 | 11.08. | 115.1 | 279.6 | 213 | 131% |
| Berlin-Tempelhof | 49 | 65.1 | 12.08. | 69.0 | 156.3 | 61 | 256% |
| Potsdam | 99 | 84.1 | 12.08. | 90.9 | 183.3 | 60 | 306% |
| Cottbus | 69 | 49.9 | 12.08. | 60.0 | 136.9 | 69 | 198% |
| Doberlug-Kirchhain | 97 | 93.8 | 12.08. | 102.2 | 165.4 | 64 | 258% |
| Oschatz | 150 | 108.5 | 12.08. | 119.0 | 181.7 | 61 | 298% |
| Dresden-Klotzsche | 222 | 158.0 | 12.08. | 168.9 | 233.1 | 76 | 307% |
| Aue | 391 | 79.9 | 12.08. | 145.8 | 230.5 | 83 | 278% |
| Chemnitz | 418 | 78.0 | 12.08. | 109.2 | 196.5 | 78 | 252% |
| Marienberg | 639 | 166.5 | 12.08. | 188.3 | 308.2 | 89 | 346% |
| **Zinnwald-Georgenfeld** | 877 | **312.0** | 12.08. | **379.9** | **469.6** | 103 | **456%** |
| Fichtelberg | 1213 | 137.8 | 12.08. | 199.7 | 299.1 | 106 | 282% |
| Grosser Arber | 1446 | 88.5 | 12.08. | 121.1 | 261.6 | 131 | 200% |

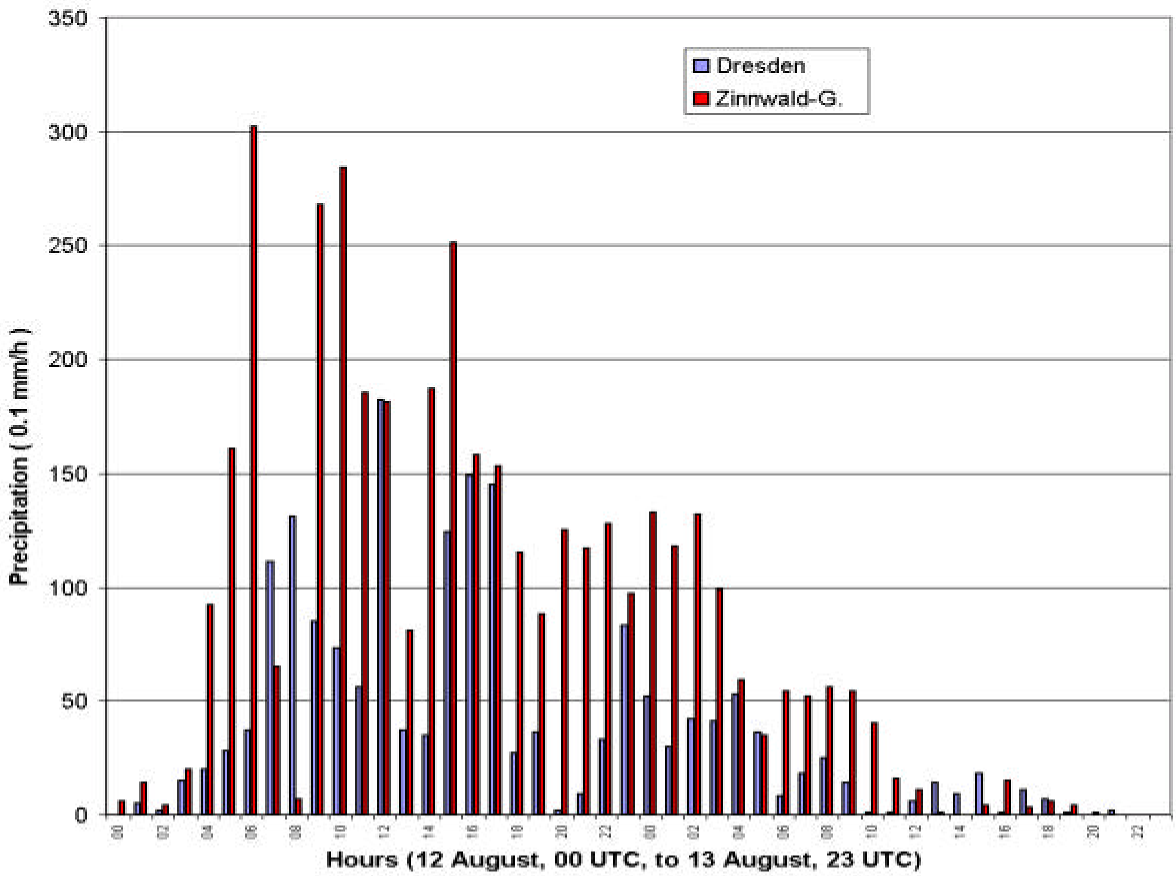


Figure 6: Hourly precipitation totals from 12 August, 00 UTC, to 13 August, 24 UTC.

Figure 7 shows the observed and prognosticated precipitation totals from DWD models, GME (global) and LM (local), for the 72-hour period from 10 August 2002, 06 UTC, to 13 August 2002, 06 UTC. The daily prognoses for the forecast period of 6 to 30 hours after model start (00 UTC) were used for the comparison. In the case of this relatively short forecast time position and time of occurrence of the maxima agreed quite well; however, in the comparison of the models with the observations, the absolute precipitation extreme in the Erzgebirge does not agree exactly.

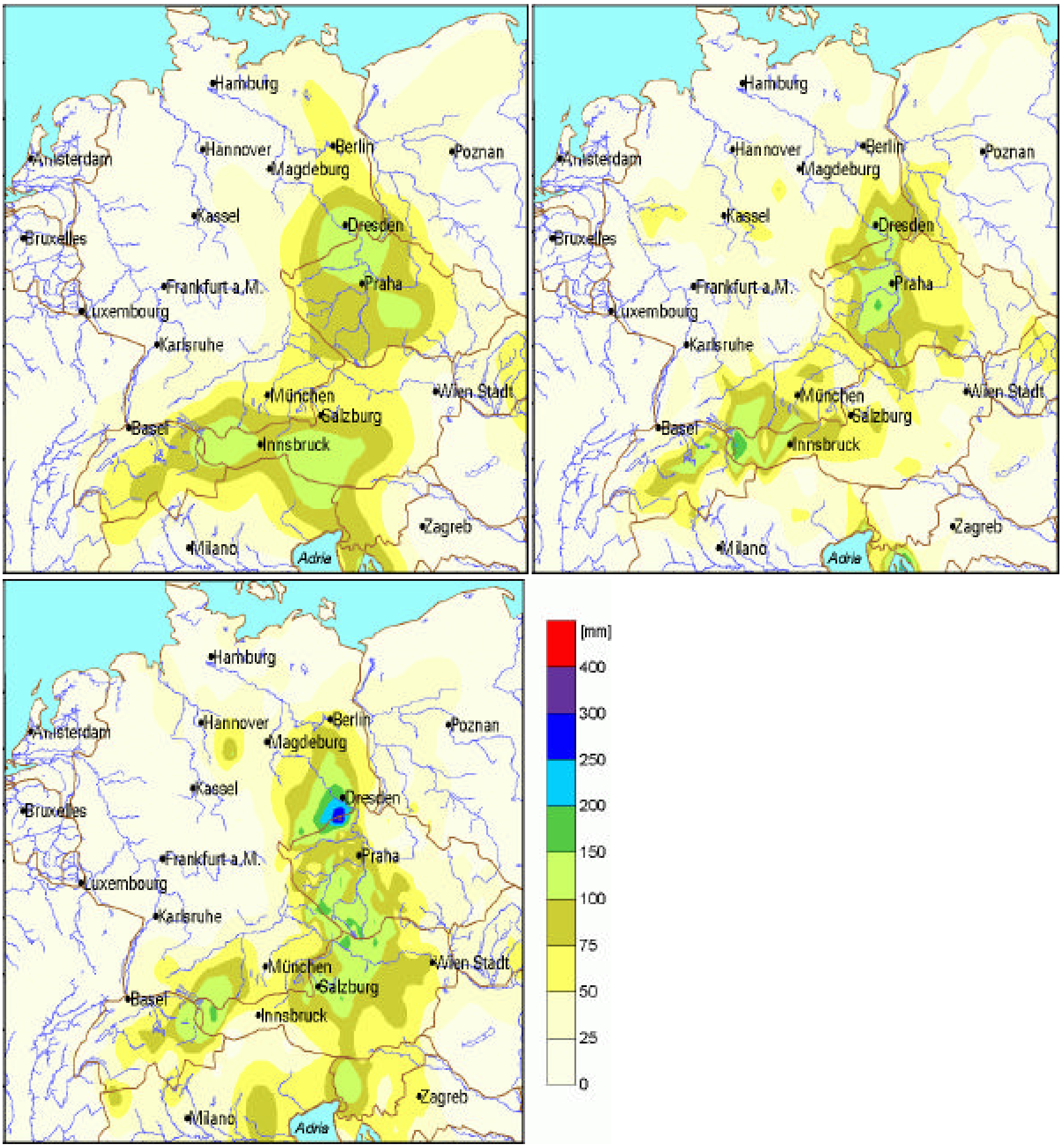


Figure 7: Comparison of forecast and observation for the three-day period 10 August 2002, 06 UTC, to 13 August 2002, 06 UTC.
Top left: Precipitation predicted by GME (global model of the DWD),
Top right: Precipitation predicted by LM (local model of the DWD),
Bottom: Precipitation observations from the DWD surface networks, mapped using kriging.

The various weather forecast models (DWD, ECMWF, USA, UKMO) showed very different prognosis signals in the medium-range period (i.e. 3 to 10 days in advance). Generally it must be stated that weather forecast models have their limits as far as accuracy goes. On the one hand this is due to the limited density of the observation networks for the data assimilation, on the other hand to the unavoidable simplifications in the simulation of sub-scaled physical processes in cloud dynamics and the microphysics of the formation of precipitation. Also the considerable influence of orography can only be taken into account in the models in a smoothed form. Therefore the actual track of a Vb-low can quite possibly differ somewhat from that which was predicted. Also the exact position and intensity of local extreme precipitation can hardly be forecasted - at most their regional probability.

Although the global model GME of the DWD issued a severe weather warning on 7 August, it rejected it again in the subsequent runs. The first consistent indication of the severe weather to be expected was provided by the US American AVN model on 11 August in the 00 UTC run. The other models (ECMWF, GME, LM) followed on 11 August at 12 UTC and on 12 August at 00 UTC. The LM had finally detected the situation very well by 0 UTC on 12 August.

The DWD already indicated the development of dangerous weather on 8 and 9 August in its standard weather forecasts. On 11 August, 13:59 CEST a preliminary severe weather warning and at 23:08 CEST an update of the severe weather warning followed. Further updates of the severe weather warnings were issued from 12 August to 14 August.

The "heavy rain area" signal was already formed several days before in some models, but the exact location, particularly in relation to individual catchment areas, and the absolute precipitation total could not be prognosticated exactly enough. Furthermore the signal was not temporally consistent in the successive model runs. From all this it can be assumed that in the sense of an "Early Warning" the models did provide indications of an extreme weather situation, which led to increased attention on the part of the forecast meteorologists, but that the accuracy was obviously not sufficient enough at this time to be able to issue concrete warnings. Throughout Europe, therefore, intensive work is being done to further improve the advance warning time and quality of flood warnings, e.g. within the scope of the EU-Projects "European Flood Forecasting System (EFFS)" and "Development of an European Land Data Assimilation System to predict floods and droughts (ELDAS).

## 4 Climatological assessment

200 per cent of the mean monthly precipitation total for August had already fallen in the first half of the month in a belt reaching from Berlin and Brandenburg via Saxony to the Czech Republic. In the Erzgebirge and in the southern Czech Republic even three times the mean monthly precipitation total occurred in this time. With a maximum monthly precipitation total of 470 mm for August 2002 in Zinnwald-Georgenfeld, more than four times the mean precipitation for August was measured.

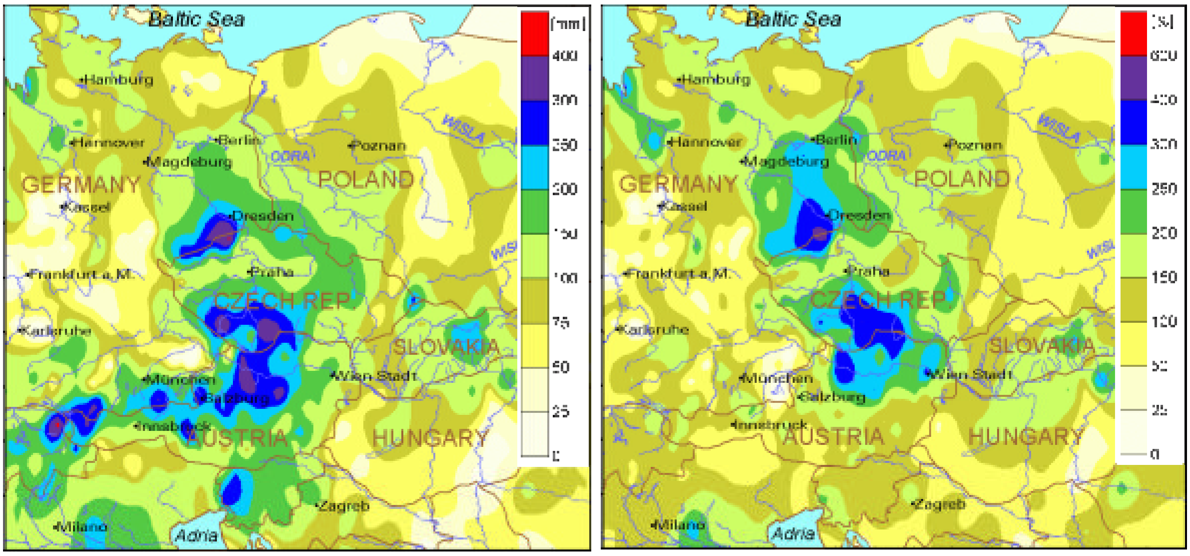


Figure 8: Monthly precipitation total in mm/mon for August 2002 (left) and the amount of precipitation in per cent in relation to the period 1961-1990 (right). Data base: Observations of 614 stations (left) and 415 stations (right).

The maximum of both, the regional precipitation total as well as the anomaly, cover the Erzgebirge, located in the Elbe catchment area. The belt of the unusually high monthly precipitation follows to a large extent the course of the Elbe river (Figure 8). The measurements from many stations in the area extending from Austria via Saxony to Berlin/Brandenburg resulted in the highest monthly precipitation totals ever measured in August since records began. Figure 9 shows the time series of the August precipitation for selected stations.

On 12 August 312 mm was recorded at the DWD station Zinnwald-Georgenfeld, the highest daily precipitation total ever measured in Germany. To be correct, this value applies to the period 12 August, 6 UTC, to 13 August 2002, 6 UTC (= 7 CET resp. 8 CEST), which corresponds to the usual observation interval. As hourly recordings are made at Zinnwald, the absolute highest 24-hour precipitation total of 352.7 mm could also be determined, i.e. in the period 12 August, 3 UTC, to 13 August, 3 UTC. Up to then 260 mm was considered as record daily precipitation total, observed on 6 July 1906 in Zeithain, district of Riesa. The three-day (406 mm) and monthly (470 mm) precipitation totals measured in Zinnwald-Georgenfeld had, however, already been clearly exceeded in Stein, district of Rosenheim, in July 1954 with 458 mm in three days and 779 mm for the month (see table 2).

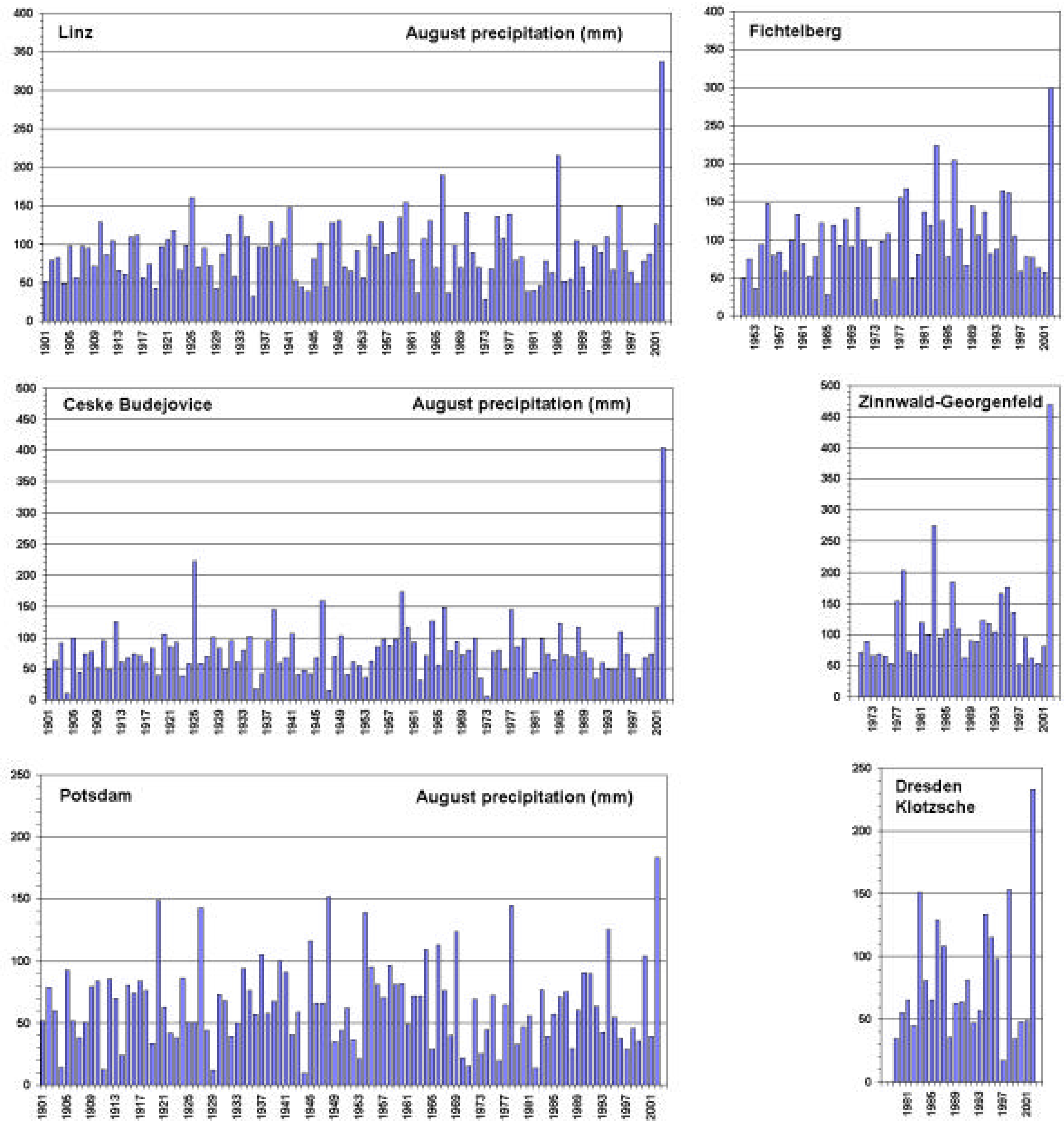


Figure 9: Time series of the monthly August precipitation totals at the stations
Linz (Danube), Ceske Budejovice (Czech Republic), Potsdam,
Dresden-Klotzsche (Elbe), Fichtelberg and Zinnwald-Georgenfeld.

A comparison with extreme values observed world-wide (cf. Figure 10) shows that for precipitation lasting for more than one hour, world-wide maximum values were by no means reached in central Europe, which is due to the favoured climatic conditions prevailing here, as compared with the tropics and areas with typhoon risk.

Table 2: The extreme precipitation totals observed in Germany for various observation time intervals (one observational day = 06 UTC to 06 UTC subsequent day). The values of August 2002 are shown in red. - Data source: DWD.

| Intervall | Precipitation depth(mm) | Station name (district / province) | Date |
|---|---|---|---|
| 8 min | 126 | Fuessen (Ostallgaeu) | 25 May 1920 |
| 1 h | 200 | Miltzow (Nordvorpommern) | 15 September 1968 |
| 2 h | 239 | Daudenzell (Baden-Wuerttemberg) | 27 June 1994 |
| 1 day | 260 | Zeithain (Riesa / Sachsen) | 6-7 July 1906 (6 – 6 UTC) |
| 1 day | 312 | Zinnwald-Georgenfeld (Sachsen) | 12-13 August 2002 (6 – 6 UTC) |
| 24h | 353 | Zinnwald-Georgenfeld (Sachsen) | 12-13 August 2002 (3 - 3 UTC) |
| 2 days | 377 | Seehaus bei Ruhpolding (Traunstein) | 7-9 July 1954 |
| 3 days | 406 | Zinnwald-Georgenfeld (Sachsen) | 11-14 August 2002 (6 – 6 UTC) |
| 3 days | 458 | Stein (Rosenheim) | 7-10 July 1954 |
| 7 days | 515 | Schneizlreuth-Weissbach (Berchtesgaden) | 7-14 September 1899 |
| 10 days | 652 | Stein (Rosenheim) | 1-11 July 1954 |
| 1 month | 470 | Zinnwald-Georgenfeld (Sachsen) | August 2002 |
| 1 month | 779 | Stein (Rosenheim) | July 1954 |
| 30 days | 810 | Baiersbronn-Zwickgabel (Schwarzwald) | 7 Dec. 1993 - 6 Jan. 1994 |
| 12 months | 3,661 | Purtschellerhaus (Berchtesgaden) | Dec. 1943 - Nov. 1944 |

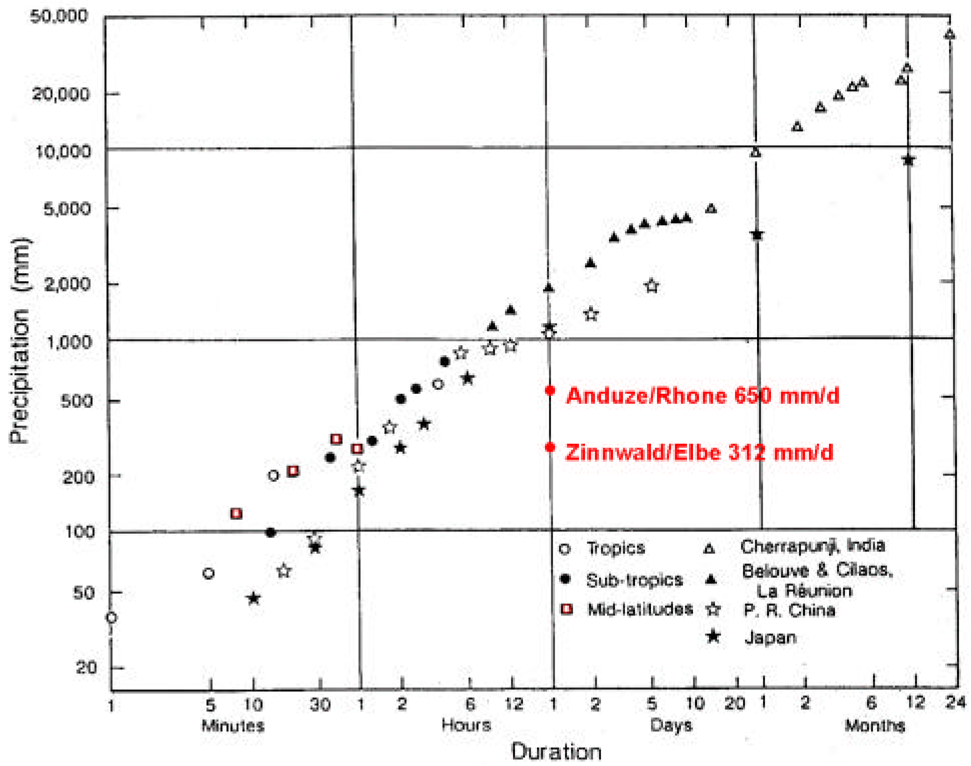


Figure 10: Extreme precipitation totals measured world-wide for various stages of duration (diagram according to Matsumoto, 1993, supplemented by the new European extreme values observed at Zinnwald, 12 August 2002, and at Anduze, southern France, 8 September 2002).

But even for our climate higher, theoretically possible precipitation totals have been calculated: The study "Maximierte Gebietsniederschlagshöhen in Deutschland" (Maximised Areal Precipitation Totals in Germany), which the DWD carried out on behalf of the Deutscher Verband fuer Wasserwirtschaft und Kulturbau e.V. (DVWK

1997), provided "a regionally adjusted maximised grid point precipitation total" of 375 mm/24h and 445 mm/72h for the eastern part of Land Brandenburg as well as 800 mm/24h and 1340 mm/72h for the eastern part of the Bavarian Alps. Corresponding values for the Erzgebirge area were not published. These values were estimated on the basis of the extreme values observed in the region, the regional land form (orography) as well as the most unfavourable values for humidity and wind speed. The authors of the study qualify that the results represent "an approximation to the possible physically/climatological maximum" and that the calculated values will not be reached "according to human estimation", they state, however, they also state that these values could apply to the current climate conditions only.

This restriction applies in particular to the recurrence times of heavy precipitation totals, used in applied hydrology, in particular in hydraulic engineering, which are based on observed precipitation data from the 30-year period from 1951 to 1980 (Bartels et al. 1997). The counting of the measured values (classified according to duration and total amount of precipitation) and application of a statistical extreme value distribution resulted in recurrence times for periods of up to 100 years depending on station. According to these statistics the maximum 24- and 72-hour precipitation totals observed in August 2002 at the stations Zinnwald-Georgenfeld, Fichtelberg, Marienberg and Dresden-Klotzsche are expected to occur less than once in 100 years.

The DWD plans to update the atlas of recurrence times for the total period 1951 to 2000. A comparison of the results for two subperiods could then supply information on changes in extreme value behaviour, particularly recurrence times, as a result of the climate change during the second half of the 20th century. The first results of another study, independent of this project, with the few available long data series (Grieser and Beck 2003) already show that a change in the extreme value behaviour of daily precipitation totals in Germany can be proved significantly.

In the previous considerations it had not been stressed that precipitation is not only a basic quantity in relation to time (there is no exact instantaneous recording, but only - although short - time intervals can be observed), but is also in principle an area-related quantity. Even the observation "point", i.e. the funnel of the precipitation gauge is, strictly speaking, an area. According to general technical opinion, the conventional local gauge measurements represent, in case of a suitable installation of the instrument, daily precipitation or of longer time intervals within a radius of approximately 3 km or for an area of 25 km².

In order to assess the meteorological conditions, which have led to the flooding of a rather large river such as the Rhine, Elbe, Vistula, Oder, Main, Moselle or Ems, the individual local precipitation measured is as such not yet decisive. The river run-off respectively the flood level, depends on the areal precipitation in the hydrological catchment area. It is thus necessary to determine the spatial distribution of the precipitation from the point data of the measuring networks, whereby radar images and numeric models can provide additional information in individual cases. From the areal distribution of the precipitation the quantities of water fallen in the relevant tributary catchments are then to be calculated.

Based on the generation mechanisms of precipitation a relationship exists between the maximum precipitation total, its duration and the spatial expansion of the affected area. To put it simply, it can be presupposed that, the longer extreme precipitation persists, the larger the affected area is. In this connection, however, different factors play a large role, firstly the regional orographic and climatic conditions in general and then, in individual cases, the weather situation.

In the already above-mentioned DVWK-Study empirically computed maximised area precipitation of different duration (1, 12, 24 and 72 hours) and area sizes (25, 100, 500 and 1000 $km^2$) separated for summer and winter conditions for Germany were mapped. With an area of 1000 $km^2$ the northern Erzgebirge falls within the classes 300 mm/24h to 400 mm/24h and/or 450 mm/72h to 550 mm/72h. The precipitation totals observed there in August 2002 show that the results of this study are by no means unrealistic.

Heavy precipitation, which leads to regional flash floods, is not at all unusual in the Erzgebirge (Marx 1966, 1966a and 1967). In the evening of 8 July 1927, for example, two unusual cloudbursts occurred over the watershed between the Mueglitz and the Gottleuba (Alt and Fickert 1936), which in the shortest time produced precipitation totals of up to 200 mm. These resulted in devastating flash floods of the rivers concerned, which were regionally limited to a small area. The precipitation responsible for the Elbe floods of August 2002 was, however, not only more intensive, it lasted considerably longer and covered - together with the Vb-cyclone moving northwards - a significantly larger area.

### The climate trend

The statistics based on time series of daily precipitation data from Grieser and Beck (2003) show in particular that the proportion of heavy precipitation (of the total annual precipitation) has increased during the period from 1961 to 2000.

A climatic scenario for the course of the next 50 years has shown a continuation of this trend (Jacob 2002, Buelow 2003). In this study of the Max Planck Institute for Meteorology, Hamburg, it was assumed that the global $CO_2$ emission will continue to rise moderately (IPCC emission scenario SRES B2). This is neither the most favourable presumption (no further rise) nor the most unfavourable (rise as before). The distribution of precipitation was simulated with the MPI regional model REMO (a variant of a DWD forecast model). The regional model was driven by the global MPI Climate Simulation Model ECHAM4 (Jacob 2002). According to this scenario the period 2040 to 2049 shows far larger proportions of the higher precipitation intensities of the total precipitation compared with the period 1990 to 1999 (Figure 11). An evaluation of this study, which has not yet been completed, is still pending.

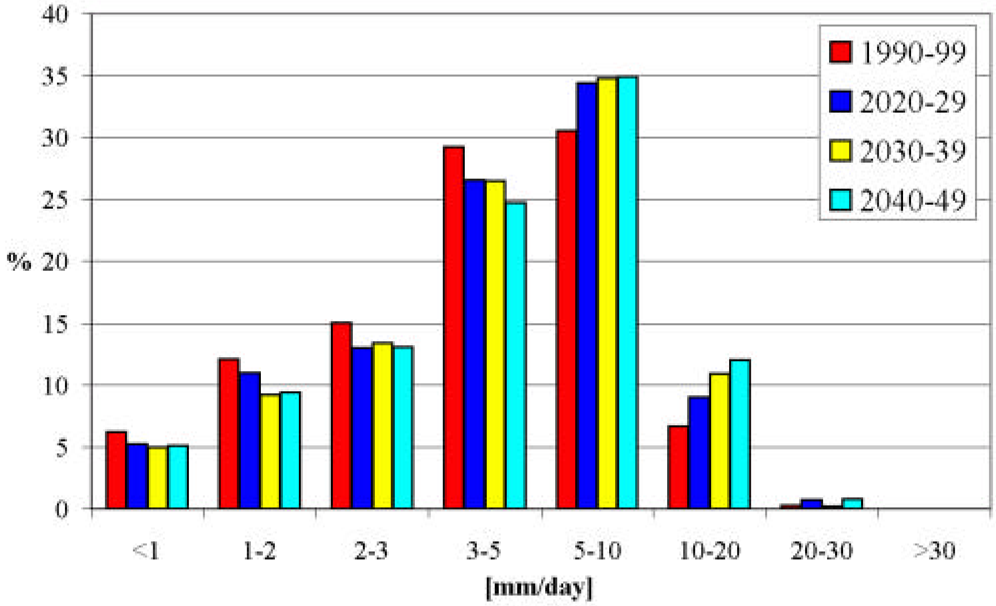


Figure. 11: Calculated precipitation for the Elbe catchment area in the course of the next 40 years, showing the increase for high intensities (GLOWA-Elbe, Buelow 2003)

## 5 On the frequency of floods

We finally come to the questions, which are asked by politicians, journalists and not least by those, who were affected by floods along rivers in recent years: Has the frequency of flooding by German rivers increased in the course of the past few years? Will German rivers flood more frequently in future?

The World Health Organisation (WHO 2002) has published a diagram showing an almost continuous and dramatic increase in the number of flood disasters in Europe between the years 1975 to 2001. But caution is advised in the interpretation! The criterion for classifying a flood as being catastrophic has been set as being the cause of death of 10 or more people. This is not suitable from a climatological or hydrological point of view. Decisive for this number is whether inhabited areas were flooded, villages buried under mud avalanches or, as has actually happened, camping sites were swept away. It is also questionable as to how indirect deaths were classified and whether, in building up the data bank, the supply of information and the sensitivity in acquiring the data have remained the same from year to year or have risen.

The last 10 years have brought us a number of unusual floods in Europe, several of them being "century floods", of which only the most important can be enumerated here:

- Century flood of Rhine and Moselle in December 1993
- Century flood again of Rhine and Moselle in January 1995
- Century flood of the Oder in July 1997
- Flood of the Danube and Lake Constance in May 1999
- Extensive and long-lasting floods in western Europe, in particular in south England and Wales, in the autumn of 2000

- Flood of the Vistula in July 2001
- Flood of the Danube in August 2002
- Century flood of the Elbe in August 2002
- Extreme precipitation and dreadful floods in southern France in September 2002
- Severe flooding in parts along many German rivers in January 2003

An evaluation of water level measurements along various rivers in southern Germany resulted in no or only very weak trend significances for the annual maximum discharges (working group KLIWA 2002). However, this result is not applicable on the probability of extreme floods. The difficulty in statistically analysing the probability of extreme floods lies on the one hand in the various causes, on the other hand in the mostly very large intervals between the individual events with comparable causes. Meteorological factors are the very varied temporal-spatial distribution of precipitation, soil moisture, snow melt and river ice formation. Non-meteorological influences are inter alia the natural and man-made changes to the river bed, which have occurred in the course of time, discharge management (e.g. opening of dams) and dam or dyke breaks during the flood events. Taking the six greatest maximum water levels of the Elbe at Dresden during the last 300 years - i.e. 857cm in March 1784, 824cm in February 1799, 877cm in March 1845, 824cm in February 1862, 837cm in June/July 1890, and 940cm in August 2002 - into consideration, the recent August flood of the Elbe is thus an event beyond compare (BfG 2002). The four earlier cases were winter floods, the summer flood of 1890 not only goes back 112 years, the water level was also 1m lower.

Despite the accumulation of extreme floods in the last few years, it cannot be concluded from flood data and with statistical methods that a climatic change has caused an increase in the flood frequency. Each flood may be regarded as an individual single event due to manifold meteorological and non-meteorological influence factors which are taken into account.

There is no doubt, however, that there has been an increase in heavy precipitation. For the past the statistics of the precipitation observations show this as do physically well-founded conclusions from the observed rise in air temperature. Concerning the future climatic development and its consequences for the frequency of extreme events, estimates of relevant climatic researchers concur (e.g. Grassl 1998, IPCC 2001, Rahmstorf 2002, MPI 2003) that the water cycle will be intensified by the global warming. Higher temperatures cause higher evaporation if the earth's surface is moist. This leads to an increased drying out of the soil in some parts, while the evaporated quantity of water must flow back to the surface somewhere as precipitation. The intensification of the water cycle is coupled directly with an intensification of the energy transformations in the atmosphere, which has to be expressed in a reinforcement of the dynamics. Thus one can also presume that there will be an increase in the instability of the atmospheric stratification. All this appears to be an indication of an increase of extreme events such as storms and heavy precipitation. Also the numeric climatic models, which contain the described physical connections, if perhaps not with final accuracy, but in numerical objective form, confirm these conclusions (MPI 2003).

## 6 Result

The large floods of the last decade have shown that, despite all attempts at regulation and damming up, catastrophic floods continue to occur. Numerous people have lost their lives, and heavy ecological and economic losses have been caused. The climatic conditions will probably get worse rather than better in future. Therefore more intensive efforts are necessary in climate protection and in the adjustment to the consequences of the climate change. Our society must take the possibility of future floods into account, in that sufficient flooding areas are restored or created. Flood risk areas should be kept free of settlements, which requires corrected land use and area planning. Not least must work also continue on improving transregional warning and flood disaster control systems, since floods like the August 2002 flood along the Elbe and its tributaries can never be completely prevented, even with the best precautions.

The authors would like to thank: Peter Finger, Tobias Fuchs, Astrid Heller, Anja Meyer-Christoffer, Peter Otto, Udo Schneider, Peter Stender and Jan Nicolas Breidenbach (all DWD/GPCC), Juergen Grieser and Christoph Beck (DWD, Project VASClimO), Hermann Maechel (DWD, Project ACSYS-APDA), Ute Heil (DWD/Nat. Climate Data Centre), Gerhard Mueller-Westermeier and Volker Zins (DWD/Climatology), Manfred Neumann (DWD/Synoptic), Gabriele Malitz and Bernd Dietzer (DWD/Hydrometeorology), Ulrich Damrath (DWD/Model Verification), Lubomir Coufal (Czech Hydromet. Inst.), Reinhard Boehm (ZAMG Vienna), Tanja Cegnar (Environm. Agency Slovenia), Katharina Buelow (MPI-Met Hamburg) and Marc Zebisch (TU Berlin) for the provision of data, tables, pictures and literature, as well as for constructive discussions.

The German version of this paper has been published in DWD Klimastatusbericht 2002. Special thanks are given to Astrid Heller, Annemarie Link and especially to Susan Wiegleb for translation into English.

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