



What made the  
June 2013 flood in  
Germany an  
exceptional event?

K. Schröter et al.

# What made the June 2013 flood in Germany an exceptional event? A hydro-meteorological evaluation

K. Schröter<sup>1,3</sup>, M. Kunz<sup>2,3</sup>, F. Elmer<sup>1,3</sup>, B. Mühr<sup>2,3</sup>, and B. Merz<sup>1,3</sup>

<sup>1</sup>Helmholtz Centre Potsdam, GFZ German Research Centre for Geosciences,  
Section Hydrology, Potsdam, Germany

<sup>2</sup>Karlsruhe Institute of Technology, Institute for Meteorology and Climate Research,  
Karlsruhe, Germany

<sup>3</sup>CEDIM – Center for Disaster Management and Risk Reduction Technology, Potsdam,  
Karlsruhe, Germany

Received: 23 June 2014 – Accepted: 30 June 2014 – Published: 15 July 2014

Correspondence to: K. Schröter (kai.schroeter@gfz-potsdam.de)

Published by Copernicus Publications on behalf of the European Geosciences Union.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures



Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



## Abstract

The summer flood 2013 sets a new record for large-scale floods in Germany since at least 1952. In this paper we analyze the key hydro-meteorological factors using extreme value statistics as well as aggregated severity indices. For the long-term classification of the recent flood we draw comparisons to a set of past large-scale flood events in Germany, notably the high impact summer floods from August 2002 and July 1954. Our analysis shows that the combination of extreme initial wetness at the national scale – caused by a pronounced precipitation anomaly in the month of May 2013 – and strong, but not extraordinary event precipitation were the key drivers for this exceptional flood event. This provides new insights to the importance of antecedent soil moisture for high return period floods on a large-scale. The data base compiled and the methodological developments provide a consistent framework for the rapid evaluation of future floods.

## 1 Introduction

In June 2013, wide parts of Central Europe were hit by largescale flooding. Particularly southern and eastern Germany were affected, but also other countries such as Austria, Switzerland, Czech Republic, Poland, Hungary, Slovakia, Croatia and Serbia. Almost all rivers in Germany showed high water levels: the Elbe between Coswig and Lenzen, the Saale downstream of Halle, and the Danube in Passau experienced new record water levels. Severe flooding occurred especially along the Danube and Elbe rivers, as well as along the Elbe tributaries Mulde and Saale. In the Weser and Rhine catchments exceptional flood magnitudes were, however, observed only locally in some smaller tributaries. The area affected most in the Rhine catchment was the Neckar with its tributaries Eyach and Starzel. In the Weser catchment the Werra catchment was affected most, in particular the discharges in the Hasel and Schmalkalde tributaries were on an exceptional flood level (BfG, 2013). As a consequence of major dike breaches at the

HESSD

11, 8125–8166, 2014

### What made the June 2013 flood in Germany an exceptional event?

K. Schröter et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

⏪

⏩

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



Danube in Fischerdorf near Deggendorf, at the confluence of the Saale and Elbe rivers at Groß Rosenberg and at the Elbe near Fischbeck large areas were inundated with strong impacts on society in terms of direct damage and interruption of transportation systems, see Fig. A1 in the Appendix for geographic locations.

Estimates on overall losses caused by the flooding in Central Europe are in the range of EUR 11.4 billion (Munich Re, 2013) to EUR 13.5 billion (Swiss Re, 2013), whereof EUR 10 billion occurred in Germany alone. Current official estimates of economic loss for Germany amount to EUR 6.6 billion (Deutscher Bundestag, 2013) with additional EUR 2 billion of insured losses (GDV, 2013). These numbers are about 60 % of the total loss of EUR 14.1 billion (normalized values by 2013) in Germany caused by the extreme summer flood in August 2002 (Kron, 2004; Thielen et al., 2005) which remains the most expensive natural hazard experienced in Germany so far.

The June 2013 flood was an extreme event both with regard to magnitude and spatial extent and its impact on society and economy (Blöschl et al., 2013; Merz et al., 2014). The Forensic Disaster Analysis (FDA) Task Force of the Center for Disaster Management and Risk Reduction Technology (CEDIM) closely monitored the evolution of the June flood 2013 including the impacts on people, transportation and economy in near real time. In this way CEDIM made science-based facts available for the identification of major event drivers and for disaster mitigation. The first phase of this activity was done by compiling scattered information available from diverse sources including in-situ sensors and remote sensing data, the internet, media and social sensors as well as by applying CEDIM's own rapid assessment tools. Two reports were issued: the first report focused on the meteorological and hydrological conditions including comparisons to major floods from the past (CEDIM, 2013a), while the second one focused on impact and management issues (CEDIM, 2013b).

The subsequent phase of this FDA activity focused on the research question: what made the June flood 2013 an exceptional event from a hydro-meteorological point of view? This question is analyzed in this paper. We check the hypothesis that the June 2013 flood was exceptional due to the superposition of extreme initial soil

## HESSD

11, 8125–8166, 2014

### What made the June 2013 flood in Germany an exceptional event?

K. Schröter et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures



Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



---

## What made the June 2013 flood in Germany an exceptional event?

K. Schröter et al.

---

[Title Page](#)[Abstract](#)[Introduction](#)[Conclusions](#)[References](#)[Tables](#)[Figures](#)[Back](#)[Close](#)[Full Screen / Esc](#)[Printer-friendly Version](#)[Interactive Discussion](#)

moisture and heavy precipitation on a large-scale. This hypothesis is contrary to the notion that the influence of catchment wetness is greater for low-return period events than high-return periods and that the magnitude of a flood is related primarily to the event precipitation and only secondly to the catchment wetness (e.g. Ettrick et al., 1987).

For this purpose we analyze key hydro-meteorological factors including circulation patterns, initial soil moisture, initial streamflow conditions in the river network, event precipitation and flood peak discharges and evaluate the recurrence intervals of these hydro-meteorological factors using methods of extreme value statistics. For a long-term classification of the June 2013 flood we draw comparisons to other large-scale high impact summer flood events in Germany specifically the August 2002 and July 1954 floods. For this purpose, we use updated information about the occurrence of 74 large-scale flood events over the last 60 years (Uhlemann et al., 2010). The analysis is deliberately limited to the national borders of Germany to be able to compare the 2013 flood with the event of Uhlemann et al. (2010).

The paper is organized as follows. Section 2 describes the data and methods used to conduct the hydro-meteorological analysis of the June 2013 flood and the past large-scale flood events. Section 3 describes the meteorological situation associated with the June flood 2013 and presents the results from the analysis of antecedent and event precipitation, initial river flow conditions and flood peak discharges. Detailed comparisons with the extreme summer floods of August 2002 and July 1954 are drawn. In Sect. 4 we discuss the key findings and provide recommendations for future work.

## 2 Data and methods

### 2.1 Data base of large-scale floods

For the analysis of the meteorological and hydrological conditions prior to and during major flood events in Germany and the relation to the climatological context, a



flood events are mainly driven by advective precipitation, this effect is of minor importance in the present study.

Additionally, weather charts and radiosounding data are used to describe the characteristics of the atmosphere on the days with maximum rainfall. Various authors established relations between large-scale weather patterns, for example according to the classification of Hess and Brezowsky (1969), and floods (e.g. Bárdossy and Caspary, 1990; Petrow et al., 2009). In 2013, the general situation was dominated by the two patterns labelled “low central Europe (TM)” and “trough central Europe (TRM)”, which persisted together on 16 days from mid-May till beginning of June. Compared to the past flood events considered in this study, this persistency is not significant and cannot explain the extraordinary situation in 2013.

### 2.3 Hydrological data sets

We use time series of daily mean discharges from 162 gauging stations operated by the water and shipment administration (WSV), the German Federal Institute of Hydrology (BfG) or by hydrometric services of the federal states. These gauges have a drainage area larger than 500 km<sup>2</sup> and provide continuous records since at least 1950. The same selection of gauges has been used by Uhlemann et al. (2010) to compile the set of large-scale flood events in Germany. For the June flood 2013 raw data of daily mean discharges were available for 121 gauges mainly covering the central, southern and eastern parts of Germany which have been mostly affected by flooding.

Based on the procedure proposed by Uhlemann et al. (2010), the point observations of discharge peaks at the 162 gauges are regionalized to represent the flood situation in a particular river stretch and its associated catchment area. The regionalization scheme uses the location of the gauges and the hierarchical Strahler order (Strahler, 1957) which accounts for the branching complexity of the river network. A gauge is assumed as representative for a upstream river reach until the next gauge and/or the Strahler order of the river stretch decreases by two orders. In downstream direction, a gauge is representative until the Strahler order of the river changes by one order or

## What made the June 2013 flood in Germany an exceptional event?

K. Schröter et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures



Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



a confluence enters the river which has the same Strahler order or one order smaller. The total length of the river network considered amounts to 13 400 km.

## 2.4 Methods

For the statistical analysis of the hydro-meteorological factors and the consistent comparison of flood events, a clear event definition including its onset and duration is required. The start of an event determines the point in time for which we evaluate the different hydro-meteorological factors instantaneously (e.g. initial river flow) forward (event precipitation, peak discharges) and backward in time (antecedent precipitation index API as a proxy for initial soil moisture conditions). Due to temporal dynamics of the precipitation fields across Germany, flood triggering precipitation affects different catchment areas at different days. Therefore, we do not consider a fixed event start date for the whole of Germany, but one that may vary in space and time, that is, from one grid point to another or from one sub-catchment to another, respectively.

### 2.4.1 Definition of event start dates

To identify the start date of a large-scale flood from a meteorological perspective, we use the maximum 3 day precipitation totals (R3d) at each grid point of the REGNIE data set. Considering R3d totals avoids local scale convective precipitation to enter the sample, which may trigger flash floods but not large-scale floods (Merz and Blöschl, 2003).

We determine flood triggering 3 day precipitation totals within a centered 21 day time window that spans from 10 days ahead to 10 days after the event start dates included in the large-scale flood event set. The dimension of the chosen time window considers the time lag which links flood triggering precipitation with discharge response (e.g. Duckstein et al., 1993) and the travel times of flood waves along the river-course (e.g. Uhlemann et al., 2010). The first day of the R3d period defines the meteorological event start for a given grid point. Depending on the space-time characteristics of the

# HESSD

11, 8125–8166, 2014

## What made the June 2013 flood in Germany an exceptional event?

K. Schröter et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures



Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



precipitation fields, these days will be more or less correlated for adjoined grid points. We have performed this analysis for maximum precipitation total of 3 to 7 days duration and found that these totals do not differ largely for the flood events investigated; thus we further consider only the former ones.

### 2.4.2 Event precipitation

For the statistical evaluation of event precipitation, annual maximum 3 day precipitation totals are determined over the entire period from 1960 to 2009. Using extreme value statistics return periods are determined for the event-triggering R3d totals independently for each grid point.

### 2.4.3 Antecedent precipitation

The meteorological event starts (first day of maximum R3d) are used to generate samples of the antecedent precipitation index (API) and initial streamflow conditions ( $Q_i$ ) reflecting wetness and initial flow conditions prior and at the onset of the flood. The API is used as a proxy for moisture stored in a catchment in the period before the event precipitation. We quantify API over a 30 day period prior to the meteorological event start dates at each grid point for each event of the large-scale flood set. API is given by the sum of daily precipitation weighted with respect to the time span (here:  $m = 30$  days) of rainfall occurrence before the reference day:

$$\text{API}(x, y) = \sum_{i=1}^{30} 0.9^i R_i(x, y)(m - i), \quad (1)$$

where  $R_i(x, y)$  is the 24 h total at a specific grid point  $(x, y)$  and  $i$  represents the day prior to the 3 day maximum. This procedure ensures that event precipitation and antecedent precipitation are clearly separated. For the statistical analysis of API we use partial series which are derived using the event start dates identified for the 74 large-scale flood events in the period 1960–2009.

## What made the June 2013 flood in Germany an exceptional event?

K. Schröter et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

⏪

⏩

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion







annual maximum discharges from the period 1950 to 2009) for each of the  $n = 162$  gauges. For each gauge a partial series is created by evaluating  $Q_i$  for the areal mean event start dates in the corresponding sub-catchment identified for the 74 large-scale flood events.

Further, we introduce an initial load severity index representing the spatially weighted sum of the initial hydraulic load level in the river network for each event  $k$ :

$$S_{Q_i}^k = \sum_n \left\{ \lambda_n \times \left( \frac{Q_i}{\text{MHQ}} \right)_n \right\} \left| \left( \frac{Q_i}{\text{MHQ}} \right)_n \geq \left( \frac{Q_i}{\text{MHQ}} \right)_n^{5\text{year RP}} \right. , \quad (3)$$

where 5 year RP denotes the discharge for a 5 year return period and the weights  $\lambda_n$  correspond to the ratio of the river stretch length ( $l_n$ ) associated with a certain gauge and the total length of the river network:  $\lambda_n = \frac{l_n}{\sum_n l_n}$ .

#### 2.4.6 Peak discharge

Peak discharge ( $Q_p$ ) is a key figure to characterize the magnitude of a flood at a specific location.  $Q_p$  is the integrated outcome of hydrological and hydraulic processes upstream of that location and provides important information for numerous water resources management issues in particular flood estimation and flood design. For the statistical evaluation of the observed flood peaks at each of the 162 gauges we use the annual maximum series (AMS) of daily mean discharges from the period 1950 to 2009. We evaluate the spatial flood extent and magnitude using an aggregated measure of event severity. For this purpose we calculate the length of the river network  $L$  for which during event  $k$  the peak discharge  $Q_p$  exceeds the 5 year return period:

$$L^k = \sum_n \{ \lambda_n \times 100 \} \left| Q_{p_n}^k \geq Q_{p_n}^{5\text{year RP}} \right. , \quad (4)$$

## What made the June 2013 flood in Germany an exceptional event?

K. Schröter et al.

[Title Page](#)

[Abstract](#)

[Introduction](#)

[Conclusions](#)

[References](#)

[Tables](#)

[Figures](#)

[⏪](#)

[⏩](#)

[◀](#)

[▶](#)

[Back](#)

[Close](#)

[Full Screen / Esc](#)

[Printer-friendly Version](#)

[Interactive Discussion](#)



where 5 year RP denotes the values for a 5 year return period and the weights  $\lambda_n$  are defined as explained above. The flood severity index represents a weighted sum of peak discharges  $Q_p$  normalized by a 5 year flood using  $\lambda_n$  as weights:

$$S_{Q_p}^k = \sum_n \left\{ \lambda_n \times \frac{Q_{p_n}^k}{Q_{p_n}^{5\text{year RP}}} \right\} \mid Q_{p_n}^k \geq Q_{p_n}^{5\text{year RP}}. \quad (5)$$

#### 2.4.7 Extreme value statistics

To calculate exceedance probabilities and return periods ( $T_n$ ) for the various hydro-meteorological factors, i.e. R3d, API,  $Q_i$ /MHQ and  $Q_p$ , observed for the June 2013, August 2002 and July 1954 floods, we applied the classical generalized extreme value distribution (Embrechts et al., 1997). Most appropriate and widely used in the case of precipitation is the Fisher–Tippett type I extreme value distribution, also known as Gumbel distribution, with a cumulative distribution function (CDF) of

$$F(x) = \exp \left[ -\exp \left( -\frac{x - \beta}{\alpha} \right) \right], \quad (6)$$

where  $\alpha$  is the scale parameter affecting the extension in x-direction and  $\beta$  is the mode that determines the location of the maximum. This distribution is also suitable to the  $Q_i$ /MHQ samples. For the statistical analysis of  $Q_p$  we fit a generalized extreme value distribution to the AMS of daily mean discharges. The CDF of the generalized extreme value distribution has a function of

$$F(x) = \exp \left\{ - \left[ 1 + \frac{\gamma(x - \zeta)}{\delta} \right]^{-1/\gamma} \right\} \quad (7)$$

where  $\delta$  is the scale parameter affecting the extension in x-direction,  $\zeta$  is a location parameter and  $\gamma$  is a shape parameter.

## What made the June 2013 flood in Germany an exceptional event?

K. Schröter et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

⏪

⏩

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



## 3 Results

### 3.1 Meteorological conditions

The second half of the month of May 2013 was exceptionally wet across most of central Europe. Two large-scale weather patterns labelled “low central Europe (TM)” and “trough central Europe (TRM)” persisted over more than two weeks. Charts with the 500-hPa geopotential height averaged for 16–31 May 2013 (Fig. 1, left panel) clearly show the area of low geopotential values stretching from the British Isles all the way to southern France, Germany, northern Italy and Poland. This quasi-stationary trough results in a deviation of geopotential values of 15 gpm and above compared to the long-term mean (1979–1995; Fig. 1, right panel). The area with maximum negative anomaly values is centered over France, Switzerland and northwestern Italy. The trough is flanked by high pressure ridges that are located over northeastern Europe and over the North Atlantic Ocean; due to this blocking situation Atlantic air masses are prevented from entering central Europe from the west. On the other side, warm and humid air masses were repeatedly forced from southeastern Europe northward and eventually curved into Germany and Austria.

Nearly all central European flooding events are caused by a complex combination and interaction of upper-level pressure systems, associated surface lows and the advection of moist and warm air over long distances. The intense and widespread rain that finally led to the severe flooding in Central Europe occurred end of May/beginning of June 2013. Responsible for the heavy rainfall was a cut-off low that moved slowly with its center from France (29 May) over northern Italy (30 May; Fig. 2a) to eastern Europe (1 June; Fig. 2b). In the latter region, three consecutive surface lows were triggered by short-wave troughs that travelled around the cut-off low (CEDIM, 2013a). On the north-eastern flank of the upper low and near the secondary surface lows, warm and moist air masses were advected from the Mediterranean and Black Sea region into Central Europe. Moisture sources by continental evapotranspiration were even more important (Grams et al., 2014).

## HESSD

11, 8125–8166, 2014

### What made the June 2013 flood in Germany an exceptional event?

K. Schröter et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures



Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



The interaction between the pronounced trough and a shallow high pressure system further to the west created quite strong horizontal wind speeds from northerly directions. The northerly flow was predominant in particular on the days with maximum rainfall. Largest rain amounts were found upstream of the west-east-oriented mountain chains, e.g. the Alps, Ore Mountains, and Swabian Jura. Substantial large-scale lifting downstream of the troughs in combination with moist and unstable air masses that caused embedded convection in the mainly stratiform clouds resulted in widespread heavy rainfall that lasted over several days.

### 3.2 Precipitation

Highest precipitation totals were observed between three and four days ahead of the flood event start, as shown by the time series of cumulated areal precipitation averaged over the upper Elbe (Fig. 3a) and Danube (Fig. 3b) catchments. Note that these characteristics are almost the same for the other two floods considered, 2002 and 1954, respectively. Especially for the Elbe catchment in May 2013, rain totals were high up to 17 days prior the event start, and higher compared to the other events (if the large totals 28 days ahead of the 2002 flooding is neglected). For the whole month of May, mean precipitation in Germany was 178 % of the long-term average for the period 1881–2012. To better explain differences and similarities of the three flood events considered, we analyzed both maximum 3 day precipitation totals (R3d) as event precipitation and precipitation in the month before the flooding in terms of API. In both cases, the quantities are calculated independently at each grid point of the REGNIE gridded precipitation data (see Sect. 2.2).

#### Event precipitation

Maximum 3 day totals (R3d) in 2013 show high values in excess of 60 mm over southern and eastern Germany (Fig. 4, left panel). The highest rain maximum with R3d = 346 mm was observed at the DWD weather station of Aschau-Stein (31 May to

## HESSD

11, 8125–8166, 2014

### What made the June 2013 flood in Germany an exceptional event?

K. Schröter et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures



Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



3 June, 06:00 UTC), which is situated in the Bavarian Alps at an elevation of 680 m a.s.l. This station also recorded the maximum 24 h rain sum of 170.5 mm on 1 June (from 1 June 06:00 UTC until 2 June 06:00 UTC). On that day, peak rainfall was recorded at many other stations in the federal states of Bavaria, Saxony, and Baden-Württemberg.

Overall, the R3d maxima were registered almost homogeneously between 30 May and 1 June (Julian day 152, Fig. 5, left panel). At the upper reaches of Danube and Elbe (German part) the maxima occurred one day later. Over the very eastern parts, especially near Dresden and Passau, the temporal difference was even two days. This consecutive shift of the main precipitation fields in west-to-east direction, i.e. following the flow direction of the Danube, caused an additional amplification of the high-water peaks.

Even if the flood-related rainfall in 2013 was mainly driven by meso-scale processes such as uplift related to the troughs and advection of moist air masses, the R3d map suggests that additional orographically-induced lifting over the mountains increased the rain totals substantially. Highest rain sums occurred over the crests of the Ore Mountains (near Dresden), the mountains of Black Forest and Swabian Jura (west and east of Stuttgart, respectively), the Alpine Foothills (south of Munich) and the Bavarian Alps. Overall, the rain enhancement over the low-mountain ranges estimated from the ratio between areal rainfall over the mountains and adjacent low-lands was between 200 and 310 %. This substantial local-scale increase in precipitation can be plausibly explained by the characteristics of the air mass on the large-scale. First of all, the lifting condensation level (LCL) was very low on the first three days in June with pressure levels around 930 hPa, i.e. near the surface, as observed at the radiosounding stations of Munich, Stuttgart, Meiningen, and Kümmersbruck. Low LCL ensures that a large amount of humidity, which decreases almost exponentially with elevation, basically can be converted into rain. Furthermore, precipitable water pw as the vertical integral of the specific water vapor content was large with values of up to 25 mm. The sounding in Stuttgart, for example, measured a pw value of 25.9 mm (1 June, 12:00 UTC), which is far outside the interquartile range of all heavy precipitation events between 1971 and

## HESSD

11, 8125–8166, 2014

### What made the June 2013 flood in Germany an exceptional event?

K. Schröter et al.

[Title Page](#)

[Abstract](#)

[Introduction](#)

[Conclusions](#)

[References](#)

[Tables](#)

[Figures](#)



[Back](#)

[Close](#)

[Full Screen / Esc](#)

[Printer-friendly Version](#)

[Interactive Discussion](#)



## What made the June 2013 flood in Germany an exceptional event?

K. Schröter et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures



Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



2000 at the same station according to the study of Kunz (2011). Together with high horizontal wind speeds between 20 and 75 km h<sup>-1</sup> (850 hPa) this led to a substantial increase of the incoming water vapor flux (Fwv). This quantity can be considered as an upper limit of the conversion of moisture into precipitation (Smith and Barstad, 2004; Kunz, 2011). Thus, the high Fwv values observed during the first days in June plausibly explain the substantial orographic rainfall enhancement over the mountains.

To relate the June 2013 precipitation event to the climatological context, we quantify statistical return periods based on REGNIE data for the period from 1960 to 2009. In Fig. 6 (left panel), the return periods are displayed only in the range between 5 and 200 years. Higher return periods are neglected as statistical uncertainty substantially increases due to the short observation period of 50 years. Over the southwestern parts of the Ore Mountains, the Swabian Jura and the very southern border of Bavaria, the return periods are in a range between 5 and 20 years. Only a limited number of grid points show peak values in excess of 100 or even 200 years, for example the aforementioned station of Aschau-Stein. Thus, one can conclude that the rainfall was unusually high, but not extraordinary, which, alone cannot explain the dimension of the 2013 flood.

The most important rainfall characteristics that were decisive for the 2013 flood can be summarized as: (i) high – but not extraordinary – 3 day totals over parts of the Danube and Elbe catchments, (ii) substantial rainfall increase over the mountains that was decisive for the onset of the flooding; and (iii) almost simultaneous areal precipitation with a slight temporal shift of two days between the western and eastern parts of Germany.

These meteorological conditions differ largely from those prevailing during the floods in 2002 and 1954. Areal 3 day rain totals averaged over the upper Elbe catchment (Germany only, up to the inflow from Saale) were 49.3 mm compared to 75.9 mm in 2002 and 68.8 mm in 1954. Over the upper Danube catchment (Germany only), the mean areal rain was 75.7 mm compared to 62.5 and 111.2 mm in 2002 and 1954, respectively. The most striking feature in 2002 was the extreme precipitation over the

Ore Mountains reaching values of 312 mm in 24 h (7 to 8 August 2002 at the station of Zinnwald-Georgenfeld, Ulbrich et al., 2003). The R3d totals (Fig. 4, middle panel) show a larger area at the eastern parts with values in excess of 300 mm. However, higher rain totals were only observed at the southern border of Bavaria as well as over the Swabian Jura. This distribution is mainly caused by northerly flow in conjunction with a so-called Vb weather situation (Ulbrich et al., 2003). Comparable to the 2013 event, flood triggering precipitation occurred with a shift of 2 days between the southern and eastern parts of Germany that correspond to the Danube and Elbe catchments, respectively (Fig. 5, middle panel). Note that the regions with larger temporal differences in the occurrence of R3d maxima are not associated with high amounts of precipitation (see Fig. 4). Application of extreme value statistics to R3d totals yield return periods of more than 200 years for the maxima. Return periods around 100 years are estimated for the lowlands north of the Ore Mountains (Fig. 6, middle panel). Precipitation in that region also contributed to the large increase in runoff of the Elbe. In 1954, most parts of Bavaria experienced 3 day accumulated rainfalls in excess of 150 mm (Fig. 4, right panel). This was even the case for the lowlands in the north of Bavaria. Near the Alps as well as over the western parts of the Ore mountains, R3d reached values of 300 mm or even more. These extreme totals recorded within a time shift of only one day (Fig. 5, right panel) correspond to statistical return periods of more than 200 years covering more than half of Bavaria (Fig. 6, right panel). Thus, considering only the observed precipitation directly prior the onset of the flooding, 1954 was certainly the most extreme event that occurred within the last 60 years.

### 3.3 Initial catchment state

#### 3.3.1 Antecedent precipitation

In the next step, we assess initial soil moisture by means of the antecedent precipitation index API. This proxy is based on the starting date of R3d (day of the year shown in Fig. 5 minus 3 days) and computed independently at each grid point of REGNIE.

## What made the June 2013 flood in Germany an exceptional event?

K. Schröter et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures



Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion





## What made the June 2013 flood in Germany an exceptional event?

K. Schröter et al.

[Title Page](#)

[Abstract](#)

[Introduction](#)

[Conclusions](#)

[References](#)

[Tables](#)

[Figures](#)

[⏪](#)

[⏩](#)

[◀](#)

[▶](#)

[Back](#)

[Close](#)

[Full Screen / Esc](#)

[Printer-friendly Version](#)

[Interactive Discussion](#)



API reached high values between 100 mm and in excess of 150 mm over large parts of Germany, especially – and most importantly – over the catchments of Elbe and Danube (Fig. 7, left panel). At a large number of grid points, especially in the upper Elbe catchment, the return periods are between 100 and 200 years, at some points even in excess of the latter (Fig. 8, left panel). Note, however, that the maximum that occurred between Hannover and Magdeburg was related to moderate flooding at the Aller, Oker and Leine rivers in the Weser catchment. The high rain totals in the month of May, especially those at the end of May (recall the increasing weighting of rain totals in API with decreasing temporal distance to R3d), resulted in very wet catchments and filling of storage capacities and thus very favorable conditions for high runoff coefficients.

Regarding the initial moisture conditions, it is found that API was significantly lower prior to the floods in 1954 and 2002, respectively (Fig. 7). In both cases, high values of API up to 150 mm can be observed only over parts of the Bavarian Alps related to orographic precipitation induced by northerly flow directions. Whereas in 2013 the maxima of API correspond well with those of R3d, this is not the case for the two other events. Especially over the Ore Mountains and north of it, where highest rainfall was observed, API was below 50 mm in both cases, yielding return periods below 20 years at most of the grid points (Fig. 8). The same applies to the API in the Danube catchment in 1954. Both in 2002 and 1954, the initial soil moisture was comparatively high, but in general not in the regions where the event precipitation was highest (compare Fig. 4 and Fig. 7). Apart from areal precipitation as described above, this is the major difference to the 2013 event.

### 3.3.2 Initial hydraulic load

As a consequence of the large amounts of rainfall accumulated during the month of May, reflected by the extended areas of high API, also the initial hydraulic load in the river network was already clearly increased at the beginning of the event precipitation in 2013. In general, the pattern of increased initial hydraulic load in the rivers shown in Fig. 9 (left panel) resembles the spatial distribution of high API values (Fig. 7, left

panel). This mostly applies to the central and south-eastern parts of Germany. Most prominent in this regard were the Saale River and its tributaries Wipper and Bode in the western part of the Elbe catchment with an initial flow ratio above 0.8 of MHQ. The Rhine, upper Main, Danube, with tributaries Naab and Isar and the Werra River were also affected. Note that, for many gauges in the Weser and lower Rhine catchments no discharge data have been available for the June 2013 flood, see Fig. A1 in the Appendix for geographic locations.

In comparison, for the August 2002 and July 1954 floods the initial hydraulic load of the river network was clearly lower with few exceptions (Fig. 9). In August 2002, basically the Danube and its tributaries Inn, Isar, Lech and Regen showed a noticeable increase of initial river discharge (ca. 0.5 of MHQ). These catchments showed also high API values. Similarly, at the beginning of the July 1954 flood for the Danube and its southern tributaries an increase of river discharges about 0.4 to 0.8 of MHQ is visible. Also the middle and upper parts of the Rhine show increased initial hydraulic loads in this range. The lower coincidence of regions of increase initial hydraulic load with regions of increased API for the July 1954 flood (compare Fig. 7 and Fig. 9) suggests that the increased initial hydraulic load particularly along the Rhine was induced by different mechanisms than high amounts of antecedent precipitation, presumably due to snow-melt in the alpine headwaters of the Rhine river and probably also of the Danube river.

From the statistical extreme value analysis applied to the  $Q_i$ /MHQ samples at each gauge we obtain an estimate for the return period of the specific initial river flow situation for the June 2013, August 2002 and July 1954 floods. The results presented in Fig. 10 show that for the June 2013 flood the initial flow ratios observed in central Germany, in particular at the upper Main (Rhine catchment), Werra (Weser catchment), Wipper, Saale, Weiße Elster, Mulde (Elbe catchment) and Naab and Vils (Danube catchment) exhibit return periods in the range of 10 to 50 years, in some river stretches even above 100 years.

## What made the June 2013 flood in Germany an exceptional event?

K. Schröter et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures



Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



For the August 2002 and July 1954 events comparable extremes are only observed for few river stretches in the Danube catchment including the Regen, upper Isar, Ilz, Inn and Salzach rivers in 2002 and the upper Iller, Lech and Isar rivers in 1954.

The initial hydraulic load of the river network (13 400 km) was clearly increased in June 2013 given the comparison to other large-scale summer flood events from the last 60 years. Hence, the aggravating effect of increased initial hydraulic load was stronger in June 2013 than in August 2002 and July 1954. However, extraordinary high initial flow ratios occurred only in particular river stretches, namely the Saale river and its tributaries.

### 3.4 Peak flood discharges

In June 2013, 45% of the total river network considered in Germany showed peak discharges above a 5 year flood. As can be seen in Fig. 11 (left panel), all major catchments showed flooding, namely the Weser, Rhine, Elbe and Danube catchments. Particularly the Elbe and Danube rivers and many of their tributaries were affected by extraordinary high flood levels. In the Elbe catchment flood peak discharges exceeded a return period of 100 years along the whole Elbe stretch between Dresden and Wittenberge, the Mulde, and the Weiße Elster and Ilm rivers tributaries of the Saale River. In the Danube catchment, the section of the Danube downstream of Regensburg as well as the Inn and Salzach rivers experienced peak discharges with return periods above 100 years. In addition, the Isar, Naab and Iller rivers showed flood peaks above 50 year return periods. Further in the Rhine catchment, the Neckar and parts of the Main as well as the Werra river in the Weser catchment experienced peak discharges above 50 year return period. New record water levels were registered at the Elbe between Coswig and Lenzen (along a total length of 250 km), at the Saale downstream of Halle, and at the Danube in Passau. Severe flooding occurred especially along the Danube and Elbe rivers, as well as along the Elbe tributaries Mulde and Saale, in most cases as a consequence of dike breaches. It is remarkable that large parts of catchments affected by flooding did not receive exceptional amounts of rain (see Fig. 4). In particular,

## What made the June 2013 flood in Germany an exceptional event?

K. Schröter et al.

[Title Page](#)

[Abstract](#)

[Introduction](#)

[Conclusions](#)

[References](#)

[Tables](#)

[Figures](#)



[Back](#)

[Close](#)

[Full Screen / Esc](#)

[Printer-friendly Version](#)

[Interactive Discussion](#)



this applies to the Saale, Werra and Main catchments. However, these regions show high amounts of antecedent precipitation and substantial initial hydraulic load.

The August 2002 and July 1954 floods show peak discharges in the order of 100 years at the Elbe between Dresden and Wittenberg, in parts of the Mulde, Regen and Mindel and of 50 years at the Freiburger and Zwickauer Mulde and the Elbe downstream of Wittenberg to Wittenberge (see Fig. 11, left panel). In July 1954 return periods of 100 years occurred at the Weiße Elster and Mulde in the Elbe catchment and the Isar, Rott and Inn in the Danube catchment. Flood peaks with a return period of 50 years were observed at the Danube downstream Regensburg, the Naab, Inn and Salzach as well as the upper Isar rivers. However, as can be seen from Fig. 11 (middle and right panels), the river stretches with high magnitude flood peaks are clearly less extended August 2002 and July 1954: the index  $L$  describing the spatial flood extent amounts to 19 % in August 2002, 27 % in July 1954 and 45 % in June 2013, see Fig. A1 in the Appendix for geographic locations.

The major differences of the June flood 2013 in comparison to August 2002 and July 1954 are that the Elbe, the Mulde and the Saale Rivers were affected simultaneously by extraordinary flooding which by superposition of flood waves resulted in unprecedented flood levels particularly in the middle part of the Elbe. Further, nearly all tributaries of the Danube showed flood responses and jointly contributed to the record flood along the Danube downstream of Regensburg. Also the Rhine and Weser catchments were considerably affected even though the magnitude of the peak discharges was not as extreme as in the Elbe and Danube catchments.

### 3.5 Index based classification

We evaluate the importance of the individual hydro-meteorological factors within the different flood events using the severity indices introduced in Sect. 2.3. The precipitation-, wetness-, initial hydraulic load- and flood severity indices enable us to compare the 74 past large-scale flood events with regard to the spatial extent and magnitude of each hydro-meteorological factor. This allows for the identification of singularities in

**HESSD**

11, 8125–8166, 2014

## What made the June 2013 flood in Germany an exceptional event?

K. Schröter et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

⏪

⏩

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion





overlaps of either factors as well as other hydrological processes, for instance snow melt or seasonal variations in base flow play a role in this regard.

## 4 Conclusions

This study provides new insight to the characteristics of hydro-meteorological factors that caused the June flood 2013 and presents a statistical evaluation of the associated return periods. The data-based approach further comprises aggregated index values which consider both the spatial extent and magnitudes of the different hydro-meteorological factors and allows for the comparison to past and future large-scale flood events.

The results illustrate that the sequence of prevalent circulation patterns in the month of May put an important boundary condition for the extraordinary precipitation anomaly observed. However, with regard to persistence, the circulation patterns did not differ significantly from situations associated with other past large scale floods in Germany and thus cannot explain alone the extraordinary outcomes of the June flood 2013 in Germany. For this flood, diverse hydro-meteorological factors showed exceptional characteristics. First, the development of event precipitation and in particular the substantial orographic rainfall enhancement was driven by a very low lifting condensation level in combination with high amounts of precipitable water in the atmosphere. This was continuously sustained by the strong influx of high water vapor resulting from a strong and persistent flow of air from the north to north east. Second, during the weeks before the onset of the flood, unprecedented amounts of “antecedent” precipitation occurred over large areas of Germany. As the areas of high antecedent and event precipitation were amply overlapping, these extremely wet initial conditions strongly intensified the runoff response to event precipitation. Hence, particularly the interplay of event precipitation and wet initial catchments within a large areal superposition turns out as the key driver for the exceptional hydrological severity of the June 2013 flood. In the Saale catchment the increased initial hydraulic load in the river network has been an additional

# HESSD

11, 8125–8166, 2014

## What made the June 2013 flood in Germany an exceptional event?

K. Schröter et al.

[Title Page](#)

[Abstract](#)

[Introduction](#)

[Conclusions](#)

[References](#)

[Tables](#)

[Figures](#)



[Back](#)

[Close](#)

[Full Screen / Esc](#)

[Printer-friendly Version](#)

[Interactive Discussion](#)



---

## What made the June 2013 flood in Germany an exceptional event?

K. Schröter et al.

---

[Title Page](#)

[Abstract](#)

[Introduction](#)

[Conclusions](#)

[References](#)

[Tables](#)

[Figures](#)



[Back](#)

[Close](#)

[Full Screen / Esc](#)

[Printer-friendly Version](#)

[Interactive Discussion](#)



aggravating factor. In the Danube, the movement of the event precipitation field from west to east, i.e. following the streamflow direction, amplified the superposition of the flood waves from the tributaries. Third, the spatial extent of high magnitude flood peaks marks a new record for large scale floods in Germany since at least 1952 and set new record water levels along extensive river sections in Germany.

In comparison, the August 2002 flood was triggered by extremely intense precipitation which was relatively localized in the Ore Mountains. Initial wetness showed considerably high values in some parts of Germany but these areas did not coincide largely with event precipitation. The flooding in July 1954 was for the main part caused by exceptional amounts of event precipitation affecting large parts of Bavaria. In contrast to the appraisal of Blöschl et al. (2013), initial wetness was a minor factor for the July 1954 flood in Germany.

The interplay of various hydro-meteorological factors has been studied primarily for small-scale catchments, (e.g. Perry and Niemann, 2007). One exception is the study of Nied et al. (2013) who investigated the role of antecedent soil moisture for floods in the Elbe catchment (ca. 150 000 km<sup>2</sup>). They emphasized the increased probability of occurrence of large-scale floods related to large-scale high soil moisture. On that note, also Klemes (1993) reasoned that high hydrological extremes are more due to unusual combinations of different hydro-meteorological factors than to unusual magnitudes of the factors themselves. Our results offer support for the hypothesis that the influence of catchment wetness is also considerable for high-return period large-scale floods. Hence, using the knowledge gained about the characteristics and the range of magnitudes of the various hydro-meteorological factors associated with large scale floods from the past 60 years, we can advance the derivation of plausible extreme scenarios. In this regard, the data base compiled for large scale floods in Germany may be analysed concerning the possibilities of coinciding extremes of individual hydro-meteorological factors as for instance the combination of initial wetness observed in June 2013 and event precipitation as in July 1954. Of course, the development of such scenarios requires an in depth analysis of synoptic meteorological situations and the





## What made the June 2013 flood in Germany an exceptional event?

K. Schröter et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

⏪

⏩

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



CEDIM: June 2013 Flood in Central Europe – Focus Germany Report 1 – Update 2: Pre-conditions, Meteorology, Hydrology, available at: [http://www.cedim.de/download/FDA\\_Juni\\_Hochwasser\\_Bericht1-ENG.pdf](http://www.cedim.de/download/FDA_Juni_Hochwasser_Bericht1-ENG.pdf), Center for Disaster Management and Risk Reduction Technology, Potsdam, 2013a.

5 CEDIM: June 2013 Flood in Central Europe – Focus Germany Report 2 – Update 2: Pre-conditions, Meteorology, Hydrology, available at: [http://www.cedim.de/download/FDA\\_Juni\\_Hochwasser\\_Bericht2-ENG.pdf](http://www.cedim.de/download/FDA_Juni_Hochwasser_Bericht2-ENG.pdf), Center for Disaster Management and Risk Reduction Technology, Potsdam, 2013b.

Cleveland, W. S.: Robust locally weighted regression and smoothing scatterplots, *J. Am. Stat. Assoc.*, 368, 829–836, doi:10.2307/2286407, 1979.

Deutscher Bundestag: Bericht zur Flutkatastrophe 2013: Katastrophenhilfe, Entschädigung, Wiederaufbau, Berlin, 2013.

Duckstein, L., Bárdossy, A., and Bogárdi, I.: Linkage between the occurrence of daily atmospheric circulation patterns and floods: an Arizona case study, *J. Hydrol.*, 143, 413–428, doi:10.1016/0022-1694(93)90202-K, 1993.

15 Embrechts, P., Klüppelberg, C., and Mikosch, T.: *Modelling Extremal Events – for Insurance and Finance*, Springer, Berlin, Heidelberg, 1997.

Ettrick, T. M., Mawdlsey, J. A., and Metcalfe, A. V.: The influence of antecedent catchment conditions on seasonal flood risk, *Water Resour. Res.*, 23, 481–488, doi:10.1029/WR023i003p00481, 1987.

GDV: Erste Schadenbilanz: Hochwasser 2013 verursacht 180.000 versicherte Schäden in Höhe von fast 2 Milliarden Euro, available at: <http://www.presseportal.de/pm/39279/2505807/erste-schadenbilanz-hochwasser-2013-verursacht-180-000-versicherte-schaeden-in-hoehe-von-fast-2>, last access: 2 July 2013.

25 Grams, C. M., Binder, H., Pfahl, S., Piaget, N., and Wernli, H.: Atmospheric processes triggering the Central European floods in June 2013, *Nat. Hazards Earth Syst. Sci. Discuss.*, 2, 427–458, doi:10.5194/nhessd-2-427-2014, 2014.

Hess, P. and Brezowsky, H.: *Katalog der Großwetterlagen Europas*, Deutscher Wetterdienst, Deutscher Wetterdienst, Offenbach am Main, 1969.

30 Klemes, V.: Probability of extreme hydrometeorological events – a different approach, in: *Extreme Hydrological Events: Precipitation, Floods and Droughts*, vol. 213, IAHS, Yokohama, 167–176, 1993.

# HESSD

11, 8125–8166, 2014

## What made the June 2013 flood in Germany an exceptional event?

K. Schröter et al.

[Title Page](#)[Abstract](#)[Introduction](#)[Conclusions](#)[References](#)[Tables](#)[Figures](#)[⏪](#)[⏩](#)[◀](#)[▶](#)[Back](#)[Close](#)[Full Screen / Esc](#)[Printer-friendly Version](#)[Interactive Discussion](#)

Kron, W.: Zunehmende Überschwemmungsschäden: eine Gefahr für die Versicherungswirtschaft?, DCM, Meckenheim, Würzburg, 47–63, 2004.

Kunz, M.: Characteristics of large-scale orographic precipitation in a linear perspective, J. Hydrometeorol., 12, 27–44, doi:10.1175/2010JHM1231.1, 2011.

5 Merz, B., Elmer, F., Kunz, M., Mühr, B., Schröter, K., and Uhlemann-Elmer, S.: The extreme flood in June 2013 in Germany, Houille Blanche, 1, 5–10, doi:10.1051/lhb/2014001, 2014.

Merz, R. and Blöschl, G.: A process typology of regional floods, Water Resour. Res., 39, 1340, doi:10.1029/2002WR001952, 2003.

Munich Re: Natural Catastrophes 2013 Analyses, Assessments, Positions, Munich, 2013.

10 Nied, M., Hundecha, Y., and Merz, B.: Flood-initiating catchment conditions: a spatio-temporal analysis of large-scale soil moisture patterns in the Elbe River basin, Hydrol. Earth Syst. Sci., 17, 1401–1414, doi:10.5194/hess-17-1401-2013, 2013.

Perry, M. A. and Niemann, J. D.: Analysis and estimation of soil moisture at the catchment scale using EOFs, J. Hydrol., 334, 388–404, doi:10.1016/j.jhydrol.2006.10.014, 2007.

15 Petrow, T., Zimmer, J., and Merz, B.: Changes in the flood hazard in Germany through changing frequency and persistence of circulation patterns, Nat. Hazards Earth Syst. Sci., 9, 1409–1423, doi:10.5194/nhess-9-1409-2009, 2009.

Rauthe, M., Steiner, H., Riediger, U., Mazurkiewicz, A., and Gratzki, A.: A Central European precipitation climatology – Part I: Generation and validation of a high-resolution gridded daily data set (HYRAS), Meteorol. Z., 22, 235–256, doi:10.1127/0941-2948/2013/0436, 2013.

20 Smith, R. B. and Barstad, I.: A linear theory of orographic precipitation, J. Atmos. Sci., 61, 1377–1391, doi:10.1175/1520-0469(2004)061<1377:ALTOOP>2.0.CO;2, 2004.

Strahler, A. N.: Quantitative analysis of watershed geomorphology, Eos T. Am. Geophys. Un., 38, 913–920, doi:10.1029/TR038i006p00913, 1957.

25 Swiss Re: Sigma preliminary estimates: natural catastrophes and man-made disasters in 2013 cost insurers worldwide USD 44 billion, Preliminary catastrophe estimates for 2013, Swiss Re – Leading Global Reinsurer, available at: [http://www.swissre.com/media/news\\_releases/nr\\_20131218\\_sigma\\_natcat\\_2013.html](http://www.swissre.com/media/news_releases/nr_20131218_sigma_natcat_2013.html), last access: 18 December 2013.

30 Thieken, A. H., Müller, M., Kreibich, H., and Merz, B.: Flood damage and influencing factors: new insights from the August 2002 flood in Germany, Water Resour. Res., 41, 1–16, doi:10.1029/2005WR004177, 2005.

Uhlemann, S., Thieken, A. H., and Merz, B.: A consistent set of trans-basin floods in Germany between 1952–2002, *Hydrol. Earth Syst. Sci.*, 14, 1277–1295, doi:10.5194/hess-14-1277-2010, 2010.

5 Ulbrich, U., Brücher, T., Fink, A. H., Leckebusch, G. C., Krüger, A., and Pinto, J. G.: The central European floods of August 2002: Part 1 – Rainfall periods and flood development, *Weather*, 58, 371–377, doi:10.1256/wea.61.03A, 2003.

## HESSD

11, 8125–8166, 2014

### What made the June 2013 flood in Germany an exceptional event?

K. Schröter et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures



Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



## What made the June 2013 flood in Germany an exceptional event?

K. Schröter et al.

[Title Page](#)

[Abstract](#)

[Introduction](#)

[Conclusions](#)

[References](#)

[Tables](#)

[Figures](#)



[Back](#)

[Close](#)

[Full Screen / Esc](#)

[Printer-friendly Version](#)

[Interactive Discussion](#)



**Table 1.** Data sources, resolution and analysis methods for hydro-meteorological parameters.

Hydro-meteorological factors	Data source	Spatial resolution	Temporal resolution	Analysis/classification	
Circulation patterns	DWD <sup>1</sup>	Europe	Daily	Relative frequency of persistency prior to past large scale flood events	
Precipitation	REGNIE DWD <sup>1</sup>	1 km <sup>2</sup>	Daily	maximum 3 day totals R3d. extreme value statistics based on annual series	
Initial catchment state	Antecedent precipitation index API	REGNIE DWD <sup>1</sup>	1 km <sup>2</sup>	Daily	Precipitation index for all past flood events
	Ratio of initial river flow to mean annual flood	Discharge gauges BfG <sup>2</sup> /WSV <sup>3</sup> and hydrometric services of federal states	Point information; 162 gauges and related sub-basins	event-based daily mean	API quantification 30 days ahead of R3d; extreme value statistics based on partial series conditional on past flood events Wetness index for all past flood events extreme value statistics based on partial series conditional on past flood events
Peak flood discharge	Discharge gauges BfG <sup>2</sup> /WSV <sup>3</sup> and hydrometric services of federal states	Point information; 162 gauges and related sub-basins	event-based daily mean	Initial hydraulic load index for all past flood events extreme value statistics based on annual maximum series	
			event-based	Flood severity index for all past flood events	

<sup>1</sup> German Weather Service,

<sup>2</sup> German Federal Institute of Hydrology,

<sup>3</sup> Water and Shipment Administration.

# HESSD

11, 8125–8166, 2014

## What made the June 2013 flood in Germany an exceptional event?

K. Schröter et al.

**Table 2.** Severity indices for June 2013, August 2002 and July 1954 floods.

Index	Jun 2013	Aug 2002	Jul 1954
Precipitation index ( $S_{R3d}$ )	16.9	30.1	55.2
Wetness index ( $S_{API}$ )	114.1	47.3	21.1
Initial hydraulic load index ( $S_{Q_1}$ )	12.7	6.0	6.1
Flood severity index ( $S_{Q_p}$ )	74.6	35.4	49.8

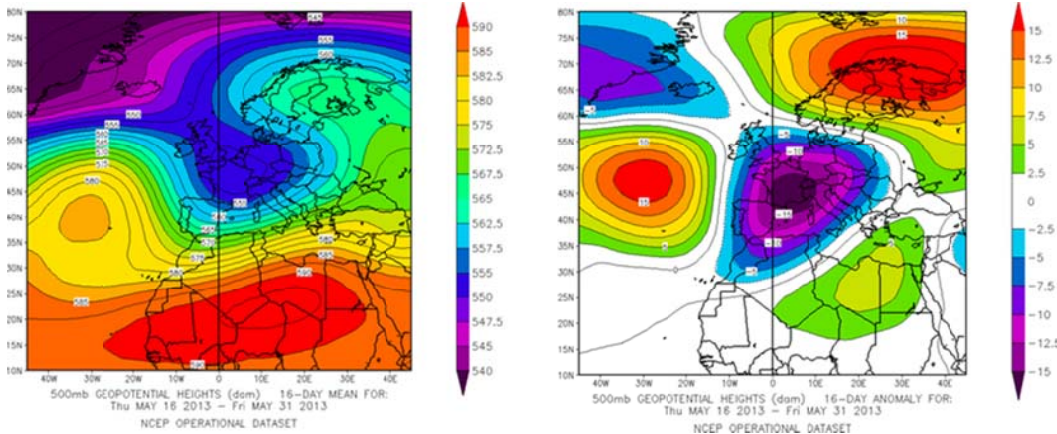
[Title Page](#)[Abstract](#)[Introduction](#)[Conclusions](#)[References](#)[Tables](#)[Figures](#)[Back](#)[Close](#)[Full Screen / Esc](#)[Printer-friendly Version](#)[Interactive Discussion](#)

# HESSD

11, 8125–8166, 2014

## What made the June 2013 flood in Germany an exceptional event?

K. Schröter et al.

[Title Page](#)[Abstract](#)[Introduction](#)[Conclusions](#)[References](#)[Tables](#)[Figures](#)[⏪](#)[⏩](#)[◀](#)[▶](#)[Back](#)[Close](#)[Full Screen / Esc](#)[Printer-friendly Version](#)[Interactive Discussion](#)

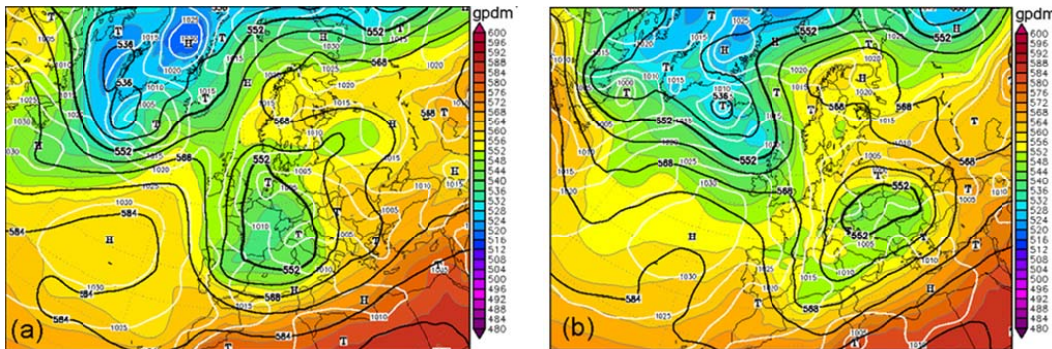
**Figure 1.** 500 hPa geopotential height, 16 day mean for 16–31 May 2013 (left panel) and anomaly in respect to the climatology based on 1979–1995. Credit: data/image provided by the NOAA/OAR/ESRL PSD, Boulder, Colorado, USA, from their Web site at <http://www.esrl.noaa.gov/psd/>.

## HESSD

11, 8125–8166, 2014

What made the  
June 2013 flood in  
Germany an  
exceptional event?

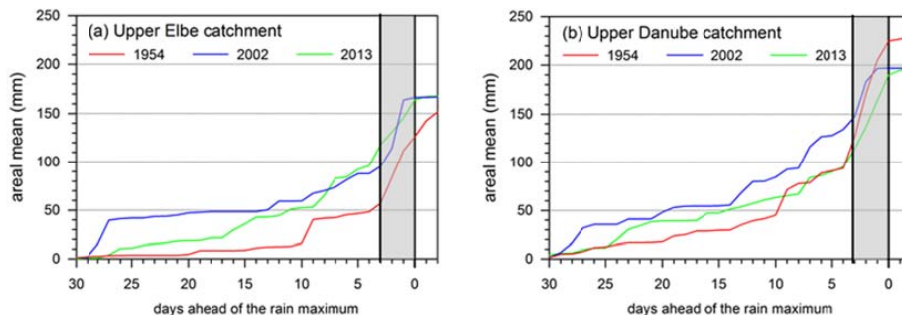
K. Schröter et al.

[Title Page](#)[Abstract](#)[Introduction](#)[Conclusions](#)[References](#)[Tables](#)[Figures](#)[Back](#)[Close](#)[Full Screen / Esc](#)[Printer-friendly Version](#)[Interactive Discussion](#)

**Figure 2.** Weather charts for 30 May (a) and 1 June 2013 (b) 00:00 UTC with analysis of 500 hPa geopotential height (black lines), surface pressure (white lines) and 1000/500 hPa relative topography (colors) from the Global Forecast System (GFS). Image credit: wetter3.de.

## What made the June 2013 flood in Germany an exceptional event?

K. Schröter et al.



**Figure 3.** Time series of cumulated areal mean precipitation for the upper Elbe catchment in Germany up to the inflow of the river Saale **(a)** and for the upper Danube catchment (Germany only); **(b)**. The  $x$  axis marks the days prior to the 3 day maximum precipitation totals. Event precipitation is highlighted in grey.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

⏪

⏩

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



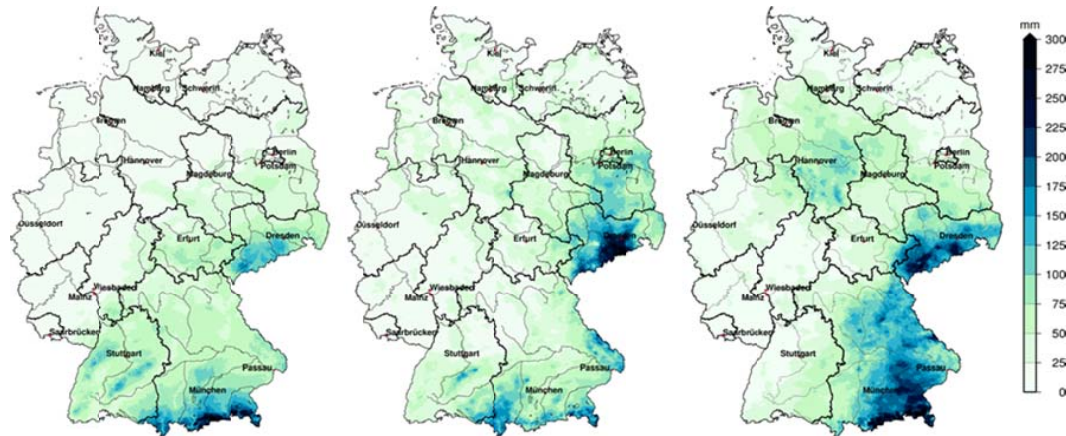


# HESSD

11, 8125–8166, 2014

## What made the June 2013 flood in Germany an exceptional event?

K. Schröter et al.



**Figure 4.** The 3 day maximum precipitation according to REGNIE data sets for June 2013 (left panel), August 2002 (middle panel) and July 1954 (right panel).

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

⏪

⏩

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion

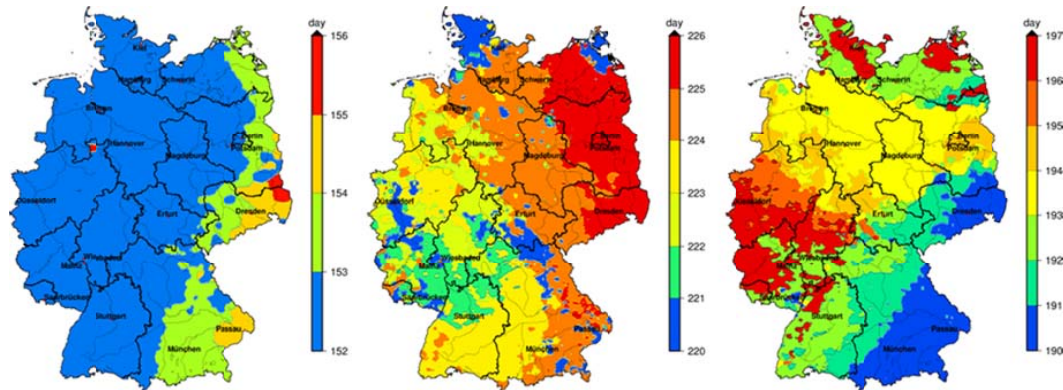


# HESSD

11, 8125–8166, 2014

## What made the June 2013 flood in Germany an exceptional event?

K. Schröter et al.



**Figure 5.** Day of the year at each REGNIE grid point where the event related maximum R3 total according to Fig. 4 occurred (end of the 3 day total) for June 2013 (left panel), August 2002 (middle panel), and July 1954 (right panel). The day 152 corresponds to 1 June, 220 to 8 August, and 190 to 9 July.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures



Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



**What made the June 2013 flood in Germany an exceptional event?**

K. Schröter et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures



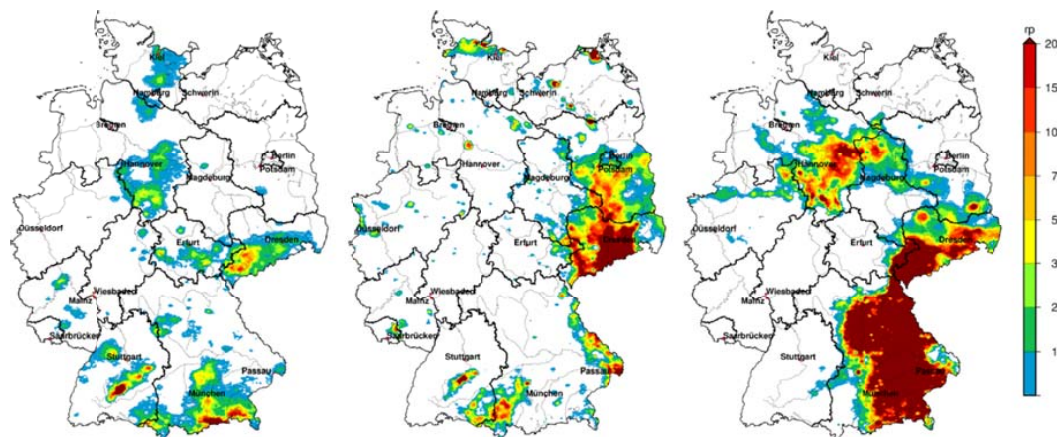
Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



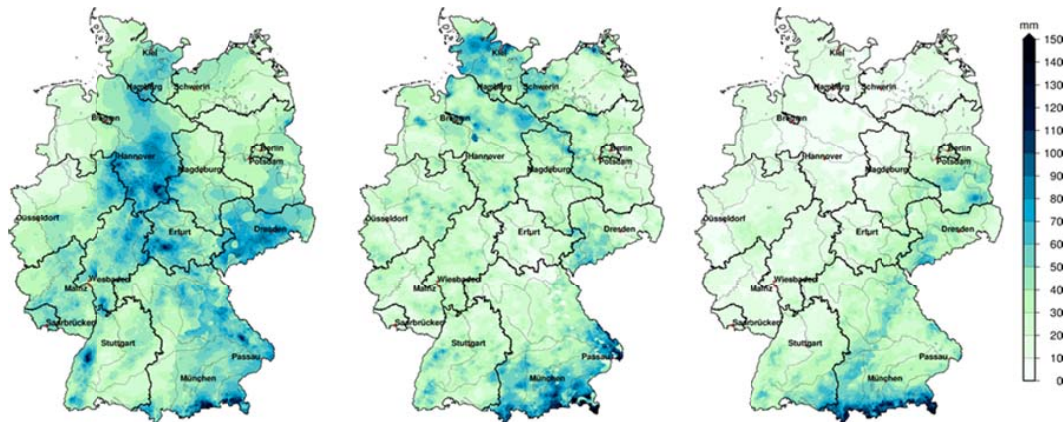
**Figure 6.** Return periods of 3 day maximum precipitation for each REGNIE grid point derived from data of the period from 1960 to 2009 for the corresponding rain totals displayed in Fig. 4: June 2013 (left panel), August 2002 (middle panel), and July 1954 (right panel).

# HESSD

11, 8125–8166, 2014

## What made the June 2013 flood in Germany an exceptional event?

K. Schröter et al.



**Figure 7.** Antecedent Precipitation Index API over 30 days for the floods in June 2013 (left panel), August 2002 (middle panel), and July 1954 (right panel). See text for further details.

[Title Page](#)[Abstract](#)[Introduction](#)[Conclusions](#)[References](#)[Tables](#)[Figures](#)[◀](#)[▶](#)[◀](#)[▶](#)[Back](#)[Close](#)[Full Screen / Esc](#)[Printer-friendly Version](#)[Interactive Discussion](#)

# HESSD

11, 8125–8166, 2014

## What made the June 2013 flood in Germany an exceptional event?

K. Schröter et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures



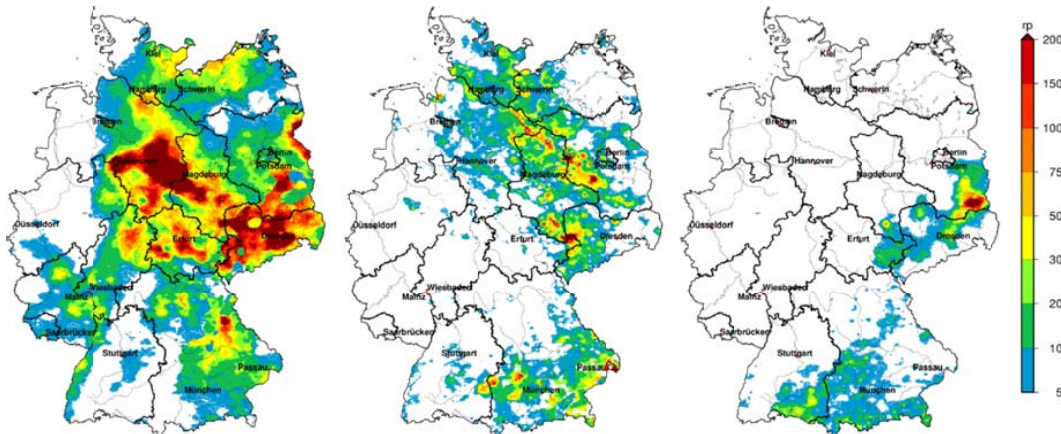
Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



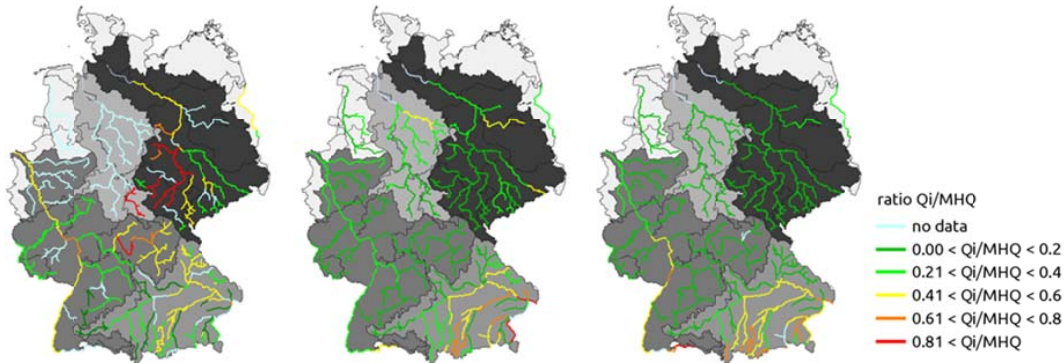
**Figure 8.** Return periods of the API displayed in Fig. 7 conditional on the occurrence of large-scale floods in the period from 1960 to 2009: June 2013 (left panel), August 2002 (middle panel), and July 1954 (right panel).

# HESSD

11, 8125–8166, 2014

## What made the June 2013 flood in Germany an exceptional event?

K. Schröter et al.

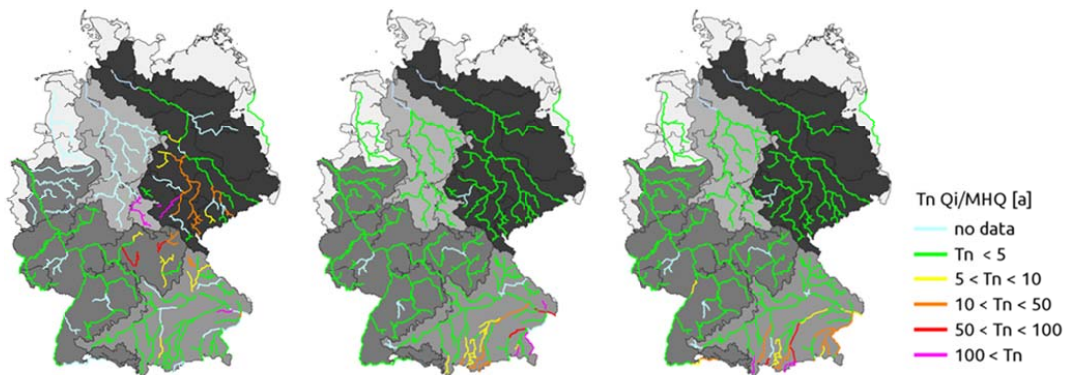


**Figure 9.** Initial flow ratio at meteorological event start  $Q$ , normalized for MHQ (calculated from AMS 1950–2009) for June 2013 (left panel), August 2002 (middle panel), and July 1954 (right panel).

[Title Page](#)[Abstract](#)[Introduction](#)[Conclusions](#)[References](#)[Tables](#)[Figures](#)[◀](#)[▶](#)[◀](#)[▶](#)[Back](#)[Close](#)[Full Screen / Esc](#)[Printer-friendly Version](#)[Interactive Discussion](#)

## What made the June 2013 flood in Germany an exceptional event?

K. Schröter et al.

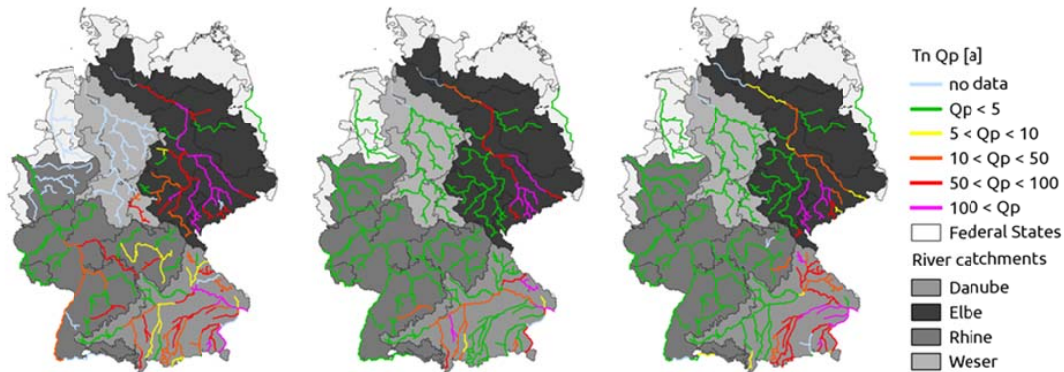


**Figure 10.** Return periods of initial flow ratio at meteorological event start ( $Q_i$  normalized for MHQ) conditional on the occurrence of large scale floods in the period from 1960–2009: June 2013 (left panel), August 2002 (middle panel), and July 1954 (right panel).

[Title Page](#)[Abstract](#)[Introduction](#)[Conclusions](#)[References](#)[Tables](#)[Figures](#)[◀](#)[▶](#)[◀](#)[▶](#)[Back](#)[Close](#)[Full Screen / Esc](#)[Printer-friendly Version](#)[Interactive Discussion](#)

## What made the June 2013 flood in Germany an exceptional event?

K. Schröter et al.



**Figure 11.** Regionalized return periods ( $T_n$ ) of flood peak discharges for June 2013 (left panel), August 2022 (middle panel), and July 1954 (right panel) floods in Germany. Gauge data were made available by the Water and Shipping Management of the Fed. Rep. (WSV) prepared by the Federal Institute for Hydrology (BfG) and environmental state offices of the federal states.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

⏪

⏩

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

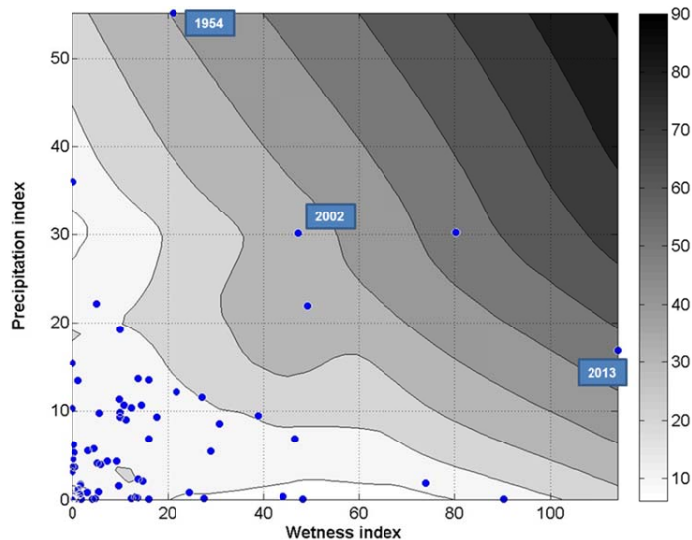
Interactive Discussion





## What made the June 2013 flood in Germany an exceptional event?

K. Schröter et al.



**Figure 12.** Locally-weighted scatter plot smooth (LOWESS) for the relationship between precipitation and wetness indices as predictors for the flood severity index (grey color code) of past large scale flood events in Germany. Note that the open right corner does not contain observed data.

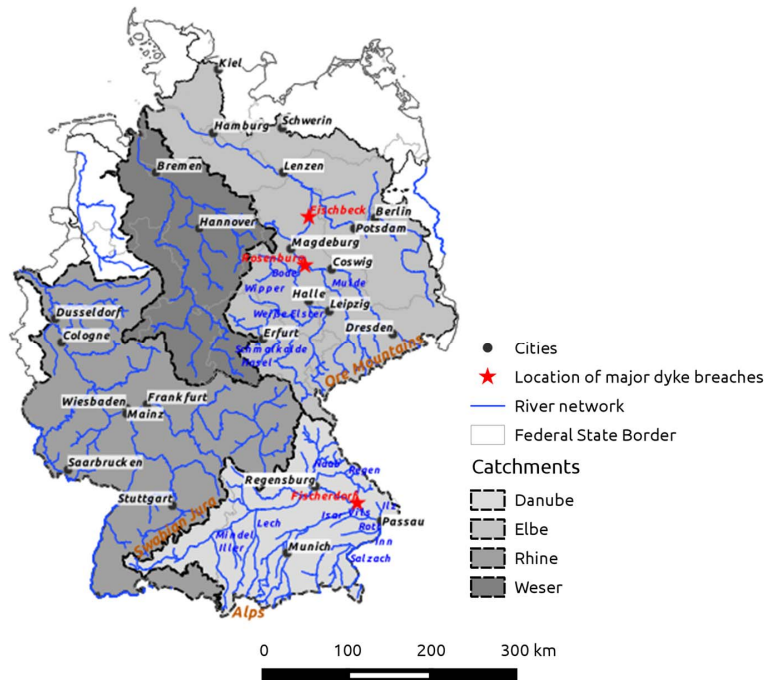
[Title Page](#)[Abstract](#)[Introduction](#)[Conclusions](#)[References](#)[Tables](#)[Figures](#)[⏪](#)[⏩](#)[◀](#)[▶](#)[Back](#)[Close](#)[Full Screen / Esc](#)[Printer-friendly Version](#)[Interactive Discussion](#)

# HESSD

11, 8125–8166, 2014

## What made the June 2013 flood in Germany an exceptional event?

K. Schröter et al.



**Figure A1.** Outline map of referred geographic locations.

[Title Page](#)

[Abstract](#)

[Introduction](#)

[Conclusions](#)

[References](#)

[Tables](#)

[Figures](#)



[Back](#)

[Close](#)

[Full Screen / Esc](#)

[Printer-friendly Version](#)

[Interactive Discussion](#)

