CEDIM Forensic Disaster Analysis Group (FDA)

High water/flooding Southern Germany May/June 2016

20 June 2016

Auhtors: Bernhard Mühr, James Daniell, Florian Ehmele, Andreas Kron, André Dittrich, Michael Kunz

1 Introduction

Almost daily from the End of May to the midst of June in 2016 the weather conditions kept whole range of summer extreme weather events at hand – there have been thunderstorms with extreme precipitation intensities, locally there have been enormous amounts of (mostly small-grained) hail and even single tornadoes led to some damage.

The greatest potential of damage however has been tied with the heavy precipitation, which caused in situ heavy floods and individual landslides. At several rivers (e.g. Ahr, Kocher) the water gauges did reach new historic highs, elsewhere tidal waves set streets meters high under water. Torrential rain did not only occur in Germany, also places in Belgium, in the Netherlands, in Austria or in France had to fight against tremendous problems caused by floods. Even though the especially heavy thundershowers always occurred only sporadically, they created, in Germany alone, damage in the billions.

In the moist-warm air mass, which has been located above Central Europe for almost three weeks, every day locally severe thunderstorms that went along with heavy rain would form anew. Although intense thunderstorms are not unusual in summer for the affected regions, but them appearing over such a long period can be described as extraordinary

The main focus of the following contemplations is set on the weather events of the 29th of May 2016, when record breaking rainfalls occurred in south western Germany and locally led to great damage.

2 Meteorological Background

2.1 Meteorological Conditions and Development

In the two-week period from the 27th of May to the 9th of June in 2016, the average 500 hPa-geopotential area was characterized by a structure that was more reminiscent of the winter. A powerful high-pressure block, which arched upwards from Great Britain till Iceland and the middle of Scandinavia, was flanked by two upper level troughs; the upper level trough in the West did push southward directing Azores, while the second extended above the East of Europe to the South to the Black Sea and Turkey.

From Poland across Germany, Figure 1 (left) indicates an area with deep geo potential, the low urge of the isohyets at the same time proposes to low wind speeds in the mid-troposphere (height around 5km). In general, such pressure constellation proves to be extremely stable and is due to the isohyets, which have the shape of the greek capital letter “Omega”, also referred to as „Omega“-Position.

Figure 1 (right) shows, how exceptionally big the geopotential anomalies have been especially over the North Atlantic during the two-week period; the positive geo potential anomaly with values around 20 hPa in the Iceland area is accompanied by a negative in the area of the Azores, which had deviations to -20 hPa.

The slight low pressure influence above Central Europe did correspond with low pressure on the ground. With only weak air pressure opposites a low pressure zone did establish, which reached from Poland to France. From the 29^{th} until the 31th of May the low “Elvira” appeared in ground pressure analysis, in the 1st of June it was replaced by "Friederike", which finally covered whole Central Europe at the 5th of June. Until the 9th of June 2016 especially in the West and the South low pressure influence and moist-warm air masses remained affecting weather conditions, while in the North-East dry air gradual enforced itself.

Given both the low wind speeds on the ground and in the height the thunderstorms especially in Central and South Germany did hardly show any relocation trends.

They did not cross any larger region with their heavy precipitation area, but dumped their wet load normally in situ and only in small amounts. The areas affected with rain intensities of 80 to 120 mm within an hour rarely had an extension of more than a few square kilometers.

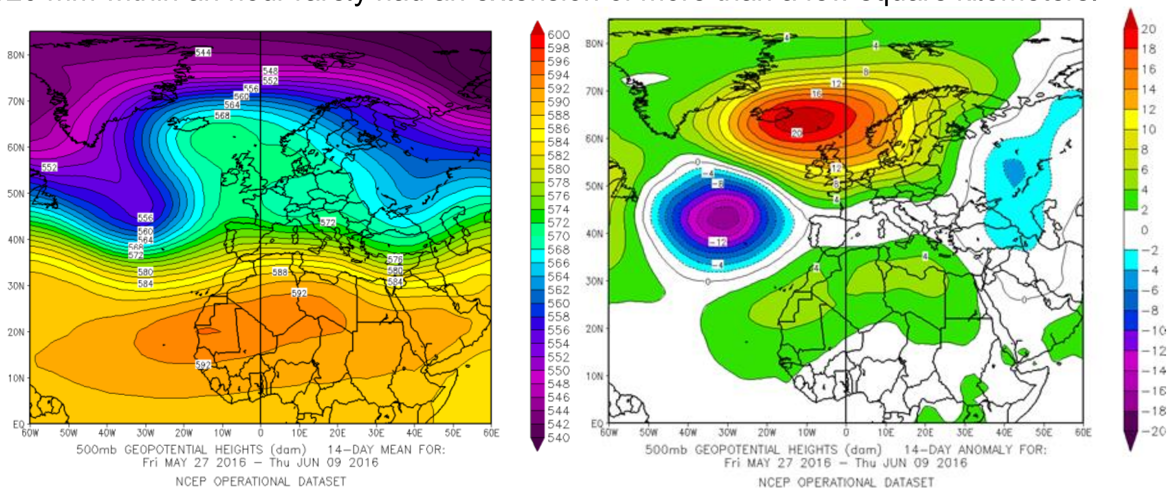

Figure 1: 500 hPa-geopotential. 14-day-average 27.5.-9.6.2016 (left) and deviation from mean 1979-1995 (right). Image source: NOAA/ESRL Physical Sciences Division, Boulder Colorado, http://www.esrl.noaa.gov/psd/

2.2 The Development on the 29th of May 2016

In warm, moist air and under low pressure influence, already on the day before numerous partly violent thunderstorms evolved with heavy rain and hail above Central Germany from North-Rhine-Westphalia to Saxony.

Towards Sunday, the 29th of May 2016, an upper level trough approached southern Germany coming from France and Switzerland. In the North of the Alps, air pressure drop set in on the ground. Due to the forth turning of the upper level trough a massive positive vorticity advection and a transport of warm and moist air in the low and central troposphere were connected, which both reached their maximum in the evening and together provided a great elevation impulse above Baden-Württemberg and Western Bavaria (Figure 4).

The existing warm and humid air already became apparent around noon (see radiosonde ascent from Kümmersbruck, Figure 3) by a large lability, as evidenced by the relevant thunderstorm indices (e.g. CAPE values around 1500 J/kg).

Figure 5 shows the values of the 850 hPa pseudo-potential temperature, a measure of the energy content of the air. Extraordinary high values from 50 to 60°C can be found on the North- and Eastside of the ground low arose above Germany, one of the essential requirements for the development of strong thunderstorms.

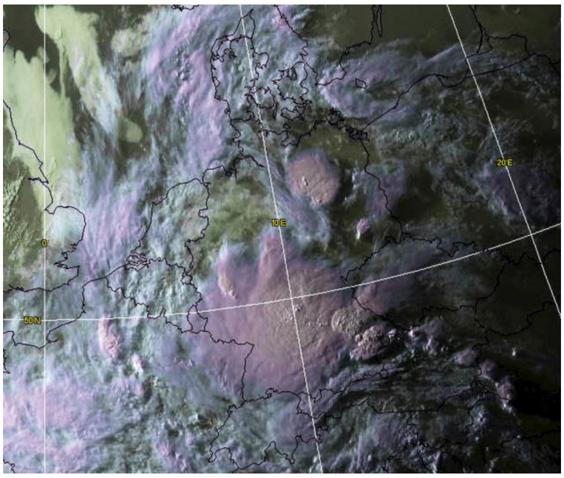

Figure 2: Satellite image MSG VIS, 29.5.2016, 18 UTC. Source: Eumetsat/B.J.Burton. http://www.woksat.info/wwp.html

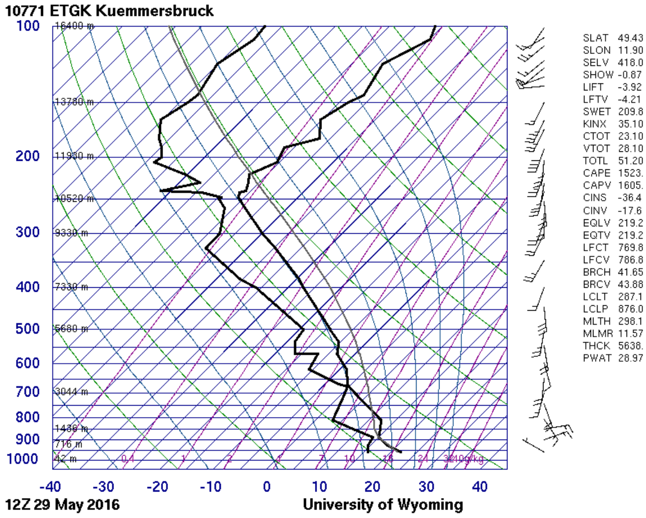

Figure 3: Radiosonde ascent Kümmersbruck (BY), 29.5.2016, 12 UTC. Source: Department of Atmospheric Science, University of Wyoming. http://weather.uwyo.edu/upperair/sounding.html

Before noon already, first thunderstorms developed above Bavaria and with the approaching elevation area also rain set in in Allgäu, starting from Switzerland. While the precipitation area expanded in the next hours towards western Baden-Württemberg, around 13 UTC new powerful thunderstorms set in at the edge of the Alps and in the Allgäu. As a result, between Munich and Salzburg, as well as between Nuremberg and Stuttgart, single powerful thunderstorms formed.

In the evening, a coherent precipitation and cloud field covered western Bavaria, all of Baden - Württemberg, southern Hessen and the east of Rhineland-Palatinate. Around 19 UTC a zone with powerful thunderstorms expanded in Germany from Passau to the Northwest of Baden-Württemberg. Given the weak upper winds, the whole precipitation area as well as the thunderstorms showed only very little displacement trends at its northern and eastern edges. There has been extreme heavy rain; the greatest amount of precipitation was registered in Gundelsheim at the Neckar with 122.1 mm.

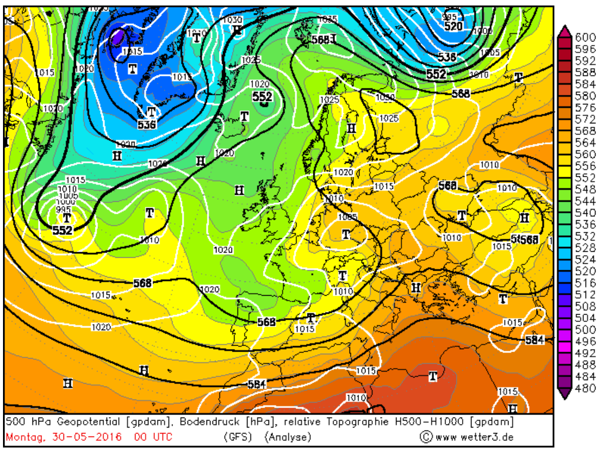

Figure 4: 500 hPa geopotential, ground pressure and relative topography. Analysis 30.5.2016, 00 UTC. Source: www.wetter3.de

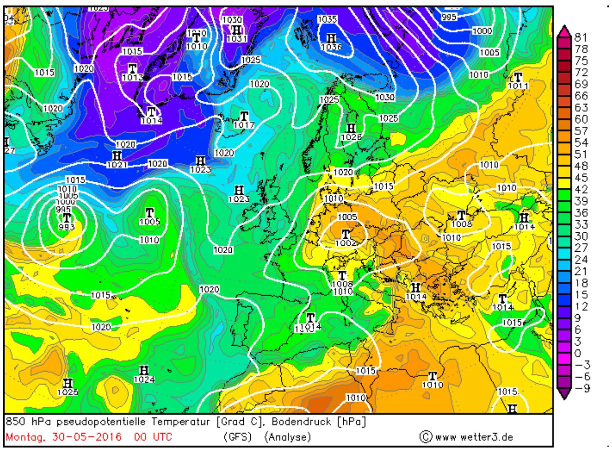

Figure 5: 850 hPa pseudo-potential temperature [°C]. Analysis 30.5.2016, 00 UTC. Source: www.wetter3.de

2.3 Amounts of Precipitation

In the period from the 28th of May until the 5th of June 2016 severe thunderstorms occurred daily in Germany, which were associated with at least 50 mm of precipitation. Table 1 provides information on the stations in Germany, where the daily totals of precipitation reached at least 80 mm. Almost always, most of the precipitation occured within a few hours (see section 2.4).

Table 1: Overview of the stations with a 24-hour precipitation amount with at least 80 mm from 26th May to 9th June 2016. Datasource: DWD

Station	RR24h [mm]	Bundesland	Betreiber	Datum
Gundelsheim	122.1	BW	DWD	29th May 16
Langenburg-Atzenrot	105.0	BW	DWD	29th May 16
Wilhelmsfeld	101.1	BW	DWD	29th May 16
Kirchberg/Jagst-Herbolzhausen	94.0	BW	DWD	29th May 16
Crailsheim	92.3	BW	LUBW	29th May 16
Ellwangen-Rindelbach	86.5	BW	DWD	29th May 16
Bullay (Kläranlage)	84.5	RP	DWD	29th May 16
Eibenstock (Talsperre)	83.3	SN	DWD	29th May 16
Mulfingen/Jagst	82.5	BW	DWD	29th May 16
Vellberg-Kleinaltdorf	82.2	BW	DWD	29th May 16
Birkenau	82.0	HE	DWD	29th May 16
Hohenpeißenberg	81.6	BY	DWD	29th May 16
Entenpfuhl	81.1	RP	DLR RP	29th May 16
Sindelfinden	80.4	BW	DWD	29th May 16
Hohenthann	80.2	BY	DWD	29th May 16
Hamminkeln-Mühlenrott	120.3	NW	DWD	1st Jun 16
Xanten	111.1	NW	DWD	1st Jun 16
Wesel-Flüren	97.5	NW	DWD	1st Jun 16
Geldern-Walbeck	88.7	NW	DWD	1st Jun 16

2.4 Statistical Analyses

With the REGNIE-Data (REGniolasierte NIEderschläge), the German Weather Service (Deutsche Wetterdienst (DWD)) possesses a longtime dataset (since 1951) of 24-hour-precipitation totals on a constant 1 x 1 km² grid for the whole of Germany.

Figure 6 shows the total precipitation of the 29th of May 2016 6 UTC until the 30th of May 2015 6 UTC. Above the entire northern half of Baden-Württemberg comprehensive amounts of rainfall with more than 40 mm have been registered. Particularly large amounts with more than 60 mm fell in the range between Heilbronn and Schwäbisch Hall (SHA) and to the north of it (white box). An analysis of the entire time series in this area results in return periods (rp) of the 24-hour-precipitation of up to 200 years or more. (Figure 7 and Table 2). Especially in the area northeast of Schwäbisch Hall (Crailsheim, Braunsbach, Künzelsau) it results to annualities of over 200 years. This is also reflected by the evaluation of the station data in this area.

While the event in relation to the total area of Baden-Württemberg only ranks at place 11 of the strongest historical events, it is the strongest observed event in the last 65 years concerning the mentioned region and even more so for the entire area in the East of the Neckar and in the North of the Schwäbische Alb.

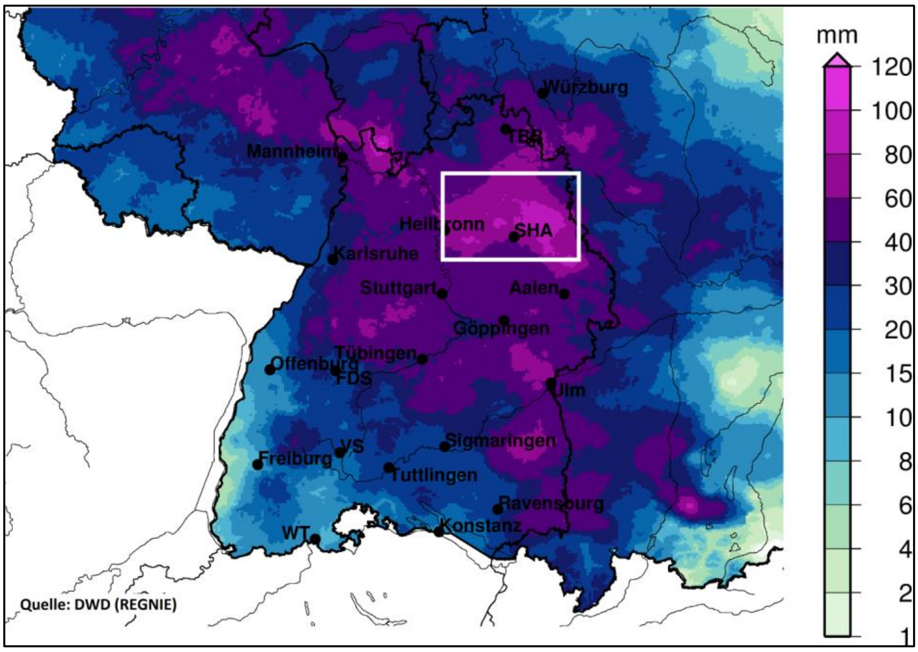

Figure 6: Extract of the REGNIE-dataset, 24 h precipitation total from 29th May 2016 6 UTC to 30th May 2016 6 UTC.

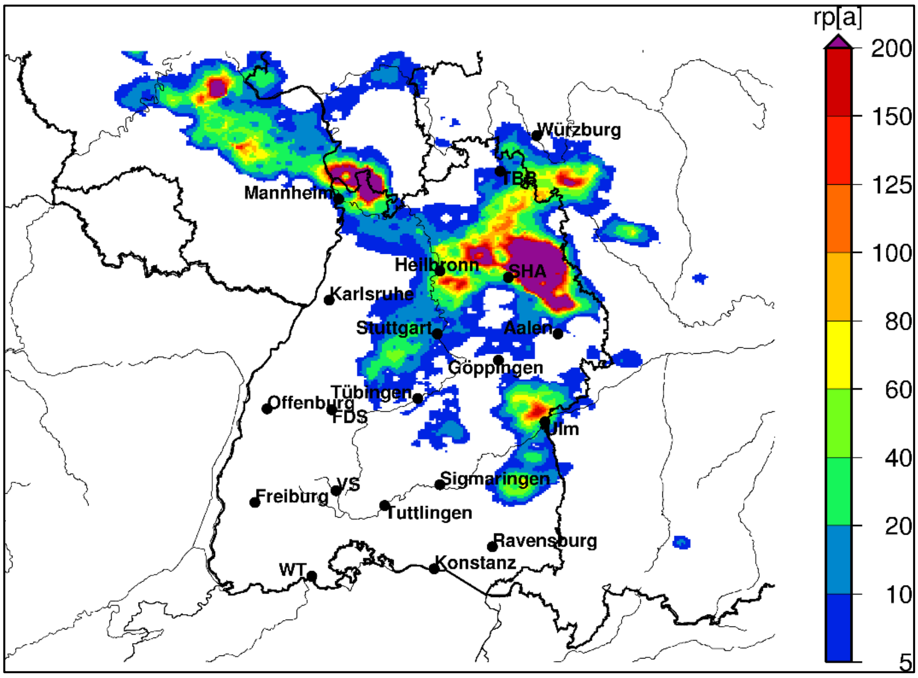

Figure 7: Repeat periods of the 24 h precipitation total from 29th May 2016 6 UTC to 30th May 2016 6 UTC.

Table 2: Overview of selected stations oft he DWD; Start of the data collection, 24 h precipitation totals with date and calculated repeat period.

Stationsname	Zeitreihe seit	24 h Niederschlag	Wiederkehrperiode
Öhringen	1889	78,8 mm (29.5.)	~200 Jahre
Kupferzell	1941	72,0 mm (29.5.)	> 30 Jahre
Kirchberg/Jagst	1981	94,0 mm (29.5.)	> 200 Jahre
Langenburg	1931	105,0 mm (29.5.)	> 200 Jahre

As can be seen from radar data (RADOLAN) and station data, the main characteristic of this event are the precipitation totals that occurred only within a few hours. Figure 8 shows the time series of the hourly precipitation totals at the stations Kirchberg/Jagst and Kupferzell as well as the accumulated amount of rain between the 28th June 2016 12 UTC and the 30th June 2016 12 UTC.

The start of the event is around hour 27 (15 UTC at the 29th of June). In Kirchheim fell around 90% of the 24-hours-total within the following few hours. In Kupferzell it was around 78%. Due to the short period for which hourly measurements are available (about 10 years), no statement can be made of the annularity of the amount of precipitation in these shorter intervals. However, it can be assumed that they will exceed the annularity of the 24-hour-total.

At the station Simbach/Inn high 24h precipitation totals have been measured in two consecutive days, which – if you look at the station data- seem to have fallen within only a few hours. On the 1st June 2016 between 7 UTC and 12 UTC, the station was not working. The missing data was replaced by the value at the relevant grid point of the RADOLAN data and accumulated.

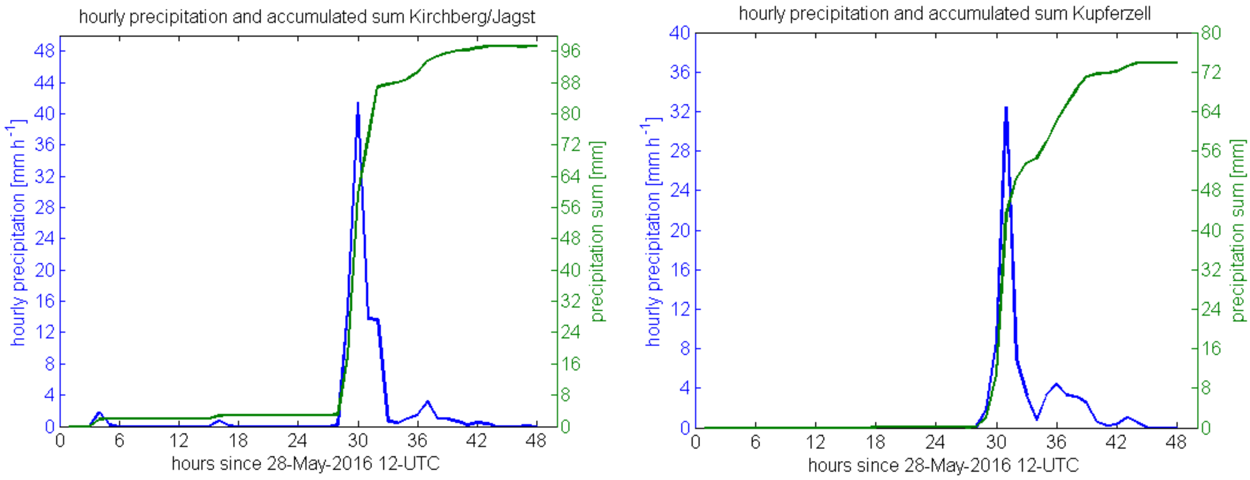

Figure 8: Hourly precipitation (blue graph) oft he DWD stations Kirchberg/Jagst (left) and Kupferzell (right) and accumulated precipitation sum (green graph) for the time span from28th May 2016 12 UTC to 30th May 2016 12 UTC.

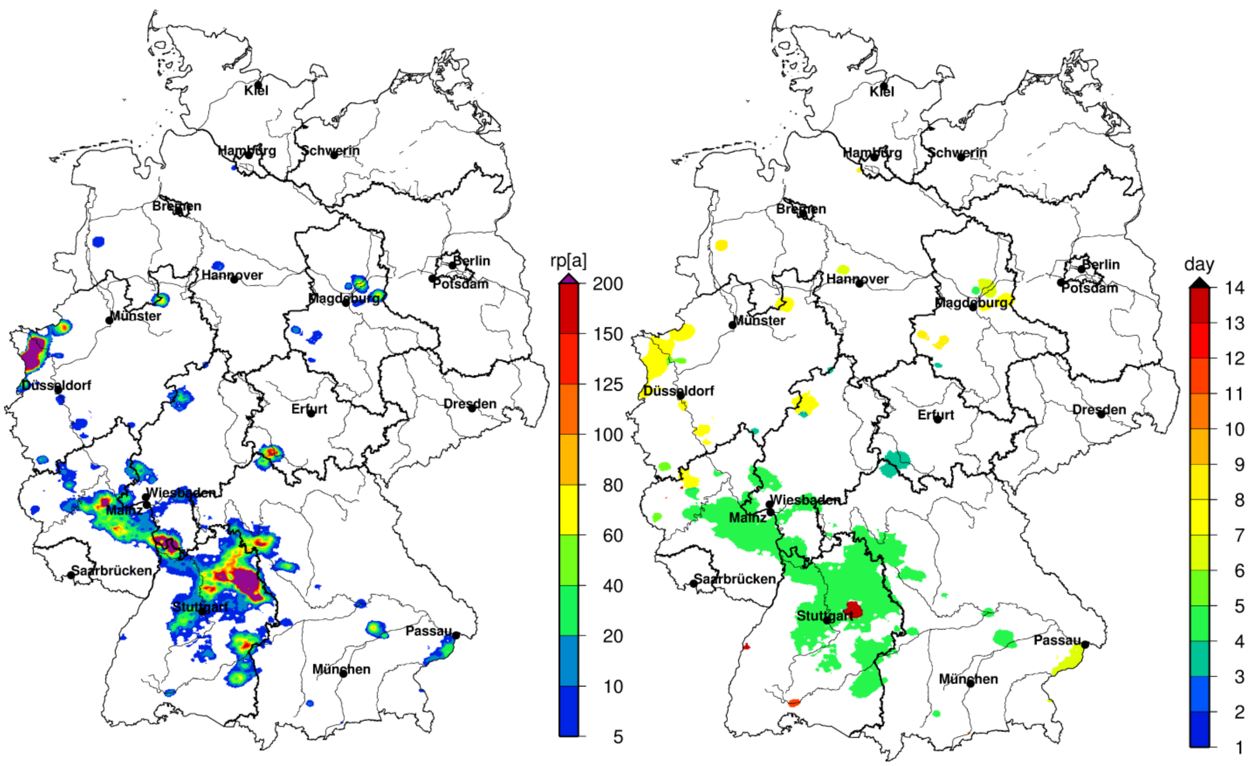

Figure 9: Maximal erreichte Wiederkehrperiode des 24 Stunden Niederschlags pro Gitterpunkt im Zeitraum 26.5.2016 6 UTC bis 9.6.2016 6 UTC (links) und am Tag deren Auftretens seit 26.5.2016 (rechts)

Throughout the period from the 26th May 2016 to the 8th June 2016 precipitation occurred with high return periods in various regions of Germany. Figure 9shows the maximum return periods per grid point, and the day, on which that value has been occurred. Only annularities higher than 5 years were considered. On day 4 the largest area was affected (corresponds to the 29th May 2016, green).

3 Hydrology and Hydraulic Systems

3.1 Overview of the Water Levels

The strong precipitation has led locally to a considerable rise of the discharge, especially in smaller water bodies. First reports of floodings in Baden-Württemberg were received in the early evening of the 29th May 2016.

In Baden-Württemberg, mainly smaller water bodies in the eastern regions were affected. The damage foci occurred in Braunsbach in the estuary area of the Kocher as well as in Schwäbisch Gmünd at the Rems. The annuality for the Neckar is at present information between a HQ2 and a HQ10.

In Bavaria, mainly estuary areas of the Rott (maximum value: 1st June 2016, notification stage 4 = built-up areas are affected in larger scale) and the Franconian Rezat were affected. At the Donau, the water level at Passau remained below notification stage 3.

Also in southern Hessen and in the headwaters of the river Fulda the notification stages were exceededg of .

3.2 Flooding Situation Kocher

The flood forecasting for large river basins is based on a nationwide level-network, which nowadays allows a reliable water level forecast at large-scale precipitations thanks to the flood control center.
A reliable” forecast on town granularity with information for the very precise moment of occurrence and intensity of the event at local heavy rain events, as in the current occasions in the period from the 29th May to the 6th June 2016, is not possible due to the minor local development and the fast reaction of the catchment area to the precipitation. The events, which mostly release water in storms, are characterized by an extreme high intensity (precipitation/time), which could lead to a considerable overload of the water bodies and the canal system in urban areas.
In addition, the water masses carry large amounts of debris with them, which can lead to an increase of the intensity of the damage. Occasionally, the peak values are reached within just a few hours and abate just as quickly. Locally this leads to extreme discharge conditions with extremely high intensity, while large-scale effects do not appear in many cases.

Figure 10shows the discharge hydrographs of the current event at level Stein/ Kocher in comparison with the discharge hydrographs of an event from December 1993.

The flood of December 1993 was characterized by the penetration of warm, moist air into the Rhine Area. Combined with an unusual temperature rise high precipitations came up, which led to enormous high damage in the entire Rhine Area. The flood wave at level Stein/Kocher did reach his peak value with ca. 690 m^3/s at the 30th of May 2016. In the statistic classification this value is close to a HQ100-Event (709 m^3/s).

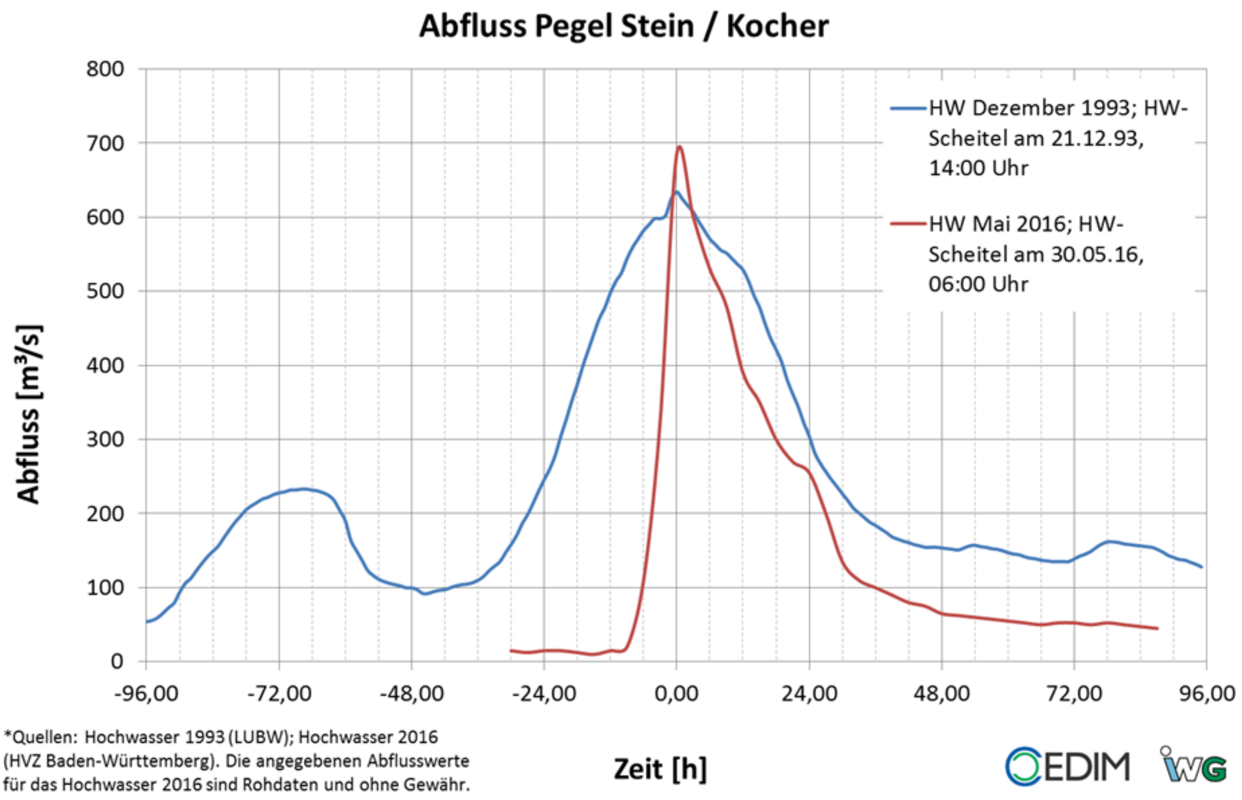

Figure 10: Comparison of the discharge hydrographes of the present Event at the Level Stein / Kocher with an Event of December 1993

4 Damage

4.1 Background

The damage resulting from the combined heavy rain and hail event from the 27th of May to the 9th of June 2016 has caused in total around 1,2 billion Euro as estimated by GDV including damage in Baden-Württemberg.

In terms of losses to buildings (houses, contents, business and industrial enterprises), this estimate is likely around 1 billion Euro extrapolating from early insurance information in Baden-Württemberg, but the data is currently preliminary. In total, around 7,000+ structures are likely affected in some way. The huge amount of damaged cars around creeks which were washed away caused an approximate loss of. 200 million Euro for vehicle insurers.

In addition, large amounts of damage to infrastructure were seen, with large cleanup costs estimated due to the amount of mud etc. In the aftermath, much effort has been made to protect houses in the resulting days, given the risk from the system of further flooding.

In following FDA reports, the damage statistics will be examined further.

4.2 Field trip

In a survey done by Dr.-Ing. Andreas Kron and Dr.-Ing. James Daniell, various damaged areas were visited on 7th June 2016 in order to examine the major cause of damage. 4 locations were visited: Braunsbach, Steinkirchen, Niedernhall and Weissbach.

All communites are sited near the Kocher, the damages however are not caused by the flooding of Kocher itself, but by congestion of his tributary rivers.

The highest damages of the events in Baden-Württemberg were done in the community of Braunsbach near the river Kocher. The floodings did not result from the Kocher, a tributary of the Neckar, but by the “Orlacher Bach” as well as the “Schlossbach”, which both (partly in pipelines) lead through the district.

The catchment area of the Orlacher Bach has a size of 7km² and is characterized by steep valley slides and a large bottom slope in his upper reaches.

Figure 11: Damage at the Ground Floor (Souterrain/Deep parterre) and First Floor (left); Flow Situation during the Event with Locally Strong Varying Water Levels (right).

The heavy precipitation has led to a large occurrence of debris from the catchment basin of the Orlacher Bach (branches, uprooted tree trunks). These have been building up in front of a bridge passage initially and were then rinsed by the inflowing water masses in the direction of the site. The steep slope caused locally very high flow rates and thus great damage to roads and buildings. After viewing various video recordings, the flow rate of the Kocher at the end of the Orlacher Straße was estimated to more than 7 m/s. The ground floor level of many houses was directly affected; locally the water levels reached the upper floors. To some extend even roofs were damaged by entrained tree trunks and their branches.

Figure 12: Structural damage to buildings in Braunsbach.

According to eyewitnesses, the maximum water levels were reached within 15 minutes; a similar event had not happened before. A local resident stated that his mother had lived in the town for 92 years and had never before experienced such a big flooding of the Orlacher Bach. In the past, mostly floods of the Kocher have resulted in the flooding of the town.

Figure 13: Buildings destroyed by flow attack and debris impact in Braunsbach.

A comparable field characteristic (elongated catchment basin with steep valley flanks) features the Reichenbach, which is located in direct neighborhood and caused damage in the town of Steinkirchen. Here, parts of the infrastructure were affected, which were partly destroyed by local load peaks. Structural damage to buildings did not occur in Steinkirchen.

Figure 14: Damage to streets after a flow-around at a bridge in Steinkirchen.

Significantly lower losses occured in the towns of Weissenbach and Niedernhall.
The damages in Weissbach were basically a direct result of the precipitation, which has flown over the road cross-sections. The freshly precipitated water volume partly led to an overload of drains and culverts. There were relatively low water levels of up to 25 cm, which have resulted in damage to lower floors and basements.

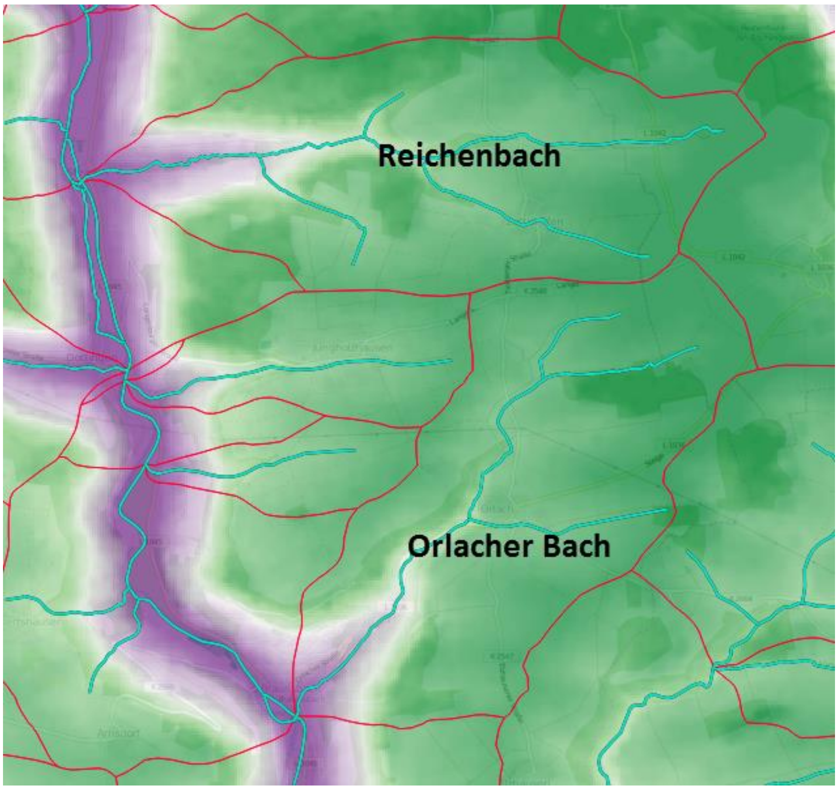

Figure 15: Orlacher Bach (Braunsbach) and Reichenbach (Steinkirchen) marked by their respective drainage area. Both have a size around 6 km² and about 200 m difference in height within their drainage area.

In Niedernhall, damage was located close to the Kocher where similar flows occurred through the town. On the town wall a water height of around 1 meter was reached, however it is unknown if this was from the Kocher river or from the creeks running through the town. In most cases the damage towards the Kocher was only very low (ca. 40cm high water and mud infiltrating cellars and the first floor of buildings.)

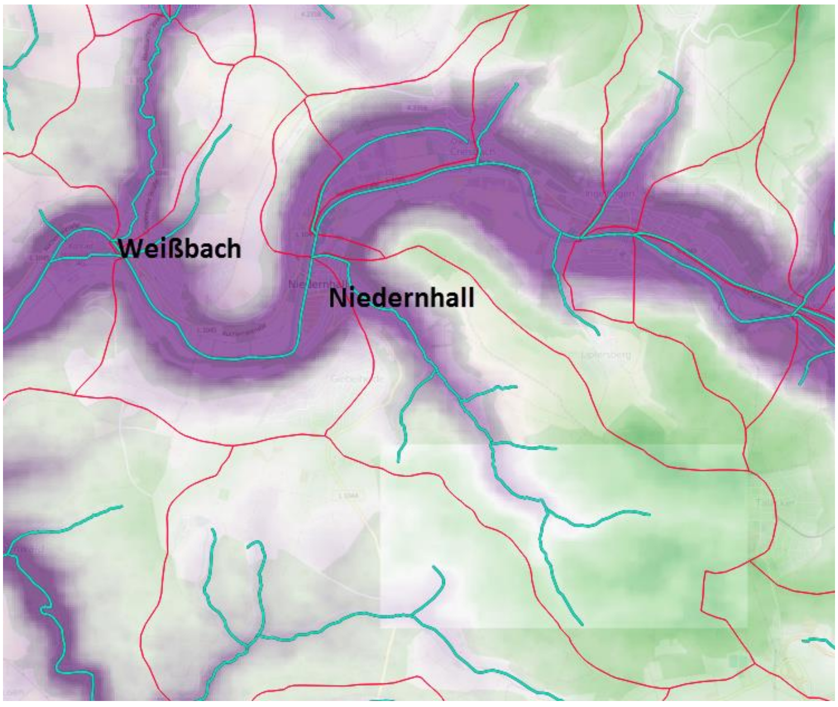

Figure 16: Red Border = Drainage Areas, Blue = Course of the Creek/ River, Violet/Green = Height.

On the 8th June 2016, various properties were examined with respect to their damage in

Künzelsau and Forchtenberg. Similar damage patterns were seen in Niedernhall and Künzelsau. Cause of the damages was the overloading of the discharge capacity of the Künsbach, which, partly drained, runs through the city of Künzelsau. Because of debris from the upper catchment area and „inner-city"-debris in the form of motor vehicles respectively, several passages were blocked in urban areas and have led to an overflowing. Many cellars were filled to around 2-2.4m height, and the average sheet flow was around the 30cm mark on the ground floor, causing damage to electrical fittings, heatings, floors and the walls in ground floors and cellars.

Figure 17: Entry to an underpass of a building, which was blocked by a motor vehicle during the High Water.

A similar scouring action was observed in Forchtenberg similar to that of Braunsbach. In both cases, there has been a blockade of passages due to debris and sediment accumulation from the upper catchment area. The thereby impounding water volume broke away abruptly when there was sufficient water pressure and caused a tidal wave that flowed along the valley line. In the area of the community Forchtenberg such a flood wave has created a main valley with a maximum depth of 3.5 m and a width at the bottom of approximately 1.5 m. Fortunately, there were no houses in the direct vicinity with a 3.5m by 1.5m chasm created as water rushed down a creek alongside an engineered 50cm pipe intended for creek flow. Some minor damage to buildings alongside the creek occurred on the bottom floor. One house had damage to the roof from debris action (probably a dragged-off tree trunk) upstream.

Figure 18: Remediation work at a building in Künzelsau. Because of the moisture damage a dismantling of the basement and ground floors to shell construction status is required in many cases.

Figure 19: High water caused erosion along an asphalted road at the border of Forchtenberg.

For more detailed information go to:
http://www.wettergefahren-fruehwarnung.de/Ereignis/20160530_e.html.

----

5 Contact

CEDIM

André Dittrich

E-mail: andre.dittrich@kit.edu

Tel: +49 721 608 23913
+49 721 608 45028

KIT Public Relations

Monika Landgraf

E-mail: monika.landgraf@kit.edu

Tel: +49 721 608 48126