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Climate change track in river floods in Europe

Z. W. Kundzewicz[1,2]
[1]Institute for Agricultural and Forest Environment, Polish Academy of Sciences, Bukowska 19,
60-809 Poznań, Poland
[2]Potsdam Institute for Climate Impact Research, Telegrafenberg 31, 14473 Potsdam, Germany

Correspondence to: Z. W. Kundzewicz (kundzewicz@yahoo.com)

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Abstract. A holistic perspective on changing river flood risk in Europe is provided. Economic losses from floods have increased, principally driven by the expanding exposure of assets at risk. Climate change (i.e. observed increase in precipitation intensity, decrease of snowpack and other observed climate changes) might already have had an impact on floods. However, no gauge-based evidence had been found for a climate-driven, widespread change in the magnitude/frequency of floods during the last decades. There are strong regional and sub-regional variations in the trends. Moreover, it has not been generally possible to attribute rain-generated peak streamflow trends to anthropogenic climate change.

Physical reasoning suggests that projected increases in the frequency and intensity of heavy rainfall would contribute to increases in rain-generated local floods, while less snowmelt flooding and earlier spring peak flows in snowmelt-fed rivers are expected. However, there is low confidence in future changes in flood magnitude and frequency resulting from climate change. The impacts of climate change on flood characteristics are highly sensitive to the detailed nature of those changes.

Discussion of projections of flood hazard in Europe is offered. Attention is drawn to a considerable uncertainty - over the last decade or so, projections of flood hazard in Europe have largely changed.

1 Introduction

Despite all the economic and social development, the progress in technology, and heavy investments in flood defence works, Europe has not been immune to severe flooding. In fact, floods are the most prevalent natural hazard throughout the continent and remain a serious problem. Many areas in Europe have been hit by major floods in recent decades, with multiple fatalities and annual multi-billion-Euro direct material damage. The most destructive deluges occurred in August 2002, when the number of flood fatalities reached 232 and the material damage soared to over USD 27 billion (Choryński et al., 2012). Most recently, there were several large, killing, floods in Europe in 2013–2014, caused by heavy and torrential rains, e.g. in Southern France, Northern Italy, Bulgaria, Greece, and Russia. A large late-spring flood (May–June) occurred in 2013 in Germany, Austria (with conservatively assessed damages in both countries in excess of EUR 6 and 2 billion, respectively), and in neighbouring countries. The water level exceeded historical maximum at a reach of the River Elbe in Germany and dikes were broken. In December 2013–February 2014, a large area of the UK experienced precipitation and streamflow highly exceeding the long-term mean. This winter flooding generated a considerable impact on infrastructure (property and transport).

The present paper reviews factors contributing to flood risk and then analyses detection of change in variables of relevance to floods – intense precipitation, maximum streamflow and flood damage. Finally, projections for the future are critically discussed, with emphasis on uncertainty.

2 Flood risk – climatic and non-climatic factors

A holistic approach to flood risk interpretation embraces a chain of flood-relevant processes and variables. Flood risk is often defined as a combination of the probability of a flood event and a measure of its adverse consequences. Flood risk depends on the flood hazard, exposure, and vulnerability and

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these three are influenced by numerous, climatic and non-climatic, factors.

The principal climatic factors determining flood hazard are: the temperature-driven water-holding capacity of the atmosphere, the water vapor content, and the characteristics of intense precipitation. The phase of precipitation (rain or snow) and its distribution in space and time; the sequence of temperature (important for freeze and thaw of snow cover, and freeze up and break up of river ice); as well as large-scale circulation patterns, also play a role.

Beyond the climate, also the characteristics of terrestrial and fluvial systems play a pivotal part in driving flood hazard (Hall et al., 2014). The river flow process is an integrated result of processes in the drainage basin – from precipitation to runoff. It depends on multiple natural factors, as well as on watershed management practices and river engineering that alters the river conveyance system over time.

Land-use and land-cover changes, e.g. caused by socio-economic factors, condition the transformation of precipitation into runoff. In an urban basin, with high portions of impermeable areas and high values of the runoff coefficient (portion of precipitation that enters a stream), the peak streamflow for the same precipitation hydrograph is higher, while the time-to-peak is shorter than in a rural (and especially forested) basin of comparable size, with similar topography and soils. Also river regulation (e.g. channel straightening and shortening, channelization) and flood defenses (dikes and dams) alter the response time of the river system to an intense precipitation or a high inflow to a river reach, hence, affect flood wave propagation.

Numerous socio-economic factors influence flood exposure and vulnerability. Particularly relevant variables in the domain of economic and social systems are the number of inhabitants of flood-prone areas and the flood damage potential accumulated there. Important socio-economic factors influencing flood risk are: vulnerability, adaptive capacity, risk awareness and risk perception. Considerable progress in reducing the vulnerability and number of flood fatalities can be achieved if flood-risk awareness is improved.

Many inhabitants of Europe live in flood-risk areas. According to the data compiled by the IWR (2011), the percentage of the population living in flood-prone areas in the UK and the Netherlands is, respectively, 9 and 55 %. In the UK, about 5.7 million properties are located in flood plains, while assets in flood plains in the Netherlands constitute 65 % of the national total.

3 Observations – change detection in flood data

There is a view that recent claims of an increase in flood risk are not warranted and simply result from the "CNN effect", i.e. the ubiquity of disaster news accompanying technological development and the advance of globalization. Possibly – say some – the world is no worse off in terms of floods than a few decades ago, yet the coverage is now much more extensive and negatively focused (cf. Kundzewicz, 2011). In the past, before the technological revolution and globalization, it was not technically possible to collect and promptly disseminate information on remote floods. Now, media organizations highlight and headline floods wherever they occur and tend to dramatize situations. As a result, a flood event in a most remote corner of Europe is reported on television news worldwide in near real-time, just hours after happening. Such an event would have been overlooked in the not-too-distant past. However, even if the CNN effect is real, the increase in flood damage and flood risk in recent decades has been beyond doubt.

As noted by Zolina (2012), intense precipitation in Europe exhibits complex variability and lacks a robust spatial pattern. However, the dominating tendency is that heavy precipitation has been increasing. This includes widespread increases in the contribution to total annual precipitation from very wet days (days in which precipitation amounts exceed the 95th percentile value), corresponding to an observed, and expected on physical grounds, increase in water vapour amount in the warmer atmosphere. In many regions (e.g. central-western Europe and European Russia), increasing trends in high percentiles of daily winter precipitation were found, confirmed by some more detailed country-based studies (e.g., Hattermann et al., 2013), but in some regions trends were decreasing. The changes in heavy precipitation are inconsistent across studies, and are region- and season-specific and statistics are strongly influenced by inter-annual and inter-decadal variability. Seneviratne et al. (2012) assessed that there is medium confidence in trends for heavy precipitation in Europe, observed to date, because of partly inconsistent signals across studies and regions, especially in summer. Also, the structure of precipitation has changed – as stated by Zolina (2012), short, isolated rain events have been regrouped into prolonged wet spells. In some countries (e.g. Germany, cf. Hattermann et al., 2013), changes in frequency of climate circulation patterns have been spotted towards "wet" patterns.

The results of change detection study of annual maximum river flows (cf. Kundzewicz et al., 2005; Svensson et al., 2005) do not support the hypothesis of a ubiquitous increase in annual maximum river flows. No gauge-based evidence of geographically organized patterns of robust and ubiquitous climate-driven change in flood magnitude and frequency of high discharge in European rivers during the last decades has been identified. Nevertheless, Kundzewicz et al. (2005), who analysed 70 long time series of river discharge in Europe, found that the overall maxima for the period 1961–2000 occurred more frequently in 1981–2000 (46 times) than in 1961–1980 (24 times).

In climates where seasonal snow storage and melting play a significant role in annual runoff, the hydrological regime is affected by changes in temperature, and there is abundant evidence for changes in the timing (earlier occurrence) of spring peak flows in snowmelt- and glacier-fed rivers. However, not all such areas are experiencing changes in the magnitude of peak flow (Kundzewicz, 2012).

The availability of 25 years of large flood records in the Dartmouth Flood Observatory Archive allowed analysis of the time series of flood indices over Europe. The countries with multiple large floods during 1985–2009 are: Romania, Czech Republic, Slovak Republic, UK, Germany and Austria, of which Romania was affected most frequently (nine large floods). Kundzewicz et al. (2013) found increase in the numbers of large flood events during 1985–2009, where large floods were defined as events above fixed thresholds of severity or magnitude. However, the clear rising trends are superimposed on considerable variability. For example, in the flood-rich years 1997 and 1998, the number of floods of large magnitude in Europe equalled 11 and 12, respectively, while in a flood-poor year, such as 2000, this number was only 4.

Wet and dry years occur in clusters, creating flood-rich and flood-poor episodes. For instance, on the Danube in Vienna, grouping of five of the six largest floods in the 19th century was observed in the last two decades of the century, illustrating pronounced clustering of extreme events (Blöschl and Montanari, 2010).

For Germany, Hattermann et al. (2013) showed that the results of change detection are far from being uniform over all parts of the country. In parts of Germany, maximum river flows are found to have increased, but in other areas, a decrease is noted. This means that no ubiquitous, general, and significant changes in observed flood flows can be detected, even at a national scale, and dissemination of this finding is very important.

Recently, large floods have become more destructive than ever in much of Europe. Overall annual aggregated losses from flood disasters in Europe, as well as insured (inflation adjusted) losses, are increasing, but with considerable volatility from year to year (Kron, 2012; Lugeri et al., 2010).

There are multiple factors contributing to the growth of flood risk that differ for different countries and for different flood generation mechanisms. Handmer et al. (2012) and Kundzewicz et al. (2014) stated that the exposure of people and economic assets has been the major cause of long-term increases in economic losses from floods. Long-term trends in economic disaster losses, adjusted for wealth and population increases, have not been attributed to climate change.

Flood risk has increased in European countries primarily as a consequence of the increase in exposure to floods and damage potential in result of social and economic advances. Problems grow as people become wealthier because technology in its various forms helps the populating of more "difficult" areas (maladaptation). This trend has been exacerbated by ill-advised planning decisions regarding the location of settlements.

The potential for flood damage is increasing because structural defences such as dikes and dams have been built. Typically, dikes offer adequate protection against small and medium size floods, i.e. the number of damaging floods in this range decreases when dikes are in place. The positive effects of dikes (or reservoirs or polders) against floods lower than the design flood are evident, but the negative side (enhancing development of flood-prone areas) is often overlooked rather than being appropriately considered beforehand.

It can be stated that, using the parlance of mechanics, human kind has contributed to increase in the load and to decrease in resistance of the system. The first part of the statement refers to the higher flood magnitudes generated by a given precipitation event (and, possibly, to anthropogenic increase in intense precipitation), while the second part can be understood as the amplification of the flood damage potential.

Finding a trend or "signal" in a system characterized by large natural variability or "noise" is difficult and requires lengthy and good-quality records. The problem of detecting a climate change signature in river flow data is quite complex, so that particular care is needed in selecting data and sites for use in studying climate impact on floods. In order to assess climatically-forced hydrological changes, data should be taken from pristine drainage basins that are not affected by human activities such as deforestation, urbanization, river engineering, or reservoir construction. However, in many areas, anthropogenic influences are strong everywhere, so that it is very difficult to select pristine basins. Data should be of high quality and extend over a long period, preferably at least 50 years (Kundzewicz and Robson, 2004). The currency of records is important, preferably extending to the present. Ideally, there should be no missing values and gaps in data.

But, even if the data are perfect, extreme events do not happen frequently, so even where a very long time series of instrumental records exists, one still deals with a small sample of truly extreme, destructive floods (cf. Kundzewicz and Schellnhuber, 2004).

The attribution of economic disaster losses is subject to a number of limitations, including data availability and the processes used to normalize loss data over time, which take account of changes in exposure of people and assets, but use only limited, if any, measures of changes in vulnerability (Bouwer, 2011). Different approaches are also used to handle variations in the quality and completeness of data on impacts over time.

4 Projections and uncertainty

4.1 Projections

Model-based projections show that heavy precipitation, as measured by various indices, will likely increase in the 21st century. Seneviratne et al. (2012) analyzed changes in regionally averaged projections of return period (in years) of 20-year return values of annual maximum 24-h precipitation, for two time horizons, 2046–2065 and 2081–2100, as compared to the late-20th century. The study was based on three different SRES emissions scenarios (B1, A1B and A2) and 14 general circulation models (GCMs). The results show that the median of the return period decreases for all three subregions of Europe considered in the study (North Europe, Central Europe, and South Europe and the Mediterranean), hence heavy precipitation is projected to be increasingly frequent. Recent model-based study by Kendon et al. (2014), with high spatial and temporal resolution, demonstrated intensification of precipitation extremes at sub-daily (hourly) time scale for the UK, including convective extremes in summer.

Climate-driven changes in flood frequency exhibit a huge complexity that depends on the generating mechanisms. That is, flood magnitudes are expected to rise where floods result from increasingly heavy rainfalls, while flood magnitudes may decrease where floods are generated by a smaller spring snowmelt. If climatic projections are correct, a notable – and beneficial – decrease in the probability of floods that generally corresponds to lower flood peaks is expected for a large part of Europe in the late 21st century, because of a reduction in snow accumulation.

Recent works by Hirabayashi et al. (2013) and Dankers et al. (2014) give flood projections for Europe that largely differ from projections produced by the same authors just a few years ago (Hirabayashi et al., 2008; Dankers and Feyen, 2008). The latter set of works projected increase of frequency of floods over a large part of Europe. Now, Hirabayashi et al. (2013) and Dankers et al. (2014) agree that 100-year floods and 30-year floods, respectively, are projected to increase over most of the globe, yet they also agree that the flood frequency is projected to decrease over most of the European continent. The recent projections by Hirabayashi et al. (2013) indicate flood frequency decrease in much of Northern, Central, and Southern Europe. Only for a part of Europe (British isles, Northern France, and part of Benelux), prevailing increases in flood frequency between 20th century (1971–2000) – control period and 21st century (2071–2100) is projected for a 100-year flood in the control period. Results of Dankers et al. (2014) show that increase in flood frequency (30-year flood in the control period) is likely to occur in even a smaller part of Europe (British isles).

Since the recent flood projections are so dramatically different from the earlier results (that were used as an input for loss projections), it is necessary to interpret the sources of these differences, and if the new results are corroborated, to translate the newest hazard assessments (Hirabayashi et al., 2013; Dankers et al., 2014) into quantitative flood loss estimates.

4.2 Uncertainty

Projections of precipitation extremes are associated with large uncertainties. They result from uncertainties in models, downscaling techniques, and the natural variability of the climate. Rainfall extremes are underestimated by the climate models (as evident in model performance when simulating historical data), due to the coarse spatial resolution used in the model simulations. Hence, projections of future changes in extreme precipitation in the warming world are also likely underestimated. There are fundamental limitations of models, such as, for example, omission of land-cover feedbacks, failure to preserve mass in the global water balance (see Liepert and Previdi, 2012), and poor representation of planetary-scale teleconnections (Kundzewicz et al., 2014). One should be cautious about regional- and local-scale projections of extreme precipitation (see Anagnostopoulos et al., 2010). Further work towards improvements in GCMs is much needed but this may take much time, while for the time being climate models are not ready “for prime time” (Kundzewicz and Stakhiv, 2010). The effect of long-term persistence, observed in real data, is typically ignored in climate-model-based studies (Koutsoyiannis and Montanari, 2007).

River discharge simulation under a changing climate scenario requires a set of GCM or RCM outputs (e.g. precipitation and surface air temperature) and a hydrological model, but the ability of models to simulate floods, and in particular the signs of past and future trends, depends on the ability of the climate models to simulate precipitation changes. Therefore, there is strong uncertainty in the projected changes in the magnitude and frequency of floods, while the GCM remains the largest source of uncertainties in hydrological projections for the forthcoming decades at the river-basin scale. Uncertainties from emissions scenarios and downscaling methods are also relevant, especially when projection horizon is further into the future.

As most of the observed warming is very likely due to anthropogenic influence (Stocker et al., 2013), one could expect the existence of a link between increasing atmospheric greenhouse gas concentrations and increasing flood proxies (e.g. maximum river flow). However, as demonstrated by Hirsch and Ryberg (2012), atmospheric concentration of carbon dioxide increases regularly, while high river flows in the USA do not. In contrast, Pall et al. (2011) undertook estimation of fractional attributable risk, trying to evaluate to what extent greenhouse gas emissions changed the likelihood of intense precipitation and high streamflow. They showed that increasing global anthropogenic greenhouse-gas emissions could have substantially increased the risk of rainfall-dominated flood occurrence in the UK, as observed in autumn 2000 and as associated with a displacement in the North Atlantic jet stream. This study showed that there is now about 50 % chance that an anthropogenic influence can be detected for UK extreme precipitation in winter.

5 Concluding remarks

A few years ago, scenarios of future climate indicate a likelihood of increased intense precipitation and flood hazard in many areas of Europe (cf. Kundzewicz et al., 2010), but observations to date do not necessarily confirm this.

The linkages between enhanced greenhouse forcing and flood phenomena are very complex and, up to the present, it has not been possible to describe the connections well. There is no doubt that current trends in human activity on the landscape continue to cause an increase in flood damages. Decreasing or reversing this trend requires substantial attention and the actions needed to accomplish this are largely the same regardless of the nature of the driver of risk increase. A concern about the climate-flood linkage and its uncertainty causes society to lose focus on the things we already know for certain about floods and flood protection. Blaming climate change for flood losses makes flood losses a global issue that appears to be out of the control of regional or national institutions (Kundzewicz et al., 2014).

The climate change issue is very important to flooding, but we have low confidence about the science. The precautionary principle and adaptive management are a right choice. The state of the science of regarding the emissions-climate-floods chain should cause decision-makers to take a more cautious approach to flood adaptation because of the added uncertainty that enhanced greenhouse forcing has introduced.

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