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Identification of coherent flood regions across Europe by using the longest streamflow records

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SUMMARY

This study compiles a new dataset, consisting of the longest available flow series from across Europe, and uses it to study the spatial and temporal clustering of flood events across the continent. Hydrological series at 102 gauging stations were collected from 25 European countries. Five geographically distinct large-scale homogeneous regions are identified: (i) an Atlantic region, (ii) a Continental region, (iii) a Scandinavian region, (iv) an Alpine region, and (v) a Mediterranean region. The months with a higher likelihood of flooding were identified in each region. The analysis of the clustering of annual counts of floods revealed an over-dispersion in the Atlantic and Continental regions, forming flood-rich and flood-poor periods, as well as an under-dispersion in the Scandinavian region that points to a regular pattern of flood occurrences at the inter-annual scale. The detection of trends in flood series is attempted by basing it on the identified regions, interpreting the results at a regional scale and for various time periods: 1900–1999; 1920–1999; 1939–1998 and 1956–1995. The results indicate that a decreasing trend in the magnitude of floods was observed mainly in the Continental region in the period 1920–1999 with 22% of the catchments revealing such a trend, as well as a decreasing trend in the timing of floods in the Alpine region in the period 1900–1999 with 75% of the catchments revealing this trend. A mixed pattern of changes in the frequency of floods over a threshold and few significant changes in the timing of floods were detected.

1. Introduction

The seemingly endless reoccurrence of destructive and costly flood events across Europe reinforces the need for further research into all aspects of flood-risk management, especially in

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understanding the risk of extreme events and in determining how the likelihood of such events might change because of drivers such as climate and land-use changes. Consequently, several studies of trends in observed series of flood events have been conducted at a national level in various European countries, from which the most recent studies involve the following: Austria (Blöschl et al., 2012; Villarini et al., 2012), Finland (Korhonen and Kuusisto, 2010), France (Renard et al., 2008; Giuntoli et al., 2012), Germany (Petrow and Merz, 2009; Bormann et al., 2011), Ireland (Murphy et al., 2013), Poland (Strupczewski et al., 2001; Kundzewicz et al., 2012), Portugal (Silva et al., 2012), Slovenia (Ulaga et al., 2008), Spain (Mediero et al., 2014), Sweden (Lindström and Bergström, 2004), Turkey (Cigizoglu et al., 2005) and the United Kingdom (Hannaford and Marsh, 2008; Prosdocimi et al., 2014). Reviews of the results obtained in these studies have been published by Hall et al. (2014) and Madsen et al. (2014).

However, the results of such studies at a national level are difficult to compare in order to derive a large-scale coherent picture, since they use different flood indicators, time periods and methods. Consequently, there is an increasing realisation of the benefits of considering the problem at a larger geographical scale, not confined within political and administrative boundaries. This applies both in terms of enlarging available datasets in time and space and a better consideration of large-scale climatic drivers (Kjeldsen, 2011; Kjeldsen et al., 2014; Hall et al., 2014). Examples of recent studies that consider changes in flood records at larger and trans-national scales include the Nordic countries (Wilson et al., 2010), Central Europe (Villarini et al., 2011), the Baltic States (Reihan et al., 2012; Sarauskiene et al., in press) and North America (Hodgkins and Dudley, 2006; Vogel et al., 2011).

Finally, some attempts have entailed a pan-European scale by using observed runoff data primarily from the Global Runoff Data Centre (GRDC) and the European Water Archive (EWA) of Flow Regimes from International Experimental and Network Data (FRIEND) (Hanna et al., 2011). Nevertheless, most of these studies have focused on monthly, seasonal and annual streamflows, as well as various streamflow indices (Gudmundsson et al., 2011; Hannaford et al., 2013; Stahl et al., 2010, 2012). Kundzewicz et al. (2005) focused on trends in long flood series from catchments located around the world. However, the European gauging stations included in Kundzewicz et al. (2005) were clustered in only seven countries in northern Europe, overlooking large areas in southern Europe. Consequently, there is a need for extending the availability of hydrological data from catchments spread more evenly throughout Europe to enable a holistic assessment of flood behaviour (trends and clustering) in a unified approach across the continent. This can unveil potential large-scale patterns, which may not be visible when comparing single studies on a national level. In addition, such patterns enable a sounder and more comprehensive connection with large-scale climatic drivers (Pires and Perdigão, 2007) and regional scale landscape–climate interactions (Perdigão and Blöschl, 2014).

Given the relatively short flow series available in practice, there will be an adverse impact on the statistical reliability of the trend estimates obtained from such series. Yue et al. (2012) recommended using records of at least 30 or even 50 years. Prosdocimi et al. (2014) found that the sample size needed to achieve a reasonable power level for a test on the regression coefficients in a linear trend model would require current streamflow records (typically initiated post-1960) to reach the end of the 21st century. In addition, it is necessary to consider the additional complications caused by long-term natural variability in flow series, such as those manifesting themselves in flood-rich and flood-poor periods (for example, Hall et al., 2014; Macdonald, 2006; Merz et al., 2012b). The findings of these studies should be contrasted with the record length typically available to researchers. For example, some countries have no records with a length in excess of 30 or 40 years, with the average length in the European gauging stations compiled by the GRDC database being 49.7 years (http://grdc.bafg.de). Clearly, a trade-off between a dataset consisting of a few sites with long records and a larger dataset with several shorter records is required.

Detected temporal trends in a region may be a result of various potential drivers that include the following: (i) climatic drivers, such as temperature, precipitation and related variables, such as evaporation and snow; (ii) drivers at the catchment scale that have an influence on rainfall-runoff transformation processes, such as land-use changes (deforestation, reforestation and urbanisation, among others) and climate-driven weathering and erosion; and, (iii) changes in rivers, such as river training and flood routing processes in reservoirs (Merz et al., 2012a). Drivers at the catchment scale (ii and iii) are expected to have a local influence on floods (Blöschl et al., 2007), though there has been some discussion on the potential role and influence of such drivers at differing flood magnitudes (Macdonald and Black, 2010) and on the propagation of influence, for example, of river training along the river network (Vorogushyn and Merz, 2013).

However, larger regional-scale trends in floods often result from changes in climatic variables. Consequently, the identification of flood regions that are under the influence of similar climatic variables is useful in enabling the interpretation of the results obtained from the statistical tests used for trend detection at a regional scale. Various approaches have been used to identify catchments with similar hydrological regimes. For example, in one study Hannaford et al. (2013) used clustering on standardised annual mean flow series to obtain homogeneous hydrological regions. In addition, Gudmundsson et al. (2011) identified seven regions in Europe in terms of cross-correlation between time series of a set of annual streamflow percentiles. In another study, Parajka et al. (2010) used cluster analysis to identify catchments with similar flood generation processes across the Alpine–Carpathian range in terms of flood and extreme precipitation regimes. Finally, Bard et al. (2012) classified catchments in Alpine regions of Europe according to mean inter-annual monthly streamflows.

The identification of homogeneous hydrological regions in terms of similar patterns in the flow response to climatic drivers may be further complemented by the characterisation of such climatic drivers. These provide the benefit of a deeper understanding of coherent large-scale atmospheric physical mechanisms that explain the patterns of precipitation, temperature, and related variables. Physical climatology references may be useful in such a sense, as they provide in-depth characterisations of such regions and their underlying physics (Peixoto and Oort, 1992; Salby, 2012).

In this study, a pan-European dataset of flow series established by the COST Action ES0901 on *European procedures for flood frequency estimation* is used, consisting of the longest flow records available in 25 European countries. This dataset combines the longest available flow series in Europe and a good spatial coverage in both northern and southern Europe. These data are used for identifying large-scale homogeneous regions in Europe in terms of flood regimes, including a hydrological characterisation of these regions in terms of flood seasonality, frequency and inter-annual clustering. Finally, detection of trends in flood series at a pan-European scale based on the identified regions is attempted. The longest records of the dataset provide a unique opportunity to study long-term trends in European flood data. Furthermore, these records can provide a more reliable and evidence-based foundation on which to detect large-scale changes in flood risk across Europe.