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Seasonality of flood processes in Austria

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Abstract Work towards an approach to flood regionalization is presented in which the seasonality of runoff and precipitation is used to infer the main flood producing processes which can in turn be used for delineating homogeneous regions. The rationale behind this study is that we believe that similarities in the seasonality of these hydrological variables are often a consequence of similarities in the underlying hydrological and meteorological processes. The analysis of the data shows, for example, that in all high Alpine catchments the mean date of occurrence of floods is in summer and the variability in the flood dates is low. Clearly, this similarity is due to glacier and snowmelt being the main flood producing processes. More detailed process interpretations are presented which are corroborated by examining the seasonality of mean monthly streamflow (i.e. runoff regime), the seasonality of mean monthly precipitation and the seasonality of annual maximum daily precipitation.

INTRODUCTION

Traditional flood frequency analysis often requires a streamflow record longer than available. In such cases and at ungauged locations, regional flood frequency analysis uses pooled information from other catchments that are in some way similar to the at-site location (Cunnane, 1988). The identification of homogeneous regions of similar catchment behaviour is not straightforward and can be based on parameters such as geographic or administrative boundaries, physiographic catchment characteristics or flood statistics. The choice of parameter in a particular case study will significantly affect the regionalization results. Ideally, the catchment grouping should be based on hydrological processes. One would expect similarities in the flood producing processes to lead to similarities in the flood response of the catchments and hence to be a sound basis for defining homogeneous regions. For inferring the process controls on floods we propose to use the seasonality of hydrological variables.

SEASONALITY AS AN INDICATOR FOR PROCESS CONTROLS ON FLOODS

Floods are the result of many meteorological and hydrological processes interacting in a complex way. The processes have specific characteristics such as periodicity, disparity or certain bounds or limits to the system (Gutknecht, 1993, Klemeš, 1993). Conversely, if the characteristics are known, it may be possible to infer which processes have led to them. In the case of flood processes, important characteristics include the degree of seasonality and the inter-annual timing of flood occurrence. Additional characteristics that are likely to be important for flood processes are the seasonality of annual maximum daily precipitation, the seasonality of mean monthly precipitation, and the seasonality of mean monthly streamflow (i.e. regimes). Various regime classifications have been proposed for mean monthly streamflow (Pardé, 1947; Kresser, 1965; Gottschalk *et al.*, 1979; Aschwanden & Weingartner, 1985). However, the focus of these studies was on water yield, climatology and ecology, rather than on flood processes. The purpose of this paper is to combine the concept of seasonality of flood occurrence with the seasonality of monthly streamflow, monthly precipitation and extreme precipitation. It is the combination of these variables that allows us to infer the important flood producing processes. For example, summer floods may be a consequence of either snowmelt, convective rainfall or synoptic rainfall. Mean monthly streamflow gives an indication of the importance of snowmelt. Maximum daily precipitation gives an indication of convective storms while mean monthly precipitation may be related to the seasonal occurrence of synoptic events. More generally, the analysis of the seasonality of averaged data like monthly streamflow or monthly precipitation should reveal differences in the climatic conditions or long term catchment characteristics. On the other hand, the analysis of the seasonality of data at a shorter time scale, such as flood peaks or maximum daily precipitation, should reveal differences in the flood processes at the event scale. A comparison of the seasonality at the monthly time scale with that at shorter time scales gives insight into the main flood producing processes.

METHOD

The seasonality of mean monthly streamflow was quantified by using the Pardé coefficient (Pardé, 1947). For a given month i between 1 and 12:

$$Pk_i = \frac{12}{n}\sum_{j=1}^{n}\left(Q_{ij} \Big/ \sum_{i=1}^{12} Q_{ij} \right)$$

where Q_{ij} is the mean monthly streamflow in month i and year j, and n is the number of years of the flow record. We examined the maximum Pardé coefficient $Pk = \max(Pk_i)$ of the 12 months as well as the month i_{max} in which Pk occurred. Values of Pk range from 1 (uniformly distributed streamflow around the year) to 12 (all of the streamflow occurs in month i_{max}). In the graphic presentation (Fig. 1) we plotted each streamgauge as one vector with the length of the vector proportional to Pk and the direction of the vector representing the month in which the maximum occurred, i_{max}. In a similar fashion we examined the seasonality of mean monthly precipitation (Fig. 2).

The seasonality of maximum annual floods was quantified by using Burn's (1997) approach. Following Burn we define D as the date of occurrence of the flood peak where $D = 1$ for 1 January and $D = 365$ for 31 December. D can be plotted in polar coordinates on a unit circle with angle $\Theta = D2\pi/365$. For all events in a flood series of a catchment the direction $\overline{\Theta}$ of the average vector from the origin indicates the mean date of occurrence of flood events around the year, while the length r of that vector is a measure of the variability of the date of occurrence (Fig. 3). Values of r range from

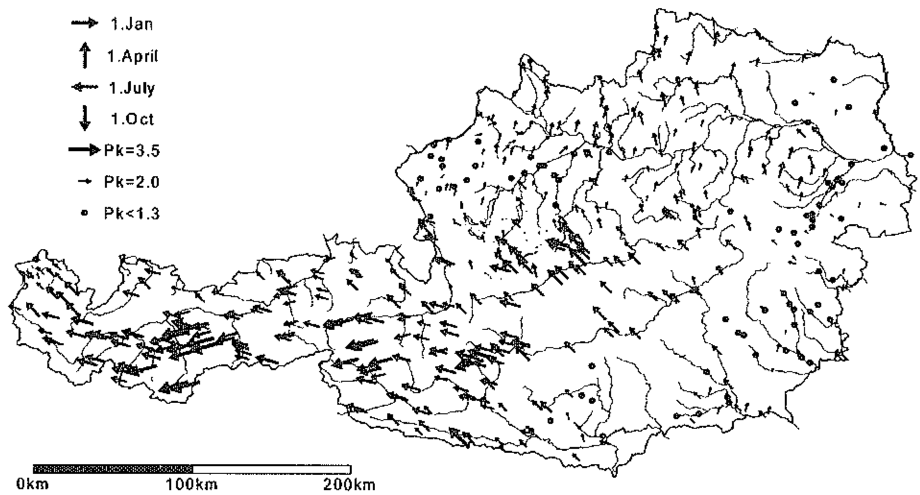

Fig. 1 Seasonality of mean monthly streamflow in Austria (680 streamgauges, 10–40 years of record).

$r = 0$ (uniformly distributed around the year) to $r = 1$ (all flood events occurring on the same day). In a similar fashion we examined the seasonality of annual maximum daily precipitation (Fig. 4).

RESULTS AND DISCUSSION

Data from the Austrian Hydrographic Service have been analysed and the results are shown in Figs 1–4. The maxima of mean monthly precipitation (Fig. 2) generally occur in summer with the exception of the very south of Austria (southern Carinthia)

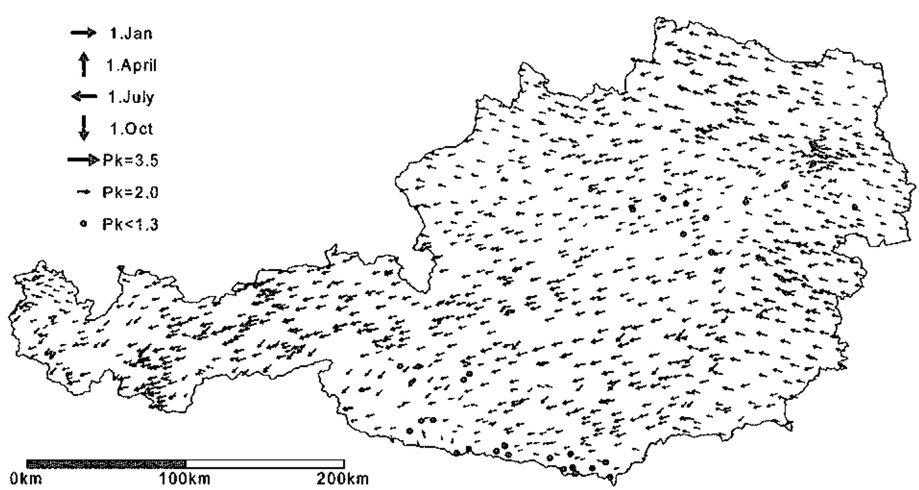

Fig. 2 Seasonality of mean monthly precipitation in Austria (1160 raingauges, 10–45 years of record).

which exhibits almost uniform rainfall over the year. The seasonality of mean monthly streamflow (Fig. 1) shows a more heterogeneous pattern, which is a consequence of the influence of catchment characteristics. In the high Alpine catchments, maxima in streamflow tend to occur in July while in lower Alpine catchments they tend to occur in May or June. Clearly, this is related to glacier and snowmelt being important processes in these regions. In the lowlands no distinct maximum can be found. This may be a consequence of a mixture of different processes contributing to runoff. The seasonality of annual maximum daily precipitation (Fig. 4) exhibits distinct regional patterns. Most striking is a band shaped region covering the northern part of the central Alps showing very little seasonality ($r < 0.2$). This may be a consequence of orographic rainfall, which occurs throughout the year. The Alps act as a topographic barrier to northwesterly airflow. In the hilly region of southeastern Austria (Styria) a distinct maximum occurs in late summer which suggests that convective precipitation is an important process. In southern Austria (Carinthia) maxima occur in autumn which is related to the characteristic weather patterns of this region.

A comparison of the seasonality of maximum annual floods (Fig. 3) with Figs 1, 2 and 4 allows a preliminary assessment of the main flood producing processes. The spatial patterns are more heterogeneous than those of annual maximum daily precipitation which, again, is due to differences in catchment characteristics. In the high Alpine catchments, floods tend to occur in summer showing a strong seasonality. In this region, the maxima of mean monthly streamflow also occur in summer, while annual maximum daily precipitation exhibits very little seasonality. This indicates that glacier melt is an important flood producing process while convective and synoptic events are less important. In southeastern Austria (hilly region of Styria) both floods and annual maximum daily precipitation tend to occur in late summer. However, mean monthly streamflow exhibits almost no seasonality and mean monthly precipitation has a weak maximum in early summer. This suggests that convective storms are an important flood producing process. Particular flood behaviour can be found in southern

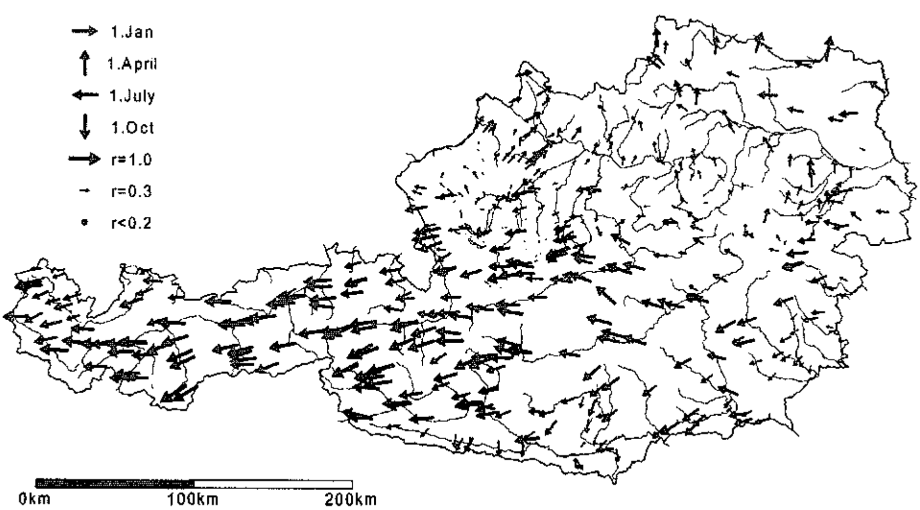

Fig. 3 Seasonality of maximum annual flood peaks in Austria (525 streamgauges, 15–44 years of record).

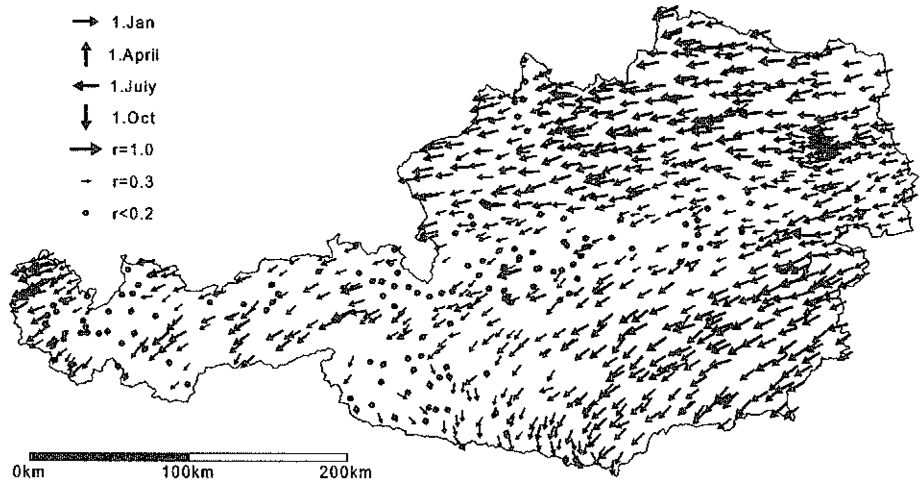

Fig. 4 Seasonality of annual maximum daily precipitation in Austria (980 raingauges, 20–100 years of record).

Carinthia. While the seasonality of streamflow is similar to that of other regions of the same altitude, the seasonalities of mean monthly precipitation, annual maximum daily precipitation and annual maximum floods are very different. This suggests that this region is climatologically and hydrologically different from the rest of Austria. Indeed, weather patterns from the south are known to cause floods in this part of Austria. In the low altitude catchments of northern Austria the mean date of occurrence of floods varies significantly between the catchments. While mean monthly streamflow data (maxima in spring) do indicate that snowmelt is an important process, there appear to exist other important flood producing processes including synoptic rainfall. In these regions, local effects may also be important which confound the interpretation of flood processes.

It is clear that some of the process interpretations in this study are speculative and cannot reveal as much detail of the processes as detailed case studies on a catchment basis. However, we believe that, for the purpose of delineating homogeneous regions in the context of regional flood frequency, these process interpretations are perfectly adequate. Future work will be directed towards refining these process interpretations, deriving homogeneous regions by multivariate statistical methods, and estimating flood statistics by using a range of methods including derived flood frequency analysis (Blöschl & Sivapalan, 1997).

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