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Review papers

Links between large-scale circulation patterns and streamflow in Central Europe: A review

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ABSTRACT

We disentangle the relationships between streamflow and large-scale atmospheric circulation in Central Europe (CE), an area affected by climatic influences from different origins (Atlantic, Mediterranean and Continental) and characterized by diverse topography and flow regimes. Our literature review examines in detail the links between mean, high and low flows in CE and large-scale circulation patterns, with focus on two closely related phenomena, the North Atlantic Oscillation (NAO) and the Western-zonal circulation (WC). For both patterns, significant relations, consistent between different studies, are found for large parts of CE. The strongest links are found for the winter season, forming a dipole-like pattern with positive relationships with streamflow north of the Alps and the Carpathians for both indices and negative relationships for the NAO in the south. An influence of winter NAO is also detected in the amplitude and timing of snowmelt flows later in the year. Discharge in CE has further been linked to other large-scale climatic modes such as the Scandinavia pattern (SCA), the East Atlantic/West Russian pattern (EA/WR), the El Niño-Southern Oscillation (ENSO) and synoptic weather patterns such as the Vb weather regime. Different mechanisms suggested in the literature to modulate links between streamflow and the NAO are combined with topographical characteristics of the target area in order to explain the divergent NAO/WC influence on streamflow in different parts of CE. In particular, a precipitation mechanism seems to regulate winter flows in North-Western Germany, an area with short duration of snow cover and with rainfall-generated floods. The precipitation mechanism is also likely in Southern CE, where correlations between the NAO and temperature are low. Finally, in the rest of the study area (Northern CE, Alpine region), a joint precipitation-snow mechanism influences floods not only in winter, but also in the spring/snowmelt period, providing some possibilities for flood forecasting.

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1. Introduction

Streamflow has been traditionally studied at the catchment scale, taking into consideration catchment processes, e.g. precipitation, evapotranspiration, runoff generation and catchment characteristics, e.g. land use and river morphology (Blöschl et al., 2007). In recent years this catchment perspective has increasingly been complemented by the large-scale view, embedding catchment hydrology in the global climate context (Merz et al., 2014). More specifically, numerous studies in various regions have investigated the possibility of linkages between local or regional hydrology and large-scale climate phenomena or atmospheric circulation patterns. For example, streamflow in various parts of the world, such as locations in Australia, Africa and North America, has been linked to the El Niño-Southern Oscillation (ENSO) (Jain and Lall, 2001; Ward et al., 2010).

The importance of such links is that they do not only give insight into the dynamical processes which govern catchment hydrology, but they also have practical implications: knowledge about linkages between streamflow and climate may improve risk analyses for hydrological extremes, and may inform design of hydraulic infrastructure and water resources management. For example, in case a substantial link between streamflow and season-ahead climate state exists, this link may offer the possibility to adapt the reservoir management based on seasonal forecasts of water availability, droughts or floods (e.g. Kwon et al., 2008).

In Europe, various studies at the local or regional scale have been made, many of them summarized by Kingston et al. (2006a), who presented a review of data and ideas in a broad scale, linking large-scale circulation and streamflow in Northern Europe and the Atlantic region. These authors highlighted the importance of the North Atlantic Oscillation (NAO) during winter as a driver for streamflow in North and West Europe. The NAO, discussed further in Section 2.1, is perhaps the most important phenomenon for the European climate and hydrology since it affects precipitation and temperature patterns throughout the region. NAO influence on streamflow is highest in Fennoscandia and the Iberian Peninsula, where high positive and negative correlations, respectively, have been calculated in winter (Bierkens and van Beek, 2009; Kingston et al., 2006b; Lorenzo-Lacruz et al., 2011; Shorthouse and Arnell, 1997). NAO effects extend in wider regions including the British Isles and Eastern Europe (Ionita et al., 2014; Kingston et al., 2006a), but it is not, however, the only climatic driver of streamflow in Europe. Other large-scale circulation patterns, such as the Arctic Oscillation (AO) or the East Atlantic/West Russian pattern (EA/WR) have also been shown to influence river flows in various areas such as Iceland (Jónsdóttir and Uvo, 2009) or Romania (Ionita et al., 2014).

The aim of this paper is to review and disentangle the links between large-scale circulation and streamflow in Central Europe (CE). These links are explained by considering the interactions between large-scale climate indices and regional variations in precipitation, temperature and streamflow. CE was not covered in full and in detail by the review of Kingston et al. (2006a) and is an area without such strong and homogeneous links with the NAO as other European regions (see for example Fig. 3 of Shorthouse and Arnell, 1997). This absence of a clear link with the NAO motivated, indeed, the current study.

Besides the NAO, we examine various large scale circulation patterns and mesoscale weather types that influence the weather/climate of CE and have been linked to river flows. These patterns act in a wide spectrum of scales from global (such as ENSO) to regional/local (weather patterns over Europe, cyclone types). Phenomena with a global coverage may affect the hydrology of extended areas at the seasonal/annual scale and with significant time lags. Small-scale phenomena, for example cyclone types with life times of a few days, on the contrary, tend to affect smaller regions. In this study, we are particularly interested in the interplay between different mechanisms acting on different scales, as we try to understand the causal mechanism and bridge the "scale gap" between large-scale circulation and local streamflow.

Our review covers the region consisting of 9 countries: Germany, Poland, Switzerland, Lichtenstein, Austria, the Czech Republic, Slovakia, Hungary and Slovenia (Fig. 1). A country-based and not a catchment-based approach is chosen, since some catchments are very large and extend far beyond the limits of our area of interest. The time frame of the study is defined by the longest measured discharge time series in CE, which start at the middle of the 19th century and covers roughly the last 150 years. We focus on peer-reviewed work in English language and consider studies based on observed streamflow data and their relation with large-scale climate indices only; studies presenting hydrological model results are not included, because doing so the inherent uncertainties of the modelling and different modelling approaches and purposes need to be taken into account in the interpretation and comparison of the results, which is difficult. Therefore the focus is set on studies using the observed discharge time series, which is, after all, the essential reference for the hydrological modelling. In addition to the peer-reviewed studies, some interesting findings from non-peer-reviewed studies and documentary sources are also examined.

A large number of studies exist that investigate links between large-scale circulation and precipitation or temperature, which are the main drivers of streamflow (e.g. Casanueva et al., 2014; Rust et al., 2015). However, streamflow is an integrated response not only to climatic parameters but also to catchment characteristics and human activities and its response time to climate conditions depends strongly on local characteristics (Ionita, 2015; Rödel, 2006). Furthermore, streamflow records of larger basins are less influenced by local precipitation variability, since it integrates the precipitation falling over a large area (Bárdossy and Filiz, 2005) so some links with large-scale circulation may be more apparent. For these reasons, we address streamflow independently and do not review previous work on other hydrological or meteorological variables. Certain relevant findings are used, however, for the interpretation of the results.

This article is structured as following: For the development of a conceptual model for the influence of large-scale climate to streamflow we elaborate streamflow generating processes in different sub-regions and seasons. For this reason, background information on streamflow seasonality and its generating processes is given in Section 2. In the same section an overview of European climatology and the main circulation patterns addressed within the review is also presented. This is followed by a detailed literature overview and summary of the known relationships between circulation patterns and the streamflow variability in different parts of the study area (Section 3). Subsequently we present a conceptual model that incorporates existing knowledge and explains the link between streamflow and large-scale climatic mechanisms for different sub-regions of CE (Section 4).