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Predictability of low flow – An assessment with simulation experiments

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SUMMARY

Since the extreme summer of 2003 the importance of early drought warning has become increasingly recognized even in water-rich countries such as Switzerland. Spring 2011 illustrated drought conditions in Switzerland again, which are expected to become more frequent in the future. Two fundamental questions related to drought early warning are: (1) How long before a hydrological drought occurs can it be predicted? (2) How long are initial conditions important for streamflow simulations? To address these questions, we assessed the relative importance of the current hydrological state and weather during the prediction period. Ensemble streamflow prediction (*ESP*) and reverse *ESP* (ESP_{rev}) experiments were performed with the conceptual catchment model, HBV, for 21 Swiss catchments. The relative importance of the initial hydrological state and weather during the prediction period was evaluated by comparing the simulations of both experiments to a common reference simulation. To further distinguish between effects of weather and catchment properties, a catchment relaxation time was calculated using temporally constant average meteorological input. The relative importance of the initial conditions varied with the start of the simulation. The maximum detectable influences of initial conditions ranged from 50 days to at least a year. Drier initial conditions of soil moisture and groundwater as well as more initial snow resulted in longer influences of initial conditions. The catchment relaxation varied seasonally for higher elevation catchments, but remained constant for lower catchments, which indicates the importance of snow for streamflow predictability. Longer persistence seemed to also stem from larger groundwater storages in mountainous catchments, which may motivate a reconsideration of the sensitivity of these catchments to low flows in a changing climate.

1. Introduction

In many parts of the world people are aware of droughts as natural hazards with significant impacts on many sectors especially when they persist for long periods or occur frequently (e.g. Tallaksen and van Lanen, 2004; Dijk et al., 2013; Viste et al., 2013). However, only recently, scientists and stakeholders in Europe have become concerned not only about floods and their forecasting, but also about droughts. Drivers of this increasing interest include recent droughts such as in summer 2003 (Rebetez et al., 2006) and in spring 2011, which have made water rich countries like Switzerland become more aware of impacts and risks related to droughts. So far, the main concerns in Europe regarding droughts are of economic, environmental, and social importance (e.g. Stahl et al., 2012). During and after droughts, conflicts between different water users can become more frequent and water management has to adapt to meet the different interests as well as possible. For these reasons drought early recognition has become an issue. The basic objective of drought early recognition is to provide timely warning, so that damages can be reduced or even avoided. However, little has been done regarding forecasting and early warning of droughts in Europe. The severity of a drought depends clearly on the climatological deficit of water, but also on the hydrological system that has to cope with this deficit. There were many attempts to quantify droughts by indices based on meteorological variables such as the Palmer drought severity index (Palmer, 1965), deciles (Gibbs and Maher, 1967), the surface water supply index (Shafer and Dezman, 1982), the standardized precipitation index (McKee et al., 1993) or the standardized precipitation and evapotranspiration index (Vicente-Serrano et al., 2010). Each of these indices has its own strengths and weaknesses. Drought indices based on meteorological variables are important, but not sufficient to describe and understand the severity of a hydrological drought. Hence, to recognize locally critical conditions early and provide that information to decision makers, requires both information of the climatological

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anomalies as well as an understanding of the underlying hydrological systems.

The persistence of a system is a measure of how a hydrological condition at a certain point in time can influence the following period and can also be seen as the memory of the system. Catchments with a small storage also usually have a small persistence while catchments with large storages can have longer persistences. The predictability of streamflow and other hydrological variables is highly connected to persistence and there exist various methods to estimate persistences. A classical approach to estimate short term persistence is to calculate the autocorrelation of the time series of streamflow observations (e.g. Vogel et al., 1998; Pagano and Garen, 2005). Applying the autocorrelation to highly seasonal data like streamflow data means that they first need to be de-seasonalized before a signal other than seasonality can be found from the autocorrelation can be found. De-seasonalization procedures for hydrological data, however, often require calibration themselves, as the seasonality rarely corresponds to calendar dates (Hipel and McLeod, 1994).

Several recent studies try to quantify the impact of initial conditions on the predictability of hydrological conditions. Snow cover (Gobena and Gan, 2010; Mahanama et al., 2012), catchment size (Li et al., 2009), North Atlantic Oscillation (NAO), El Niño-Southern Oscillation (ENSO) driven by the Sea Surface Temperature (SST) (e.g. Bierkens and Van Beek, 2009) are generally found to be sources of predictability and they are all highly dependent on the region, system and season. While temperature and precipitation are in part predictable because of the low-frequency variability in global energy stores, particularly in the ocean, (Westra and Sharma, 2010; Feng et al., 2011), on a local scale there are feedbacks because of, for instance, albedo or catchment moisture storages that affect the partitioning between sensible and latent heat fluxes. Predictability in streamflow is controlled by storages, including snow, soil moisture and groundwater, which attenuate the high-frequency rainfall variability to a lower-frequency streamflow response. Singla et al., 2012 assessed the predictive skill of seasonal hydrological forecast in France with two experiments looking at the influence of land surface initial states on the one hand and atmospheric forcing on the other hand. They focused on the spring season as it is critical to the onset of low flows and droughts. One of their important findings was that the predictability of hydrological variables in France mainly depends on temperature and precipitation in lower elevation areas and mainly on snow cover in high mountains. We built on these studies by looking at the predictability of streamflow with focus on low flows in Switzerland using a conceptual hydrological model. These models are important tools in hydrology as they are able to capture dominant catchment dynamics while remaining parsimonious and computationally efficient (Kavetski and Kuczera, 2007). Conceptual hydrological models can reach, for specific purposes, considerable performance and, thanks to their computational efficiency, can also be used in ensemble prediction systems (Cloke and Pappenberger, 2009). In flood forecasting systems conceptual models like the NAM model (Van Kalken et al., 2004), the Sacramento model (Grijsen et al., 1993), the PDM model (Moore and Jones, 1997) and the HBV model (Bürgi, 2002) are often applied and use for low flow ensemble forecasting is also emerging (Fundel et al., 2013).

In this study we used the HBV model (Bergström, 1992; Lindström et al., 1997) to perform streamflow simulation experiments and to answer the following questions: How long is the persistence of the initial hydrological state in model simulations of streamflow and does it vary in space and time? Can the persistence be attributed to catchment storage?

2. Data and methods

2.1. Data

The catchments investigated in this study are meso-scale (3–350 km^2), near natural catchments located in Switzerland (Fig. 1). The mean elevation of the catchments ranges between 480 m a.s.l. and 2400 m a.s.l. (Table 1). Henceforth, specific catchments are referred to by catchment numbers (Table 1). The data used are daily streamflow from the selected Swiss catchments over the period 1970–2008 (FOEN, 2011). The meteorological forcing variables for the HBV model, precipitation and temperature, stem from interpolated observations from climate stations (MeteoSwiss) in Switzerland. The selection of the meteorological stations as well as interpolation and aggregation of the variables for each catchment were carried out by the pre-processing tool WINMET (Viviroli et al., 2009). In brief, the spatial and temporal interpolation of

Fig. 1. Location of the selected Swiss catchments.