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Identification of changes in hydrological drought characteristics from a multi-GCM driven ensemble constrained by observed discharge

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SUMMARY

Drought severity and related socio-economic impacts are expected to increase due to climate change. To better adapt to these impacts, more knowledge on changes in future hydrological drought characteristics (e.g. frequency, duration) is needed rather than only knowledge on changes in meteorological or soil moisture drought characteristics. In this study, effects of climate change on droughts in several river basins across the globe were investigated. Downscaled and bias-corrected data from three General Circulation Models (GCMs) for the A2 emission scenario were used as forcing for large-scale models. Results from five large-scale hydrological models (GHMs) run within the EU-WATCH project were used to identify low flows and hydrological drought characteristics in the control period (1971–2000) and the future period (2071–2100). Low flows were defined by the monthly 20th percentile from discharge (Q20). The variable threshold level method was applied to determine hydrological drought characteristics. The climatology of normalized Q20 from model results for the control period was compared with the climatology of normalized Q20 from observed discharge of the Global Runoff Data Centre. An observation-constrained selection of model combinations (GHM and GCM) was made based on this comparison. Prior to the assessment of future change, the selected model combinations were evaluated against observations in the period 2001–2010 for a number of river basins. The majority of the combinations (82%) that performed sufficiently in the control period, also performed sufficiently in the period 2001–2010. With the selected model combinations, future changes in drought for each river basin were identified. In cold climates, model combinations projected a regime shift and increase in low flows between the control period and future period. Arid climates were found to become even drier in the future by all model combinations. Agreement between the combinations on future low flows was low in humid climates. Changes in hydrological drought characteristics relative to the control period did not correspond to changes in low flows in all river basins. In most basins (around 65%), drought duration and deficit were projected to increase by the majority of the selected model combinations, while a decrease in low flows was projected in less basins (around 51%). Even if low discharge (monthly Q20) was not projected to decrease for each month, droughts became more severe, for example in some basins in cold climates. This is partly caused by the use of the threshold of the control period to determine drought events in the future, which led to unintended droughts in terms of expected impacts. It is important to consider both low discharge and hydrological drought characteristics to anticipate on changes in droughts for implementation of correct adaptation measures to safeguard future water resources.

1. Introduction

Drought events and their related impacts on society and environment are expected to increase in severity due to changing climate (e.g. Bates et al., 2008; Dai, 2011; Romm, 2011). Droughts occur across the world in all climatic regions and are still difficult to quantify (Wilhite, 2000; Tallaksen and van Lanen, 2004; Mishra and Singh, 2010). Drought remains one of the natural hazards for which predictions are most uncertain. Many studies have investigated the effect of climate change on discharge regimes (e.g. Arnell, 1999; Nijssen et al., 2001a; Manabe et al., 2004; Milly et al., 2005; Nohara et al., 2006; Sperna Weiland et al., 2012). Besides investigating changes in the regime, low flows are included in some studies as well (e.g. Arnell and Gosling, 2013). The main conclusions about the expected changes are in agreement. For example, the discharge is expected to increase in cold climates and a shift of the snow melt peak in these areas is projected (e.g. Sperna Weiland

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et al., 2012). In addition to the impact of climate change on discharge, effects on drought have been investigated. In the 21st century, drought may intensify in parts of Europe, central North America, Central America and Mexico, northeast Brazil and southern Africa (Seneviratne et al., 2012). Studies on drought in the future have mainly focused on soil moisture (e.g. Sheffield and Wood, 2008; Vidal et al., 2012; Dai, 2013; Orlowsky and Seneviratne, 2013). A decrease in soil moisture was detected at the global scale by Sheffield and Wood (2008), leading to more soil moisture drought events. Vidal et al. (2012) found that all characteristics of soil moisture or agricultural drought events in France increased in the 21st century. Severe drought conditions in the 21st century over large parts of the globe were determined with the PDSI by Dai (2013). A large range in soil moisture drought projections at global scale was found by Orlowsky and Seneviratne (2013), but increased drought was consistent in several regions, namely the Mediterranean, South Africa and Central America/Mexico. Less is known about changes in hydrological drought events (drought in groundwater and surface water). Hirabayashi et al. (2008) have studied changes in number of drought days at the global scale by taking the annual drought days from discharge data. Significant increases in drought were found for many regions across the globe (Hirabayashi et al., 2008). For Europe, Feyen and Dankers (2009) investigated changes in streamflow drought by deriving low flows and drought deficits. They concluded that in many rivers, with the exception of rivers in the most northern and northeastern parts of Europe, minimum river flows and flow deficit volumes became more severe in the frost-free season. Most studies on changes in discharge are carried out at the catchment scale instead of the global scale. For example, Madadgar and Moradkhani (2013) used trivariate copulas to determine changes in drought characteristics for a specific catchment in Oregon. They concluded that drought events will become less severe in the future in this catchment. Knowledge on hydrological drought events is important for water resources and needed for adequate planning and assessment of drought impacts in the future. This knowledge across the globe is rather limited.

In recent years, more and more gridded models have been developed for hydrological studies at the global scale. However, many scenario studies employ only one global hydrological model (GHM) in combination with one or an ensemble of General Circulation Models (GCMs) that provide forcing data (e.g. Sperna Weiland et al., 2012; Arnell and Gosling, 2013). Because GHMs can show large differences in the representation of runoff for the previous century (e.g. Gudmundsson et al., 2012; Van Huijgevoort et al., 2013), including multiple GHMs for future analysis is important. This was also concluded by Hagemann et al. (2013), who used 8 GHMs and 3 GCMs to analyse water resources and found that spread in hydrological models in some regions is larger than that of climate models. They recommend that analyses of global climate change impacts should use results from multiple impact (hydrological) models.

To reduce or to better adapt to the impacts of hydrological drought across the globe, more knowledge regarding changes in hydrological drought characteristics (e.g. frequency, duration) in the future is needed in addition to already existing knowledge regarding changes in meteorological and soil moisture drought. In this study, effects of a climate change scenario on drought in several river basins across the globe with contrasting climates and catchment characteristics were investigated using a multi-model analysis. The aim of this study is to investigate changes in both low flows and drought events, and to illustrate the challenges associated with this kind of drought analysis. Results of five GHMs forced with three GCMs have been used for the analysis over two periods, the control period (1971–2000) and future period (2071–2100). As a first step towards reducing the range of projected changes in drought, model combinations (GHM and GCM) have been constrained for analysis in the future period through comparison with observed discharge in the control period. Monthly low discharge values from selected model combinations for the control period and future period and changes therein have been determined. Changes in hydrological drought characteristics relative to the control period were identified from the selected model combinations using the variable threshold level method.

2. Data

2.1. Observed river discharge

From the Global Runoff Data Centre (GRDC, 2013) discharge data were available for selected river basins across the globe. The locations of the discharge gauges of these 41 selected (sub)basins are given in Fig. 1. Table 1 gives an overview with the names of the rivers, abbreviations, locations of gauging stations, periods of data used for comparison with large-scale models and the basin areas. The selection of the river basins was based on the following criteria:

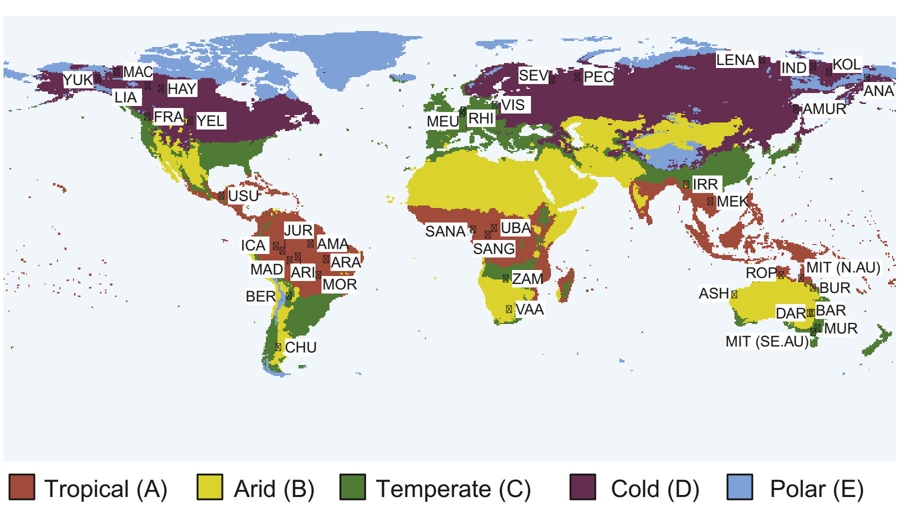

Fig. 1. Location of the gauging station for each river basin in the major climate zones (see Table 1 for river basin abbreviations).