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Impact of climate change on soil moisture dynamics in Brandenburg with a focus on nature conservation areas

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ABSTRACT

Global warming impacts the water cycle not only by changing regional precipitation levels and temporal variability, but also by affecting water flows and soil moisture dynamics. In Brandenburg, increasing average annual temperature and decreasing precipitation in summer have already been observed. For this study, past trends and future effects of climate change on soil moisture dynamics in Brandenburg were investigated, considering regional and specific spatial impacts. Special Areas of Conservation (SACs) were focused on in particular. A decreasing trend in soil water content was shown for the past by analyzing simulation results from 1951 to 2003 using the integrated ecohydrological model SWIM [Krysanova, V., Müller-Wohlfeil, D.-I., Becker, A., 1998. Development and test of a spatially distributed hydrological/water quality model for mesoscale watersheds. Ecol. Model. 106, 261–289]. The trend was statistically significant for some areas, but not for the entire region. Simulated soil water content was particularly low in the extremely dry year 2003. Comparisons of simulated trends in soil moisture dynamics with trends in the average annual Palmer Drought Severity Index for the region showed largely congruent patterns, though the modeled soil moisture trends are characterized by a much higher spatial resolution. Regionally downscaled climate change projections representing the range between wetter and drier realizations were used to evaluate future trends of available soil water. A further decrease of average available soil water ranging from −4% to −15% was projected for all climate realizations up to the middle of the 21st century. An average decrease of more than 25 mm was simulated for 34% of the total area in the dry realization. Available soil water contents in SACs were generally higher and trends in soil moisture dynamics were lower mainly due to their favorable edaphic conditions. Stronger absolute and relative changes in the simulated trends for the past and future were shown for SACs within Brandenburg than for the state as a whole, indicating a high level of risk for many wetland areas. Nonetheless, soil water content in SACs is expected to remain higher than average under climate change conditions as well, and SACs therefore have an important buffer function under the projected climate change. They are thus essential for local climate and water regulation and their status as protected areas in Brandenburg should be preserved.

1. Introduction

Soil moisture is a key component of the hydrological cycle, controlling the partitioning of precipitation between runoff, evapotranspiration and deep infiltration (Daly and Porporato, 2005). As a link between the biosphere and the edaphic zone, soil water plays a crucial role for terrestrial ecosystems by determining plant growth. If the soil water level falls below a species-specific threshold, plants experience water stress, and decreased soil moisture under warmer conditions can inhibit photosynthesis (Lindroth et al., 1998).

Various feedbacks between soil moisture and the biological and hydrological cycles exist. For example, vegetation can influence the soil water regime by offsetting drier conditions through decreased transpiration, a phenomenon which is expected to occur more frequently in summer months under a warmer climate (Etchevers et al., 2002; Seneviratne et al., 2002; Yang et al., 2003). In addition, dry soils can cause a negative feedback by amplifying the impact and duration of heat waves (Brabson et al., 2005) and prolonging the effects of meteorological droughts (Nicholson, 2000). The exceptionally hot summer of 2003 in Europe led to large-scale soil moisture depletion and associated ecosystem impacts (Reichstein et al., 2007). If average soil moisture conditions had been maintained in the spring and summer of 2003, then summer heat anomalies would have been about 40% less severe in some regions of Europe (Fischer et al., 2007).

Long-term historical soil moisture records of in situ observational data or estimates derived from remote sensing are available only for a few regions (Trenberth et al., 2007). Examples of studies based on such data have shown significantly decreasing trends

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in soil moisture in recent decades for Eastern Hungary (Makra et al., 2005), and an increasing trend in recent decades for Ukraine (Robock et al., 2005).

Future projections on soil moisture are represented by only a few studies. For example, Gerten et al. (2007) concluded a global scale decline in soil moisture for many regions up to 2100. This does not necessarily mean that ecosystems are water-limited, as this model assumes increasing water-use efficiency in plants under increasing CO_2 levels. Projections for the regional scale using models require downscaling of climate scenarios (Seneviratne et al., 2002; Bronstert et al., 2003). Expected climate change could generally lead to decreased soil water content in the United Kingdom (Naden and Watts, 2001), and a strong decrease in soil moisture in summer in Switzerland (Jasper et al., 2006) and Southern Europe (Gregory et al., 1997). Etchevers et al. (2002) analyzed the impact of climate change on the Rhone river catchment, finding strong regional variations in simulated soil moisture changes. Naden and Watts (2001) studied future soil moisture changes in areas of ecological interest in the UK, but with a single vegetation type and a limited number of soil types. Larger changes in soil moisture were found for soils with higher clay content. A very fine spatial resolution was applied by Jasper et al. (2006) for soil water analysis in the Thur river basin in Switzerland. They limited the study to a few soil types and concentrated on changes in the summer months. Smaller changes in available soil water were shown for sandy soils compared to clay soils and for forests compared to grasslands or farmland.

The present study aims at investigating past and future trends in soil water dynamics in the Federal State of Brandenburg (Fig. 1), Germany, from 1951 until 2055. The case study area was chosen because it is characterized by relatively dry conditions and predominantly sandy soils (Landgraf and Krone, 2002), and is considered to be one of the most vulnerable regions to climate change in Germany as regards nature and biodiversity conservation, agriculture, forestry and water availability aspects (Zebisch et al., 2005).

The study aimed to carry out an area-wide analysis of past and future soil water changes in the State of Brandenburg, and used the regional ecohydrological model SWIM (Krysanova et al., 1998), which considers major vegetation and soil types with a high spatial resolution. SWIM is particularly suited for this analysis since it offers flexibility of spatial resolution, incorporates both hydrological and ecological processes and it has been successfully applied in various studies analyzing hydrological dynamics in the Elbe basin and Brandenburg (Hattermann et al., 2005; Krysanova et al., 2005; Post et al., 2007; Wattenbach et al., 2007).

Trends in simulated soil moisture were compared to trends in average annual values of the Palmer Drought Severity Index (PDSI). Thus simulated soil moisture results could be compared with those produced by an independent method of analyzing drought severity. Furthermore, the impacts for different soil and vegetation types were analyzed. Particular emphasis in this study was given to Special Areas of Conservation (SACs) as defined by the EU Habitats Directive (92/43/EEC) in order to assess the spatially explicit risk for targets of this directive concerning these areas, which are of particular ecological and conservational value. Simulated soil water values for the whole area of the state were compared to results obtained for the SACs.

2. Methods

2.1. Case study area

Brandenburg is characterized by a relatively low average annual precipitation, below 600 mm in the period 1951–2000 (Gerstengarbe et al., 2003), and a dense network of rivers and streams (Landesumweltamt Brandenburg, 2006). The spatial differences in average annual temperatures range from 7.8 °C to 9.5 °C in this time period (Gerstengarbe et al., 2003), while precipitation values range from below 500 mm in the north-east to over 600 mm in the south-west and north-west. More than half of Brandenburg is covered by poor sandy soils. About half of the area is used for agricultural production, and about a third for forestry, with pine trees being the dominant species (Landgraf and Krone, 2002).

The protected areas considered in this study, so called SACs, comprise 620 sites in Brandenburg in total (Fig. 1b), representing about 11.3% of the state's area (Landesumweltamt Brandenburg, 2006). Brandenburg has one of the largest shares of wetlands of all German states, most of which are under agricultural use (Landesumweltamt Brandenburg, 2006). Many of these wetlands have already been negatively impacted by regional water shortages with decreasing water levels in ground water, water bodies and fenlands (Landgraf and Krone, 2002). A pilot study showed that Brandenburg is characterized by biotopes with a large share of species adapted to wet and cold conditions due to the relatively

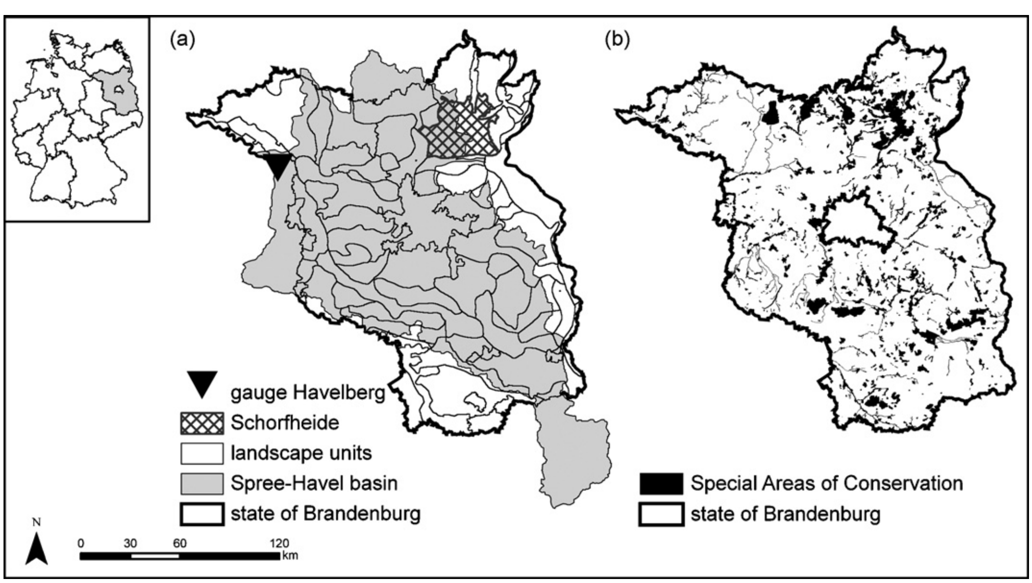

Fig. 1. (a) Location of the Spree–Havel basin with the corresponding gauge "Havelberg" together with the landscape units and the selected unit "Schorfheide". (b) Special Areas of Conservation (SACs) within Brandenburg.