20th - Century regional hydro-climatic Variability across Germany and Impact of 21st - Century predicted Climate Change on the Water Balance in a Mesoscale Catchment in central Germany

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It is now commonly accepted that, owing to the increased anthropogenic CO_2 production over the last century, the earth's climate will be affected in the foreseeable future globally as well as regionally. These climate changes will have strong implications on the future living conditions, for the good or the bad.

As for Germany, recent regional climate models have predicted significant seasonal changes of, mainly, temperatures and precipitation for the coming century that will require regional adjustments of the management of water resources, particularly, for agriculture. While the average citizen in Germany may have the perceived feeling that climate change, namely, a warming trend with summer extremes has affected the country several times during the last decade - also supported by meteorological measurements - it is still not clear whether such variations are just outliers in the observed hydro-meteorological time series with it's well-known stochastic nature, or whether they are just part of a long-term trend pattern that has already been ongoing over most of the 20th century.

As part of a comprehensive study to understand the variability of stochastic hydro-meteorological time series we apply several sophisticated analysis methods, such as the Continuous Wavelet Transform (CWT), Detrended Fluctuation Analysis (DFA) and Singular Spectrum Analysis (SSA) to various hydro-meteorological data recorded over most of the 20th century, namely (1) climatic data of monthly extremal precipitation at stations throughout Germany and, (2) long-term monthly discharge series of the Elbe river. As it is now commonly recognized that the observed variability of such climatic records can be characterized by a nonstationary stochastic process with a few periodic or nearly periodic components acting within time-scales that range from annual, over decadal, centennial to millennial and even longer time periods, the goal is to understand the exact nature of the stochastic process, namely, whether the various observed periodicities are an inherent property of the time series or if they are triggered by external events that act on more or less regular time-scales.

Given the maximum record length of ~100 years in the present study, we are able to retrieve periodicities and the degree of persistence - as indicated by the calculation of the Hurst parameter with DFA - acting up to the decadal scale. Cross-correlations of the observed hydro-climatic time series with the North Atlantic Oscillation (NAO) - whose teleconnective effect on the European weather pattern on the inter-decadal scale has been surmised for some time, indicate a strong influence of the NAO on the long-term precipitation, though with somewhat different local effects throughout Germany.

Extending the named analysis tools to various Elbe river discharge series provides further evidence of such structural breaks in the time-series variability over Germany between the first and second half of the 20th century. While these results can somewhat be taken as indicators of some climate change that has been taking place in this country recently, the abnormal weather conditions experienced here in the last decade may then also be explained more as an inter-decadal intermittency phenomenon than as a hint of a long-term climatic trend.

To get a finer picture of the deterministic origins of past and possible future variations of a basin's streamflow, the mesoscale Fulda catchment area, with a size of nearly 7000 km^2 and located in central Germany is analyzed in more detail. For this purpose the future surface water budget in the catchment has been simulated with the distributed hydrological model SWAT (Soil and Water Assessment Tool). The model is driven by high resolution climate modeling data for the years 2001-2100 assuming the IPCC-SRES Scenarios A1B, A2, and B1. The comparison-, i.e. calibration and verification period is 1960-2000. The dynamic downscaling of the global circulation model ECHAM5 MPI-OM as carried out by the regional model REMO is the basis of the SWAT's water balance's projection.

The SWAT-model is calibrated for the 1960-1977 and validated for the 1977-2004 time period using measured climate and hydrological data across the Fulda basin. A very good fit of the modeled to the measured runoff data is obtained for daily, monthly, and yearly flows. Specific consideration had to be given during the SWAT calibration process to properly incorporate the managed water flows from the large Edertal reservoir. To that regard an artificial neural network approach has been used whereby flow output at a particular station is trained on SWAT's results to reduce the models systematic errors.

The results of the REMO-predictions for the 21th - century precipitation indicate that there are periods when the mean yearly amount of precipitation will be significantly higher than in the 20th –century reference period 1960-2000. Although in the long term there is no observed trend in the yearly precipitation, as seasonal redistribution of the latter is obtained. Thus there will be more precipitation in the winter and, accordingly, less rain in the summer. Notwithstanding this invariance of the yearly precipitation, the yearly flow rate will rise, especially, for the climate scenario B1. This is because the runoff will increase during the winter half year, whereas it barely changes during the summer. The evapotranspiration will decline between 2001 and 2100 in all three scenarios simulated. It turns out that

the predicted climate changes impact more the distribution of the precipitation within a year as well as other boundary conditions (e.g. temperature) that affect the system's processes.

In the subsequent step flood time series HQ(a) are derived from the 21st century REMO-SWAT modeled runoff time series, using SRES-scenarios A1B, A2, and B1. Then these flood projections are extensively tested with regard to stationarity, homogeneity and statistical independence. All these tests indicate that the SWAT-predicted 21st -century trends in the flood regime are not significant. Within the projected time the members of the flood time series are proven to be stationary and independent events. Hence, the classical stationary approach of flood frequency analysis can still be used within the Fulda catchment area, notwithstanding the fact that some regional climate change has been predicted using the IPCC scenarios.

It should be noted, however, that the present results are not necessarily transferable to other river basins in Germany, as the REMO- 21st -century climate predictions of precipitation and temperature do show variations in space and time across the country which will lead to regional changes of the water balance there as well.

Keywords: Hydro-climatic variability, Germany, climate change, REMO-climate model, SWAT-hydrological model, Fulda-catchment water balance.