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Strong increase in discharge and flood frequency of the River Meuse over the last four millennia: impact of climate variability and anthropogenic land-use changes

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In recent years the frequency and magnitude of peak flow events in the Meuse Basin (northwest Europe) has been relatively great, and river flooding and flood risk mitigation have become issues of practical significance. To date, the vast majority of research carried out on Meuse discharge has concentrated on records of the last century and simulations of the coming century. However, it is difficult to delineate changes caused by human activities and natural fluctuations on these timescales. We have coupled a climate model (ECBilt-CLIO-VECODE) and a hydrological model (STREAM) to simulate daily Meuse discharge in two time-slices: (a) 4000-3000 BP (minimal anthropogenic influence), and (b) 1000-2000 AD (including anthropogenic influence). The climate model is forced by changes in greenhouse gas concentrations, orbital parameters, volcanic aerosols, and solar irradiance. For the period 4000-3000 BP the basin is assumed to be almost fully forested; for 1000-2000 AD land cover is reconstructed using CORINE data and historical sources. For the period 1000-2000 AD the simulated mean annual discharge (260.9 m^3s^{-1}) is significantly higher than that for 4000-3000 AD (244.8 m^3s^{-1}), as a result of a significant increase in precipitation and a significant decrease in actual evapotranspiration (AE) (due to deforestation). Over the period 1000-2000 AD mean annual discharge shows a positive increasing trend, whilst precipitation shows no such trend; the main causal mechanism appears to be a decreasing trend in AE due to deforestation. This inference is supported by sensitivity experiments of the effects of deforestation: the change in land cover be-

tween the periods 4000 BP and present can account for an increased mean discharge of ca. 25 $m^3 s^{-1}$. However, during the 20^{th} century AE increased due to reforestation and an increase in temperature, but the simulated mean discharge also increased by a large amount relative to the 19^{th} century; this can be explained by a relatively large increase in annual precipitation. High flow events (discharge $>$ 3000 $m^3 s\text{-}^1$) are simulated more frequently for the period 1000-2000 AD (recurrence time: 65 years) than for the period 4000-3000 BP (recurrence time: 77 years), and appear to have become even more frequent since 1700 AD (recurrence time: 50 years); this is likely to be a result of the reduced soil water holding capacity of deforested soils in combination with increased precipitation. Simulations of the coming century will be run to assess the potential influence of future anthropogenic climate change.