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Snow cover reduction and changing hydrological regime due to climate change and rain-on-snow events in southwestern Germany

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Rapid warming has reduced seasonal snow cover and changed the hydrological regimes over many areas of the globe. Temperature increase cannot only stimulate snowmelt but also favors a shift of wintertime precipitation towards rainfall, especially in Western and Central Europe that has temperate and humid winters. We assume that the mid-season (January-February) instead of the end-season (March) snow is particularly sensitive to warming in the low mountain ranges of Europe, and increased rain-on-snow events are associated with the currently frequent winter floods. To validate this assumption, we simulated the snow water equivalent (SWE), rain-on-snow (ROS) events, evapotranspiration, runoff and percolation for the period 1961-2016 in Rhineland-Palatinate, southwestern Germany (< 820 m a.s.l.) using a distributed hydrological model (TRAIN). We analyzed the intra- and inter-annual variations of the simulated hydrological variables and the synchronous climate variables (air temperature and precipitation). Early spring (March) displayed the strongest warming and the January-February warming was less severe or insignificant. Precipitation amounts did not show significant trends. However, the snowpack in February experienced the most striking reductions, which is likely explained by both the highest susceptibility of snow to warming and the increased ROS occurrence in February since the early 1990s. An increment in runoff and percolation in the earlier winter is probably related to a combination of high temperatures and more rainfalls at that time. The expected changing climate towards warmer and wetter winters but drier springs will probably exacerbate the winter flooding and spring/summer drought risks in the future.