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Identification of soil-cooling rains from soil temperature and soil moisture observations

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Over natural and agricultural land surfaces, the frequency and intensity of rainfalls govern soil moisture dynamics from topsoil layers to the root-zone. While these processes are represented in land surface models (LSMs), sensible heat input from liquid water into the soil and its impact on the soil temperature profile is often overlooked. Rainwater temperature is rarely measured and raindrop temperature is not explicitly simulated in atmospheric models. In this study, the frequency and intensity of soil-cooling rains is assessed using in situ observations of atmospheric and soil profile variables in southern France. Rainfall, soil temperature and topsoil volumetric soil moisture (VSM) observations, measured every 12 minutes at 21 stations of the SMOSMANIA (Soil Moisture Observing System - Meteorological Automatic Network Integrated Application) network, are analyzed over a time period of 9 years, from 2008 to 2016. The spatial and temporal statistical distribution of the observed rainfall events presenting a marked soil-cooling effect is investigated. It is observed that the soil temperature at a depth of 5 cm can decrease by as much as 6.5 ºC in only 12 minutes during a soil-cooling rain. We define marked soil-cooling rains as rainfall events triggering a drop in soil temperature at a depth of 5 cm larger than 1.5 °C in 12 minutes. Under Mediterranean and Mediterranean-mountain climates, it is shown that such events occur up to nearly 3 times a year, and about once a year on average. This frequency decreases to about once every 3.5 years under semi-oceanic climate. Under oceanic climate, such pronounced soil-cooling rains are not observed over the considered period of time. Rainwater temperature is estimated for 13 cases of marked soil-cooling rains using observed changes within 12 min in soil temperature at a depth of 5 cm, together with soil thermal properties and changes in VSM. On average, the estimated rainwater temperature is generally lower than the observed ambient air temperature, wet-bulb temperature, and topsoil temperature at a depth of 5 cm, with mean differences of -5.1 ºC, -3.8 ºC, and -11.1 ºC, respectively. The most pronounced differences are attributed to hailstorms or to hailstones melting before getting to the soil surface. Ignoring this cooling effect can introduce biases in land surface energy budget simulations. Our results show that using automatic temperature and volumetric moisture observations in a porous medium of known thermal properties has potential to estimate rainwater temperature and possibly the amount of hailstones in real time. More research is needed to develop measurement techniques for rainwater temperature and perform such measurements in contrasting climate conditions.