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Coevolution of heatwaves and soil moisture droughts: Past, present, and future

Luis Samaniego (1), Stephan Thober (1), Rohini Kumar (1), Andreas Marx (1), Ming Pan (2), Niko Wanders (3), Eric F. Wood (2), and Oldrich Rakovec (1)

(1) Department Computational Hydrosystems, Helmholtz Centre - UFZ, Leipzig, Germany (luis.samaniego@ufz.de), (2) Civil and Environmental Engineering, Princeton University, Princeton NJ, United States, (3) Department of Physical Geography, Faculty of Geosciences, University Utrecht, Utrecht, Netherlands

The link between soil moisture (SM) and maximum daily temperature (TX) leading to the mutual enhancement of droughts and heatwaves has been established in the literature. Moreover, it is expected that the intensify of this feedback will increase in the future because of climate change (1,2). This phenomenon will have serious consequences for the society and the ecosystems. For example, in extreme drought situations, ecosystems will be transformed from net carbon sinks to net carbon sources while the extreme heat and drought conditions will induce societal impacts that will be critical for the human health, food security and energy generation. Concluding statements regarding the degree of enhancement caused by soil moisture droughts on heatwaves have not been drawn for several reasons. The main reasons for the lack of progress can be attributed to the large uncertainties in projected changes using emission scenarios that cover a wide range of temperature projections, the coarse spatial and temporal resolution of the existing simulations, and the lack of a metric tailored to quantify the SM-TX enhancement as a function of the degree of warming.

Our analysis is driven by the hypothesis that mutual enhancement between soil moisture droughts and heat waves is intensified as the climate warms. EDgE and HOKLIM (3,4) projects provide an unique opportunity to test this hypothesis because high-resolution multi-model hydrologic simulations over the Pan-EU domain at a scale of 5x5 km^2 have been completed for the historical period 1955-2018 using the E-OBS data set and from 2000-2100 based on five CMIP5 GCMs under three representative concentration pathways (2.6, 6.0, 8.5). All simulations were carried put with four hydrologic models: mHM, Noah-MP, PCR-GLOBWB and VIC. Using these unprecedented multi-model simulations, daily soil moisture index (2) and a percentile based heat wave index (5) are estimated for the historical and future periods. A copula-based metric that estimate the strength of the stochastic dependence between these two indices is used to quantity their mutual enhancement for a given lag time. Additionally, based on these simulations, the evolution of past larger events (e.g., 1976, 2003, 2018) will be also analysed to estimate the size of areas enduring combined extreme drought&heatwaves since 1955.

Results confirm the hypothesis that “rising global temperature will bring drier soils and higher heatwave temperatures in Europe” at the daily time scale. The mean area under heatwaves with a magnitude of greater than 11 will increase from 5% under 1.5 K to 18% under 3 K global warming. With respect to the mutual enhancement, at least 25% increase in the SM-TX feedback can be expected by 3 K warming. Ensemble results also show that the uncertainty of the enhancement decreases with lag time (up to 25 days) and the degree of warming level. Different HMs show varying sensitivity to the enhancement metric at different SM lag times. These expected changes would bring unprecedented socio-economic consequences to Europe. Being able to better predict such hot-spot regions will allow mitigating their impacts and reducing socio-economic losses and saving human lives in the Future.

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