Journal: Hydrology and Earth System Sciences

Title: A Study of the Dependence between Soil Moisture and Precipitation in different Ecoregions of the Northern Hemisphere

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Manuscript No.: egusphere-2025-762

We highly appreciate the editor for the very helpful and insightful comments that lead to the significant improvement this manuscript. We have checked our work carefully according to these comments and made the requested changes. In this revised version, we reorganized the conclusions to emphasize the new findings.

Below we indicate the comments and use blue font for our responses. The corresponding revised texts are also used blue font in the revised version of our manuscript.

Comments from Editor

Please, let us know what are YOUR original conclusions. About statements in the conclusions: Do you confirm/extend a well-known observation? Provide citation..Is this a completely new concept? ...state it clearly.

Response: Thank you for your comments. We revised the statements in the conclusions, by providing citations for the well-known parts and emphasizing the new findings, based on the version of "egusphere-2025-762-manuscript-version5".

Examples of statements:

"Precipitation volume predominantly controlled soil moisture in the Boreal forest/taiga, temperate grasslands, savannas, and shrublands, while precipitation frequency primarily controlled soil moisture in the high-latitude regions of the Northern Hemisphere."

Response: "Our studies have new insight for the dependence of soil moisture to precipitation varying in different ecoregions. We concluded that, precipitation volume predominantly controlled soil moisture in the Boreal forest/taiga, temperate grasslands, savannas, and shrublands, while precipitation frequency primarily controlled soil moisture in the high-latitude regions of the Northern Hemisphere." (Lines 634-638)

"Evapotranspiration was the dominant driver of soil moisture dynamics during the growing season"

Response: "While evapotranspiration is known to dominate soil moisture dynamics during the growing season (Kozii et al., 2020), this study quantified that this dominance are with regression coefficients more than 75% of the total sum of the three covariates." (Lines 639-642)

Kozii, N., K. Haahti, P. Tor-ngern, J. Chi, E.M. Hasselquist, H. Laudon, S. Launiainen, R. Oren, M. Peichl, J. Wallerman, and N.J. Hasselquist. 2020. Partitioning growing season water balance within a forested boreal catchment using sap flux, eddy covariance, and a process-based model. *Hydrol. Earth Syst. Sci.* 24:2999-3014.

"In regions such as temperate grasslands, savannas, shrublands, deserts, xeric shrublands, and tundra, negative dependencies between precipitation and soil moisture, driven by LST and Ta:GPP interactions, were observed..."

Response: "For the factor driving the dependence of soil moisture to precipitation, this study found that the negative dependences were distributed across temperate grasslands, savannas, shrublands, deserts, xeric shrublands, and tundra, primarily driven by LST and T_a:GPP interactions.” (Lines 648-651)

"At the annual scale, the area of negative dependence increased with soil depth, with the most pronounced negative dependencies occurring in the montane grasslands and shrublands region. In this region, negative dependencies at all three soil depths were driven by the GPP:LST interaction..."

Response: “At the annual scale, the negative dependences were mainly in the montane grasslands and shrublands region (Wei et al., 2008). This study further revealed that this negative dependence increased with soil depth, and were driven by the GPP:LST interaction across all three soil layers.” (Lines 661-664)

Wei, J., R.E. Dickinson, and H. Chen. 2008. A Negative Soil Moisture–Precipitation Relationship and Its Causes. *Journal of Hydrometeorology*. 9:1364-1376.

The reorganized conclusion section is as follows.

This study explored the dependence relationships between precipitation and soil moisture at depths of 0 to 7 cm, 7 to 28 cm, and 28 to 100 cm from 2000 to 2019, by examining the control effect of precipitation volume, precipitation frequency, and evapotranspiration on soil moisture. Bayesian models were used to analyze the driving factors and relative contribution in the dependence of soil moisture to precipitation in different time scales and ecoregions of the Northern Hemisphere. The results showed that, the negative dependence proportion reached 19.2%, 0.7%, and 2.3% at monthly scale, while it was 3.0%, 4.0%, and 8.6% at annual scale, respectively, for the three soil layers. Our studies have new insight for the dependence of soil moisture to precipitation varying in different ecoregions. We concluded that, precipitation volume predominantly controlled soil moisture in the Boreal forest/taiga, temperate grasslands, savannas, and shrublands, while precipitation frequency primarily controlled soil moisture in the high-latitude regions of the Northern Hemisphere. The combined influence of evapotranspiration and precipitation exhibited clear seasonal patterns. While evapotranspiration is known to dominate soil moisture dynamics during the growing season (Kozii et al., 2020), this study quantified that this dominance are with regression coefficients more than 75% of the total sum of the three covariates. In contrast, precipitation volume played a more significant role in the surface and middle layer of non-growing season, with areas under strong univariate control accounting for over 40% of the total area. Additionally, the influence of precipitation frequency on soil moisture increased with latitude, the proportion of the regression coefficient averaging from 36.5% to 91.3%, highlighting a shift in controlling factors across climatic gradients.

For the factor driving the dependence of soil moisture to precipitation, this study found that the negative dependences were distributed across temperate grasslands, savannas, shrublands, deserts, xeric shrublands, and tundra, primarily driven by LST and T_a:GPP interactions. These negative dependences were mainly attributed to the seasonality of precipitation in arid and semi-arid areas and the freeze–thaw processes in the soil, which hinder effective moisture replenishment, especially during winter when soil freezing prevents rainwater infiltration. In the intermediate and deep soil layers, negative dependences were primarily driven by single variables, whereas positive dependences resulted from multivariate interactions, likely due to the lack of compensatory mechanisms when a single variable dominated, or the enhancement of ecosystem feedbacks when both GPP and LST interacted. Additionally, when the ecosystem is simultaneously driven by GPP and LST, greater resilience may be exhibited.

At the annual scale, the negative dependences were mainly in the montane grasslands and shrublands region (Wei et al., 2008). This study further revealed that this negative dependence increased with soil depth, and were driven by the GPP:LST interaction across all three soil layers. A possible explanation is the long-term variability in precipitation and temperature, which may have influenced geomorphology, vegetation structure, and soil water retention capacity.

Again, we thank for your recommendation and valuable comments.