Rainfall-Soil Moisture Event Responses near Baton Rouge, Louisiana

Ali Haghighi (ahaghighi@ut.ac.ir), Afshin Ashrafzadeh September 27, 2025

Introduction

Rainfall controls soil moisture variability and drives hydrological processes from infiltration to contaminant transport. This study investigates event-scale rainfall-soil moisture interactions near Baton Rouge, Louisiana, during 2022-2024. We detect and analyze individual rainfall events, quantify associated soil moisture responses, and assess seasonal patterns in their magnitude and variability. The focus is on the change in soil moisture ($\Delta\theta$) as an indicator of infiltration dynamics.

Our results provide insight into how antecedent wetness and event precipitation shape soil moisture responses across seasons. Beyond immediate hydrological interpretation, this framework offers a basis for future extensions, including nitrate leaching and surface-subsurface contamination analysis, once nutrient datasets are integrated.

Resources: Codes and processed data (spatially and temporally subsampled; easy-to-use CSV) are available on GitHub repository. My personal website and other projects can be found at Ciarel.com.

Study Area and Data

The analysis domain is a 25 × 25 km box surrounding Baton Rouge, Louisiana (SW: 30.34, -91.28; NE: 30.56, -91.02), as shown in Fig. 1. This bounding box was chosen to capture regional hydroclimatic variability while maintaining a tractable spatial scale for event-based soil moisture analysis. Both precipitation and soil moisture datasets were subsetted spatially to this domain and temporally to the period 2022–2024.

Figure 1: Study area near Baton Rouge, Louisiana. The analysis domain (25 × 25 km box) is outlined and overlain on regional context.

Soil moisture conditions were obtained from the NASA Soil Moisture Active Passive (SMAP) mission, using the Enhanced Level-3 Radiometer Global Daily product (9 km resolution), which provides surface soil moisture retrievals representative of the top ∼5 cm of soil [1]. Precipitation data were obtained from the Global Precipitation Measurement (GPM) mission's Integrated Multi-satellite Retrievals (IMERG) Final Run product, available at 0.1° spatial and daily temporal resolution [2].

Together, SMAP and IMERG provide harmonized, global-scale, open-access satellite observations suitable for characterizing - moisture interactions in regions such as Baton Rouge, where high-frequency precipitation events and strong seasonal cycles affect vadose-zone hydrology.

Methods

Rainfall events were defined from daily precipitation P_t. A wet day is $P_t \geq 1$ mm, and an event is a sequence of wet days that (i) starts after a dry day, and (ii) includes a burst of at least 5 mm on the first or second day. For an event with start s and end e, total rainfall and duration are

$$R = \sum_{t=s}^{e} P_t, \qquad D = e - s + 1.$$

Antecedent soil moisture is the mean of the three days before the event, but if these overlap with the previous event, we trim them. Let A denote this window and θ_A its average. The post-event response window is

$$B = \big[s,\ \min(e+3,\ s_{\text{next}}-1)\big], \qquad \theta_{\max} = \max_{t\in B} \theta_t.$$

The main metric is the soil moisture increment

$$\Delta\theta = \theta_{\max} - \theta_A.$$

We also compute a nominal lag between antecedent and response times. However, we do not analyze it further because SMAP provides only surface soil moisture (∼0–5 cm) at daily resolution. With no information from deeper layers, infiltration timing and true lags cannot be extracted reliably. If multi-depth soil measurements were available, lag analysis would be a valuable extension.

Results

Hydroclimatic context. Monthly precipitation and domain-mean soil moisture (Fig. 2) track each other closely, with wetter months yielding higher soil moisture. Peaks occur at the end of winter and early spring, reflecting cumulative cool-season rainfall and low evaporative demand.

Rainfall events. Event characteristics are shown in Fig. 3. The median event produced 25 mm over 2 days. High-depth, long-duration outliers (above the 75th percentile in both) occurred mainly in summer. Seasonal counts were Winter 31, Spring 31, Summer 29, and Autumn 23.

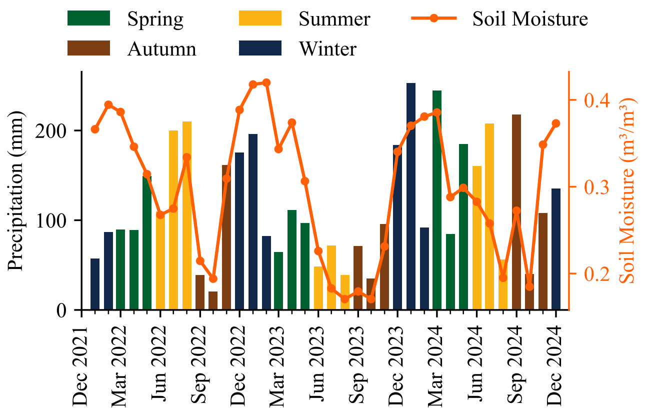

Figure 2: Monthly precipitation totals and averaged soil moisture from 2022-2024.

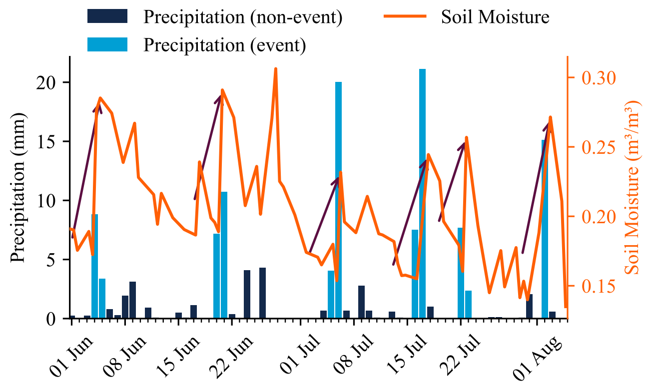

Figure 4: Example rainfall event: daily precipitation and soil moisture response.

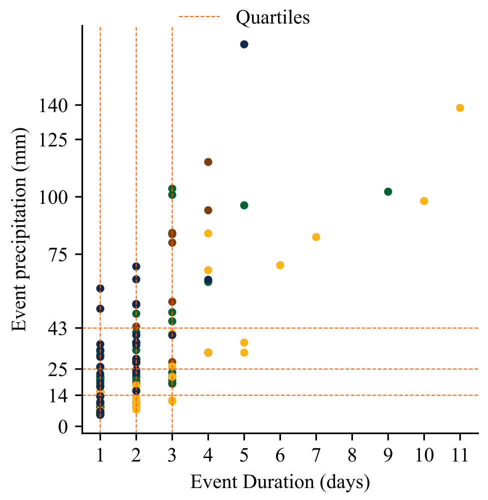

Figure 3: Event rainfall depth versus duration.

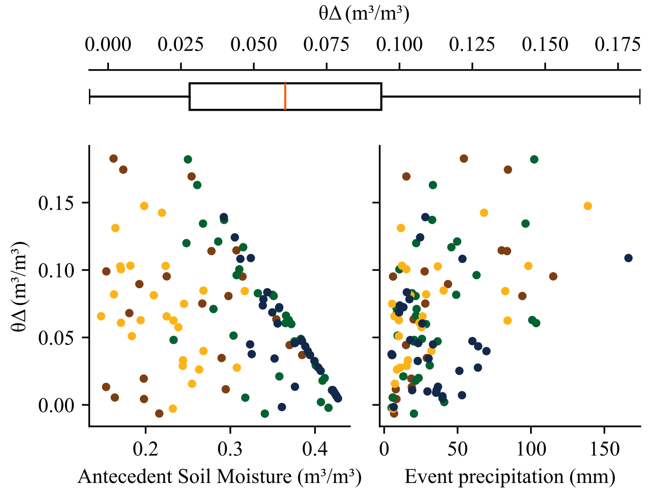

Figure 5: Distribution of soil moisture change ($\Delta\theta$) versus antecedent soil moisture and event precipitation.

Soil moisture responses. For each event, the soil moisture increment ($\Delta\theta$) was calculated. Fig. 4 illustrates sample events; smaller storms were sometimes missed by detection rules. Across all events (Fig. 5, top), $\Delta\theta$ had a median of 6% and a maximum near 18%. The left panel shows a clear saturation boundary: high antecedent moisture limits responses, while drier soils allow larger increases. Winter and spring cluster near saturation, consistent with Fig. 2, whereas summer-autumn span drier antecedent states with responses from 0-18%. The right panel relates $\Delta\theta$ to precipitation: most events (0-50 mm) produced variable responses, indicating rainfall depth alone does not constrain soil moisture change.

Future Research

Future research could potentially extend this event-based framework by coupling - moisture responses with a fully integrated water-heat-nitrate modeling approach, similar to recent work by Boujoudar et al. [3]. Such coupling would allow assessment of how storm-driven infiltration dynamics influence not only moisture but also temperature effects and nitrate mobilization in the vadose zone, thereby linking observed $\Delta\theta$ signatures to broader water-quality implications under seasonal variability.

References

[1] P. E. O'Neill et al. *SMAP Enhanced L3 Radiometer Global and Polar Grid Daily 9 km EASE-Grid Soil Moisture, Version 6*. Subset: Baton Rouge, Louisiana, 2022–2024. Accessed 2025-09-27. Boulder, Colorado USA, 2021. DOI: 10.5067/M20OXIZHY3RJ. URL: https://nsidc.org/data/SPL3SMP_E.

[2] G. J. Huffman et al. *GPM IMERG Final Precipitation L3 1 day 0.1 degree × 0.1 degree V07 (GPM_3IMERGDF)*. Subset: Baton Rouge, Louisiana, 2022–2024. Accessed 2025-09-27. Greenbelt, Maryland, USA, 2023. DOI: 10.5067/GPM/IMERGDF/DAY/07. URL: https://data.nasa.gov/dataset/gpm-imerg-final-precipitation-l3-1-day-0-1-degree-x-0-1-degree-v07-gpm-3imergdf-at-ges-dis-13ed8.

[3] Mohamed Boujoudar et al. *Modeling Water, Heat, and Nitrate Dynamics in the VadoseZone: A Case Study of the Beauce Aquifer (Orleans, France)*. Tech. rep. Copernicus Meetings, 2025.