Rainfall-Triggered CO_2 Pulses ("Birch Effect") in the Californica Coastal Sage Scrub

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Motivation & Background

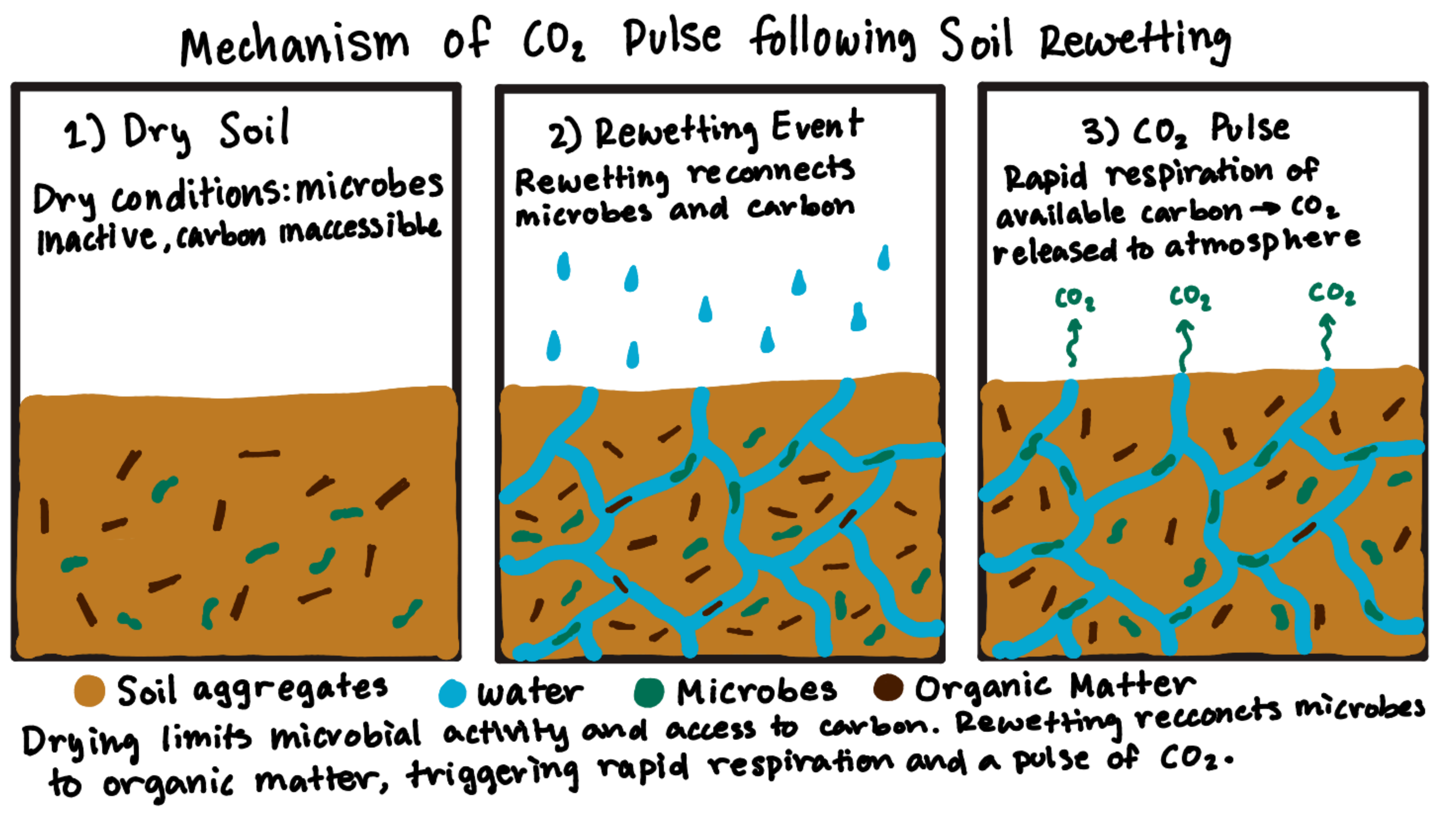
Dry soils often show a rapid pulse of microbial respiration when rewetted, known as the Birch effect. These pulses can produce short-lived but important CO_2 losses, especially in drylands and Mediterranean ecosystems where rainfall is episodic.
At US-BFS, long dry periods followed by winter storms provide an opportunity to test whether rainfall events trigger ecosystem-scale CO_2 efflux pulses. However, eddy covariance measurements during rain can be unreliable, so detecting these pulses requires careful event selection and flux quality control.

Questions & Goals

1. Which rainfall events at US-BFS followed sufficiently dry antecedent conditions?
2. Do valid post-rain nighttime CO_2 fluxes show short-term emission pulses?
3. Does pulse magnitude depend on antecedent dryness, soil temperature, or storm size?
4. How much do wet-instrument periods and missing data limit Birch-effect detection?

Methods

- Used 30-minute US-BFS eddy covariance CO_2 fluxes and meteorological observations.
- Identified rainfall events from rain-rate data and grouped contiguous rain periods into storms.
- Classified candidate rewetting events using storm total rainfall and antecedent dry-period length.
- Excluded active rain/wet-canopy periods and low-quality fluxes using EC quality-control variables.
- Focused on nighttime carbon flux as a proxy for ecosystem respiration.
- Calculated post-rain CO_2 flux anomalies relative to pre-event nighttime baselines.
- Estimated peak pulse magnitude and integrated carbon loss for each event.



Drying limits microbial activity and access to carbon. Rewetting reconnects microbes to organic matter, triggering rapid respiration and a pulse of CO_2.

Citations. (Birch, 1958, Plant and Soil) & (Fierer & Schimel, 2003, Soil Biology & Biochemistry)

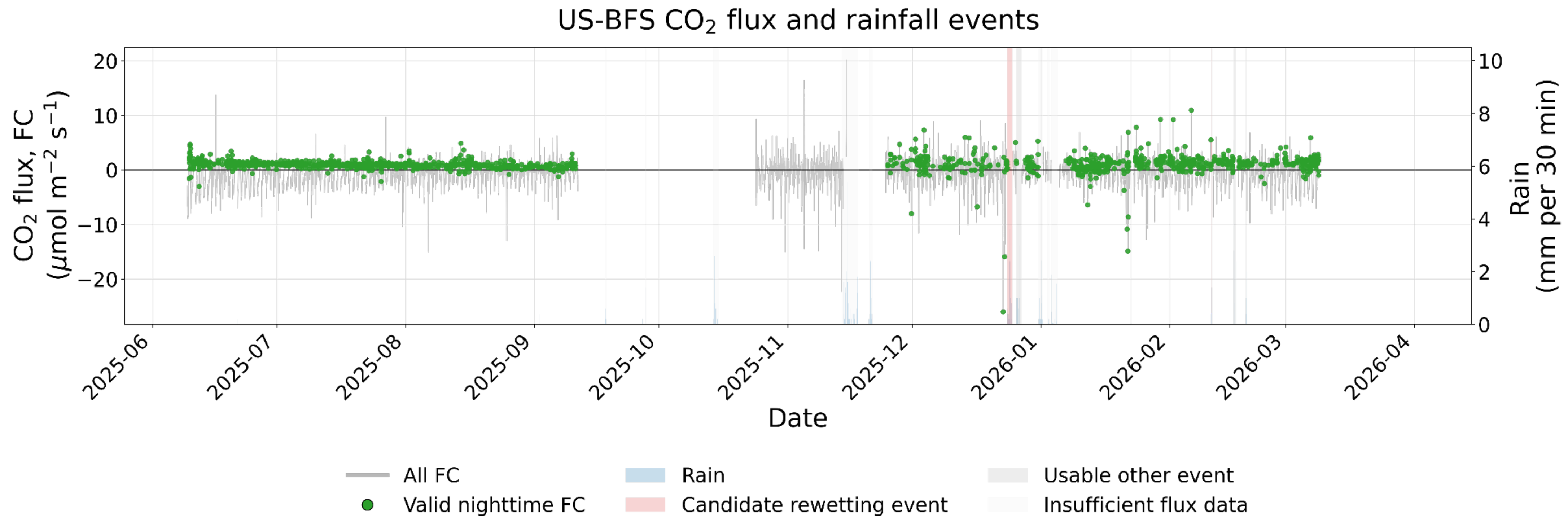


Figure 1. Rainfall events and usable nighttime CO_2 flux observations at US-BFS. Thirty-minute CO_2 flux and rainfall are shown from June 2025–March 2026. Gray points/lines show all available CO_2 flux data, while green points show nighttime fluxes retained for pulse analysis after filtering for low light, active rain, basic flux validity, and turbulence ($u^* \geq 0.1$ m s^{-1}). Blue bars show rainfall per 30-minute period. Shaded rain periods indicate detected storm events; final candidate rewetting events are those with dry antecedent conditions and sufficient valid CO_2 flux data before and after rainfall.

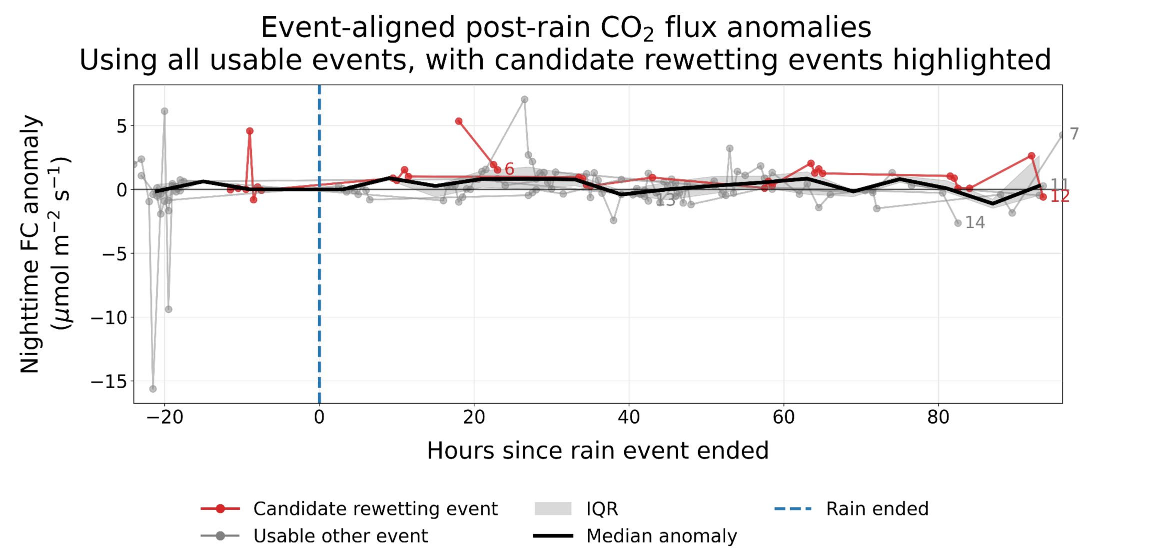


Figure 2. Event-aligned nighttime CO_2 flux anomalies following rainfall. Rain events are aligned at the end of rainfall, and nighttime CO_2 flux anomalies are calculated relative to each event's pre-rain nighttime baseline. Positive values indicate enhanced nighttime CO_2 efflux after rain, consistent with a possible rainfall-triggered respiration pulse. The black line and shaded region show the median and interquartile range across the plotted events. Because only a small number of events contribute, the median should be interpreted as a descriptive summary rather than a robust statistical average.

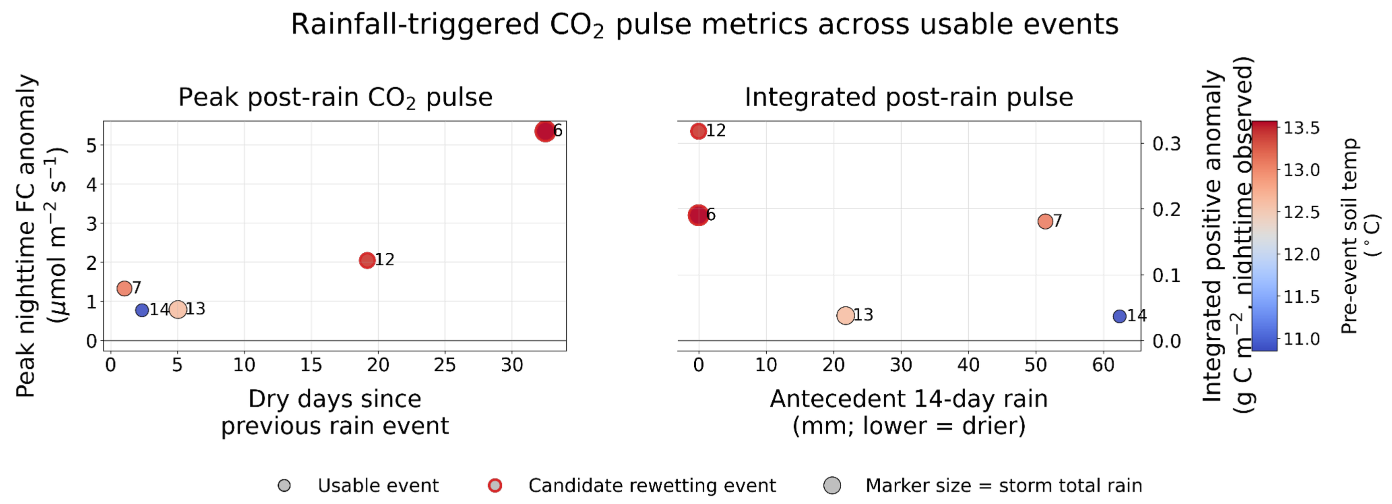


Figure 3. Rainfall-triggered CO_2 pulse metrics across events. Each point is a storm with sufficient nighttime flux data. Panel A plots peak CO_2 anomaly vs. dry days since prior rain; Panel B shows integrated post-rain anomaly vs. prior 14-day rainfall. Marker size reflects storm rainfall, color indicates pre-event soil temperature, and red outlines mark selected rewetting events. Event IDs link to case studies. Event 11 had the largest pulse but is excluded from temperature-colored plots due to missing soil temperature.

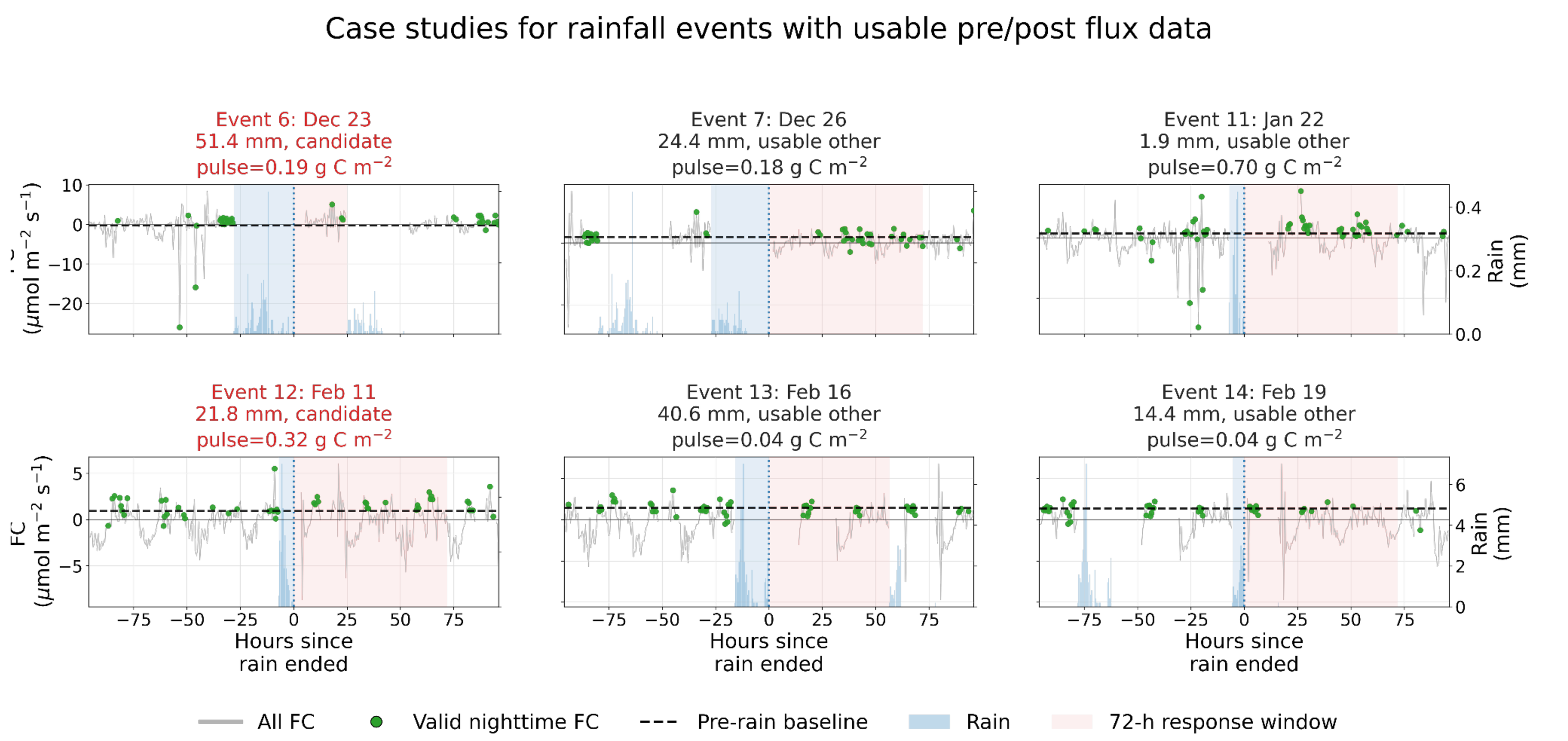


Figure 4. Event-scale CO_2 flux responses for rain events with usable pre- and post-rain flux data. Each panel shows one rainfall event aligned to the end of rainfall, with blue bars showing rainfall and green points showing valid nighttime CO_2 fluxes used as a respiration proxy. The dashed horizontal line is the pre-rain nighttime baseline calculated from 72 to 12 hours before the event. Positive nighttime fluxes above this baseline after rain indicate enhanced CO_2 efflux consistent with a possible rewetting response. Red panel titles identify final candidate rewetting events, while dark titles indicate usable rain events that did not meet the dry-antecedent rewetting criteria.

Limitations

- Open-path EC fluxes can be unreliable during rain, high humidity, or wet optical-path conditions.
- Daytime NEE changes after storms can reflect cloud-driven reductions in photosynthesis, not only respiration pulses.
- Soil moisture/tension observations are limited, making antecedent drought difficult to quantify.
- Small numbers of suitable storms may limit statistical inference.

Results

We identified 14 rainfall events ≥1 mm between June 2025 and March 2026, totaling 386 mm of rainfall. Five events met dry-antecedent hydrologic criteria for potential rewetting, but only two also had sufficient valid nighttime CO_2 flux data before and after rainfall. These final candidate rewetting events showed positive nighttime CO_2 flux anomalies, with integrated observed positive anomalies of 0.190 and 0.318 g C m^{-2}. Across all six usable rain events, the median 72-hour nighttime observed positive anomaly was 0.186 g C m^{-2}, with a maximum of 0.697 g C m^{-2}. The strongest response occurred after a small 1.85 mm event, suggesting that low-intensity wetting may also produce measurable CO_2 efflux responses. These results are consistent with possible rainfall-triggered respiration pulses, but limited post-rain flux availability and missing soil moisture data prevent definitive attribution.

Conclusion

CO_2 flux at US-BFS is highly variable, with rainfall events associated with short-term increases in nighttime CO_2 flux consistent with possible Birch-effect pulses. However, limited post-rain data and missing soil moisture measurements prevent definitive attribution, highlighting the need for more complete observations.

Future Work

- Incorporate soil moisture data to better capture rewetting dynamics
- Analyze additional rainfall events with higher-quality measurements
- Use higher-resolution data to detect short-term CO_2 pulses

Acknowledgements

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