From rainfall to soil moisture: Capturing spatio-temporal forest water dynamics with a novel ecohydrological sensor network

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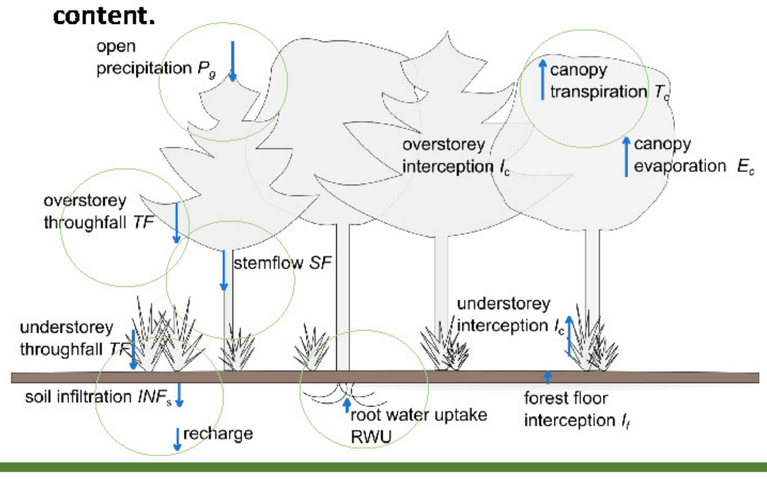
Forest water dynamics

- Rainfall reaches the tree canopy and partitions **into three fractions: interception, stemflow and throughfall.**
- Throughfall is **spatially highly heterogeneous** as rainfall redistributes within the canopy.
- **Spatio-temporal patterns emerge** and influence near-surface hydrological processes in particular **soil water content.**



Research objectives

Using a novel measurement network, we will …

- **identify spatio-temporal throughfall, infiltration and soil moisture patterns** in a forest at the intra-event and intra-stand scale.
- analyze **pattern stability over time** (persistence) and the **propagation of soil infiltration patterns into near-surface soil moisture**.
- understand the **impact of vegetation**, in particular species-specific patterns and **precipitation characteristics** on dynamics.

Methods: The Ecohydrological sensor network

Throughfall trough systems (5)

Infiltration network* (60 samplers)

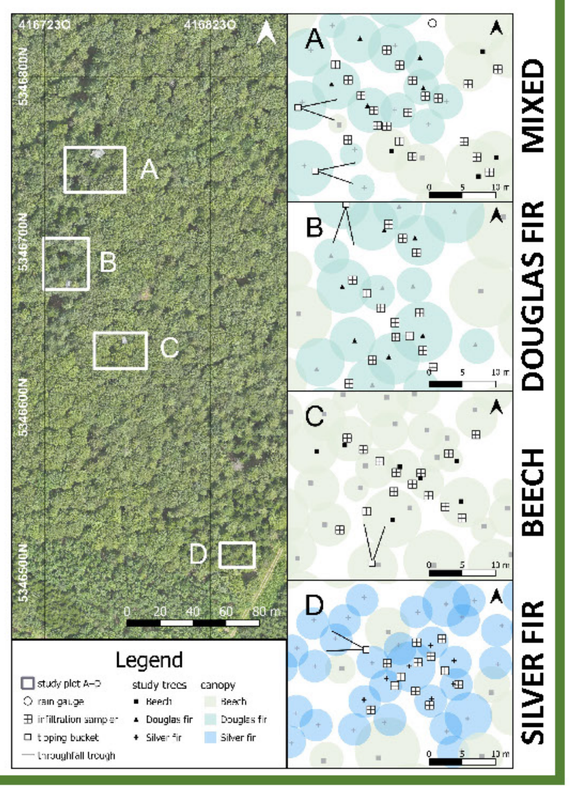
SMT100 near-surface (400) & profiles (20 x 4 depths)

Stemflow systems (12)

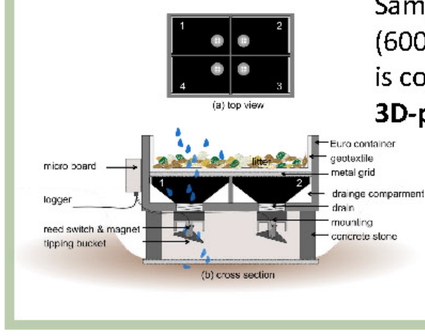
Sapflow sensors (56)

*newly deleoped in ECOSENSE

- All network instruments operate **continuously, automated** and with **near real-time data transmission.**
- Measurement instruments are arranged in a **tree-centered, stratified manner across four study plots** (see map).
- Network covers **variations in forest structure** and positions below the canopy near the stem, at the canopy edges and in the canopy center.
- Network is **minimally invasive to water fluxes** and with Low-maintenance operation.



Infiltration sampler



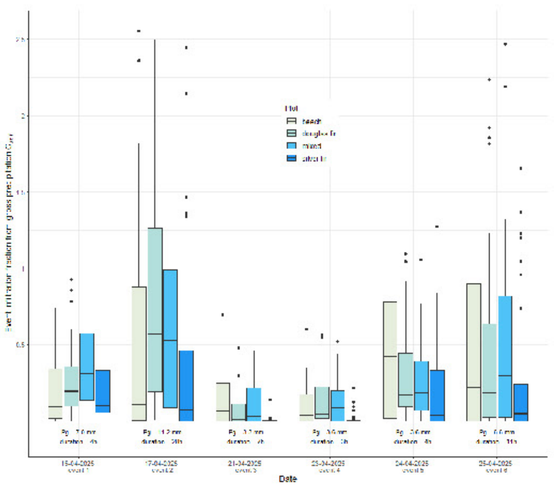
Sampler have **4 drainage compartments** (600 cm² catch area). The collected water is continuously measured using 240 **3D-printed tipping buckets.**

Tip counts from the tipping unit are transmitted to the logger via self-developed micro board (SDI-12).

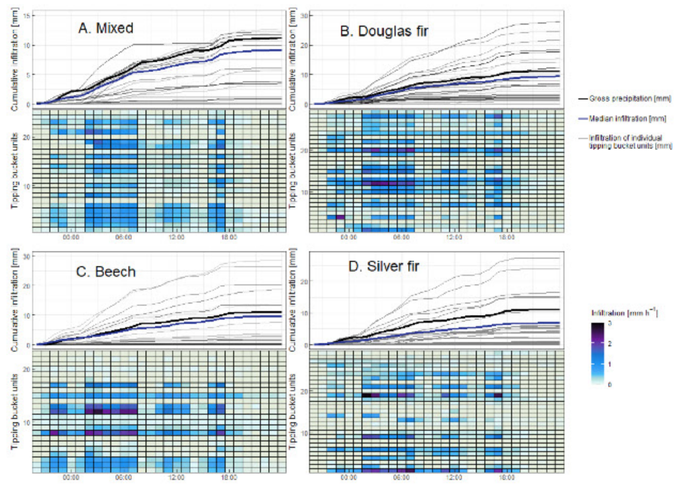
Preprint of Dedden & Weiler (2025):
TN: An innovative monitoring approach to measure spatio-temporal throughfall patterns in forest

Results: Spatio-temporal patterns of soil infiltration and soil water content

Boxplots show event infiltration measured across all four plots. The differences in infiltration between e.g. Silver fir and Beech plot for the same events are **results of interception losses and canopy redistribution** during the event.
The heat maps visualize infiltration measured at single locations. **Spatial differences of infiltration depth between two proximate locations** can amount to 300% and vary during the event.

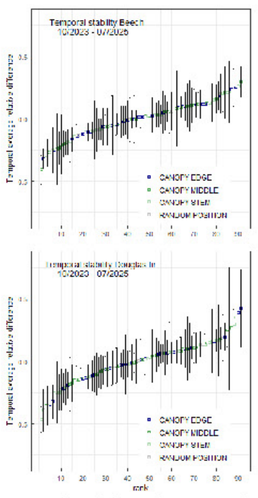


Event infiltration measured by infiltration sampler during two weeks in spring 2025; boxplots show four sub plots

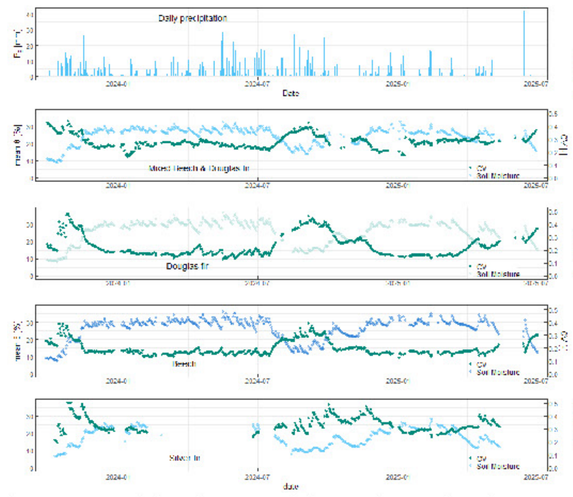


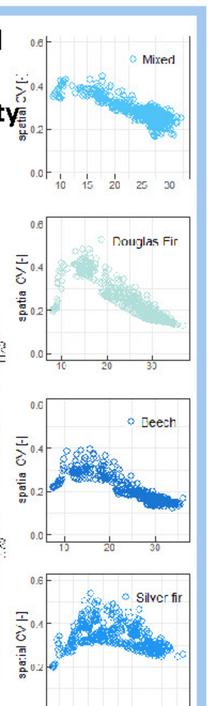
Spatio-temporal infiltration variability during a rainfall event on April 17th 2025 (total event Pg 11.2 mm, 28h)

Means of daily soil moisture near-surface (12 cm depth) follow an **annual trend: lowest during summer** and **highest in winter**. CVs are generally negatively related to mean SM, indicating **increasing spatial heterogeneity of soil moisture during drying periods**. Temporal stability analysis of 2 years data show similar patterns for Douglas fir and Beech.



Temporal stability of near-surface soil moisture for Beech and Douglas fir

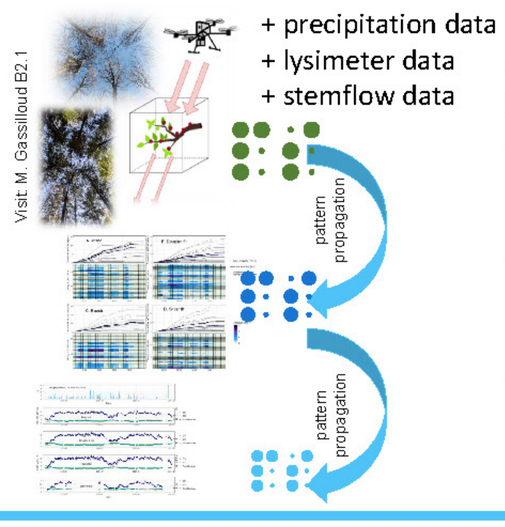




Mean daily soil moisture (%), spatial SD and CV from September 2023 to July 2025 at the four subplots

Conclusion

- We established a **novel ecohydrological sensor network** comprising a **large number of newly developed infiltration samplers** and soil moisture measurements at both high spatial and temporal resolution
- Quantification of forest **throughfall, infiltration** and **soil moisture spatial variability at tree-level** and **intra-event** and **intra-stand scale** from stands of **mono-** and **mixed deciduous** and **coniferous species**
- **Continuous and automated measurements** capture ecohydrological fluxes during rainfall events of different sizes and during seasonal changes in vegetation characteristics



Outlook

With the continuously growing dataset, the following questions will be answered:

- **Temporal stability** and **depth propagation of throughfall spatial patterns** through forest floor percolation (soil infiltration) into **near-surface soil moisture**
- Hot moments and hot spots in the throughfall and soil moisture spatio-temporal patterns, considering **species-specific differences** and **seasonality effects** and using geostatistical analysis approaches
- Influence of vegetation architecture and precipitation characteristics on throughfall and soil moisture using **LiDAR-derived PAD** and **precipitation data** for different foliage conditions over the year in correlation and geostatistical analysis

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