An innovative monitoring approach to measure spatio-temporal throughfall patterns in a forest

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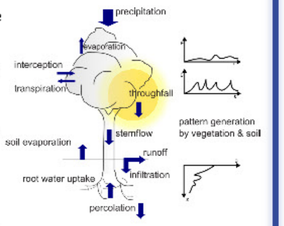
HYDROLOGY

Forest hydrology

- 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,** influencing near-surface hydrological processes and regulating nutrient and plant-water availability.



Throughfall collection gutters with commercial tipping bucket

Challenges of throughfall measurement

- Common approaches: Trough and funnel sampler in random or stratified design of varying sample sizes.
- No agreement on standard measurement instrumentation and schemes.
- In particular, measuring spatio-temporal throughfall variability in complexly structured forest stands remains experimental challenge.

Research objectives

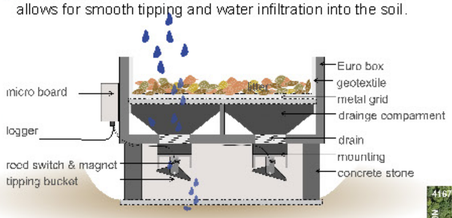
Using a novel **measurement network of throughfall boxes** and tipping buckets, we will

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

Methods

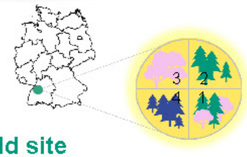
Throughfall (TF) sampling box

- Eurobox containers were divided into **4 drainage compartments** (60 cm² collection area).
- The collected water is continuously measured using **3D-printed tipping buckets.**
- Tip counts from the tipping unit are transmitted to the logger via self-developed micro board (SDI-12).
- Forest floor litter in the boxes reduces splash & clogging.
- Installation on leveled hollow concrete stones near ground allows for smooth tipping and water infiltration into the soil.



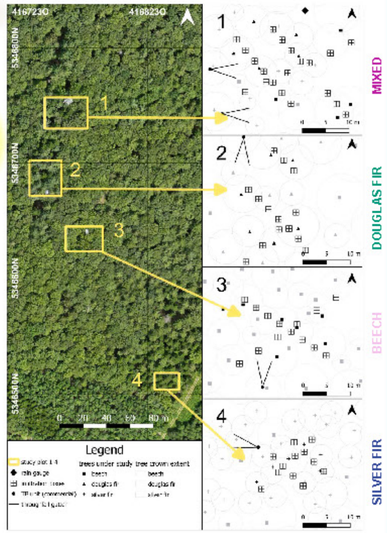
TF measurement network

- **60 throughfall boxes** were distributed in a stratified manner across **4 study plots**, totaling **240 tipping bucket units**.
- Covering variations in forest structure and positions below the canopy near the stem, at the canopy edges, and in the canopy center.
- Five complementary throughfall gutters and two rain gauges.



ECOSENSE field site

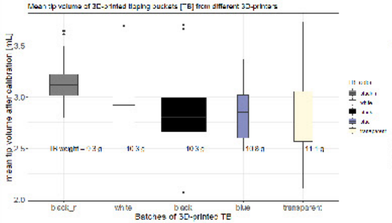
- Experimental forest research site near Ettenheim between Upper Rhine Valley and Black Forest in SW Germany.
- Beech-dominated mixed forest with Silver & Douglas fir patches (60 /80 years old; 25/35 m height).
- Study plots of:
  1) **Mixed Beech and Douglas fir,**
  2) **Douglas fir,**
  3) **Beech and**
  4) **Silver fir**
- Elevation 500 m a.s.l., temperate-humid climate, mean annual precipitation of 1120 mm and mean annual temperature of 9.5°C.
- Pseudogley and Cambisol soils, forest floor is moder.



Field site with adjacent test plots (left) and schematic sampling design of measurement boxes on transects below canopy (right)

Results

Tipping unit calibration



- Accuracy of printed buckets and within-batch precision vary among printers.
- Individual calibration factors for the tipping units and regular field calibration is required.

Forest floor water storage

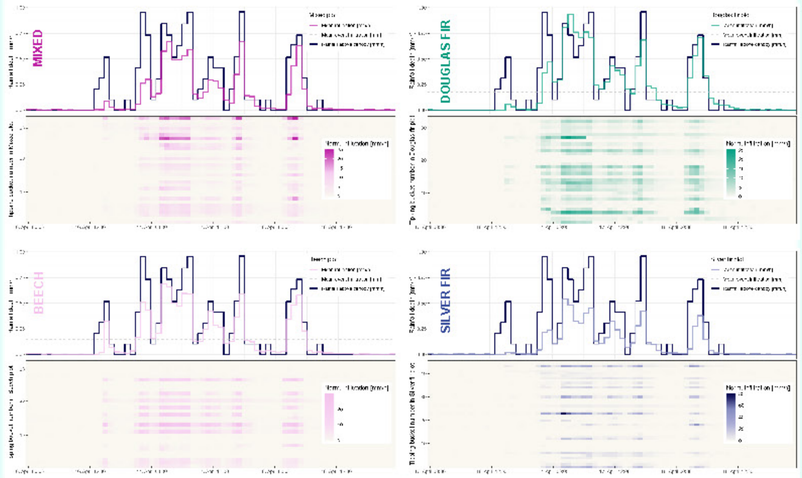
Forest floor litter	Water storage (dry) [g g⁻¹ dry weight]	Water storage (wet) [g g⁻¹ dry weight]	Evaporation rate* [g h⁻¹]
Mixed	1.64 g g⁻¹	1.43 g g⁻¹	10.6 / 14.8
Douglas fir		same as mixed litter	
Beech	2.14 g g⁻¹	1.24 g g⁻¹	10.4 / 11.8
Silver fir	3.82 g g⁻¹	3.98 g g⁻¹	11.1 / 65.2

laboratory lysimeter experiment to determine forest floor water storage capacity and evaporation; rain of 2.8 mm h⁻¹(30 min); 21°C room temperature
*mean hourly weight loss over first 12h after rain

- Silver fir litter has the highest water storage capacity, up to 4 times its dry weight, followed by beech litter and litter from mixed forest.
- Dry forest floor conditions seem to increase water storage capacity for beech litter; here is no hydrophobicity effect due to rest moisture in dried litter material

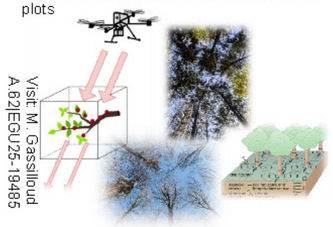
Infiltration measurements in the forest

- Heat maps show differences in infiltration depth; spatial variability of infiltration within and across the four plots for the same precipitation event from April 16th – April 18th at the ECOSENSE field site



Conclusion

- We established a **novel throughfall measurement network of box sampler** with individual tipping buckets
- Quantification of forest **throughfall spatial variability at intra-event and intra-stand scale** from **mono- and mixed deciduous and coniferous species**
- **Continuous and automated measurements** capture throughfall for rainfall events of different sizes and during seasonal changes in vegetation characteristics
- Measurement is **minimally invasive (percolation beneath the boxes)** and allows for soil moisture measurements in the same plots



Outlook

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

- Identifying hot moments and hot spots in the throughfall spatio-temporal patterns, considering **species-specific patterns** and seasonality effects using geostatistical analysis approaches.
- Relating throughfall patterns with vegetation structure using **correlation analysis of spatial patterns with LiDAR-derived PAD** for different foliage conditions over the year.
- Using **temporal stability analysis** of the throughfall patterns controlled by rainfall characteristics.
- Joint analysis with a additional large soil moisture dataset to **identify propagation of spatial throughfall patterns into soil moisture.**

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ECOSENSE
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