EcoSense
Conference 2025

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Freiburg

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International ECOSENSE Conference

The Collaborative Research Center ECOSENSE (CRC-1537, funded by the German Research Foundation DFG) investigates all relevant scales in a next generation ecosystem research assessment. Our vision is to detect and forecast critical changes in ecosystem functioning based on the understanding of hierarchical process interaction. To do so ECOSENSE develops, implements, and tests a new versatile, distributed, cost-effective, autonomous, intelligent sensor network based on novel microsensors tailored to the specific needs in remote and harsh forest environments.

Following our ECOSENSE project on development of smart autonomous sensor networks to study high spatial and temporal resolution of ecosystem carbon, water and VOC fluxes across scales to detect stress impacts in forests, we will host an interdisciplinary event bringing together environmental scientists and engineers. We welcome contributions on novel approaches to study ecosystem processes and stress impacts along the soil-plant-atmosphere as well as novel sensor principles, distributed sensor networks and modelling. We aim to share novel ideas, recent results and discuss about innovative technologies to monitor ecosystem processes on a multiscale level.

IMTEK unr INATECH KIT Karlsruher Institut für Technologie IMT KIT-Campus Alpin IMK-IFU: Atmosphärische Umweltforschung

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Venue & Map

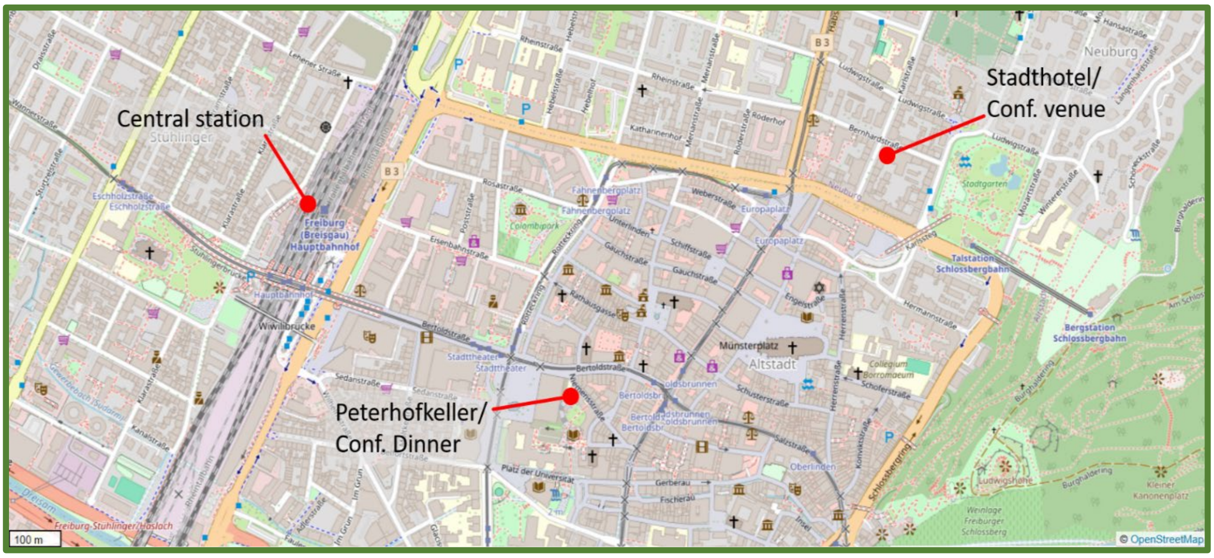
The ECOSENSE Conference 2025 will take place at the **Stadthotel Freiburg**. Arranged rooms for keynote and invited speakers will be at the hotel as well.

Karlstraße 7, 79104 Freiburg,
www.hotel-freiburg.de/de/stadthotel-freiburg/

Coffee, tea and snacks will be served during coffee breaks. Lunch will be provided on Tuesday and Wednesday in the conference hotel, including non-alcoholic beverages. On Monday evening, there will be a 3-course menu for dinner in the hotel.

The conference dinner on Tuesday, September 29th, will take place at the **Peterhofkeller,** in a historical building of the University of Freiburg.

Niemensstraße 10, 79098 Freiburg



Program

Monday Sep 29, 2025	
12:00-13:30	On-site check-in
13:30-13:35	**Welcome** Christiane Werner, Ulrike Wallrabe (University of Freiburg)
13:35-13:40	**Welcome** Stefan Rensing (Vice President for Research and Innovation, University of Freiburg)
13:40-14:00	**Introduction to ECOSENSE** Christiane Werner, Ulrike Wallrabe (University of Freiburg)
14:00-14:45	**Monitoring Hypertension in Plants** Tim Brodribb (University of Tazmania, Australia)
14:45-15:15	**A trait-based perspective on plant drought responses** Alexandra Weigelt (University of Leipzig, Germany)
15:15-15:30	**Hydraulic redistribution in European forests assessed with a unique deep soil isotopic labelling experiment** Matthias Beyer (TU Braunschweig, Germany)
15:30-15.45	**Five Years of Ecohydrological Research at WaldLab Zürich – Revealing Surprises Along the Forest Water Cycle** Marius Floriancic (ETH Zurich, Switzerland)
15:45-16:00	**The timing of drought-induced declines in stem water and growth occurs earlier in isohydric than anisohydric tree species** Sharath Paligi (Georg August University Goettingen, Germany)
16:00-16:30	Coffee break
16:30-17:15	**Automated lab-on-chip system for extracting soil solution and taking time-series nitrate measurements** Martina Gerken (Kiel University, Germany)
17:15-17:30	**Roots, Robots, and the Carbon Cycle: Automating Belowground Dynamics to Improve Understanding of Ecosystem Greenhouse Gas Exchange** Richard Nair (Trinity College Dublin, Ireland)
17:30-17:45	**Automated On Site Nucleic Acid Sequencing Using Centrifugal Microfluidics** Jacob Hess (Hahn-Schickard, Germany)
17:45-18:00	**AgraSim: an experimental simulator for the comprehensive analysis of global change impacts on biogeochemical, hydrological and physiological processes in agricultural systems** Nicolas Brüggemann (Forschungszentrum Jülich GmbH, Germany)
18:00-20:00	Dinner (Stadthotel Freiburg)

Tuesday Sep 30, 2025	
9:00-9:45	**Listening to Trees in the Miyawaki Forest Using Redox Amplifiers** Marc Madou (Instituto Tecnológico y de Estudios Superiores de Monterrey, Mexico)
9:45-10:30	**The importance of physiological data networks to understand tree - environment interactions** Ansgar Kahmen (University of Basel, Switzerland)
10:30-11:00	Coffee break
11:00-11:30	**From Innovation to Small Series Production** Christian Siffl, Josef Greitemann (Robert Bosch GmbH)
11:30-11:45	**Evidence from new Czech site network suggests hydraulic divergence between forest types through emergent processes under drier climate** Martin Bouda (University of Hohenheim, Germany)
11:45-12:00	**Intra-individual variation: Insights into mechanisms for plant drought resistance revealed through within-plant measurements and optical imaging** Kate Johnson (Centre de Recerca Ecològica i Aplicacions Forestals (CREAF), Spain)
12:00-12:15	**Tradeoffs between leaf heat tolerance and thermal regulation in dryland plants** Kevin Hultine (Desert Botanical Garden, United States)
12:15-12:30	**Monitoring Extreme Heat Responses of Tropical Forest Tree Leaves inside Biosphere 2** Joost van Haren (University of Arizona, United States)
12:30-14:00	Lunch (Stadthotel Freiburg)
14:00-15:30	Postersession
15:30-16:00	Coffee break
16:00-16:45	**Deep roots, dry soils: root water uptake legacies shaping forest drought resilience** Katrin Di Bella Meusburger (Eidg. Forschungsanstalt für Wald, Schnee und Landschaft WSL, Switzerland)
16:45-17:00	**Soil and tree stem xylem water isotope data from two pan-European sampling campaigns** Marco Lehmann (Eidg. Forschungsanstalt für Wald, Schnee und Landschaft WSL, Switzerland)
17:00-17:15	**Forest Response to Drought – from Tree to Ecosystem Scale** Sebastian Wolf (ETH Zurich, Switzerland)
17:15-17:30	**SOA precursor emissions in and above a forest consisting of beech and Douglas fir** Xuefeng Shi (Karlsruhe Institute of Technology, Germany)
17:30-17:45	**Field transcriptomics for forest stress assessment** Cristina Zamora (University of Freiburg, Germany)
17:45-18:00	N.A.
19:00-21:00	Conference Dinner (Peterhofkeller)

Wednesday Oct 1, 2025	
9:00-9:45	**Ion mobility spectrometry – On-site detection of ppt-level gas concentrations in one second** Stefan Zimmermann (Leibniz University Hannover, Germany)
9:45-10:15	**Development of diversified agroecosystems with robotics, AI, and environmental sensing** Paul Hofmann (ELLIS Institute Tübingen gGmbH & Max-Planck-Institute for intelligent systems, Germany)
10:15-10:45	Coffee break
10:45-11:00	**Architectural Traits Predisposing Trees to Damage: Usage of LiDAR Time Series** Alice Penanhoat (Swedish University of Agricultural Sciences (SLU), Sweden)
11:00-11:15	**Carotenoids increase as an indicator of early stress of trees: estimations using Green Shoulder Indices from hyperspectral drone data and radiative transfer model PROSAIL** Langning Huo (Swedish University of Agricultural Sciences (SLU), Sweden)
11:15-11:45	**ECOSENSE Field Site** Katrin Kühnhammer, Jasmin Tesch (University of Freiburg, Germany)
11:45-12:00	**Closing remarks** Christiane Werner, Ulrike Wallrabe
12:00-13:00	Lunch (Stadthotel Freiburg)
13:00	Excursion to ECOSENSE Forest from Stadthotel Freiburg (registered participants only); planned arrival back in Freiburg 17:30/18:00

Keynote speakers

(Sorted by last name of presenting author)

Monitoring Hypertension in plants

Timothy Brodribb

University of Tasmania, Australia

Just like animals, plants operate a vascular system under pressure. The range and dynamics of plant vascular pressures can provide critical insights into water use, water storage, productivity and stress exposure of whole trees. Considering the wealth of information available from the xylem pressure potential, it is only recently that tools have become available to monitor and interpret the way that trees regulate xylem pressure in the face of highly dynamic atmospheric drivers. Here I will discuss the concept of optical dendrometry as a tool for sensing changes in xylem water potential at very high temporal resolution. I will show how stomatal behaviour can be inferred form xylem water potential, discussing recent results comparing trees grown in contrasting soils.

Automated lab-on-chip system for extracting soil solution and taking time-series nitrate measurements

Martina Gerken

Kiel University, Germany

The soil nitrate concentration is an important indicator for plant growth analysis. Current soil nutrient assessments rely on manual sampling, though electrochemical sensors are emerging. Inspired by lab-on-chip systems for water nitrite and nitrate monitoring, we present an automated lab-on-a-chip platform for in-situ nitrate sensing in soil. The system uses a ceramic suction cup to extract soil water, which is mixed in the well-established Griess assay. The colorimetric analysis is done via an LED-photodetector pair. The 3-layer PDMS-on-glass chip is fabricated with photolithography and integrated with pumps and valves to manage fluid handling, calibration, and waste collection. Measurements of nitrate concentration, soil temperature, and humidity are controlled remotely. We detail the microfluidic control strategy and demonstrate system performance in lab tests covering 0–50 mg/L nitrate concentrations, as well as initial pot and field trials.

This work is supported by EIC Transition grant SOILMONITOR, 101097989.

The importance of physiological data networks to understand tree - environment interactions

Ansgar Kahmen; Richard Peters; Roman Zweifel; Sophia Etzold; David Steger; Günter Hoch

University of Basel, Switzerland

The physiological behavior of trees and forests is sensitive to their physical environment. Understanding how variability in temperature, VPD or soil moisture influence the ability of trees, e.g. to assimilate carbon or to build new tissue and grow, requires new approaches, including new sensors and data networks that deliver comprehensive datasets against which physiological and biophysical theory can be tested. In my talk I will give examples for such new sensors, data networks and comprehensive datasets and illustrate how these can be used to address the response of tree water relations and growth of temperate trees and forests in the context of their (changing) environment.

Listening to Trees in the Miyawaki Forest Using Redox Amplifiers

Marc Madou

Instituto Tecnológico y de Estudios Superiores de Monterrey, Mexico

We are improving the detection (LOD) limit of redox amplification-based sensors to monitor "wired communication" based on non-volatile compounds within one and the same plant. We are exploring two novel types of IDEA (Interdigitated Electrode Array) geometries that, at least in a lab setting, are capable of redox amplification factors between 50 and 200. One type involves Au electrodes with gaps and widths of less than 100 nm, the other is based on 3D carbon electrodes. As a testbed we are using three Miyawaki forests planted on our Tecnológico de Monterrey (TEC) campus in Monterrey, Mexico. A Miyawaki forest is a densely planted, biodiverse forest designed to mimic natural forests with a high density of native species, fostering competition for space and resources with up to 10 times faster growth. Our promising sensors will be compared and inserted in various plants in these Miyawaki forests to learn how they cope with the harsh Monterrey urban environment.

Deep roots, dry soils: root water uptake legacies shaping forest drought resilience

Katrin Meusburger; Alexis Shakas; Arthur Gessler; Marcus Schaub

Swiss Federal Research Institute WSL, Switzerland

Across Switzerland, deep soil moisture is no longer recharged regularly, leaving both shallow- and deep-rooted trees more exposed to drought. In a dry Scots pine forest, geophysics, drones, and soil sensors revealed that 20 years of irrigation stimulated deeper rooting and more efficient water use. Yet this adjustment occurred only under favourable conditions; under persistent stress, roots failed to adapt, highlighting the legacy of past conditions in shaping tree resilience.

Ion mobility spectrometry – On-site detection of ppt-level gas concentrations in one second

Stefan Zimmermann

Leibniz University, Hannover

When it comes to on-site detection of trace compounds in air, ion mobility spectrometry is one promising approach providing high selectivity and detections limits down to ppt-levels within one second of measurement time. Low instrumental effort allows for compact devices for hand-held and drone applications. Current research concentrates on further improving sensitivity and resolving power for reliable detection of target compounds even in complex environments. New developments in ion mobility spectrometry will be presented covering new methodology and hyphenated techniques to bring analytical instrumentation to the field.

Invited Talks

(Sorted by last name of presenting author)

Development of diversified agroecosystems with robotics, AI, and environmental sensing

Paul Hofmann; Georg Martius; Wieland Brendel

Max-Planck-Institute for Intelligent Systems, Tübingen

To address agriculture's key challenges, we develop biodiverse, agroforestry-inspired strips for integration into existing farming systems to enhance productivity and ecosystem services. Small, flexible robots enable economically scalable automation, and serve as mobile sensing platforms that monitor yield, plant health, soil fertility and biodiversity. These data form the basis of digital twins for complex agroecosystems, guiding adaptive robotic management and site-specific transferability.

The ECOSENSE forest: Realizing a distributed sensor and data management system for real-time monitoring of forest ecosystem functioning and stresses

Kathrin Kühnhammer; Jasmin Tesch; Delon Wagner

University of Freiburg, Germany

The ECOSENSE project aims at capturing forest carbon and water flux dynamics in space and time with a wide range of established measurement technologies and newly developed sensors. In this talk we present the infrastructure in the ECOSENSE forest supporting such novel and complex environmental sensor networks. We will talk about physical structures, power supply, communication network, and data management as well as our thoughts and learnings from trying to design a stable, flexible and secure infrastructure that simultaneously serves the needs of a range of interdisciplinary working groups.

From Innovation to Small Series Production

Christian Siffl, Josef Greitemann

Robert Bosch GmbH, Stuttgart, Germany

From a brilliant prototype to a reliable product: How can research teams successfully navigate the complex path to scalable manufacturing? This presentation, from an industrial engineering perspective, introduces the state-of-the-art industrial methods and models as essential tool box to bridge the gap between research & development and industrial-grade production.

A trait-based perspective on plant drought responses

Alexandra Weigel

University of Leipzig, Germany

Plant traits could give us mechanistic insight on plant resistance and resilience to drought that might help us to navigate future directions under ongoing climate change. Studies linking well-known trait spectra such as the leaf economics or plant economics spectrum to hydraulic strategies in plants are so far inconsistent but mostly claim independent trait axes for hydraulic traits. For fine roots, and the recent development of the root economics space, might offer potential links to aboveground hydraulic traits as well as drought resistance that is largely unexplored. I will show how we use our research arboretum and global trait databases in an attempt to answer these questions and will offer new insight on fine root shrinkage as a mediator trait between fine root morphology and hydraulic behaviour.

Oral contributions

(Sorted by last name of presenting author)

Hydraulic redistribution in European forests assessed with a unique deep soil isotopic labeling experiment

Matthias Beyer; Alberto Iraheta; Ramona Riedel; Malkin Gerchow; Clara Rohde; Johannes Hoppenbrock; Aljoscha Gildemeister; Maren Dubbert; Matthias Bücker

Affiliation of presenting author: TU Braunschweig, Germany

Little is known on hydraulic redistribution (HR) in European forests and its overall impact on the water balance. We installed a unique monitoring system (continuous in situ water stable isotopes, sap flow, water potential, soil moisture, matric potential and ERT) in a mixed forest in Lower Saxony. Through seven L-shaped deep water infiltration tubes (depths 1 - 3,5m), the forest was provided with thousands of liters of isotopically labelled water and transport through the ecosystem monitored.

Evidence from new Czech site network suggests hydraulic divergence between forest types through emergent processes under drier climate

Martin Bouda; Vaclav Sipek; Qi Liu; Nikol Zelikova; Miroslav Tesar

Affiliation of presenting author: University of Hohenheim, Germany

We are establishing forest hydrodynamic monitoring at Czech sites with long-term hydrologic records. Our first results (a) suggest transpiration of a lowland beech stand was limited by functional xylem during drought recovery years and (b) reveal an accelerating transition to water limitation of ET in a montane headwater catchment that puts beech and spruce forest water balance on diverging trajectories. We plan to further develop site instrumentation with a focus on soil-plant hydrodynamics.

AgraSim: an experimental simulator for the comprehensive analysis of global change impacts on biogeochemical, hydrological and physiological processes in agricultural systems

Nicolas Brüggemann; Joschka Neumann; Patrick Chaumet; Normen Hermes; Thomas Pütz; Jan Huwer; Peter Kirchner; Werner Lesmeister; Wilhelm August Mertens; Jörg Wolters; Ghaleb Natour; Harry Vereecken

Affiliation of presenting author: Forschungszentrum Jülich GmbH, Germany

AgraSim is a large-scale research infrastructure with six mesocosms designed to study the effects of future climate conditions on agroecosystems. Each mesocosm includes a temperature-controlled soil lysimeter and transparent plant chamber within adjustable climate chambers. The system allows precise control of climate variables and enables detailed analysis of soil water balance, gas exchange, nutrient and water use efficiency, and greenhouse gas emissions under different climate scenarios.

Five Years of Ecohydrological Research at WaldLab Zürich – Revealing Surprises along the Forest Water Cycle

Marius Floriancic

Affiliation of presenting author: ETH Zurich, Switzerland

At WaldLab we observe water fluxes & stable isotopes across the soil-plant-atmosphere continuum since 2020. These long-term data revealed surprises that challenge our understanding of the forest water cycle. In my presentation I'll highlight seasonal patterns in soil water recharge & plant water uptake, show age distributions of streamflow & soil waters, evaluate the retention & evaporation behavior of forest floor litter layers & explore the role of capacitance and deep roots for water uptake.

Monitoring Extreme Heat Responses of Tropical Forest Tree Leaves inside Biosphere 2

Joost van Haren

Affiliation of presenting author: University of Arizona, USA

Tropical forest canopies will heat up with increased climate change, but no high temperature (T) forests exists on Earth. In the Biosphere 2 tropical forest enclosed in glass canopy T can reach over 50C in the summer. To monitor how the canopy is responding to heat, we deployed autonomous sensors to measure stem diameter, sap flux, leaf fluorescence, and canopy/leaf environment (T, RH, light) that report directly to the internet. We present tropical leaf and plant responses to extreme heat.

Automated On-Site Nucleic Acid Sequencing Using Centrifugal Microfluidics

Jacob Hess; Caitlin Turney; Bharat Sawant; Tobias Hutzenlaub; Nils Paust

Affiliation of presenting author: Hahn-Schickard, Germany

We present advances toward fully automated on-site nucleic acid sequencing using centrifugal microfluidics combined with Oxford Nanopore Technologies' MinION device. We are developing a platform that automates sample and library preparation, as well as flow cell loading directly on disk, minimizing equipment needs and user intervention. This will enable rapid, field deployable sequencing with reduced complexity and enhanced reproducibility.

Tradeoffs between leaf heat tolerance and thermal regulation in dryland plants

Kevin Hultine; Alberto Iraheta; Ramona Riedel; Malkin Gerchow; Clara Rohde; Johannes Hoppenbrock; Aljoscha Gildemeister; Maren Dubbert; Matthias Bücker;

Affiliation of presenting author: Desert Botanical Garden, Phoenix, USA

Experimental heat waves that produced air temperatures that exceeded 50 C revealed functional tradeoff between leaf heat tolerance and leaf thermoregulation in heat adapted plants. These results highlight the intraspecific diversity of leaf physiological responses to extreme heat, with enhanced rates of leaf cooling potentially reducing the need for a high capacity for photosynthetic heat tolerance and acclimation.

Carotenoids increase as an indicator of early stress of trees: estimations using Green Shoulder Indices from hyperspectral drone data and radiative transfer model PROSAIL

Langning Huo

Affiliation of presenting author: Swedish University of Agricultural Sciences (SLU), Sweden

This study tests green shoulder indices (490–550 nm) for sensitivity to carotenoid content in tree crowns. Five indices were derived from PROSAIL-simulated reflectance with varied pigment and canopy traits, then applied to hyperspectral drone data from a forest in the early stage of spruce bark beetle infestation. Across four times of image acquisition, crown carotenoids rose and chlorophyll declined with increasing infestation time and stress.

Intra-individual variation: Insights into mechanisms for plant drought resistance revealed through within-plant measurements and optical imaging

Kate Johnson; Eva Castells; Margaux Didion-Gency; Matilda Brown; Gerard Sapes; Jordi Martinez-Vilalta

Affiliation of presenting author: Centre de Recerca Ecològica i Aplicacions Forestals (CREAF), Spain

Within-plant variation in both leaf vulnerability to water transport system failure (detected with optical sensors) and Turgor Loss Point increased with the aridity of the source population in *S. pterophorus* plants. This suggests that greater intra-individual variation in key mechanistic traits is linked to drought-resistance. This also shows that continuous monitoring with optical sensors is critical for revealing the understudied role of intra-individual variation in plant drought-resistance.

Soil and tree stem xylem water isotope data from two pan-European sampling campaigns

Marco M. Lehmann; Josie Geris; Ilja van Meerveld; Daniele Penna; Youri Rothfuss; The WATSON sampling team; Katrin Meusburger

Affiliation of presenting author: Swiss Federal Research Institute WSL, Switzerland

The stable isotope ratios of hydrogen and oxygen help study forest ecohydrology, but most work is site-specific. We present the first systematic pan-European dataset of soil and stem xylem water from 40 beech, spruce, or mixed sites sampled in spring and summer 2023. Samples were collected with standardized protocols, analyzed in one lab, and quality-checked. First results show geographic and seasonal variation, indicating species-specific differences in root water uptake strategies.

Roots, Robots, and the Carbon Cycle Automating Belowground Dynamics to Improve Understanding of Ecosystem Greenhouse Gas Exchange

Richard Nair

Affiliation of presenting author: Trinity College Dublin, Ireland

Roots, the ‘hidden half’ of plants drive critical but cryptic C exchanges with soil and air. But root dynamics in experiments and models are often ignored or assumed to match leaves because measurements belowground are slow and difficult. We developed custom automated minirhizotrons for high-frequency imaging of field dynamics from sub-daily to phenological scales, interpreted with

AI. Here I show our ongoing work improving these systems, to understand plant physiology, and link to GHG fluxes.

The timing of drought-induced declines in stem water and growth occurs earlier in isohydric than anisohydric tree species

Sharath Paligi; Christina A. Hackmann; Jan Schick; Michela Audisio; Heinz Coners; Martina Mund; Christian Ammer; Christoph Leuschner

Affiliation of presenting author: Georg August University Goettingen, Germany

Using synchronous sap flow and dendrometer data in anisohydric beech and isohydric Douglas fir, we quantified the elapsed time (in kPa hours) and REW thresholds for declines in stem water content (SWC), stem rehydration, sap flow, and growth during severe soil dry-down. Douglas fir showed faster trait reductions, indicating higher drought sensitivity. In mixture, both species reached 30–90% declines 200–500 kPa hours later than in monocultures, suggesting improved drought resistance.

Architectural Traits Predisposing Trees to Damage: Usage of LiDAR Time Series

Alice Penanhoat

Affiliation of presenting author: Swedish University of Agricultural Sciences (SLU), Sweden

Architectural traits of trees are indicators of previous growing conditions and determine future tree growth and response to short and longer-term disturbances such as storm or drought. Traits beneficial in the steady state may prove detrimental when a severe disturbance occurs. Using time series of laser scans repeated at one-year intervals before and after two different kind of disturbances (a wind-storm and a bark-beetle outbreak), we investigated tree traits predisposing to damages.

SOA precursor emissions in and above a forest consisting of beech and Douglas fir

Xuefeng Shi

Affiliation of presenting author: Karlsruhe Institute of Technology (KIT), Germany

Biogenic volatile organic compounds play a dominating role in the formation of secondary pollution due to their large emissions and high reactivity. Secondary organic aerosol generated from oxidation of monoterpenes results in the formation of oxygenated volatile organic compounds with a wide range of volatility. The mechanisms controlling emissions of VOCs, especially monoterpenes, and their influence and contribution to the formation and aging of SOA in forests are still unclear.

Forest Response to Drought – from Tree to Ecosystem Scale

Sebastian Wolf; Eugénie Paul-Limoges; Andrea Carminati

Affiliation of presenting author: ETH Zurich, Switzerland

Drought stress in forests has been increasing with climate warming, resulting in tree mortality and shifts in species composition. This is concerning because forests currently mitigate increases in atmospheric CO2 concentrations. Important questions remain regarding responses in tree water status, stress-related declines in photosynthesis, enhancing (i.e. positive) forest-atmosphere feedbacks, linking from tree to ecosystem scale, and forest management strategies in a changing climate.

Field transcriptomics for forest stress assessment

Cristina Zamora-Ballesteros, Kathrin Heer

Affiliation of presenting author: University of Freiburg, Germany

Plants sense environmental stress perturbations and trigger signalling to adjust gene activity. When perception is weak or late, susceptibility increases. These responses are species-specific. Viewing tree and microbiome as a holobiont, we combine field transcriptomics (host and microbiome) with physiological data to identify RNA-seq biomarkers and track them by qPCR, improving stress attribution. We will present possibilities and challenges from ongoing and planned work in the ECOSENSE Forest.

Poster contributions

(Sorted by last name of presenting author)

Enhanced Signal Detection for Chlorophyll a Fluorescence Signal

Samaneh Baghbani; Ali Sarlak; Stefan J. Rupitsch

Affiliation of presenting author: ECOSENSE, University of Freiburg, Germany

Monitoring the quantum yield efficiency of Photosystem II is a key method for assessing plant health and stress. It is typically measured using Pulse Amplitude Modulation with saturation pulses. The resulting fluorescence signal is often weak, noisy, and has a very low duty cycle. We propose a hybrid signal processing method combining boxcar averaging and lock-in amplification to extract signals from below the noise floor. It detects duty cycles as low as 0.01% with SNRs down to –30 dB.

Improved UAV-based thermal imaging for the estimation of transpiration on the leaf scale

Malkin Gerchow; Steffen Dohmen; **Matthias Beyer**

Affiliation of presenting author: TU Braunschweig, Germany

Through energy balance approaches, leaf temperatures can be used to calculate transpiration from vegetation. However, leaf temperature estimates derived with UAV have large uncertainties. Using a novel flight planning and calibration approach, we improved the accuracy of derived leaf temperatures with the advantage of generating spatial data with a leaf resolution. Correlating the estimations with measured sap flow shows strong correlations but also large absolute differences.

Spatio-temporal controls of soil respiration in a mixed forest in the southwestern foothills of the Black Forest (Germany)

Julian Brzozon; Helmer Schack-Kirchner; Friederike Lang

Affiliation of presenting author: ECOSENSE, University of Freiburg, Germany

Soil respiration (RS) reflects the second largest CO2 flux and accounts for 60-90% of total ecosystem respiration, yet spatio-temporal controls across scales are difficult to quantify. RS was measured on weekly-biweekly base. We found a strong spatio-temporal pattern, which is supported by high resoluted measurements of soil CO_2 efflux in dependence of distance to trees. Analysis showed influences of weather phenomena, which are of importance in the scope of climate change. Spatial patterns as the distance to the tree stem also show an important explanatory pattern.

A Smart Sensor Node for Leaf Area Index Measurement with Adaptive Field of View

Jonathan Larochelle; Paul Kilger; Johannes Klüppel; **Laura Comella**

Affiliation of presenting author: Hochschule Karlsruhe (HKA), Germany

We present a novel LAI sensor that allows accurate measurement of heterogeneous canopies considering leaf clumping affects. The measurement is executed with one sensor below and one above the canopy and without the need for an operator that measure multiple times at different positions under the canopy. The sensing system consists of an imaging lens that collects the incoming light, a programmable LCD, acting as an optical shutter, a diffuser, and a multispectral sensor.

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

Lea Dedden; Markus Weiler

Affiliation of presenting author: ECOSENSE, University of Freiburg, Germany

We present a novel ecohydrological sensor network to capture spatio-temporal forest water dynamics across four plots of mono- and mixed deciduous and coniferous trees. Using high resolution data, we identify spatio-temporal throughfall, infiltration and soil moisture patterns at intra-event and intra-stand scale. We investigate the pattern stability over time (persistence), the propagation of soil infiltration patterns into near-surface soil moisture and the influence of vegetation structure and precipitation characteristics.

A novel, continuous multi-cuvette measurement system to assess spatiotemporal dynamics of leaf gas exchange and BVOC emissions

Stefanie Dumberger; Yasmina Frey, Clara Stock, Kathrin Kühnhammer, Delon Wagner, Ullrike Wallrabe, Christiane Werner, Simon Haberstroh

Affiliation of presenting author: ECOSENSE, University of Freiburg, Germany

Knowledge on carbon and water fluxes in forest canopies is limited due to restricted crown access and harsh conditions for sensor deployment. We deployed an in-situ multi-cuvette leaf gas exchange system in a *Pseudotsuga menziesii – Fagus sylvatica* stand for continuous measurements of H_2O and $^{13}CO_2$, as well as manual sampling of biogenic volatile organic compound emissions (BVOCs). Both species showed rapid, spatially and temporally variable responses of leaf gas exchange and BVOC emissions. Linking leaf-level dynamics to tree-level fluxes will enhance our understanding of water and carbon dynamics in mature trees.

Hydrogen Drives a Novel Metabolic Shift in Streptomyces Bacteria

Yasmin Elnaggar; Johannes Berger; Simon P. Pfäffle; Erik Schleicher; Stefan Günther

Affiliation of presenting author: University of Freiburg, Germany

Streptomyces are known for their metabolic versatility, but their ability to use hydrogen as an energy source opens exciting new paths in green biotech. We cultivated different Streptomyces species under H_2 stress and observed altered gene expression, pigment formation and new redox-regulated pathways linked to secondary metabolite production. These findings reveal a promising platform for sustainable, hydrogen-powered bioproduction.

Who listens to whom? Exploring Cross Spatio-Temporal Dependencies of Climate and Tree Response Variables with a Deep Learning Model Zoo

Sina Ranjbarkoohfarhadi; Carsten Dormann

Affiliation of presenting author: ECOSENSE, University of Freiburg, Germany

In this study, we introduce a season-aware framework for spatio-temporal dependency analysis across environmental time series using deep learning models. While models like vanilla autoencoders (VAEs) capture spatial structure, the sequence models (LSTM, GRU, CNN) extend analysis to spatio-temporal dependencies. This fused dependency knowledge leads us to mutual correlation between the climatic drivers and the tree responses, such as sap flow to these variables.

The ECOvette: A minimally invasive leaf cuvette for leaf-level gas exchange and volatile organic compound fluxes

Yasmina Frey; Stefanie Dumberger; Simon Haberstroh; Christiane Werner; Ulrike Wallrabe

Affiliation of presenting author: ECOSENSE, University of Freiburg, Germany

The ECOvette enables quantitative real-time measurement of CO_2, H_2O, and volatile organic compound (VOC) fluxes at the leaf level under natural conditions, combining laboratory precision with field applicability. The ECOvette is lightweight, robust, and durable, and minimises artificial microclimates. The leaf-wearable design allows for long-term deployment without altering leaf physiology, with integrated sensors recording ambient and leaf temperatures, thus opening new possibilities for long-term assessment of plant responses to environmental stress.

Understanding Throughfall Dynamics with ULS Forest Structure Metrics

Matthias Gassiloud; Anna Göritz

Affiliation of presenting author: ECOSENSE, University of Freiburg, Germany

This study explores the relationship between forest structure and spatio-temporal throughfall dynamics using ULS-derived metrics and in-situ measurements. By analyzing multi-temporal LiDAR data and continuous throughfall data from the Ecosense plot, the study aims to identify the potential of LiDAR-derived metrics for forest hydrology research and to develop approaches for integrating these metrics into water flux investigations.

Development of a Novel Energy-Autonomous Soil Probe for Monitoring Vertical CO_2 and Temperature Profiles

Timo Gerach; Peter Woias

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We present a novel, energy-autonomous soil probe for high-resolution vertical profiling of CO_2 concentration and temperature. Combining low-power electronics, photovoltaic operation, and wireless data transmission via LoRaWAN, the system provides automated, multi-depth measurements at 15-minute intervals. This enables continuous, long-term monitoring of soil CO_2 and temperature dynamics, providing valuable insights into soil respiration and its responses to environmental change.

Isodrone: A Low-Cost Drone-Based System for Branch and Leaf Sampling

Malkin Gerchow; Matthias Beyer; Jonas Withelm

Affiliation of presenting author: TU Braunschweig, Germany

Samples of branches and leaves provide essential information about tree condition. Conventional sampling methods—telescopic pruning shears or climbing-are labor-intensive, time-consuming, and often cannot reach upper crowns or sun-exposed leaves. We present a low-cost gripper-saw unit mounted below an UAV that can cut, grab and retrieve branches from the upper canopy. We detail the design and operational workflow, and we discuss the method's risks, limitations, and potential applications.

Enhancing above-belowground coupling for predictive modelling of tree water stress due to deep soil drought

Louis Graup; Katrin Meusburger

Affiliation of presenting author: Swiss Federal Research Institute WSL, Switzerland

An unseen threat of increasing drought stress in forests emerges from the belowground: the lack of deep soil water storage refilling. However, the reliance of trees on deep soil water is not well understood. We combine measurements of soil water potential with a SVAT model in the experimental forest Pfynwald, CH to assess ecohydrological responses to irrigation and drought scenarios. Results show that release of severe water stress allows more efficient root water uptake from deep soils.

Tracking drought-induced declines in stem water status and growth

Christina A. Hackmann; Sharath Paligi; Jan Schick; Michela Audisio; Heinz Coners; Martina Mund; Christian Ammer; Christoph Leuschner

Affiliation of presenting author: Georg August University Goettingen, Germany

Understanding tree-level water relations and drought response is crucial for predicting ecosystem-level water and energy fluxes. We synchronously assessed sap flow, stem water content, stem rehydration, and growth, as well as root water uptake depth of anisohydric European beech and isohydric Douglas fir in monospecific and mixed neighborhood. Growth and water use strategies differed between species, whereas stem rehydration was consistently maintained longest under drought.

Varifocal Vector Scanner

Shahab Haidarian; Ulrike Wallrabe

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The ChlF LiDAR sensor of ECOSENSE needs a scanning system to cover a target area. Since we're scanning trees, focusing the light at various heights within the canopy would improve the system's signal-to-noise ratio (SNR). To ensure compactness, we've developed a lightweight, compact device that handles both scanning and focusing in a single unit.

Talking trees: advancing research and public awareness

Steven Jansen; Hannes Fischer Steven; Swetlana Kreinert; Judith Schepers

Affiliation of presenting author: Ulm University, Germany

Talking trees use simple sensors to monitor plant growth and environmental conditions in real time. Beyond supporting research on plant–climate interactions, this approach enables citizens to build their own low-cost systems, fostering curiosity and engagement. Based on 'Berti' at Ulm University's botanical garden, we showcase how shared monitoring links science and the public.

Novel Photoacoustic Carbon Dioxide Soil Probe

Johannes Kapp; Jürgen Wöllenstein

Affiliation of presenting author: ECOSENSE, University of Freiburg, Germany

For quantitative data on below-ground CO2 concentrations advanced CO_2 sensors are developed. They are designed with emphasis on fast response, compactness, and robustness, utilizing two-chamber photoacoustic technology. Multiple modules are integrated into a 2 cm probe to measure at different depths with minimal intrusion. The probe is rugged and sealed against liquids and soil, offering 1 ppm resolution over 0–20,000 ppm.

Multi-Spectral Photosynthetically Active Radiation Sensor

Johannes Klüppel; Laura Comella

Affiliation of presenting author: ECOSENSE, University of Freiburg, Germany

Multi-spectral photosynthetically active radiation (PAR) sensors have emerged as a promising alternative to conventional single-channel systems, as they offer comparable accuracy with additional spectral information. The spectral accuracy of the calibration model is demonstrated by the quantum response curve of a calibrated multi-spectral PAR sensor. To further validate performance, we conducted a field experiment comparing the multi-spectral sensor against a commercial PAR device and a spectrometer.

Towards a Talking Forest: Low-Cost Sensors for Monitoring Plant Water Status and Environmental Conditions

Swetlana Kreinert; Luciano Pereira; Steven Jansen

Affiliation of presenting author: Ulm University, Germany

We present a low-cost system to monitor the plant water status across different tree species in a German forest. We use humidity and temperature sensors to calculate the water potential status with high temporal resolution, and correlate these data with pressure chamber measurements. Moreover, we measure stem water content, while FylloClip sensors monitor transpiration. This system allows precise and long-term monitoring by capturing environmentally driven plant physiological responses.

AngleCam V2: Predicting leaf angles across taxa from daytime and nighttime photos

Luis Kremer; Jan Pisek; Ronny Richter; Julian Frey; Daniel Lusk; Christiane Werner; Christian Wirth; Teja Kattenborn

Affiliation of presenting author: ECOSENSE, University of Freiburg, Germany

Leaf angles control plant light capture, influencing ecosystem productivity and satellite vegetation signals. They can change throughout day-night cycles, yet scalable monitoring methods are limited. We present AngleCam V2, a deep learning approach that estimates leaf angle distributions from standard camera imagery. Trained and validated on over 4,800 images across 200 species, it processes both RGB and near-infrared imagery for continuous monitoring. Validation demonstrates robust performance and reliable detection of diurnal patterns. This open-source tool is applicable for ecosystem monitoring, satellite data interpretation, and citizen science applications, helping to understand plant responses to environmental changes at various scales.

Multi-Scale Measurements of BVOC Dynamics in the Black Forest, Germany

Hojin Lee; Christiane Werner; Jürgen Kreuzwieser

Affiliation of presenting author: ECOSENSE, University of Freiburg, Germany

While BVOCs have been studied at individual scales, integrated research linking stem, soil, and ecosystem fluxes remains scarce. We use a relaxed eddy accumulation (REA) system together with soil, stem, and vertical profile measurements in the ECOSENSE forest, a mixed European beech–Douglas fir ecosystem. Preliminary results show distinct species-specific differences and strong spatiotemporal variability in BVOC dynamics, underscoring the need for multi-scale integration.

Disentangling direct effects of temperature and vapour pressure deficit on leaf gas exchange: mechanistic insights from online stable isotope techniques

Haoyu Diao; Lucas A. Cernusak; Matthias Saurer; Arthur Gessler; Rolf T.W. Siegwolf; **Marco M. Lehmann**

Affiliation of presenting author: Swiss Federal Research Institute WSL, Switzerland

We separated the effects of temperature (T) and vapour pressure deficit (VPD) on leaf gas exchange in four European tree species under controlled T (5–40 °C at constant VPD) and VPD (1–4 kPa at constant T). At high T, assimilation and stomatal conductance decoupled; isotope data suggest biochemical rather than CO_2 diffusional limits. At high VPD, isotopes showed unsaturation in leaf air spaces, altering gas exchange estimates. Consequently, this affects intrinsic plant water use efficiency.

Belowground signaling between temperate forest trees under simulated herbivory

Mirjam Meischner; Simon Haberstroh, Jürgen Kreuzwieser, Jörg-Peter Schnitzler, Christiane Werner

Affiliation of presenting author: University of Freiburg, Germany

In this study, belowground plant-plant signaling was explored between *Picea abies* and *Fagus sylvatica* saplings by preventing communication via VOCs between the shoots combined with stable isotope labeling. Our results indicate, that labeled sender plants exuded C into the rhizosphere and N was transferred from sender to receiver plants. When herbivory was simulated on sender plants, untreated receivers emitted more VOCs, indicating primed defenses triggered by belowground stress cues.

Matching scales of eddy covariance measurements and process-based modeling – Assessing spatiotemporal dynamics of carbon and water fluxes in a mixed forest in Southern Germany

Hassane Moutahir; Markus Sulzer; Ralf Kiese; Andreas Christen; Markus Weiler; Lea Dedden; Julian Brzozon; Pia Labenski; Rüsiger Grote

Affiliation of presenting author: ECOSENSE, Karlsruhe Institute of Technology (KIT), Garmisch-Partenkirchen, Germany

Eddy-covariance (EC) data are vital for studying carbon and water fluxes but often mask species-specific responses in mixed forests. At a Black Forest site of beech and Douglas fir, we combined EC data with ecosystem modeling to separate species contributions. Results show EC fluxes reflect species abundance within flux footprints, though responses vary seasonally. Considering these differences is key for gap-filling, accurate annual budgets, and understanding mixed forests' role in climate resilience.

Anti-biofouling and Anti-soiling Sensor Coatings

Sanam Rajak; Yasmina Frey; Ulrike Wallrabe; Oswald Prucker; Jürgen Rühe

Affiliation of presenting author: ECOSENSE, University of Freiburg, Germany

Sensors exposed to environmental conditions such as rain, wind, etc. face problems such as soil-film and bio-film formations on the sensor substrate. When a sensor is placed in the forest, it remains unattended and its maintenance is difficult. Therefore, surface contamination is common, which will lead to slow but steady, decrease in its functioning. To solve this problem and allow the functionality of such sensors for the whole growth period, the sensor substrate was be modified into a stable nanorough self-cleaning surface. The nanorough coating was developed via spray-coating a dispersion of functionalized silica nanoparticles and a self-synthesized CHic-able perfluoroacrylate copolymer solution. This surface also acts as an anti-biofouling coating and protects the sensor substrate from bio-film formation. The coating repels water. As a result, the coating lacks moisture which essential for growth of bio-molecules and thus bio-film formation.

Methane uptake and emission by tree stems depend on tree-internal processes

Judith Schepers; Lion Schöpfer; Radim Sarlej; Clara García-Sanchez; Emma Sayer

Affiliation of presenting author: Ulm University, Germany

Forests are known as net carbon dioxide sinks, but tree methane fluxes (CH4) are often overlooked. It is unclear whether tree stem CH4 fluxes are solely microbial or if tree internal processes contribute. To test this, we measured CH4 fluxes in beech and spruce in winter and spring of 2025. Both species showed net CH4 emissions after leaf flush, but CH4 uptake was only observed on spruce, and only above 10°C in winter. This suggests that tree activity is contributing to CH4 fluxes.

Sensitive Photoacoustic Setup to Study Stress-induced Isoprene Emissions

Sebastian Schnell; Carl Hild; Jürgen Wöllenstein

Affiliation of presenting author: ECOSENSE, University of Freiburg, Germany

We present a photoacoustic setup for highly sensitive isoprene detection at 11 µm using an external-cavity quantum cascade laser as the excitation source. A resonant, dumbbell-shaped photoacoustic cell provides real-time, selective measurements with excellent stability. Characterization demonstrates a detection limit below 10 ppb. The compact system is well suited for studying tree stress, as indicated by isoprene production.

A Symmetric Boost Converter with 6 mV Input Voltage and 66% Peak Efficiency for Thermoelectric Energy Harvesting

Uttunga Shinde; Vishnu Subbulakshmi; Peter Woias

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This work presents the design, simulation, and experimental validation of an ultra-low input voltage symmetric boost converter tailored for thermoelectric energy harvesting in energy-autonomous wireless sensor nodes. The proposed DC–DC architecture combines a Meissner oscillator with a forward converter stage, thereby extending cold-start capability and sustaining high efficiency across a broad input range. Further, the whole circuit operates without any auxiliary voltage and is fully powered from its input voltage. A custom micro-transformer was developed and optimized through rigorous PSpice simulations, ensuring reliable operation under the extremely constrained power conditions typical of thermoelectric generators. Within the practical input voltage range of 20–50 mV, the converter delivers a maximum output power between 1.33 mW and 7.18 mW, achieving a peak efficiency of 66.9% at 20 mV input with 5.5 V output voltage. Efficiency remains consistently above 63.9% across the tested input range. The Meissner oscillator used as a cold-start circuit enables successful operation from input voltages as low as 18 mV, producing 17.95 µW. Stable operation is further sustained for input voltages down to 6 mV, with regulated outputs of 2.12 V after start-up. These results establish the converter as a viable solution for harvesting energy from the minute thermal gradients available in real-world environments, thereby enabling long-term, maintenance-free wireless sensor operation.

Development of an Ultra-Low-Power Bidirectional LoRa Backscatter Tag

Till Steinmann; Frederik Riedel; Stefan J. Rupitsch

Affiliation of presenting author: ECOSENSE, University of Freiburg, Germany

The increasing demand for IoT applications calls for more wireless low-power sensor systems. We present a bidirectional LoRa backscatter tag for low-power IoT applications. The tag uses commercial off the shelf components, including the microcontroller, and can receive and send data over long distances and works with commodity LoRa transceivers. It modulates the backscatter signal by shifting LoRa symbols within the bandwidth such that the receiver interprets them as a different symbol. Bits in the bit string are recognized as logical ones when the bits differ from a control bit sequence due to the shifting of the LoRa symbols. Unchanged symbols are interpreted as zeros. A switch performs windowing on the transmitter's continuous wave for downlink and wake-up. We achieved a downlink range of 60 m and a backscatter range over 500 m in open space, with the tag consuming 670 µW.

Chlorophyll fluorescence dynamics of two temperate tree species during a summer cold spell

Clara Stock; Stefanie Dumberger; Kathrin Kühnhammer; Markus Sulzer; Andreas Christen; Simon Haberstroh; Christiane Werner

Affiliation of presenting author: ECOSENSE, University of Freiburg, Germany

To improve our understanding of the dynamics of photoinhibition of the photosystem II (PSII) during sudden cold spells combined with high light intensities, we continuously assessed ecosystem carbon exchange and the photosynthetic efficiency by measuring leaf level chlorophyll fluorescence (ChlF) of mature *F. sylvatica* and *P. menziesii* trees. While the deciduous *F. sylvatica* was highly susceptible to photoinhibition during both cold spells, the evergreen *P. menziesii* showed higher tolerance to low air temperatures. Both species increased thermal energy dissipation at PSII during the cold spells indicating the activation of protective mechanisms. The combination of continuous ChlF and gas flux measurements at different scales gives valuable insights into the dynamics of photoinhibition and will, therefore, be crucial for further research of photosynthetic stress reactions in forest trees.

First Year of Tower-Based Eddy Covariance Measurements Assessing Ecosystem CO_2 Fluxes at the ECOSENSE Forest

Markus Sulzer; Julian Brzozon; Andreas Christen; Stefanie Dumberger; Yasmina Frey; Simon Haberstroh; Friederike Lang; Hojin Lee; Jürgen Kreuzwieser; Teja Kattenborn; Luis Kremer; Helmer Schack-Kirchner; Clara Stock; Ulrike Wallrabe; Christiane Werner

Affiliation of presenting author: ECOSENSE, University of Freiburg, Germany

The eddy covariance measurements above the ECOSENSE forest provide data to assess net ecosystem CO_2 and H_2O fluxes of the forest on an ecosystem scale. After the first year of eddy covariance measurements, the ECOSENSE forest is a CO_2 sink (-141 ± 83 g C m^{-2} $year^{-1}$). For a better understanding of the ecosystem fluxes and the underlying processes, the eddy covariance data is combined with measurements inside the forest, e.g., soil respiration, leaf level gas exchange, and chlorophyll fluorescence.

Simultaneous multinuclear MRI towards portable hardware-efficient plant monitoring systems

Mohammad Rasool Vaezi Kakhki; Jan G. Korvink; Mazin Jouda

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Magnetic resonance imaging (MRI) is a versatile noninvasive technique with widespread applications in medicine and industry. Its ability to probe multiple nuclei offers valuable multidimensional information, yet this typically requires separate hardware for each nucleus. In this work, we present a scalable approach for simultaneous multinuclear MRI using a single RF channel, enabled by digital lock-in amplification. We demonstrate fully parallel ^1H and ^19F imaging without additional hardware or scan time. The method extends naturally to further nuclei, with scalability constrained only by digital processing performance. Our results show that image quality (SNR = 54) surpasses that of conventional single-channel systems (SNR = 43), underscoring its potential to lower scan time, system complexity, and cost while maintaining performance. In addition, the compatibility of this

approach with compact magnets and small gradient coils enables promising in-field applications, such as noninvasive monitoring of flow velocity and water content in plants.

Assessing water and solute fluxes below a forest's root zone

Carolin Winter; Jochen Kieninger; Nils Bork; Stefan J. Rupitsch; Markus Weiler

Affiliation of presenting author: University of Freiburg, Germany

We introduce a new sub-project for the second ECOSENSE phase to identify hot spots and hot moments of water and solute fluxes below a forest's root zone. Using a novel setup for continuous in-situ measurements, fiberglass wicks will passively extract soil water at field capacity, enabling water quality measurements via low-cost electrochemical and optical sensors. This sub-project will provide new insights into the critical yet threatened ecosystem service of clean water provision by forests.

Design and Characterization of a Novel and Compact Multi-Wavelength Chlorophyll Fluorescence Light Detection and Ranging Sensor (ChloroFLiDAR) for Remote Plant Stress Assessment

Mohammad-Hossein Zakariapour; Annette Schmitt; Alexander Reiterer

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To study the impacts of climate change on forest ecosystems, the ECOSENSE project monitors carbon, water fluxes and Chlorophyll Fluorescence (ChlF) in real-time at leaf and ecosystem scales to detect early signs of plant stress. In this study, we present a novel, portable dual-wavelength Chlorophyll Fluorescence Light Detection and Ranging sensor (ChloroFLiDAR). This allows UAV-based remote plant stress assessment. The experiments conducted in the laboratory and in the forest have shown promising results.

Rethinking Thermal Safety Margins: The Role of Seasonal Dynamics and Exposure Duration for Leaf Thermal Tolerance of Temperate Tree Species

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Leaf thermal tolerance (e.g. T50) and thermal safety margins (Δ (Tleaf – T50)) are widely used to assess plant heat resistance. While these thresholds are often assumed to be static, they may vary seasonally and are strongly influenced by measurement methods, such as heat exposure duration. In this study, we examine these effects and combine them with continuous leaf temperature data to obtain an ecologically relevant understanding of leaf thermal tolerance.

The Potential of Dendrometer-Derived Tree Water Deficit for Continuous Drought Stress Monitoring in Forest Ecosystems

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Dendrometer-derived tree water deficit (TWD) is a promising indicator of drought stress. Controlled experiments with potted trees revealed strong links between TWD, water potential, and gas exchange, identifying clear thresholds for stress onset, stomatal closure, and loss of immediate recovery potential, as well as tipping points turning the whole-tree carbon flux from a sink to a source. These findings highlight the diagnostic value of stem diameter dynamics for real-time drought monitoring.