

ASI 2026

Annual Meeting of the German Association for Stable Isotope Research

Stable Isotopes in geoscience,
ecology, environmental science,
medicine, and forensics

5 – 7 October 2026

Albert-Ludwigs-Universität Freiburg



Book of Abstracts

WILLKOMMEN

Liebe Kolleginnen und Kollegen, liebe Isotopencommunity,
wir möchten Sie hiermit herzlich zur Jahrestagung der Arbeitsgemeinschaft Stabile Isotope (ASI 2026) einladen. In diesem Jahr wird die Tagung am Institut für Geo- und Umweltwissenschaften der Universität Freiburg stattfinden.

Ein besonderer Fokus liegt dieses Jahr auf 'Tracing Soil-Plant-Atmosphere Processes with Stable Isotopes' aber der ASI-Tradition folgend, wird auch die diesjährige Veranstaltung wieder ein breites Themenspektrum abdecken und wir hoffen damit viele

Interessierte anzusprechen.

Wir freuen uns, wenn wir Sie Anfang Oktober in Freiburg begrüßen dürfen.

Mit besten Grüßen

Ihr Organisationsteam ASI 2026

Vorstand der ASI

WELCOME

Dear colleagues, dear isotope community,

We would like to invite you to the annual meeting of the German Association for Stable Isotope Research. This year's meeting will take place at the Institute of Earth and Environmental Natural Sciences of the University of Freiburg.

This year, there is a particular focus on 'Tracing Soil-Plant-Atmosphere Processes with Stable Isotopes', but in keeping with ASI tradition, this year's event will once again cover a wide range of topics, hopefully attracting many isotope enthusiasts.

We are looking forward to welcoming you in autumn in Freiburg,

Local organization team

Board of ASI / GASIR

LOCAL ORGANIZATION

Dr. Barbara Herbstritt

Dr. Kathrin Kühnhammer

Prof. Dr. Markus Weiler

Prof. Dr. Christiane Werner

A big thank you to the companies that supported the ASI 2026!



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Conference Agenda | Programme

Sunday, 4 October 2026

15:00 - 18:00 **ASI PhD-/ Master workshop**
Professur für Ökosystemphysiologie, Seminarraum Georges-Köhler-Allee Gebäude 053 / 054

Monday, 5 October 2026

12:00 **Poster Set Up** at HS Physiologie / Biochemie

ID: 115 / Poster-No: 1

Topics: 1. Ecohydrology, Ecosystems and Biogeochemistry

Estimating hydrogen isotope metabolic terms in the cellulose model by linear regression: kinetic isotope effects are more important than isotope exchange processes in autotrophic systems

Jochem Baan^{1,2}, Daniel Nelson², Ansgar Kahmen², Saša Bjelić¹, Meisha Holloway-Phillips^{2,3}

1: Advanced Analytics Platform – Laboratory for Energy Technologies and Innovation, Center for Energy and Environmental Sciences, Paul Scherrer Institute, Villigen, Switzerland; 2: University of Basel, Dept. Environmental Sciences – Botany, Basel, Switzerland; 3: ETH Zürich, Institute of Agricultural Sciences – Grassland Sciences, Zürich, Switzerland

ID: 151 / Poster-No: 2

Topics: 1. Ecohydrology, Ecosystems and Biogeochemistry

SEEKING STABILITY: INHIBITORS FOR PRESERVING ISOTOPE RATIOS OF DISSOLVED GASES IN FRESHWATER SAMPLES

Wishah Bilal, Alexander Frank Griffiths

University of Bayreuth, Germany

ID: 143 / Poster-No: 3

Topics: 1. Ecohydrology, Ecosystems and Biogeochemistry

Matrix-bound oxygen and hydrogen affect the isotopic composition of water extracted from soil

Jens Dyckmans¹, Lena Franz¹, Caroline Buchen-Tschiskale², Luitgard Schwendenmann³

1: Kompetenzzentrum Stabile Isotope, Georg-August Universität Göttingen, Germany; 2: Thünen-Institut für Agrarklimaschutz, Braunschweig, Germany; 3: School of Environment, University of Auckland, New Zealand

ID: 153 / Poster-No: 4

Topics: 1. Ecohydrology, Ecosystems and Biogeochemistry

A reliable protocol for measuring primary production by tracing ¹³CO₃- incorporation into phytoplankton to substitute radiotracers

Alexander H. Frank Griffiths^{1,2}, Tobias Goldhammer², Christine Kiel², Monika Degebrodt², Stella A. Berger², Robert van Geldern³, Johannes A. C. Barth³, Mark O. Gessner²

1: Universität Bayreuth, Center of Stable Isotope Research (BayCenSI), Germany; 2: Leibniz Institute of Freshwater Ecology and Inland Fisheries (IGB), Germany; 3: Friedrich-Alexander-Universität Erlangen-Nürnberg (FAU), GeoZentrum Nordbayern, Germany

ID: 166 / Poster-No: 5

Topics: 1. Ecohydrology, Ecosystems and Biogeochemistry

Hillslope-controlled capillary fringe dynamics and subsurface water storage in a mixed broadleaf temperate forest ecosystem

Alberto Iraheta, Ramona Riedel, Malkin Gerchow, Matthias Beyer

TU Braunschweig, Germany

ID: 110 / Poster-No: 6

Topics: 1. Ecohydrology, Ecosystems and Biogeochemistry

Spatial and temporal patterns of nitrogen isotopes in nitrate and ammonium across precipitation and ecosystem samples

Marco M. Lehmann¹, Peter Waldner², Patrick Schleppe²

1: University of Zurich, Switzerland; 2: WSL Birmensdorf, Switzerland

ID: 136 / Poster-No: 7

Topics: 1. Ecohydrology, Ecosystems and Biogeochemistry

Towards improved IRMS analysis of $^{15}\text{N-N}_2$ and $^{15}\text{N-N}_2\text{O}$ for denitrification research – lessons learned from an international laboratory intercomparison

Ulrike Ostler¹, Taleta Bailey², Naoya Takeda², Michael Dannenmann¹, Clemens Scheer¹

1: Institute of Meteorology and Climate Research - Atmospheric Environmental Research (IMKIFU), Karlsruhe Institute of Technology (KIT), Garmisch-Partenkirchen, Germany; 2: Centre for Agriculture and the Bioeconomy, Queensland University of Technology, Brisbane, Australia

ID: 164 / Poster-No: 8

Topics: 1. Ecohydrology, Ecosystems and Biogeochemistry

Hydraulic Redistribution barely replenishes soil water

Ramona, Riedel¹, Alberto Iraheta¹, Clara Rohde², Malkin Gerchow¹, Aljoscha Gildemeister¹, Johannes Hoppenbrock^{1,3}, Natalie Müller³, Maren Dubbert², Matthias Bucker³, Matthias Beyer¹

1: TU Braunschweig, Germany; 2: Leibniz Centre for Agricultural Landscape Research, Germany; 3: Christian-Albrechts-Universität zu Kiel, Germany

ID: 138 / Poster-No: 9

Topics: 1. Ecohydrology, Ecosystems and Biogeochemistry

Microbial, thermogenic, or oxidised? Isotopic characterisation of methane sources in an Arctic permafrost landscape overlying documented oil and gas seeps

Moritz Schroll-Reiß¹, Getachew Agmuas Adnew^{2,3}, Kajsa Roslund⁴, Frank Keppler^{1,5}, Christian Juncher Jørgensen⁶, Jesper Riis Christiansen²

1: Institute of Earth Sciences, Heidelberg University, Heidelberg, Germany; 2: Dept. Geosciences and Natural Resource Management, University of Copenhagen, Denmark; 3: Center for Landscape Research in Sustainable Agricultural Futures (Land-CRAFT), Dept. Agroecology, Aarhus University, Denmark; 4: Center for Volatile Interactions, Dept. Biology, University of Copenhagen, Denmark; 5: Heidelberg Center for the Environment (HCE), Heidelberg University, Heidelberg, Germany; 6: Arctic Environment, Dept. Ecoscience, Aarhus University, Denmark

ID: 146 / Poster-No: 10

Topics: 1. Ecohydrology, Ecosystems and Biogeochemistry

Model demonstrating the differences between intrinsic and apparent temperature dependence of nitrification by substrate availability

Florian Stange, David Schoner,
BGR, Germany

ID: 154 / Poster-No: 11

Topics: 1. Ecohydrology, Ecosystems and Biogeochemistry

Photosynthesis results in ^2H -depleted carbohydrates, but why?

Roland A. Werner¹, Meisha Holloway-Phillips²

1: ETH Zurich, Switzerland; 2: University of Basel, Switzerland

ID: 126 / Poster-No: 12

Topics: 1. Ecohydrology, Ecosystems and Biogeochemistry

ISOfun – A database for fungal natural abundance of stable isotopes

Franziska Zahn^{1,2}, Christina Marburger³, Finn Zajewski³, Andrey Zuev⁴, Erik Hobbie⁵, Gerhard Gebauer⁶, Lisa Hülsmann⁷, Johanna Pausch³

1: Naturalis Biodiversity Center, Leiden, the Netherlands; 2: Bayreuth Center of Ecology and Environmental Research (BayCEER) University of Bayreuth, Germany; 3: Dept. Agroecology, BayCEER, University of Bayreuth, Germany; 4: Senckenberg Museum of Natural Sciences, Görlitz, Germany; 5: Earth Systems Research Center, University of New Hampshire, USA; 6: BayCEER – Lab. Isotope Biogeochem. University of Bayreuth, Germany; 7: Ecosystem Analysis and Simulation (EASI) Lab, Bayreuth Center of Ecology and Environmental Research (BayCEER), University of Bayreuth, Germany

ID: 156 / Poster-No: 13

Topics: 2. Hydro(geo)logy including German Isotope Network

Isotope biogeochemistry of the inorganic carbon system in a subterranean estuary of a temperate high energy beach

Michael Böttcher^{1,2,3}, Anja Reckhardt⁴, Patricia Roesser⁵, Sascha Plewe¹, Iris Schmiedinger¹

1: Marine Geosciences, Leibniz IOW, Warnemünde, Germany; 2: Marine Geochemistry, Greifswald University, Germany; 3: Rostock University, Germany; 4: Institute for Chemistry and Biology of the Marine Environment (ICBM), Carl von Ossietzky Universität Oldenburg, Germany; 5: Environmental Geology, Institute for Geosciences, University of Bonn, Germany

ID: 113 / Poster-No: 14

Topics: 2. Hydro(geo)logy including German Isotope Network

Hochauflösende Langzeit-Isotopenuntersuchung der Uferfiltration für die Bewirtschaftung flussnaher Grundwasserressourcen am Beispiel des LURCH-IsoGW-Pilotstandortes Ofterschwang im Oberallgäu

Anne Breßler, Michael Heidinger,

Hydroisotop GmbH, Germany

ID: 152 / Poster-No: 15

Topics: 2. Hydro(geo)logy including German Isotope Network

Class-A-Pan and small pond evaporation experiments in a humid climate – A first step towards quantifying pit-lake evaporation in Lusatia

Maïke Gröschke¹, Paul Königer¹, Aphra Jennifer Linse-Ostermeier¹, Paul Werner¹, Frank Gatzke¹, Silvio Janetz¹, Robert van Geldern², Anne Gädeke¹

1: Bundesanstalt für Geowissenschaften und Rohstoffe (BGR), Germany; 2: Geozentrum Nordbayern (GZN), Friedrich-Alexander-Universität Erlangen-Nürnberg (FAU), Germany

ID: 139 / Poster-No: 16

Topics: 2. Hydro(geo)logy including German Isotope Network

Ergebnisse von Laborvergleichsmessungen für stabile Wasserisotope im Deutschen Isotopennetzwerk (GIN)

Paul Königer¹, Michael Ernst Böttcher², Stefan Terzer-Wassmuth³, Kay Knöller⁴, Andrej Voropaev⁵, Florian Eichinger⁵, Diana Burghardt⁶, Axel Schmidt⁷, Jessica Landgraf⁷, Barbara Herbsttritt⁸, Franziska Schmid⁹, Dörthe Tetzlaff⁹, Stoyanka Schumann⁴, Sebastian Friebe¹, Iris Schmiedinger², Falk Bratfisch¹⁰, Heinrich Eisenmann¹⁰, Robert van Geldern¹¹, Claudia Cosma¹², Nils Michelsen¹², David Dubbert¹³, Maren Dubbert¹³, Julian Zinke¹⁴, David Windhorst¹⁵, Lutz Breuer¹⁵, Heiko Moossen¹⁶, Magdalena Hofmann¹⁷, Matthias Beyer¹⁸, Caroline Buchen-Tschiskale¹⁹, Miriam Kreher²⁰, Natalie Orłowski²⁰, Jens Dyckmans²¹

1: BGR, Hannover, Germany; 2: IOW Leibniz Institut, Warnemünde, Germany; 3: IAEA International Atomic Energy Agency, Wien, Austria; 4: UFZ, Halle, Germany; 5: Hydroisotop, Schweitenkirchen, Germany; 6: TU Dresden, Germany; 7: BFG, Koblenz, Germany; 8: Universität Freiburg, Germany; 9: IGB Leibniz Institut, Berlin, Germany; 10: Isodetect, Leipzig; 11: FAU Universität Erlangen; 12: TU Darmstadt; 13: ZALF, Müncheberg; 14: Universität Kassel; 15: University Gießen, Germany; 16: BGC Max-Planck-Institut, Jena, Germany; 17: Picarro, USA; 18: TU, Braunschweig, Germany; 19: Thünen-Institut, Braunschweig, Germany; 20: TU Tharandt, Germany; 21: Universität Göttingen, Germany

ID: 147 / Poster-No: 17

Topics: 2. Hydro(geo)logy including German Isotope Network

Eine Webseite für das Deutsche Isotopennetz (GIN): Stabile Isotope und Tritium in Niederschlag, Oberflächenwasser und Grundwasser

Paul Königer¹, Stephan Braune¹, Robert Kringel¹, Eric Habiryayo¹, Martin Leistner¹, Aixala Gaillard², Johannes A.C. Barth², Andreas Neuner², Blake Walker², Andreas Wagner³, Sarah Jelinski³, Dominik Kremer³, Jessica Landgraf⁴, Axel Schmidt⁴, Michael Heidinger⁵, Heinrich Eisenmann⁶, Philip Schuler⁷, Robert van Geldern¹

1: Bundesanstalt für Geowissenschaften und Rohstoffe (BGR), Germany; 2: Geozentrum Nordbayern (GZN), Friedrich-Alexander-Universität Erlangen-Nürnberg (FAU), Erlangen, Germany; 3: Leibniz Institut für Länderkunde (IFL), Leipzig, Germany; 4: Bundesanstalt für Gewässerkunde (BfG), Koblenz, Germany; 5: Hydroisotop, Schweitenkirchen; 6: Isodetect, Leipzig, Germany; 7: CDM Smith SE, Berlin, Germany

ID: 149 / Poster-No: 18

Topics: 2. Hydro(geo)logy including German Isotope Network

Sources and Fate of Carbon and Sulfur in Travertine Formation: A Multi-Isotope Study of the Dreimühlen Waterfall, Eifel

Patricia Roeser¹, Mario Valdivia Manchego¹, Michael Böttcher^{2,3,4}

1: Environmental Geology Group, Institute for Geosciences, University of Bonn, Germany; 2: Geochemistry & Isotope Biogeochemistry, Leibniz Institute for Baltic Sea Research (IOW), Warnemünde, Germany; 3: Marine Geochemistry, University of Greifswald, Germany; 4: Interdisciplinary Faculty, University of Rostock, Germany

ID: 129 / Poster-No: 19

Topics: 3. Climate and Atmosphere

How to investigate short-term carbon turnover and sequestration in paludicultures during the vegetation period?

Caroline Buchen-Tschiskale¹, Elaheh Amiri², Tim Eickenscheidt²

1: Thünen Institute of Climate-Smart Agriculture, Braunschweig, Germany; 2: Peatland Science Center (PSC), University of Applied Science Weihenstephan-Triesdorf, Germany

ID: 157 / Poster-No: 20

Topics: 3. Climate and Atmosphere

Four-year precipitation isotope monitoring in the Bale Mountains, Ethiopia, and implications for paleoclimate interpretations of ^2H and ^{18}O records

Samuel Chernet¹, Karla Michaela Trinks¹, Bruk Lemma², Michael Zech¹

1: Physical Geography, TU Dresden, Germany; 2: Institute of Geological Sciences, Freie Universität Berlin, Germany

ID: 134 / Poster-No: 21

Topics: 3. Climate and Atmosphere

SOC content of paddy soils under different residue management as a driver for CO_2 and CH_4 emissions

Seraina Nohl¹, Manoj Hari¹, Florian Gschwend², Sonja Paul¹

1: Climate and Agriculture, Agroscope, Switzerland; 2: Molecular Ecology, Agroscope, Switzerland

ID: 105 / Poster-No: 22

Topics: 4. Paleoclimate, Sedimentology and Soil

Isotope signatures along high-resolution soil moisture release curves in natural soils: coupling Cavity Ring-down Spectroscopy with HYPROP-systems

Susanne Stadler, Martin Thullner, Paul Königer

BGR-Federal Institute for Geosciences and Natural Resources, Germany

ID: 125 / Poster-No: 23

Topics: 5. Physiology, Metabolism, Forensics, Food

Isotopic fluxes in pine - disentangling assimilate transfer and phloem loading in conifer trees

Carlo di Bello¹, Pierre Vollenweider¹, Nathalie Valle², Marco M Lehman¹, Matthias Saurer¹, Arthur Gessler¹, Stanislaus J Schymanski²

1: WSL Birmensdorf, Switzerland; 2: Luxemburg Institute of Science and Technology LIST

ID: 111 / Poster-No: 24

Topics: 6. Analytics, Methods, Quality Assurance

Isotope signature as an assessment method for contamination cases involving trifluoroacetic acid (TFA) and short-chain PFAS in drinking water and groundwater

Andreas Auernhammer^{1,3}, Andreas Tiehm², Michael Seidel³, Martin Elsner³, Florian Eichinger¹, Siegmund Ertl¹

1: Hydroisotop GmbH, Germany; 2: TZW Karlsruhe; 3: Analytical Chemistry and Water Chemistry, Technical University of Munich, Germany

ID: 132 / Poster-No: 25

Topics: 6. Analytics, Methods, Quality Assurance

Carbon and Nitrogen Stable Isotope Analysis of Sulfamethoxazole During Abiotic Degradation Processes

Christopher Dirr, Aoife Canavan, Martin Elsner

Institute of Water Chemistry and Chair of Analytical Chemistry and Water Chemistry, Technical University of Munich, Germany

ID: 131 / Poster-No: 26

Topics: 6. Analytics, Methods, Quality Assurance

How Well Do We Know VPDB—Part 2: Interlaboratory Assessment of Existing $\delta^{13}\text{C}_{\text{VPDB}}$ Reference Materials

Heiko Moossen¹, Pharahilda M. Steur², Federica Camin³, Bor Krajnc⁴, Anett Enke¹, Heike Geilmann¹, Dipayan Paul², Markus Lange¹, Isabell von Rein¹, Harro A. J. Meijer²

1: Max Planck Institute for Biogeochemistry, Jena, Germany; 2: Centre for Stable Isotope Research, University of Groningen, Netherlands; 3: Terrestrial Environmental Radiochemistry Laboratory, International Atomic Energy Agency, Vienna, Austria; 4: Dept. Environmental Sciences, Jozef Stefan Institute, Ljubljana, Slovenia

ID: 109 / Poster-No: 27

Topics: 6. Analytics, Methods, Quality Assurance

Fully integrated TOC and TNb analysis of estuarine and sea water samples with the Elementar iso TOC cube®

Calum Preece¹, Toby Boocock¹, Mike Seed¹, Marian de Reus², Kathrin Rosenthal²

1: Elementar UK Ltd; 2: Elementar Analysensysteme GmbH, Germany

ID: 165 / Poster-No: 28

Topics: 6. Analytics, Methods, Quality Assurance

Open source hard- and software for in situ sampling of water vapor

Stefan Seeger

Universität Freiburg, Germany

ID: 160 / Poster-No: 29

Topics: 6. Analytics, Methods, Quality Assurance

Improving detection limits for carbon isotopic analysis of BTEX by GC-IRMS using headspace SPME Arrow sampling

Mario Tuthorn¹, Maria de Castro¹, Vanessa Peiro², Harald Hertle¹

1: Thermo Fisher Scientific; 2: SIdI, Universidad Autónoma de Madrid, Spain

ID: 158 / Poster-No: 30

Topics: 7. Further Topics

¹³C pulse branch bag labelling in mature stands of European beech and Norway spruce in a long-term drought experiment

Marie Bellanger, Florian Wilms, Fabian Weikl, Thorsten Grams

Technical University of Munich, Land Surface-Atmosphere Interactions, AG Ecophysiology of Plants, Dept. Life Science Systems

ID: 106 / Poster-No: 31

Topics: 7. Further Topics

Development of an information and eLearning portal for stable isotope applications

Veronika Erl, Steffen Kümel, Ivyonne Nijenhuis

Helmholtz-Zentrum für Umweltforschung – UFZ, Leipzig, Germany

ID: 142 / Poster-No: 32

Topics: 7. Further Topics

Methane Hydrogen Isotope Signatures ($\delta^2\text{H-CH}_4$) as an Early-Warning Indicator for Process Instability in Anaerobic Digestion

Daniela Polag¹, Felix Müller², Michael Lebuhn³, Konrad Koch², Frank Keppler¹

1: Universität Heidelberg, Germany; 2: Technische Universität München, Germany; 3: bioBit GmbH, Germany

ID: 167 / Poster-No: 33

Topics: 6. Analytics, Methods, Quality Assurance

Sealing Samples in the Field: An Evaporation-Proof Autosampler Benchmarked Against Standard Practice

Jonas Pyschik^{1,2}, Markus Weiler^{1,2}

1: University of Freiburg, Germany; 2: hydro.tools GmbH, Germany

ID: 168 / Poster-No: 34

Topics: 1. Ecohydrology, Ecosystems and Biogeochemistry

Partitioning of Evapotranspiration in an intensively managed grassland ecosystem

Daniel Schulz, Jannis Groh, Matthias Claß, Nicolas Brüggemann, Youri Rothfuss

Jülich Research Centre, Germany

12:00 - 13:00

Registration

13:00 - 13:15

Opening

HS Physiologie/Biochemie

13:15 - 13:45

Keynote 1

HS Physiologie/Biochemie

Tracing water through the landscape – Stable isotopes for identifying hydrological processes and water transit times

Christine Stumpp

BOKU University, Institute of Soil Physics and Rural Water Management, Austria

13:45 - 15:00

Session A – Water Stable Isotopes (Trees, RWU)

HS Physiologie/Biochemie

Session Chair: **Mirjam Meischner**, University of Copenhagen

13:45 - 14:00 ID: 116

Linking isotope based seasonal origin and depth of root water uptake across European beech and spruce forests

Marco M. Lehmann¹, Thanh Thi Luong², Marius Floriancic³, Ilja van Meerveld¹, Josie Geris⁴, Daniele Penna⁵, Youri Rothfuss⁶, Natalie Orlowski², Katrin Meusburger⁷

1: University of Zurich, Switzerland; 2: TU Dresden, Germany; 3: ETH Zürich, Switzerland; 4: University of Aberdeen, United Kingdom; 5: University of Florence, Italy; 6: Forschungszentrum Jülich GmbH, Germany; 7: WSL Birmensdorf, Switzerland

14:00 - 14:15 ID: 107

Daily water stable isotope data reveal shifts in root water uptake depth in *Fagus sylvatica* in response to drought and species interaction

Simon Haberstroh¹, Laura Kinzinger¹, Judith Mach², Kathrin Kühnhammer¹, Markus Weiler², Natalie Orlowski³, Christiane Werner¹

1: Ecosystem Physiology, University of Freiburg, Germany; 2: Hydrology, University of Freiburg, Germany; 3: Institute of Soil Science and Site Ecology, TU Dresden, Germany

14:15 - 14:30 ID: 155

Drought impact on the water uptake depths of five temperate tree species in a mature mixed forest using continuous measurement of water stable isotopes

Franziska Geuchen, Stefan Seeger, Lukas Kleine, Markus Weiler, Simon Haberstroh, Christiane Werner

University of Freiburg, Germany

14:30 - 14:45 ID: 121

$\delta^{18}\text{O}$ -derived root water uptake depth explains the drought sensitivity and vulnerability of temperate tree species

David N. Steger¹, Richard L. Peters^{1,2}, Tobias Zhorzel¹, Raphael Dups¹, Günter Hoch¹, Daniel B. Nelson¹, Cedric Zahnd^{1,8}, David Basler¹, Katrin Meusburger^{3,4}, Fabian Bernhard⁵, Matthias Arend⁶, Bernhard Schuldt⁷, Ansgar Kahmen¹

1: University of Basel, Switzerland; 2: Technical University of Munich, Germany; 3: Swiss Federal Research Institute WSL, Switzerland; 4: ETH Zürich, Switzerland; 5: University of Bern, Switzerland; 6: Universität Trier, Germany; 7: Dresden University of Technology, Germany; 8: University of Antwerp, Belgium

14:45 - 15:00 ID: 135

The beech and spruce transpiration explored by a combination of soil moisture, sap flow and stable isotopes

Václav Šípek¹, Karel Pátek^{1,2}, Jiří Kocum¹, Miroslav Tesař¹

1: Institute of Hydrology of the Czech Academy of Sciences, Czechia; 2: Faculty of Environmental Sciences, Czech University of Life Sciences, Czechia

15:00 - 15:30

Coffee

15:30 - 16:45

Session B – Water Stable Isotopes (General)

HS Physiologie/Biochemie

Session Chair: **Simon Haberstroh**, University of Freiburg

15:30 - 15:45 ID: 102

Dual Isotope Labelling Reveals Contrasting Spatial and Temporal Water Uptake in Boreal Scots Pine

Ruth-Kristina Magh^{1,2}, Nils Henriksson², Hyungwoo Lim², Reimo Lutter^{2,3}, Tomas Lundmark², John Marshall²

1: Friedrich Schiller University, Germany; 2: Swedish University of Agricultural Science, Sweden; 3: Estonian University of Life Sciences, Estonia

15:45 - 16:00 ID: 130

Stem water of *Helianthus annuus* (sunflower) as a quickly accessible reservoir for transpiration: evidence from *in-situ* and continuous monitoring of the xylem water isotopic composition

Youri Rothfuss¹, Samuel Le Gall¹, Nicolas Brüggemann¹, Sharmin Jahan¹, Mathieu Javaux², Julian Klaus³, Harry Vereecken¹, Dagmar van Dusschoten⁴

1: Institute of Bio- and Geosciences, Agrosphere (IBG-3), Forschungszentrum Jülich GmbH, Jülich, Germany; 2: Earth and Life Institute, Environmental Sciences (ELIE), Université catholique de Louvain, Louvain-la-Neuve, Belgium; 3: Dept. Geography, University of Bonn, Bonn, Germany; 4: Institute of Plant Sciences (IBG-2), Forschungszentrum Jülich GmbH, Jülich, Germany

16:00 - 16:15 ID: 150

High-resolution isotope monitoring of soil-plant-atmosphere water dynamics within an agricultural system using the automated chamber system (FluxCrane) and machine learning

Adrian Dahlmann^{1,2,4}, David Dubbert¹, Mathias Hoffmann¹, John Marshall^{1,3}, Gunnar Lischeid^{1,2}, Maren Dubbert^{1,4}

1: Leibniz Centre for Agricultural Landscape Research (ZALF), Germany; 2: Institute of Earth and Environmental Sciences, University of Potsdam, Germany; 3: Dept. Earth Sciences, University of Gothenburg, Sweden; 4: Institute of Crop Science and Resource Conservation, University of Bonn, Germany

16:15 - 16:30 ID: 137

Topics: 1. Ecohydrology, Ecosystems and Biogeochemistry

Water uptake depth response in a cropland: Insights from multi-scale measurements across two contrasting growing seasons

Goekben Demir¹, David Dubbert¹, Christian Markwitz², Anas Emad², Alexander Knohl², Maren Dubbert¹

1: Ecophysiology of Water and Matter Cycling (ECO), ZALF, Muencheberg, Germany; 2: Bioclimatology, University of Gottingen, Germany

16:30 - 16:45 ID: 118

Isotopic insights into the dynamics of soil water pools along an elevation gradient

Jiří Kocum¹, Kristýna Falátková¹, Václav Šípek¹, Karel Pátek^{1,2}, Jan Haidl¹, Ondřej Gebouský^{1,2}, Jan Hnilica¹, Michal Jeníček³, Martin Šanda⁴, Lukáš Trkal⁵, Lukáš Vlček¹

1: Institute of Hydrology, Dept. Hydrology, Czech Academy of Sciences, Prague, Czechia; 2: Faculty of Environmental Sciences, Dept. Water Resources and Environmental Modeling, Czech University of Life Sciences, Prague, Czechia; 3: Faculty of Science, Dept. Physical Geography and Geoecology, Charles University, Prague, Czechia; 4: Faculty of Civil Engineering, Dept. Landscape Water Conservation, Czech Technical University in Prague, Prague, Czechia; 5: Dept. Environmental Geosciences, Czech University of Life Sciences, Prague, Czechia

16:45 - 18:00

Poster Session 1

HS Physiologie/Biochemie

19:00 - 22:00

Thermo Fisher User Meeting

Gasthaus Schiff Freiburg > Schwarzwaldstraße 82, <https://freiburgerschiff.de/>

Tuesday, 6 October 2026

08:30 Registration

09:00 - 09:30 **Keynote 2** HS Physiologie/Biochemie

Assessing plant physiological responses to 150 years of rising atmospheric CO₂ using historical plant collections

Ansgar Kahmen, Daniel Nelson, Jurriaan de Vos, David Basler
University of Basel, Switzerland

09:30 - 10:30 Session C – Carbon and Nitrogen Isotopes

HS Physiologie/Biochemie
Session Chair: **Caroline Buchen-Tschiskale**, Thünen Institute

9:30 - 9:45 ID: 117

Tracing belowground plant-soil and plant-plant interactions via ¹³CO₂ and ¹⁵N-ammonium nitrate

Miriam Meischner^{1,2}, Simon Haberstroh¹, Riikka Rinnan², Jürgen Kreuzwieser¹, Jörg-Peter Schnitzler³, Christiane Werner¹

1: Ecosystem Physiology, University of Freiburg, Germany; 2: Center for Volatile Interactions (VOLT), Dept. Biology, University of Copenhagen, Denmark; 3: Research Unit Environmental Simulation, Helmholtz Center Munich, Neuherberg, Germany

9:45 - 10:00 ID: 112

Rhizosphere strategies of crops to cope with soil resource limitation: From old landraces to modern inbred lines and hybrids

Johanna Pausch^{1,2}, Anna Hollweg¹, Andreas Wild¹

1: Agroecology, Bayreuth Center of Ecology and Environmental Research (BayCEER), University of Bayreuth, Germany; 2: Bayreuth Center for Stable Isotope Research in Ecology and Biogeochemistry (BayCenSI), University of Bayreuth, Germany

10:00am - 10:15am ID: 127

Isotopic analyses on intensively manured first medieval pea varieties

Frank Schlütz¹, Hannah Keller², Jens Schneeweiß³, Wiebke Kirleis^{1,2}

1: Exzellenzcluster ROOTS, Kiel; 2: Institut für Ur- und Frühgeschichte, Kiel; 3: LEIZA, Schleswig

10:15 - 10:30 ID: 148

The carbonate factory above a dormant volcanic lake (Laacher See, Germany): A multi-isotope approach

Patricia Roeser¹, Anna Jentsch², Iris Schmiedinger³, Christian März¹, Michael Böttcher^{3,4,5}

1: University of Bonn, Institute for Geosciences, Environmental Geology Group, Bonn, Germany; 2: Helmholtz Centre for Geosciences, GFZ, Geodynamic Modelling, Potsdam, Germany; 3: Leibniz Institute for Baltic Sea Research IOW, Geochemistry and Isotope Biogeochemistry, Warnemünde, Germany; 4: University of Greifswald, Institute for Geography & Geology, Germany; 5: University of Rostock, Interdisciplinary Faculty, Germany

10:30 - 11:00 Coffee

11:00 - 12:00 Session D – Microorganisms and Soil Invertebrates

HS Physiologie/Biochemie
Session Chair: **Johanna Pausch**, University of Bayreuth

11:00 - 11:15 ID: 122

Hydrogen isotopes of fatty acids reflect the tricarboxylic acid cycle activity in bacterial two-species culture

S. Nemiah Ladd¹, Nathalie Amacker¹, Reto Wikjer², Laura K. Meredith³, Daniel B. Nelson¹

1: University of Basel, Switzerland; 2: ETH-Zurich, Switzerland; 3: University of Arizona, USA

11:15 - 11:30 ID: 119

What can we learn from the combined application of stable isotopes, microbiological investigations, and numerical modeling of the hyporheic zone with different sediment characteristics for understanding methane emissions from streams?

Yujia Wang, Anja Wunderlich, Florian Einsiedl

Lehrstuhl für Hydrogeologie, School of Engineering and Design, Technische Universität München, Germany

11:30 - 11:45 ID: 101

Soil invertebrates actively regulate nitrogen cycling in forests

Xiaoyi Zeng¹, Michael J.W. Boyle¹, Gbadamassi G.O. Dossa², Michael Scherer-Lorenzen³, Juan Zuo⁴, Han Xu⁵, Lais Ferreira Maia⁶, Yanpeng Li⁵, Yuen Nok Lam¹, Jonathan D. Cybulski^{1,7}, Xiaodong Yang², Runxi Wang¹, David M. Baker^{1,7}, Timothy C. Bonebrake¹, Paul Eggleton⁸, Hannah M. Griffiths⁶, Louise A. Ashton¹

1: School of Biological Sciences, University of Hong Kong, Hong Kong SAR, China; 2: Yunnan Key Laboratory of Forest Ecosystem Stability and Global Change, Xishuangbanna, Tropical Botanical Garden, Chinese Academy of Sciences, Yunnan, China; 3: Faculty of Biology, Geobotany, University of Freiburg, Freiburg, Germany; 4: Wuhan Botanical Garden, The Chinese Academy of Sciences, Hubei, China; 5: Research Institute of Tropical Forestry, Chinese Academy of Forestry, Guangdong, China; 6: School of Biological Sciences, University of Bristol, Bristol, UK; 7: The Swire Institute of Marine Science, University of Hong Kong, Hong Kong SAR, China; 8: Dept. Life Sciences, Natural History Museum, London, UK

11:45 - 12:00 ID: 133

Using stable isotopes to trace the fate of fungal necromass in soil

Valentin B. Kurbel¹, Veronica Vasilica¹, Viktoria Gaul¹, Eva Lehndorff², Jan Jansa³, Richard P. Phillips⁴, Johanna Pausch¹

1: Agroecology, Bayreuth Center of Ecology and Environmental Research (BayCEER), University of Bayreuth, Bayreuth, Germany; 2: Soil Ecology, Bayreuth Center of Ecology and Environmental Research (BayCEER), University of Bayreuth, Bayreuth, Germany; 3: Laboratory of Fungal Biology, Institute of Microbiology, Czech Academy of Science, Prague, Czech Republic; 4: Dept. Biology, Indiana University Bloomington, Indiana, USA

12:00 - 13:30 Lunch

13:30 - 15:00 **Isotope Award** HS Physiologie/Biochemie

15:00 - 16:15 **Poster Session 2** HS Physiologie/Biochemie

Session E – Human Metabolism

16:15 - 17:00 HS Physiologie/Biochemie
Session Chair: **Matthias Beyer**, TU Braunschweig

16:15 - 16:30 ID: 145

Doubly Labelled Water as a Reference Method for Validating Wearable-Derived Total Energy Expenditure

Helena Lutz¹, Christopher Mancke¹, Regina Oeschger², Rahel Gilgen-Ammann², Juliane Heydenreich¹

1: Universität Leipzig, Germany; 2: Swiss Federal Institute of Sport Magglingen SFISM, Switzerland

16:30 - 16:45 ID: 144

A Pilot Method for Measuring Endogenous and Exogenous Carbohydrate Utilization

Mahaylia Datars¹, Tim Podlogar², Gareth Wallis³, Markus Hertlein⁴, Bjoern Geesmann⁴, Isabel Beer¹, Katie Rainsberger¹, Robert Van Geldern⁵, Karsten Koehler¹

1: TUM School of Medicine and Health, Technical University of Munich, Germany; 2: Dept. Public Health and Sport Science, University of Exeter, UK; 3: School of Sport, Exercise and Rehabilitation Sciences, University of Birmingham, UK; 4: HCYCYS Sports Performance GmbH, Cologne, Germany; 5: GeoZentrum Nordbayern, Friedrich-Alexander University Erlangen-Nuremberg, Germany

16:45 - 17:00 ID: 103

Supercritical Fluid Chromatography for Sample Clean-up in IRMS Including Cholesterol as New ERC

Thomas Piper¹, Jana Drewes^{1,2}, Mario Thevis^{1,3}

1: German Sport University Cologne, Germany; 2: University of Münster - Institute of Inorganic and Analytical Chemistry, Germany; 3: European Monitoring Center for Emerging Doping Agents (EuMoCEDA), Germany

17:00 - 18:15 **ASI General Meeting** HS Physiologie/Biochemie

19:00 - 22:00 **Dinner** Restaurant „Der Kaiser“ (Günterstalstr. 38), www.freiburgerkaiser.de

Wednesday, 7 October 2026

8:30 **Registration**

9:00 - 10:30 **Session F – Soil and Trees**

HS Physiologie/Biochemie

Session Chair: **Ruth-Kristina Magh**, Friedrich Schiller University

9:00 - 9:15 ID: 161

Tracing the flux of C through the Amazon forest – using a FACE experiment as a ^{13}C -labeling tool

Thorsten Grams

LSAI-Ecophysiology of Plants, Technical University of Munich, Germany

9:15 - 9:30 ID: 123

Mechanistic models identify source water and leaf water effects in a European tree-ring cellulose oxygen isotope network

Daniel B. Nelson¹, Haoyu Diao², Matthias Saurer², Meisha Holloway-Phillips¹, Ansgar Kahmen¹, Kerstin Treydte², Marco M. Lehmann²

1: University of Basel, Switzerland; 2: Swiss Federal Institute for Forest, Snow and Landscape Research WSL, Switzerland

9:30 - 9:45 ID: 104

Disentangling Soil and Atmospheric Drought Imprints: Intra-Annual $\delta^{13}\text{C}$ in tree rings across ecological gradients

Valentina Vitali^{1,2}, Jernej Jevšenak³, Matthias Saurer²

1: ETH Zurich, Dept. Environmental Systems Science, Switzerland.; 2: Swiss Federal Institute for Forest, Snow and Landscape Research WSL, Switzerland.; 3: Dept. Forest and Landscape Planning and Monitoring, Slovenian Forestry Institute, Slovenia

9:45 - 10:00 ID: 114

^2H -enrichment of plant carbohydrates is not necessarily associated with a low-biomass “stress” state

Selina Hugger¹, Daniel Nelson¹, Ansgar Kahmen¹, Meisha Holloway-Phillips^{1,2}

1: University of Basel, Dept. Environmental Sciences – Botany, Basel, Switzerland; 2: ETH Zürich, Institute of Agricultural Sciences - Grassland Sciences, Zürich, Switzerland

10:00 - 10:15 ID: 140

Bicarbonate leakage from the chloroplast explains the environmental sensitivity of mesophyll conductance

Florian Busch^{1,2}, Diego Marquez^{1,2}, Meisha Holloway-Phillips³, Hilary Stuart-Williams⁴, Abraham Stroock⁵, Graham Farquhar⁴

1: University of Birmingham, United Kingdom; 2: Birmingham Institute of Forest Research; 3: University of Basel, Switzerland; 4: Australian National University, Australia; 5: Cornell University, USA

10:30 - 11:00 **Coffee**

11:00 - 12:15 **Session G – Climate & Atmosphere + Methods**

HS Physiologie/Biochemie

Session Chair: **Marco Lehmann**, University of Zurich

11:00 - 11:15 ID: 124

Sweet Deception: Using Sorbitol to Detect C4-type Sugar Adulteration in Apple Juice

Marco Schmidt¹, Mike Seed², Philipp I. Schodder¹, Hesham Abdallah¹, Mikko Hofsommer³, Simon Kelly⁴, Jan Hartwig¹, Kathrin Rosenthal¹

1: Elementar Analysensysteme GmbH, Langenselbold, Germany; 2: Elementar UK Ltd., Isoprime House, Earl Road, Cheadle Hulme, Stockport, UK; 3: GfL Gesellschaft für Lebensmittel-Forschung mbH, Berlin, Germany; 4: Fera Science Ltd., York Biotech Campus, Sand Hutton, York UK

11:15 - 11:30 ID: 159

Advancing molecular-level isotope ratio analysis with an integrated Orbitrap-IRMS workflow

Nils Kuhlbusch, Sukanya Sengupta, Dieter Juchelka, Mario Tuthorn

Thermo Fisher Scientific, Germany

11:30 - 11:45 ID: 128

Toward Robust GC×GC-C-IRMS Through the Development of Ni-Wall-Coated Microreactors

Habib Al-Ghoul, Martin Elsner

Chair of Analytical Chemistry and Water Chemistry, Technical University of Munich, Garching, Germany

11:45 - 12:00 ID: 120

High-temporal resolution measurements of radiocarbon in atmospheric CO₂ for source sector attribution of urban emissions

Joachim Mohn¹, Patrick Siegwolf¹, Andrew R. Whitehill¹, Stephan Henne¹, Samuel Hammer², Lukas Wacker³, Lukas Emmenegger¹, Béla Tuzson¹

1: Empa, Laboratory for Air Pollution / Environmental Technology, Switzerland; 2: Heidelberg University, ICOS Central Radiocarbon Laboratory, Germany; 3: ETH Zürich, Laboratory of Ion Beam Physics, Switzerland

12:00 - 12:15 ID: 141

Comparison of different observational methods to quantify methane emissions from an active landfill in Romania

Hannes Keck¹, Kerstin Zeyer¹, Alexandru Dandocsi², Dominik Brunner¹, Michael Steiner¹, Christoph Riess¹, Stefan Nicolae², Ioannis Binietoglou^{2,3}, Martin Fährdrich¹, Leonie Bernet¹, Lukas Emmenegger¹, Benjamin Wolf⁴, Joachim Mohn¹

1: Empa, Laboratory for Air Pollution / Environmental Technology, Dübendorf, Switzerland; 2: National Institute of Research and Development for Optoelectronics (INOE2000), Magurele, Romania; 3: School of Physics and Astronomy, University of Leicester, Leicester, United Kingdom; 4: Karlsruhe Institute of Technology (KIT), Institute of Meteorology and Climate Research, Atmospheric Environmental Research (IMK-IFU), Garmisch-Partenkirchen, Germany

12:15 - 12:45	Awards, Announcements, Closing remarks
12:45 - 13:15	Lunchboxes
13:15 - 17:15	Excursions

Keynote 1

Tracing water through the landscape – Stable isotopes for identifying hydrological processes and water transit times

Christine Stumpp

BOKU University, Institute of Soil Physics and Rural Water Management, Austria

Water stable isotopes are powerful environmental tracers that preserve information on how water moves through the landscape. They can be used to identify hydrological processes and quantify water fluxes and water transit times that are otherwise difficult to resolve. In this talk, I will demonstrate how isotopic approaches, in combination with complementary methods, can be used to assess water resources across different spatial scales, climatic regions, and components of the water cycle. Specifically, I will present examples of using stable isotopes to (i) partition precipitation and quantify soil water fluxes, (ii) identify groundwater recharge and groundwater-surface water interactions, and (iii) quantify water transit times in headwater catchments and large watersheds. Finally, I will introduce new in-situ setups for water stable isotope analysis designed to investigate beech resilience to drought in the BOKU Research Forest Rosalia.

Session A - Water Stable Isotopes (Trees, RWU)

Linking isotope based seasonal origin and depth of root water uptake across European beech and spruce forests

Marco M. Lehmann¹, Thanh Thi Luong², Marius Florianic³, Ilja van Meerveld¹, Josie Geris⁴, Daniele Penna⁵, Youri Rothfuss⁶, Natalie Orlowski², Katrin Meusburger⁷

¹University of Zurich, Switzerland; ²TU Dresden, Germany; ³ETH Zürich, Switzerland; ⁴University of Aberdeen, United Kingdom; ⁵University of Florence, Italy; ⁶Forschungszentrum Jülich GmbH, Germany; ⁷WSL Birmensdorf, Switzerland

Understanding when and from where trees acquire water is essential for predicting forest resilience under changing environmental conditions. Stable isotope data provide unique insights into plant water sources, yet most studies have focused either on the temporal origin or the depth of water uptake at individual sites. The recently established WATSON isotope dataset, based on paired stem xylem and soil water isotope sampling across 40 European beech (*Fagus sylvatica*) and Norway spruce (*Picea abies*) sites during spring and

summer 2023, offers a unique opportunity to investigate both dimensions simultaneously.

Here, we combine the Seasonal Origin Index (SOI) (Allen et al., 2019), which characterizes the seasonal origin of xylem water, with isotope-profile matching to infer the dominant depth of root water uptake (RWU) for beech and spruce trees. SOI was used to distinguish whether trees relied predominantly on winter-or-summer-derived precipitation, while RWU depth was estimated by matching xylem isotope signatures with vertically resolved soil isotope profiles. Seasonal changes in both metrics were related to antecedent meteorological conditions (based on ERA5 reanalysis data), soil characteristics, and tree parameters.

Preliminary results show coherent patterns in both the timing and depth of root water uptake across Europe. At mixed spruce-beech sites, spruce generally took water from shallower soil depths than beech. SOI values were higher for spruce than beech, particularly in summer, indicating a stronger dependence on growing-season precipitation. Antecedent meteorological conditions integrated over ~30 days before sampling explained seasonal variation in RWU better than shorter term weather conditions. Seasonal RWU plasticity increased with accessible soil depth, suggesting that subsurface storage constrains the capacity of trees to adjust their uptake strategies.

By jointly analyzing the temporal origin and vertical source depth of water taken up by trees, this study provides one of the first continental-scale assessments for tree water-use across European forests and seasons. Together, SOI and RWU offer a complete ecohydrological framework for understanding vegetation responses to drought and constraints for process-based ecohydrological and land-surface models.

Watson isotope data:

<https://doi.org/10.16904/envdat.542>

Watson data description paper:

<https://doi.org/10.5194/essd-17-6129-2025>

Allen et al. 2019:

<https://doi.org/10.5194/hess-23-1199-2019>

Daily water stable isotope data reveal shifts in root water uptake depth in *Fagus sylvatica* in response to drought and species interaction

Simon Haberstroh¹, Laura Kinzinger¹, Judith Mach², Kathrin Kühnhammer¹, Markus Weiler², Natalie Orłowski³, Christiane Werner¹

¹Ecosystem Physiology, University of Freiburg, Germany; ²Hydrology, University of Freiburg, Germany; ³Institute of Soil Science and Site Ecology, TU Dresden

The promotion of mixed forests – in comparison to monocultures – promises a higher resilience to climatic extremes. However, we are still lacking a clear understanding of belowground processes, e.g., competition for water resources. Here, we continuously measured water stable isotopes, sap flow and tree water deficit in mixed and monospecific *Fagus sylvatica* and *Picea abies* plots (near Ettenheim, DE). With the collected data we observe shifts in root water uptake depth and evaluate how these shifts interact with species composition. Our dataset includes the European summer drought 2022 and we follow the fate of a simulated 23 mm rainfall event labelled with $^2\text{H}_2\text{O}$. Root water uptake depths showed a highly dynamic response: In mixed plots, *F. sylvatica* trees profited from the admixture with *P. abies* and maintained a constant root water uptake depth, reducing tree water stress compared to trees in monospecific stands. *F. sylvatica* growing in monoculture experienced lower sap flow and higher tree water deficits during peak drought, forcing these trees to exploit deeper soil water resources due to increased intraspecific competition in the topsoil. Contrarily, *P. abies* in mixed stands suffered from belowground competition with *F. sylvatica*, albeit root water uptake depths between mixed and monospecific *P. abies* did not differ significantly. With this study, we demonstrate that continuous measurements of water stable isotopes in tree xylem are an invaluable tool to illuminate the dynamic belowground response of temperate forest trees to drought and help improve our ecohydrological knowledge on species interactions. Such knowledge is especially important given the frequent reoccurring droughts in Central Europe.

Drought impact on the water uptake depths of five temperate tree species in a mature mixed forest using continuous measurement of water stable isotopes

Franziska Geuchen, Stefan Seeger, Lukas Kleine, Markus Weiler, Simon Haberstroh, Christiane Werner
University of Freiburg, Germany

Projected increases in drought frequency and severity threaten forests' water supply in Central European forests and thereby the trees' survival, yet belowground processes of tree water uptake are still understudied. Previous studies using water stable isotope tracers in a mature *Fagus sylvatica* and *Picea abies* forest revealed species-specific dynamic shifts in root water uptake (RWU) depth in response to drought and subsequent rain events (Kinzinger et al. 2025). In this study, we will complement these results broaden this knowledge including three additional key species (*Quercus petraea*, *Abies alba*, and *Pseudotsuga menziesii*) with diverse architecture and hydraulic strategies, and investigate drought effects on RWU dynamics. Therefore, we simulate a severe summer drought in a mature mixed forest using individual tree rainout shelters, while monitoring water stable isotopes in the tree xylem and in the soil at different depths at a daily interval using a water isotope probe system based on cavity ring-down spectroscopy. Simultaneously, we continuously monitor important ecophysiological measurements, such as sap flow rate, tree water deficit and water potential, as well as ecohydrological measurements, such as soil moisture and soil matric potential, to complement the isotope data at the soil-tree interface. Using a deuterium enriched pulse label at the end of the drought treatment, we will track water uptake depths and rates of severely drought-stressed trees. We will test if different species show diverse RWU responses to drought and rewetting depending on their overall rooting pattern and hydraulic strategies and if RWU patterns play a central role in species-specific tree water status during drought. This study will broaden our knowledge of how five European key tree species' structural traits might influence RWU dynamics and in turn tree water status under drought stress and during recovery.

$\delta^{18}\text{O}$ -derived root water uptake depth explains the drought sensitivity and vulnerability of temperate tree species

David N. Steger¹, Richard L. Peters^{1,2}, Tobias Zhorzel¹, Raphael Dups¹, Günter Hoch¹, Daniel B. Nelson¹, Cedric Zahnd^{1,8}, David Basler¹, Katrin Meusburger^{3,4}, Fabian Bernhard⁵, Matthias Arend⁶, Bernhard Schuldt⁷, Ansgar Kahmen¹

¹University of Basel, Switzerland; ²Technical University of Munich, Germany; ³Swiss Federal Research Institute WSL; ⁴ETH Zürich; ⁵University of Bern; ⁶Universität Trier; ⁷Dresden University of Technology; ⁸University of Antwerp

Climate change is increasing drought frequency, duration, and severity in large parts of the world, thereby reducing soil water availability and increasing risks for forest decline and mortality. The drought response of a tree can be described by the tree's 'drought sensitivity', indicating reversible processes such as stomatal responses to soil drying, and 'drought vulnerability', indicating irreversible damages, such as the risk of hydraulic failure. Different tree species that co-occur in the same ecosystem often differ substantially in their drought sensitivity and vulnerability. Yet, the underlying physiological, anatomical and morphological mechanisms remain poorly understood. We tested whether species-specific differences in root water uptake depth (RWUD) can explain differences in drought sensitivity and vulnerability of mature trees belonging to nine temperate European tree species. Using a six-year dataset (2018–2024) from the Swiss Canopy Crane II site, we quantified drought sensitivity from the response of daily maximum sap flux density to soil drying. We quantified drought vulnerability by calculating hydraulic safety margins of trees relative to species-specific critical xylem hydraulic thresholds. RWUD was estimated using $\delta^{18}\text{O}$ values of mobile soil water, precipitation, and xylem water, which was extracted by cryogenic vacuum distillation. Between 2020 and 2024 we collected >2000 xylem, >3600 soil water, and >400 precipitation and throughfall samples, and the resulting RWUD estimates were analyzed against sensitivity and vulnerability traits.

Species differed markedly in both drought sensitivity and drought vulnerability. These differences were largely determined by variation in the tree's maximum RWUD: With progressive soil drying, shallow-rooted species closed stomata early and rapidly approached hydraulic thresholds during drought, while deep-rooted species sustained transpiration and maintained wide hydraulic safety margins. RWUD alone explained more than 65 % of the interspecific variation in both drought sensitivity and vulnerability. Our results demonstrate that soil water access under drought, as determined by maximum RWUD, is a primary control on drought

sensitivity and vulnerability. These findings link belowground water uptake to aboveground drought physiology and highlight the value of stable isotopes for understanding tree drought responses. By quantifying this connection in mature trees, our study identifies RWUD as a strong predictor of forest drought resistance and a critical parameter for ecosystem and Earth system models to improve forecasts of forest–climate feedbacks under intensifying drought regimes.

The beech and spruce transpiration explored by a combination of soil moisture, sap flow and stable isotopes

Václav Šípek¹, Karel Pátek^{1,2}, Jiří Kocum¹, Miroslav Tesař¹

¹Institute of Hydrology of the Czech Academy of Sciences, Czechia; ²Faculty of Environmental Sciences, Czech University of Life Sciences, Czechia

Transpiration of the two dominant Central European tree species, beech and spruce, plays an important role in the regional water cycle. Three approaches were used to study and compare the transpiration of these tree species during the year 2025. The first approach was based on the thorough analyses of soil water regime, second involved measuring tree sap flow, and the third approach was to measure the isotopic composition of water in the tree sap. The study was conducted in the small mountainous forested catchment in the Czechia representing energy-limited environment. The transpiration flux of beech and spruce trees was similar only at the beginning and end of the season. During warm summer days, the transpiration of beech was more than two times higher than that of spruce. This was also documented by significantly lower soil water potentials occurring in the late summer. The early onset of transpiration in spruce after winter caused spring shift of xylem water isotopic composition towards winter precipitation stored in the soil. The same shift was observed in beech slightly later as transpiration flux began. The most pronounced differences were observed during the dry period at the end of June and became less evident in the wetter part of the summer that followed. The beech trees relied more on water stored deeper in the soil during the drought period. This information is important not only to describe the actual water balance, but it can be also used to predict the expected impacts of climate change related to the rise of temperatures or the transition of forest species.

Session B - Water Stable Isotopes (General)

Dual Isotope Labelling Reveals Contrasting Spatial and Temporal Water Uptake in Boreal Scots Pine

Ruth-Kristina Magh^{1,2}, Nils Henriksson², Hyungwoo Lim², Reimo Lutter^{2,3}, Tomas Lundmark², John Marshall²

¹Friedrich Schiller University, Germany; ²Swedish University of Agricultural Science; ³Estonian University of Life Sciences

Trees are major drivers of the terrestrial water cycle but quantifying where and when individual trees acquire water and nutrients in the field remains challenging. Root distribution alone is often a poor predictor of actual resource uptake.

We used stable isotopes of water and nitrogen to trace uptake from different soil depths and horizontal distances at two contrasting boreal Scots Pine stands. One site was a long-term nitrogen addition site, the other one the unfertilized reference. Tracking ²H in the xylem sap and the wood provided a direct indication of water uptake, while combining both tracers allowed us to assess the coupling between water uptake and nitrogen acquisition.

At each stand, a 1 m² soil patch was labeled either at the surface, at 15 or 30 cm depth beneath the Ah horizon using 15.5 L of water enriched in ²H (>200.000‰) and 2.49 g ¹⁵N as KNO₃. All trees in an 8 m radius were monitored daily for water stable isotopes using a semi *in situ* approach, and weekly sampling of foliage to observe the nitrogen incorporation. Additionally, all trees were sampled again at the end of the growing season, this time to measure ²H incorporation into wood to evaluate how water uptake propagates within stems.

Label recovery was higher at the fertilized site for both isotopes suggesting stronger belowground competition at the unfertilized site. At both sites label uptake decreased exponentially with distance from the labeled patch, regardless of labeling depth. However, this decrease was less steep at the unfertilized site, where we found trees at 5 m distance still contained both tracers, indicating a wider horizontal foraging strategy.

At the fertilized site, trees accessed deeper water sources, although recovery was lower than from the surface layer. In contrast, uptake from deeper layers at the unfertilized site was negligible, indicating that root activity was highest near the soil surface.

This was reflected in the temporal dynamics. Surface uptake occurred immediately at both sites, whereas uptake from deeper soil layers at the fertilized site was delayed by approximately two weeks.

Axial transport followed a spiraling ascent, indicating spiral grain, with little tangential mixing, demonstrating

that placement for *in situ* isotope measurement requires careful consideration.

Together, these findings demonstrate that long-term nitrogen availability alters the spatial extend of the functionally active root system in boreal Scots Pine, while spiral xylem transport has important implications for interpreting *in situ* isotope measurements.

Stem water of *Helianthus annuus* (sunflower) as a quickly accessible reservoir for transpiration: evidence from in-situ and continuous monitoring of the xylem water isotopic composition

Youri Rothfuss¹, Samuel Le Gall¹, Nicolas Brüggemann¹, Sharmin Jahan¹, Mathieu Javaux², Julian Klaus³, Harry Vereecken¹, Dagmar van Dusschoten⁴

¹Institute of Bio- and Geosciences, Agrosphere (IBG-3), Forschungszentrum Jülich GmbH, Jülich, Germany; ²Earth and Life Institute, Environmental Sciences (ELIE), Université catholique de Louvain, Louvain-la-Neuve, Belgium; ³Department of Geography, University of Bonn, Bonn, Germany; ⁴Institute of Plant Sciences (IBG-2), Forschungszentrum Jülich GmbH, Jülich, Germany

In situ observation is crucial for the study and modeling of plant root water uptake (RWU) to gain knowledge about plant water stress regulation mechanisms. One of the documented mechanisms is the ability of a plant to mobilize the water contained in one particular organ or non-conducting tissue for further transport to the transpiring sites. This ability is often quantified by the capacitance metric, the derivative of the (organ or tissue) retention curve.

We present a proof of concept and a first application of a straightforward method for online, minimally invasive monitoring of the water stable isotopic composition of sap xylem water of *Helianthus annuus* (sunflower). The method consisted of inserting a sampling tube tightly in the plant stem and connecting it to a laser spectrometer. After careful calibration of our method in hydroponics settings, we applied it successfully to individual sunflower plants grown in soil columns in a climate-controlled growth chamber. We followed the dynamics in stem water isotopic composition in response to changing light intensity and to depth-specific, isotopically labeled water pulses. We further establish that these isotopic dynamics matched changes in RWU profiles monitored simultaneously, independently, and non-destructively at vertical cm-resolution by the Soil Water Profiler, a capacitive sensor measuring the electric permittivity as a proxy for the soil volumetric water content.

We finally highlight from modeling exercises the significance of the role of stem capacitance in sunflower: water exchanges between xylem and stem

non-conducting tissues were estimated to amount to about one sixth of RWU of *Helianthus annuus*, showing that the stem of a forb can be expected to be a quickly accessible reservoir of water for transpiration, very similar to what is found in woody species.

High-resolution isotope monitoring of soil-plant-atmosphere water dynamics within an agricultural system using the automated chamber system (FluxCrane) and machine learning

Adrian Dahlmann^{1,2,4}, David Dubbert¹, Mathias Hoffmann¹, John Marshall^{1,3}, Gunnar Lischeid^{1,2}, Maren Dubbert^{1,4}

¹Leibniz Centre for Agricultural Landscape Research (ZALF), Germany; ²Institute of Earth and Environmental Sciences, University of Potsdam, Potsdam, Germany; ³Department of Earth Sciences, University of Gothenburg, Gothenburg, Sweden; ⁴Institute of Crop Science and Resource Conservation, University of Bonn, Bonn, Germany

Quantifying water fluxes within the soil-plant-atmosphere continuum (SPAC) is essential for sustainable agricultural management under climate-induced water scarcity. However, tracing water stable isotope compositions of evapotranspiration (δ_{ET}) and ambient water vapor (δ_A) over various years with a high resolution is challenging.

We monitored two growing seasons of oilseed rape and winter wheat in northeast Germany along an erosion gradient featuring three distinct soil types (non-eroded, strongly eroded, extremely eroded). Our automated experimental setup (FluxCrane) coupled a closed chamber system with high-resolution, in-situ laser spectroscopy to continuously measure evapotranspiration (ET), ambient water vapor (δ_A), and we additionally sampled precipitation (δ_{Pr}). The isotopic signatures of ET (δ_{ET}) were calculated using the Keeling plot method, and plant water stress was captured via soil water potential (SWP) sensors. Machine learning (Random Forest, RF; and Self-Organizing Maps with Sammon's Mapping, SOM-SM) was integrated to identify key ecohydrological drivers and predict sub-daily isotopic dynamics.

Our isotopic observations revealed seasonal and diurnal dynamics. Seasonally, showed a distinct shift from depleted winter values dominated by soil evaporation to enriched summer values driven by transpiration. This active isoforcing (I_{ET}) directly follows transpiration dynamics and actively drives atmospheric water vapor away from isotopic equilibrium with precipitation. Furthermore, diurnal crop-specific differences were visible with winter wheat reaching ISS faster than rapeseed.

This study traces SPAC water dynamics across small-scale soil hydraulic gradients and evaluates how crop transpiration feeds back on the atmosphere. We demonstrate that high-resolution isotope monitoring coupled with machine learning successfully traces crop-specific physiological regulation and active soil-plant-atmosphere feedbacks across heterogeneous landscapes. SOM-SM was used to successfully identify key environmental drivers and random forest modeling to predict half-hourly δ_{ET} .

Water uptake depth response in a cropland: Insights from multi-scale measurements across two contrasting growing seasons

Goekben Demir¹, David Dubbert¹, Christian Markwitz², Anas Emad², Alexander Knohl², Maren Dubbert¹

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Rainfed croplands are among the most vulnerable land systems to shifts in precipitation regimes and prolonged droughts, particularly in temperate climates. Characterising root water uptake patterns, therefore, is essential to understand how crops maintain their functions and sustain transpiration under drought stress. We investigated the water uptake patterns of winter cereals (wheat and barley) across two contrasting growing seasons (2024 and 2025) in a cropland in central Germany. The research site is characterised by a mean annual temperature of 9.0 °C, a mean annual precipitation of 628 mm (1970–2000) and shallow groundwater (ca at 1.5 m depth). Further, it is equipped with eddy covariance (EC) measurements and additional high-resolution soil moisture (SM) monitoring at three profiles across nine depths (5–100 cm).

Within the tower footprint, we conducted weekly sampling at five locations, collecting plant leaves and soil water at four depths. Similarly, we also collected precipitation, river water and groundwater for stable water isotope analysis (δ_2H , $\delta_{18}O$) at natural abundance, and estimated the composition of xylem water using the Craig–Gordon model.

In 2024, frequent rainfall maintained relatively wet soil conditions, with only short dry spells around peak LAI in May. In contrast, 2025 was characterised by earlier dry spells in March and more frequent dry spells, resulting in marked differences in the timing and severity of drought conditions between the two seasons. By combining high-resolution, SM-based estimates of water uptake with dual-isotope mixing models, we were able to determine how crops utilise different water

sources in response to dry spells and rainfall events at various plant growth stages. In other words, this multi-method approach provided a level of understanding of the processes involved that could not be achieved by EC, SM or isotope data alone.

We showed that both crop types exhibited flexibility in water uptake depth in response to dry spells. However, the median uptake depth was 20–60 cm for wheat in 2024, whereas barley primarily met its transpiration demand from 10–40 cm in 2025 despite drier conditions, with limited contribution from deeper layers and less event-scale variability than wheat. Our findings demonstrate that combining stable water isotopes with multi-depth soil moisture monitoring provides a powerful framework for unravelling water uptake dynamics across event, daily and seasonal scales. This framework reveals how root plasticity and access to stable water sources jointly influence the impact of drought timing on transpiration and ecosystem productivity.

Isotopic insights into the dynamics of soil water pools along an elevation gradient

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Recent intensive research on the soil–plant–atmosphere continuum enables the tracing of water movement and plant responses at much finer spatial and temporal scales. However, the soil water dynamics are still not fully understood. This study aims to provide a comprehensive characterisation of the dynamics of distinct soil water pools—mobile versus tightly bound water—along an elevation gradient from lowland agricultural areas to upper mountain catchment in the Bohemian Forest (Czechia). In contrast to single plot experiments and conventional bulk soil water sampling, a key innovation of this study lies in the experimental design across the elevation gradient combined with a novel extraction method that selectively isolates tightly bound soil water for isotopic analysis. In addition, a new method for correcting extracted soil water isotope data was proposed to improve the comparability of individual ecohydrological

studies. The results indicate a prolonged residence time of winter-derived soil water in lowland sites, in contrast to a rapid turnover at the highest elevation, where the winter water signal dissipates shortly after snowmelt. Distinct isotopic compositions among water pools—mobile versus tightly bound water—were particularly evident in lowland areas at the edges of the growing season, while tightly bound and bulk soil water exhibited—on average—only minor or no isotopic differences. In the context of the projected ongoing changes in the distribution and intensity of precipitation in Central Europe, these findings are of critical importance for improving predictions of soil water storage and, consequently, plant water availability under ongoing climate change.

Keynote 2

Assessing plant physiological responses to 150 years of rising atmospheric CO₂ using historical plant collections

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Anthropogenic carbon emissions cause elevated CO₂ concentrations (eCO₂) in the atmosphere which causes climate change. eCO₂ also stimulates photosynthesis (A_n) and reduces stomatal conductance (g_s) of plants with impacts for carbon and water relations in terrestrial ecosystems. Approximately 25 % of anthropogenic CO₂ emissions are taken up by the biosphere, which slows the accumulation of CO₂ in the atmosphere and dampens climate change. The stimulation of A_n and g_s by eCO₂ is thought to be the main driver for this carbon uptake.

The extent to which eCO₂ affects A_n and g_s in plants growing in their natural environment and if these effects differ in ecosystems across major global biomes remains, however, unclear. This makes it difficult to quantify how changes in A_n and g_s caused by eCO₂ impact the global carbon sink and constitutes a major gap in understanding the coupled carbon-climate system.

In my talk I will introduce an innovative modelling framework that uses foliar carbon isotope and nitrogen data for quantifying rates of A_n and g_s from historical plant collections. We have applied this new approach to more than 3'000 herbarium specimens from the Herbaria Basel and have turn these historical plant collections into archives of physiological processes to directly quantify how eCO₂ has affected A_n and g_s in plants over the past 125 years.

Our analysis identified a significant increase of A_n over the past 150 years of 28.9 %. Contrary to expectations, g_s also significantly increased over the same period by 14.6 %. Generalized additive models revealed that only half of the observed increases in A_n (13.2 %) could be attributed to eCO_2 while rising T_{air} accounted for the other half. Even more striking, eCO_2 reduced g_s as expected (-6.6 %), but these effects were overridden by the direct effect of T_{air} on g_s , explaining a net increase over the last 150 years. While reconstructed A_n and g_s values fall into physiologically realistic ranges of values obtained with conventional methods, the detected eCO_2 effects on A_n and g_s are at least 50% lower than effects described in previous model- or proxy-based studies (Lammertsma et al. 2011; Ehlers et al, 2015; Walker et al. 2021).

Our study shows that the new modelling framework can generate potentially transformative new process-based understanding of the effects that eCO_2 has on the exchange of carbon and water by plants and can help with this to close critical knowledge gaps in ecosystem and earth system sciences.

Session C - Carbon and Nitrogen Isotopes

Tracing belowground plant-soil and plant-plant interactions via $^{13}CO_2$ and ^{15}N -ammonium nitrate

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Stable isotope labelling is a powerful approach to study carbon allocation of plants into primary and secondary metabolism. The latter yields a wide variety of volatile organic compounds (VOCs), which play an important role in plant defense and signaling

In this labelling experiment, we investigated belowground nutrient exchange between neighboring trees and *de novo* synthesis of VOCs under simulated herbivory. We addressed, whether forest trees sense, via their root systems, if their neighbors are suffering from herbivore attack, and if, as part of these belowground interaction, nutrients are transferred from stressed senders to neighboring receivers.

To this end, pairs of Norway spruce (*Picea abies*) and European beech (*Fagus sylvatica*) were grown in mixed- and monospecific combinations (n = 6) using a split-root design. Continuous measurements of VOC

emissions and gas exchange from shoots and soil were conducted over a 10-day period using PTR-TOF-MS and $^{13}CO_2$ spectroscopy. Following an initial control phase, sender plants were treated with jasmonic acid (JA) to simulate herbivory and subsequently labeled with $^{13}CO_2$ and $^{15}NH_4NO_3$. After completion of the labeling experiment, plants were destructively harvested and $\delta^{13}C$ and $\delta^{15}N$ signatures were determined in leaves or needles, branches, stems, coarse roots, and fine roots via EA-IRMS.

JA treatment induced a significant increase in *de novo* VOC biosynthesis in sender plants, as reflected by enhanced terpenoid emissions and strong incorporation of ^{13}C into emitted compounds. VOCs emitted during daytime exhibited higher $\delta^{13}C$ values than those emitted at night, suggesting a greater contribution of recently assimilated carbon during the day and older carbon pools during the night. Isotopic analyses further revealed carbon exudation into the rhizosphere as well as nitrogen transfer from sender to receiver plants.

These results suggest that belowground signaling enables early up-regulation of herbivore-induced defenses in neighboring plants

Future ^{13}C -labeling experiments will focus on quantifying the proportion of recently fixed photoassimilates allocated to the synthesis of root VOCs and determining the extent to which these compounds are subsequently mineralized by the soil microbiome.

Rhizosphere strategies of crops to cope with soil resource limitation: From old landraces to modern inbred lines and hybrids

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A comprehensive understanding of crop strategies for soil resource acquisition is critical for achieving sustainable food security as climate change progresses. Root and rhizosphere traits are central for the acquisition of water and nutrients, yet variety-specific rhizosphere strategies, their plasticity, and their responses to changing resource availability remain largely obscure. Here, we investigated root and rhizosphere traits along two contrasting belowground strategies, do-it-yourself (DIY) vs. outsourcing, and how these strategies respond to soil resource limitation.

In controlled greenhouse experiments, landraces and modern cultivars of wheat, maize and barley were exposed to drought or nutrient limitation to analyse modifications in rhizosphere strategies for soil resource

acquisition. We analysed key functional root and rhizosphere traits along with their connection to the acquisition of ^{15}N -labelled fertilizer and the cycling of soil organic matter (SOM) quantified using $^{13}\text{CO}_2$ labelling of plants.

We found that maize landraces invest in long root systems with high specific root length and follow a DIY strategy, whereas hybrids were classified as outsourcers showing high associations with mycorrhizal fungi. Moreover, landraces were more drought-responsive compared to modern cultivars. Thus, we suggest that intensive breeding led to distinct rhizosphere strategies in maize. In contrast to maize, however, wheat breeding did not cause divergent rhizosphere strategies despite significant differences in performance and biomass allocation. Finally, new barley hybrids were assumed to exhibit root traits for efficient N acquisition and acceleration of SOM decomposition for nutrient mineralization. However, N acquisition and SOM cycling was mainly controlled by plant age and less by the cultivar or N fertilization.

Overall, our findings suggest that the effect of intensive breeding on crop rhizosphere strategies is highly species-specific. This effect was pronounced in maize but was not observed in wheat, indicating that intensive breeding has not homogenized wheat rhizosphere strategies to the same extent as in maize. In barley, factors such as plant age had a strong influence on variations in rhizosphere strategy. In conclusion, our results provide a better understanding of the factors that determine crop-specific rhizosphere strategies, which is essential for harnessing the functional diversity of root and rhizosphere traits in future agricultural systems.

Isotopic analyses on intensively manured first medieval pea varieties

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Today, peas are among the most important sources of calories and essential amino acids worldwide. They were one of the first crops cultivated in the Neolithic period, and their wise cultivation, including intensive manuring management, enabled the emergence of Neolithic settlements with thousands of inhabitants (Schlütz et al. 2023). In the mid-19th century, Mendel discovered the fundamentals of genetics by crossing varieties of peas, of which there are now well over a hundred adapted to different needs and requirements. However, the history of pea varieties has hardly been studied until now.

Here we demonstrate based on morphological and isotopic analyses of a rich charred mass find from

medieval middle Germany, that at least four distinctly different varieties were already being cultivated some 700 years ago, with characteristic differences in morphology, starch, amino acid and isotope content of their seeds. They were bred for various purposes. Achieving high yields required a labour-intensive process in which the natural sandy soil was transformed into fertile garden soil through intensive manuring with dung.

Schlütz, F., Hofmann, R., Dal Corso, M., Pashkevych, G., Dreibrodt, S., Shatilo, M., Terna, A., Fuchs, K., Filipović, D., Flohr, P., Makarewicz, C.A., Terna, S., Videiko, M., Rud, V., Müller, J., Kirleis, W., 2023. Isotopes prove advanced, integral crop production, and stockbreeding strategies nourished Trypillia mega-populations. *Proc. Natl. Acad. Sci. U.S.A.* 120(52), e2312962120. doi:10.1073/pnas.2312962120.

The carbonate factory above a dormant volcanic lake (Laacher See, Germany): A multi-isotope approach

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The Laacher See, an enclosed lake system in the German Eifel Region, was formed by a phreatomagmatic eruption about 13000 years ago. The catchment is still affected by underlying volcanic activity, that acts as a source of CO_2 for the lake and surrounding groundwater. This setting makes a unique natural laboratory for investigating carbonate mineral proxy formation and the role of benthic diagenetic transformations in the sedimentary filter, that modifies the CO_2 fluxes towards surface water and finally the atmosphere.

We investigated the lake water column, porewaters, and sediments on a seasonal base using sediment cores of up to 6 m length; and groundwater samples from springs and wells in the larger catchment area. While the porewater's carbon isotope composition of dissolved inorganic carbon (DIC) indicates for the first time very different microbially catalyzed diagenetic processes, the oxygen and hydrogen isotope compositions of porewaters reflect distinct water sources. In combination with the stable isotope composition of sedimentary FeMnCa carbonate solid-solutions, these results allow for the characterization of sites of primary

authigenesis and allow for the interpretation of carbonate proxy records.

The lake water contains typical low sulfate concentrations. The porewater generally reflects a shallow zone of intense net microbial sulfate reduction in the surface sediments, thereby contributing to DIC accumulation. Deeper porewater gradients indicate a constant flux of low concentrations of dissolved sulfate from a subterrestrial source. The stable isotope signatures of extracted iron sulfides in the surface sediments demonstrate an enrichment of ^{32}S when compared to the present water column sulfate and, at depth, temporal dynamics in the relation between sulfate fluxes versus sulfide fixation, probably further impacted by primary productivity.

Session D - Microorganisms and Soil Invertebrates

Hydrogen isotopes of fatty acids reflect the tricarboxylic acid cycle activity in bacterial two-species culture

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The hydrogen isotope composition of fatty acids ($\delta^2\text{H}_{\text{FA}}$) is strongly associated with central metabolism in microbes. In single species cultures of diverse bacteria, $\delta^2\text{H}_{\text{FA}}$ values increase with higher tricarboxylic acid cycle (TCA) activity. If this signal is conserved in complex communities, $\delta^2\text{H}_{\text{FA}}$ values can serve as an *in situ* as proxy for group-specific microbial metabolism, with potential applications for reconstructing past community metabolism and modern carbon use efficiency. Here, we used single- and two-species cultures of the Gram-positive *Bacillus aerius* and the Gram-negative *Pseudomonas* sp. grown on glucose or succinate to test whether species interactions impact the metabolic signals encoded in $\delta^2\text{H}_{\text{FA}}$ values. Consistent with previous investigations, we found that $\delta^2\text{H}_{\text{FA}}$ values from single species cultures grown on succinate, the TCA-cycle intermediate, were as much as 210 ‰ higher as compared to cultures from the same species when grown on glucose. These differences were generally maintained in two-species cultures. However, glucose-cultured *Pseudomonas* $\delta^2\text{H}_{\text{FA}}$ values increased by ~78 ‰ when grown together with *Bacillus aerius* as compared to *Pseudomonas* $\delta^2\text{H}_{\text{FA}}$ values when grown alone on glucose. This ^2H -enrichment of *Pseudomonas* fatty acids from mixed vs. single-species cultures was due to the consumption of acetate released by *Bacillus*. These results demonstrate that $\delta^2\text{H}_{\text{FA}}$ values reflect high TCA-cycle

activity in two-species cultures, providing a foundation for applications in more complex systems.

What can we learn from the combined application of stable isotopes, microbiological investigations, and numerical modeling of the hyporheic zone with different sediment characteristics for understanding methane emissions from streams?

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Methane (CH_4) is one of the most important anthropogenic greenhouse gases alongside CO_2 and contributes to global warming. Although inland waters cover only a small proportion of the terrestrial surface, they are thought to contribute disproportionately to atmospheric methane emissions. A deeper understanding of methane cycling in streams is, therefore, essential for quantifying their contribution to the global methane emission budget and for developing mitigation strategies.

The hyporheic zone (HZ), where surface water and groundwater interact, represents a hotspot of microbial activity in streams. Under anoxic conditions, organic matter is converted to CH_4 via intermediates such as hydrogen, acetate, and methanol. During advective or diffusion-controlled transport of methane through the HZ, CH_4 may be oxidized to CO_2 either aerobically by dissolved oxygen or anaerobically using nitrate, nitrite, iron, or sulfate.

As part of a field study, high-resolution porewater profiles were obtained at several sites along a stream using peepers. The sediments are characterized by different sediment compositions and sediment permeabilities. In coarse-grained, highly permeable sediments, predominantly advective exchange may transport dissolved O_2 , NO_3^- and SO_4^{2-} to depths of tens of centimeters, and no methane accumulation was observed. At stream-sites with finer-grained sediments and probably diffusion-limited supply of electron acceptors, a methanogenic zone developed, and methane ebullition seems to be an important transport mechanism. Analysis of depth profiles of CH_4 concentrations and $\delta^{13}\text{C}\text{-CH}_4$ signatures provided some evidence of microbial methane production and oxidation and their spatial redox zonation. These findings were also supported by the monitored microbial community composition.

However, the close spatial overlap of the O_2 and NO_3^- gradients within the methane oxidation zone meant that the dominant electron acceptor for methane oxidation

could not be identified from the microbiological data and concentration and isotope profiles. For quantitative assessment, a one-dimensional reactive transport model was developed using PHREEQC. The model coupled solute transport with Monod kinetics and integrated hydrochemical profiles, transport parameters, and microbiological data. Model results suggest that nitrate-/nitrite-dependent anaerobic oxidation of methane is an important process contributing to microbial methane oxidation.

Based on our results, we hypothesize that sediment composition and particularly the sediment permeability may influence microbial community composition and, in turn, the development and spatial distribution of biogeochemical reactions and chemical gradients. Our results suggest that numerical modeling is an important tool for process-understanding in the HZ and that, under transport-limited conditions, anaerobic methane oxidation using nitrate/nitrite as electron acceptors seems to be a relevant process.

Soil invertebrates actively regulate nitrogen cycling in forests

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Nitrogen (N) is a key nutrient for plant productivity in many terrestrial ecosystems where invertebrates play a crucial role in nitrogen mineralization through litter decomposition. Yet, the role of invertebrates in mediating plant nitrogen assimilation remains unclear. In a field experiment using nitrogen stable isotope ¹⁵N-labeled leaf litter across three tropical rainforests and two temperate forests, we found that invertebrate access accelerated litter nitrogen loss in both forest biomes. However, we found contrasting downstream effects of invertebrates on plant nitrogen assimilation between temperate and tropical forests. In tropical rainforests, the presence of invertebrates reduced plant assimilation of litter-derived nitrogen by ~80%, while we

found no detectable effect of invertebrates on plant nitrogen status in temperate forests. We hypothesize that tropical invertebrates, such as termites, act as potential nitrogen reservoirs, immobilizing nitrogen within their biomass or colony and potentially mitigating soil nitrogen loss from the system via leaching. By quantifying the functional role of invertebrates in plant nitrogen assimilation, our findings provide experimental evidence that soil invertebrates represent an underappreciated pathway linking soil biodiversity, nutrient cycling and plant nutrition, particularly in tropical rainforests. Given that the nutrition status mediates plant carbon sequestration, the patterns and new concepts we present here are important in predicting how the forest biosphere-atmosphere interface will respond in an era of rapid global change.

Using stable isotopes to trace the fate of fungal necromass in soil

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Soil fungi are major agents in soil carbon (C) cycling, both actively decomposing soil organic matter (SOM) and passively via the input of SOM as fungal necromass. Most plants live in symbiosis with mycorrhizal fungi (MF), where plants provide assimilates in exchange for nutrients. Thus, MF represent a key entry point for C into the soil, further emphasizing their complex role in soil C sequestration. Although fungal necromass often exceeds bacterial or plant residues, we still lack fundamental knowledge of its fate in the soil.

We carried out three experiments using both tracer and natural-abundance stable isotopes of C and nitrogen (N) to understand necromass decomposition, recycling, and stabilization in SOM fractions. First, we quantified the contribution of fungal necromass to particulate and mineral-associated SOM in temperate forests dominated by trees with arbuscular mycorrhiza (AM) and ectomycorrhiza (ECM) using Bayesian mixing models informed by ¹³C and ¹⁵N natural abundance data from leaves, roots, MF, and saprotrophic fungi. Second, we investigated the formation of mineral-associated SOM with fungal necromass by producing highly ¹³C-enriched necromass of an AM fungus. We traced ¹³C in respiration and SOM fractions in mesocosms with

grassland soils of varying texture. Lastly, we performed a microcosm experiment with different ECM fungal species growing without a host plant on necromass and leaf litter using isotopically enriched (^{13}C , ^{15}N) medium to analyze their recycling of OM-C and N.

We found that fungal necromass was the main source of mineral-associated OM; however, in forest systems dominated by AM trees, saprotrophic fungi contributed more, whereas MF contributed more in systems with ECM trees. This indicates a suppression of saprotrophs by ECM fungi. Despite its high contribution to stable OM, fungal necromass has recently been assumed to be quickly decomposed. Confirming that, tracing the necromass-derived ^{13}C in mesocosms with different

grassland soils revealed both rapid decomposition and formation of mineral-associated OM. Surprisingly, the latter was negatively correlated with the clay content, potentially related to organic-organic associations on mineral surfaces. The freshly formed mineral-associated OM was unstable in most soils, indicating its dynamic nature. Finally, consistent with the rapid decomposition of necromass, our microcosm study showed that ECM fungi recycled more N and C from fungal necromass than from leaf litter. Collectively, the use of natural-abundance stable isotopes and stable-isotope labeling revealed a high importance of fungal necromass in both the stabilization as mineral-associated OM and as a source for C and N recycling.

Session E - Human Metabolism

Doubly Labelled Water as a Reference Method for Validating Wearable-Derived Total Energy Expenditure

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Accurate measurement of total energy expenditure (TEE) is relevant to health, nutrition, and sports research. Wearable sensors provide practical estimates of TEE, but their validity under free-living conditions remains uncertain. This study evaluated four wearable sensors using the gold-standard doubly labelled water (DLW) method as an independent reference.

Fifty-six healthy adults (66% female; age: 29.4 ± 7.2 years; body mass index: $22.9 \pm 2.6 \text{ kg}\cdot\text{m}^{-2}$) simultaneously wore four activity sensors during waking hours for ten consecutive days: two wrist-worn consumer watches (Polar Ignite 3 and Garmin vívoactive 4), an optical heart-rate sensor (Polar Verity Sense), and a research-grade accelerometer (GENEActiv). A valid measurement period required at least eight out of ten days with ≥ 12 hours of wear time per day. Valid periods were determined from wear-time logs and, where available, sensor software, yielding 33–51 valid datasets across devices and wear-time definitions.

Reference TEE was assessed using DLW containing deuterium (^2H) and oxygen-18 (^{18}O). After an individualised oral dose, participants collected repeated urine samples. Urinary isotope ratios were measured by continuous-flow isotope ratio mass spectrometry. The differential elimination of ^2H and ^{18}O was used to calculate carbon dioxide production and subsequently habitual TEE. Agreement and error were assessed using paired comparisons, percentage errors, and Bland–Altman analyses.

Mean DLW-derived TEE was $2930 \pm 697 \text{ kcal}\cdot\text{d}^{-1}$. Results were broadly consistent across the two wear-time definitions. Mean biases for the Polar Ignite 3 and Polar Verity Sense ranged from +302 to +119 $\text{kcal}\cdot\text{d}^{-1}$, and neither device differed significantly from the DLW reference after correction for multiple comparisons. Garmin vívoactive 4 and GENEActiv significantly underestimated TEE, with mean biases ranging from –264 to –418 $\text{kcal}\cdot\text{d}^{-1}$.

All devices showed substantial individual estimation errors. Across sensors and wear-time definitions, mean absolute percentage errors ranged from 14% to 17%, and only 30% to 57% of participants had an individual absolute percentage error of $\leq 10\%$. Bland–Altman

analyses showed wide limits of agreement for all devices.

Some sensors provided reasonable group-level estimates of TEE, but none were consistently accurate for individual estimates. Wearable-derived TEE should therefore be interpreted cautiously in nutritional, health, or training contexts. The study demonstrates an interdisciplinary application of stable isotope analysis for validating digital methods of assessing human metabolism.

A Pilot Method for Measuring Endogenous and Exogenous Carbohydrate Utilization

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Carbohydrates (CHO) are the primary energy substrate during endurance exercise and are supplied by exogenous (ingested) and endogenous (stored) sources. Isotopic tracer techniques quantify oxidation via carbon-13 (^{13}C) enrichment in expired CO_2 following administration of carbon-13 (^{13}C) enriched foods. Typically, exogenous CHO oxidation is measured directly, whereas endogenous CHO oxidation is estimated. This study investigated whether naturally ^{13}C -enriched CHOs can label endogenous CHO sufficiently to directly quantify endogenous CHO oxidation during exercise.

Seven endurance-trained cyclists (3 women, 4 men; age: 30 ± 6 y; BMI: $23.4 \pm 1.0 \text{ kg}\cdot\text{m}^{-2}$; $\text{VO}_{2\text{peak}}$: $52.9 \pm 5.9 \text{ mL}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$; Wmax : $380 \pm 75 \text{ W}$) completed a randomized, blinded, repeated measures study. Each participant completed one background and two test conditions, each consisting of an initial cycling session aimed to deplete endogenous stores, an overnight CHO refeed ($1.2 \text{ g}\cdot\text{kg}^{-1}\cdot\text{h}^{-1}$ for 4-h), and a 2-h steady state (SS) cycling session at 50% Wmax the following morning, during which $60 \text{ g}\cdot\text{h}^{-1}$ CHO were ingested as fuel. Test conditions were 1) high/low (high ^{13}C refeed/low ^{13}C fuel), and low/high (low ^{13}C refeed/high ^{13}C fuel). Breath samples were analyzed by isotope ratio mass spectrometry, and substrate oxidation was determined via indirect calorimetry. Exogenous and endogenous CHO oxidation were calculated using revised equations. Differences between conditions and over time were assessed using repeated-measures

two-way ANOVA with Bonferroni-adjusted post hoc tests.

Expired breath $^{13}\text{CO}_2$ enrichment changed over time in both conditions ($p < 0.001$), decreasing with high/low and increasing with low/high. Total CHO and fat oxidation rates did not differ between conditions ($p = 0.48$ and $p = 0.78$) or over time ($p = 0.29$ and $p = 0.21$). Although exogenous CHO oxidation increased and endogenous CHO oxidation decreased over time ($p < 0.001$) in both conditions, absolute rates of exogenous ($p = 0.04$) and endogenous ($p = 0.008$) CHO oxidation rates differed between conditions.

Naturally ^{13}C -enriched CHOs can be used to label endogenous CHO stores and subsequently be detected in expired breath during exercise, supporting the feasibility of directly tracing endogenous CHO oxidation. Revised equations produced estimates consistent with total CHO oxidation. However, the refeeding period may have been too short to fully label endogenous CHO stores, thus underestimating endogenous and overestimating exogenous CHO oxidation in the high/low condition. Future studies should optimize glycogen labelling protocols and further validate this approach.

Supercritical Fluid Chromatography for Sample Clean-up in IRMS Including Cholesterol as New ERC

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Doping control samples showing elevated urinary concentrations of testosterone or testosterone metabolites are forwarded to isotope ratio mass spectrometry-based determinations in order to differentiate between naturally elevated concentrations and doping offenses. The sample preparation encompasses liquid-liquid and solid-phase extraction steps and enzymatic deconjugation of steroid glucuronides. In order to separate all steroids of interest from the biological matrix and to obtain sufficiently clean urinary extracts, high performance liquid chromatography (HPLC) with fraction collection is currently employed in routine doping controls. This preparation step is very time consuming as each HPLC run requires approx. 45 min, and the evaporation of collected fractions containing water and acetonitrile lasts for up to 90 min.

Supercritical fluid chromatography (SFC) employs liquid carbon dioxide as eluent combined with other organic solvents like methanol or acetonitrile as modifiers. The unique physiochemical properties of liquid carbon

dioxide enable to accelerate the chromatographic separation of different compounds and subsequently collected fractions only contain the modifier and additional methanol as make-up solvent which enables a very fast evaporation within 10 minutes.

Considering the potential benefits, a method was developed and validated in-line with current World Anti-Doping Agency-based regulations for doping control purposes encompassing testosterone, epitestosterone, dehydroepiandrosterone, androsterone, etiocholanolone, 5 α - and 5 β -androstanediol as target analytes and cholesterol, pregnanediol, 16-androstenol, and 11-oxo-etiocholanolone as endogenous reference compounds. The observed measurement uncertainties ranged from 0.3 to 0.7 ‰ and limits of quantification were found between 3 (dehydroepiandrosterone and testosterone) to 56 (androsterone) ng/mL for a 20 mL urine specimen. Reference population data encompassed 40 female and 40 male routine doping control samples. Cholesterol as a potential new endogenous reference compound was carefully investigated employing additionally dried blood spots collected together with the 80 urine samples used for the population-based studies. As proof-of-concept, samples derived from a testosterone gel administration trial were investigated, comparing the current HPLC-based and the new SFC-based sample clean up, resulting in comparable carbon isotope ratios.

Session F - Soil and Trees

Tracing the flux of C through the Amazon forest – using a FACE experiment as a ^{13}C -labeling tool

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Tropical forests are important global carbon sinks, accounting for around one third of the total land-based carbon sink. They therefore annually compensate for a significant proportion of global anthropogenic CO_2 emissions. Therefore, understanding the flux of C through tropical forests, and what will drive their capacity to sequester C in the future, is of key importance. Studying forest acclimation to elevated CO_2 concentrations is made possible through Free Air CO_2 Enrichment (FACE), an experimental infrastructure that is currently being set up in the Amazon forest north of Manaus, Brazil. This contribution will introduce the experimental setup in a tropical rainforest and exemplify how FACE experiments can be used to trace the flux of C through forest ecosystems. It will also present initial

baseline data on carbon isotopes from different biomass fractions and respiratory fluxes of this hyperdivers forest.

The AmazonFACE experimental site is an old-growth, closed-canopy terra firma forest growing on Ferralsol/Oxisol soil with strong phosphorus limitation. It is located approximately 70 km north of Manaus. The forest experiences an annual dry season from July to September, with an average air temperature of around 26 °C and approximately 2,400 mm of rainfall per year. Over the past two years, six experimental plots, each with a diameter of 30 m, have been set up and equipped with FACE towers and canopy cranes. The CO₂ enrichment experiment aims to increase the atmospheric CO₂ concentration by 200 ppm, with the intention of starting within the next six months. The ¹³C-depleted CO₂ used to increase the concentration will also reduce the δ¹³C of the atmospheric CO₂ by around 10 ‰. This change will enable the flux of C through the forest to be traced and the turnover of C in different pools to be analysed. Particular focus will be given to fast-turnover C pools, such as leaf C, sugars transported in the stem phloem, and respiratory C pools. In the long term, the focus will shift to C turnover in trees biomass fractions of different functional types such as light- and shade adapted species, lianas, palms and epiphytes, as well as C allocation to belowground biomass and processes.

Mechanistic models identify source water and leaf water effects in a European tree-ring cellulose oxygen isotope network

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The oxygen isotopic composition of tree-ring cellulose (δ¹⁸O_{cellulose}) carries information about the δ¹⁸O values of plant source water, and therefore hydroclimate conditions during cellulose formation. Linking the measurement to climate and environmental conditions can be challenging because the seasonal origin of plant source water, and the temporal climate coupling is typically poorly constrained. Oxygen isotope mixing between leaf and source water pools and exchange with carbohydrates (*p_{expx}*), variable isotope fractionation between water and carbohydrates (*ε_{wc}*), and other such factors further modify the isotope signal in δ¹⁸O_{cellulose} values and can potentially dominate, so that local climate conditions such as relative humidity and temperature become the primary driver.

Over the past several decades, the duration and quality of the instrumental climate record have increased, as has spatiotemporal coverage of monthly precipitation isotope data. This has been augmented by improved climate reanalysis products such as ERA5, and PIsO.AI, a model that hindcasts historical monthly precipitation isotope values using instrumental climate data. We used monthly products from these sources from 1950 to 2020 together with established mechanistic δ¹⁸O_{cellulose} models to predict values and compare with annual tree-ring measurements from 45 European sites. Our mechanistic modelling framework allowed us to evaluate different seasonal averaging for plant source water and climate, and different parameterizations of inputs such as *p_{expx}*, *ε_{wc}*, leaf temperature, recycled moisture, and wind. By comparing predictions with measurements across all sites, we identified the model choices consistently associated with the best accuracy. More importantly, we could identify main drivers underlying the site-specific dominance of source water or leaf water. This provided improved seasonality constraints on the δ¹⁸O_{cellulose} signal, the relative importance of specific parameterizations, and the capacity to resolve post-source water isotope effects. Our analysis shows that summer and annual source water δ¹⁸O signals were the most dominant seasonal signal across the site network, in contrast to other seasons. We also found mixed importance of cellulose-, leaf water-, and source water-effects by site, which could not be definitively attributed to specific regions or climate conditions. This supports the assertion that tree-ring δ¹⁸O_{cellulose} interpretations are best informed by local calibration in order to best understand how a given record carries information about the hydroclimate signal from a particular season, and the degree to which it is shaped by climate driven isotopic modification of leaf water, and mixing and exchange with source water during cellulose formation.

Disentangling Soil and Atmospheric Drought Imprints: Intra-Annual δ¹³C in tree rings across ecological gradients

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Tree-ring stable carbon isotopes (δ¹³C) are cornerstone proxies for reconstructing past ecohydrological variations and evaluating tree physiological responses to environmental stress. Their signature reflects the physiological balance between photosynthetic carbon assimilation and stomatal conductance, altering δ¹³C

fractionation as trees regulate water loss during environmental stress. However, conventional annual-resolution analyses compress a full growing season into a single value, obscuring sub-seasonal environmental signals and wood formation dynamics. To overcome this limitation, we used high-resolution laser-ablation isotope-ratio mass spectrometry (LA-IRMS) to evaluate ten sequential $\delta^{13}\text{C}$ measurements within individual tree rings, disentangling the concurrent influences of atmospheric demand (vapour pressure deficit, VPD) and soil moisture.

We established a regional baseline across a climatic gradient in the Swiss Alps and evaluated three co-occurring conifers: Scots pine (*Pinus sylvestris*), Norway spruce (*Picea abies*), and silver fir (*Abies alba*). The intra-ring profiles showed high synchrony driven by seasonal variations in VPD and soil water potential (SWP). Under moist conditions, profiles exhibited a characteristic "bell-shaped" pattern, reflecting the incorporation of spring and autumn "cool" carbon. Conversely, severe drought shifted this to a "monotonic rise," with compounding summer atmospheric dryness and soil water limitations driving continuous $\delta^{13}\text{C}$ enrichment before premature growth cessation. *P. sylvestris* emerged as the most consistent and responsive recorder of these dual environmental drivers.

Building on this framework, we present a 23-year LA-IRMS chronology from the long-term Pfywald irrigation experiment (Switzerland). Because naturally dry control trees and irrigated trees share identical atmospheric demand (VPD) but differ in soil volumetric water content (VWC), this setup provides a robust experimental test to separate effects on $\delta^{13}\text{C}$ magnitude from seasonal signal timing. Control trees exhibited persistent $\delta^{13}\text{C}$ enrichment relative to irrigated counterparts, consistent with stronger stomatal limitation. Crucially, this treatment offset was non-uniform, amplifying significantly in the middle and late portions of the ring. Using daily climate moving windows, we linked the onset of soil drought to the duration of the carbon-integration window. Control trees experienced early truncation of xylem carbon incorporation under late-season drought, whereas irrigated trees sustained gas exchange and wood formation over an extended seasonal window.

Together, these studies demonstrate that soil water aridity does not merely shift the baseline $\delta^{13}\text{C}$ signal; it fundamentally reconfigures the seasonal window during which atmospheric drought is recorded in wood. Transitioning from static annual averages to high-resolution carbon-incorporation kinetics is critical for refining forward models of forest carbon sequestration and improving paleoclimate reconstructions under global change.

²H-enrichment of plant carbohydrates is not necessarily associated with a low-biomass "stress" state

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Hydrogen isotope variability in plant carbohydrates has been suggested to reflect shifts in carbon routing through primary metabolism. Carbohydrates often become relatively ²H-enriched when reactions enriching cellulose sugar substrates are upregulated (e.g. low CO₂ or low light), metabolite cycling increases (e.g. heterotrophic tissues or sink-limited growth), or stored carbon reserves are remobilized. This has led to the expectation that ²H-enrichment reflects stress and reduced growth. However, whether this relationship holds across environmental drivers remains unclear.

We analysed cellulose $\delta^2\text{H}$ across a 100-year record (1914–2013) from the long-term Rothamsted Park Grass Experiment and found no consistent relationship between cellulose $\delta^2\text{H}$ and biomass. Instead, cellulose was relatively ²H-enriched under higher nutrient supply, contrary to the expectation that enrichment reflects low carbon autonomy or reduced growth. To isolate the effects of atmospheric CO₂ and nutrient availability, we conducted a controlled-environment experiment using a dominant grassland herb and grass species grown under factorial CO₂, nitrogen and phosphorus treatments. We measured $\delta^2\text{H}$ of leaf sucrose and cellulose, normalized to leaf water, alongside biomass and sugar–starch partitioning.

Across both species, leaf sucrose and cellulose showed similar isotope responses, indicating that much of the treatment signal was already present in source-leaf sucrose before cellulose synthesis. Carbohydrates were relatively ²H-enriched under low CO₂ and full nitrogen and phosphorus supply, whereas nutrient deficiency shifted sucrose and cellulose towards more ²H-depleted values, particularly at moderate to high CO₂. Because the largest growth response was driven by nutrient availability, this produced a positive, rather than negative, relationship between carbohydrate $\delta^2\text{H}$ and biomass. Nutrient treatments also altered sugar–starch partitioning, but this mechanism aligned more clearly with the starch-buffering herb than with the fructan-buffering grass. The shared isotope response across species with contrasting storage strategies suggests that $\delta^2\text{H}$ cannot be attributed solely to transitory starch dynamics, but instead reflects a broader nutrient-dependent shift in source-leaf sucrose metabolism and carbon allocation.

Together, these results indicate that carbohydrate ^2H -enrichment may not be a universal marker of stress or reduced biomass. Instead, the direction of $\delta^2\text{H}$ change appears to depend on the environmental driver and the metabolic route by which carbon is partitioned among soluble sugars, storage pools and structural carbohydrates. This complicates simple attribution of ^2H -enrichment to stress while highlighting the potential of carbohydrate $\delta^2\text{H}$ as a sensitive tracer of source-leaf carbon allocation.

Bicarbonate leakage from the chloroplast explains the environmental sensitivity of mesophyll conductance

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The CO_2 concentration present at the site of carboxylation is a key determinant of the rate of photosynthesis in C_3 plants. Just as stomata restrict CO_2 diffusion from the ambient air into the intercellular air space (IAS), mesophyll components restrict the diffusion from the IAS to the site of carboxylation. However, unlike stomatal conductance, the magnitude and nature of mesophyll conductance (g_m) has been highly debated over the years. Increasing evidence suggests that g_m is not a constant, but variable in the short-term to changes in environmental parameters, such as CO_2 concentration, light intensity, and temperature. However, to date, no conclusive agreement has been reached as to what are the major contributors to this variability (Márquez and Busch, 2024).

Previous work has shown that g_m needs to be separated into a wall and a chloroplast component, which causes some of the observed variability of g_m (Tholen *et al.*, 2012, Busch *et al.*, 2020). Here, we investigate other physiological mechanisms that influence how g_m responds to short-term environmental changes and formulate a mechanistic model that explains this variability by accounting for bicarbonate leakage from the chloroplast. By integrating the subcellular network of CO_2 sinks and sources with the parallel and counter-directional diffusion of CO_2 and bicarbonate, the model identifies chloroplast envelope permeability to bicarbonate as a likely major contributor to g_m variability. This framework accurately predicts g_m responses across environmental gradients that were estimated by photosynthetic carbon isotope discrimination. The model uses only two fitted parameters linked to physical leaf properties and couples seamlessly with the

Farquhar-von Caemmerer-Berry photosynthesis model. By resolving the mechanistic basis of g_m variability, our approach improves predictions of plant CO_2 assimilation and offers a scalable tool for modeling photosynthesis from the leaf to the global level.

BUSCH, F. A., HOLLOWAY-PHILLIPS, M., STUART-WILLIAMS, H. & FARQUHAR, G. D. 2020. Revisiting carbon isotope discrimination in C_3 plants shows respiration rules when photosynthesis is low. *Nature Plants*, 6, 245-258.

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THOLEN, D., ETHIER, G., GENTY, B., PEPIN, S. & ZHU, X.-G. 2012. Variable mesophyll conductance revisited: theoretical background and experimental implications. *Plant, Cell & Environment*, 35, 2087-2103

Session G - Climate & Atmosphere + Methods

Sweet Deception: Using Sorbitol to Detect C_4 -type Sugar Adulteration in Apple Juice

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Apple juice is one of the world's most widely consumed fruit juices and is therefore a potential target for economically motivated adulteration (EMA). Such adulteration may involve dilution with water, substitution with other, cheaper juices, or the addition of exogenous sugars, each requiring robust analytical methods for detection. Here, we present a new method for identifying the addition of exogenous C_4 -type sugars to apple juice by using the naturally occurring sorbitol compound as an endogenous isotopic reference marker.

The method uses liquid chromatography coupled to isotope-ratio mass spectrometry (LC-IRMS) to determine the $\delta^{13}\text{C}$ values of the major endogenous sugars, as well as sorbitol, in apple juice. We show that the $\delta^{13}\text{C}$ value of sorbitol can be measured in the same analytical run as the other major sugar components and that this value remains unaffected by the addition of exogenous C_4 -type sugars to apple juice. Detection levels of the C_4 adulterants were found to be in the range of 5–10%. This method offers significant advantages over existing approaches, notably by

eliminating the need for extensive sample preparation and the use of multiple analytical methods, thereby improving analytical throughput and ease of use.

Advancing molecular-level isotope ratio analysis with an integrated Orbitrap-IRMS workflow

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Stable isotope measurements are widely used to investigate sources, transport, and transformation processes in environmental and geochemical systems. Orbitrap-based isotope ratio mass spectrometry (Orbitrap-IRMS) complements conventional approaches by measuring isotope and isotopologue ratios directly from intact molecular ions using high-resolution accurate-mass detection, thereby retaining molecular context. We present a new, integrated workflow combining the Thermo Scientific™ Orbitrap™ Isora™ MS, Vanquish™ Duo UHPLC System, and Isotope Discoverer™ Software. The workflow streamlines alternating sample/reference introduction, isotope ratio acquisition, calibration, visualization, and reporting, converting raw Orbitrap mass spectra into calibrated δ values through a transparent processing sequence.

The analytical breadth of the approach is demonstrated using nitrate and glutamic acid. Analysis of intact nitrate ions provides $\delta^{15}\text{N}$, $\delta^{17}\text{O}$, and $\delta^{18}\text{O}$ information within a single method, supporting investigation of nitrogen sources and transformation pathways. High-resolution detection also resolves low-abundance, multiply substituted isotopologues, extending the isotopic information available from nitrate.

Glutamic acid extends this molecular-level analysis by combining intact molecular ion measurements with controlled HCD fragmentation, enabling simultaneous measurement of $\delta^{15}\text{N}$, $\delta^{13}\text{C}$, $\delta^2\text{H}$, and $\delta^{13}\text{C}$ of the fragment on a single analytical platform. Fragment-ion measurements provide position specific information, including the ^{13}C composition of the C1 carboxyl group and the C₂-C5 backbone.

Together, these applications demonstrate how Orbitrap-IRMS can connect multi-isotope measurements with molecular structure, broadening the information available for environmental, geochemical, and biogeochemical research.

Toward Robust GC×GC-C-IRMS Through the Development of Ni-Wall-Coated Microreactors

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The online combustion of analytes between gas chromatography and isotope ratio mass spectrometry (GC-C-IRMS) has enabled compound-specific isotope analysis (CSIA) for various applications, such as assessment of environmental contaminants or doping in sports. However, CSIA is challenged by the need for complete peak separation and improved sensitivity. Comprehensive gas chromatography (GC×GC) could deliver a breakthrough, but hinges on the development of robust miniaturized online combustion tubes that offer sufficient oxidation capacity and catalytic surface area to accomplish complete analyte conversion to CO₂, while being narrow enough to preserve sharp peak shapes within the continuous flow carrier stream.

The current setup involves a transition from narrow GC capillary columns (inner diameter, i.d.: 0.22–0.32 mm) to comparatively wide commercial combustion tubes (i. d. 0.5 mm) generating substantial peak broadening. Even smaller GC capillaries are needed, however, to support GC×GC applications and to improve sensitivity by reducing flows and minimizing losses in an open split before the IRMS. Consequently, alternative miniaturised reactor tubes are needed that are sufficiently narrow, yet robust enough for routine applications.

To drive this development with a step change in the miniaturization and robustness of conversion reactors, we developed nickel wall-coated microreactors through electroless plating. This design drastically reduced the reactor volume while maintaining the catalytic surface area and ensuring robustness and longevity with several hundred measurements per reactor. Reactor performance was validated with challenging heterocyclic aromatics such as caffeine which showed excellent accuracy ($\Delta\delta^{13}\text{C} = -0.16\text{‰} \pm 0.12\text{‰}$). A proof of principle test with n-alkanes demonstrated a strong reduction in the peak width (FWHM) from 2.2s to 0.61s resulting higher sensitivity and better peak resolution compared to the current commercial configuration [1]. Thus, our setup lays the foundations for developments requiring high sensitivity and narrow peak widths, such as GC×GC-C-IRMS.

1) Al-Ghoul, H., & Elsner, M. (2026). Nickel Wall-coated Microreactors for Enhanced Sensitivity and Peak Resolution in Compound-specific Carbon and Nitrogen Isotope Analysis. *Analytical Chemistry*, 98(21), 15565-15575.

High-temporal resolution measurements of radiocarbon in atmospheric CO₂ for source sector attribution of urban emissions

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Urban areas dominate anthropogenic CO₂ emissions and play a key role in climate change mitigation. Efficient emissions reduction requires improved knowledge of the attribution of carbon emissions. Measuring the ¹⁴C (radiocarbon) content of atmospheric CO₂ is the most direct method to distinguish fossil CO₂ emissions (ffCO₂) from biogenic and natural fluxes due to their lack of ¹⁴CO₂ content. Hence, CO₂ produced from the combustion of fossil fuels causes a measurable decrease in the atmospheric ¹⁴CO₂/CO₂ isotope ratio. Results from flask sampling campaigns indicate the potential of high time resolution ¹⁴C measurements to attribute flux estimates using urban-scale inversions.

We present a novel analytical platform for autonomous and semi-continuous analysis of Δ¹⁴C-CO₂ in atmospheric air samples with sub-hourly time resolution. The core of the analytics is based on a saturated-absorption cavity ring-down (C14-SCAR) spectrometer (ppqSense). This is coupled to a custom-developed compact quantum cascade laser absorption spectrometer (C13-QCLAS) to provide CO₂ purity and δ¹³CO₂. The C14-SCAR and C13-QCLAS share an automated pre-concentration device (NC Technologies), to purify CO₂ from air applying a temperature-swing zeolite adsorbent trap and remove N₂O interferences. We showcase performance characteristics of the coupled C14-SCAR / C13-QCLAS system for sensitive, i.e. ppm-level detection of fossil CO₂ contributions in urban environments, and present first time series data for a monitoring site in the vicinity of Zürich (Dübendorf). Results will be discussed in conjunction with city-wide observations of CO₂ and high-resolution simulations of ffCO₂ variability.

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Comparison of different observational methods to quantify methane emissions from an active landfill in Romania

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On a global level, solid waste management represents a significant source of atmospheric methane (CH₄), yet methodological limitations contribute to their emissions remaining poorly constrained. In this study, we investigate CH₄ emissions from a landfill near Bucharest, Romania, using a variety of continuous and campaign-based monitoring methods and atmospheric modelling approaches. A 30 m observational tower was installed 10 km NW of the landfill site and continuous measurements of CH₄ and C₂H₆ mole fractions as well as δ¹³CH₄ (G2201-i, Picarro; MIRA ULTRA, Aeris) have been initiated in June 2026. As different CH₄ sources are characterised by differences in their isotopic signatures and CH₄/C₂H₆ ratios, these characteristics provide valuable constraints for identifying emission sources and quantifying their emissions strength in inverse modelling approaches. First results indicate frequent CH₄ plumes attributable to the landfill (δ¹³CH₄: -58 ‰, CH₄/C₂H₆ > 1500) as well as contributions from other nearby biogenic and fossil sources (δ¹³CH₄: -38 ‰, CH₄/C₂H₆ < 100). Campaign-based mobile CH₄ measurements (LI-7810, Licor) perpendicular to the main wind direction are used for Gaussian plume emission quantification. Initial transect measurements in June 2026 indicate landfill emissions of about 2 Mg CH₄ h⁻¹, consistent with the average emission rate quantified by Carbon Mapper (August 2024 to June 2026; 1.9 ± 0.5 Mg CH₄ h⁻¹). In addition, bag samples are collected in the emission plume of the landfill to provide δ¹³CH₄ (June 26: -57.3 ± 0.29 ‰) and CH₄/C₂H₆ ratios to aid the interpretation of the tower measurements. Both continuous tower and campaign-based mobile measurements will continue with the aim of resolving seasonal variability and providing a robust annual average emission estimate.

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State Secretariat for Education, Research and Innovation (SERI).

POSTERS – Ecohydrology, Ecosystems and Biogeochemistry

P 1 Estimating hydrogen isotope metabolic terms in the cellulose model by linear regression: kinetic isotope effects are more important than isotope exchange processes in autotrophic systems

ID: 115

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The landmark study by Yakir & DeNiro (1990) established the framework still used to interpret cellulose $\delta^2\text{H}$ variation, defining three metabolic terms within the cellulose isotope model: the fraction of carbon-bound hydrogen modified after assimilation (f_{H}), the assimilatory isotope effect (ϵ_{HA}), and the post-assimilatory isotope effect (ϵ_{HH}). In the original formulation, variation in cellulose $\delta^2\text{H}$ was attributed primarily to changes in f_{H} , an interpretation supported by Luo & Sternberg (1992) and subsequently adopted widely to resolve residual $\delta^2\text{H}$ variation. However, theoretical considerations suggest that all three terms may vary with metabolic state, yet their independent estimation has remained difficult.

Yakir & DeNiro used a linear regression approach to estimate model parameters but, because fresh assimilate $\delta^2\text{H}$ could not be measured directly, ϵ_{HH} and f_{H} were derived from heterotrophically grown *Lemna gibba* and then applied to autotrophic plants to estimate ϵ_{HA} . This assumes ϵ_{HH} and f_{H} remain constant across metabolic states. Here, by measuring leaf sucrose $\delta^2\text{H}$ directly, we estimated ϵ_{HH} and f_{H} under autotrophic growth conditions for the first time.

We applied this approach to wild-type and starchless *pgm* tobacco (*Nicotiana sylvestris*) grown hydroponically across a source-water $\delta^2\text{H}$ gradient. By comparing leaf sucrose, root sucrose, leaf cellulose and root cellulose, we tested whether post-export isotope modification occurs during phloem loading, sucrose cycling or sink-tissue carbohydrate metabolism. Roots provided a particularly constrained system because root cellulose synthesis depends on imported sucrose and is

not complicated by the heterotrophic-to-autotrophic developmental transition that occurs in leaves.

Contrary to expectations, root sucrose showed little evidence of strong ^2H -enrichment relative to leaf sucrose, suggesting limited hydrogen isotope fractionation during phloem transport or sucrose cycling. Instead, our estimates indicated substantially higher ϵ_{HH} values and lower f_{H} than previously reported, with only small differences between leaf and root cellulose. These findings suggest that ^2H -enrichment during cellulose synthesis is more likely to reflect kinetic isotope effects than hydrogen-exchange-related equilibrium isotope effects in sink-cell metabolism. In the starchless *pgm* mutant, ^2H -enrichment was partly attributable to source-leaf isotope effects, as previously hypothesized, but also indicated continued post-export ^2H -enrichment despite lower ϵ_{HH} than in the wild type. Together, these results provide the first independent estimates of ϵ_{HH} and f_{H} in an autotrophic system and demonstrate the value of linear regression approaches for separating leaf assimilatory signals from downstream carbohydrate processing.

P 2 SEEKING STABILITY: INHIBITORS FOR PRESERVING ISOTOPE RATIOS OF DISSOLVED GASES IN FRESHWATER SAMPLES

ID: 151

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Photosynthesis and respiration are the two most relevant processes in aquatic ecology, referred as ecosystem metabolism. Isotopic fractionation during those processes drives the stable isotope ratios of the resulting dissolved oxygen and carbon dioxide. Thus, ecosystem metabolism may be monitored using stable isotope analyses of dissolved gases. Storage of the samples in airtight vials is a standard procedure where immediate analysis is not feasible. Mercury chloride is widely accepted as the best-performing preservative. However, due to its toxicity and environmental hazardousness, its use is restricted in some areas, e.g. Sweden. An alternative inhibitor, preferably less toxic, is therefore needed. While several studies have evaluated alternative preservatives for carbon dioxide in freshwater samples, few have focused on conserving accurate oxygen isotope ratios. To address this gap, we compared the time-dependent performance of silver nitrate, sodium azide, zinc chloride, benzalkonium chloride, and sterile-filtration. Water samples from multiple depths within several lotic water bodies showing various chemical and physical states and productivity patterns were compared over up to one year. Concentration and isotopic ratio of the dissolved

gases were measured using highly specialized flow injection GC-IRMS. The findings of this research highlight the influence of different inhibitors on stability of stable isotope ratios providing practical guidance for aquatic ecologists to choose an effective and safe substitute for mercury chloride.

P 3 Matrix-bound oxygen and hydrogen affect the isotopic composition of water extracted from soil

ID: 143

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The effects that alter the isotopic composition of water added to soil samples that have been oven-dried previously are not fully understood, but seem to be related with exchange of oxygen and hydrogen isotopes bound to the soil matrix. To clarify the role of different soil compartments (organic matter, clay, carbonate) and the extraction efficiency in this exchange process, soils rewetted with two waters of strongly differing isotopic composition were extracted with two different cryogenic extraction approaches. This allowed to determine the amount and the isotopic composition of soil-bound oxygen and hydrogen that exchange with spike water after rewetting under different conditions. The results show that oxygen and hydrogen are differently affected from exchange with different compartments of the soil matrix

P 4 A reliable protocol for measuring primary production by tracing $^{13}\text{CO}_3^-$ incorporation into phytoplankton to substitute radiotracers

ID: 153

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Pelagic primary production is one of the most central processes in aquatic ecosystems. For more than six decades now, the standard method to monitor aquatic productivity has been paired dark and light bottle incubations with ^{14}C -labelled bicarbonate. However, with growing environmental awareness, increasingly restrictive regulations, and associated rising costs,

these monitoring programs have become increasingly challenging and, at times, prohibitively expensive. Here we take advantage of advances in stable-isotope technology to evaluate whether incubations with non-radioactive $^{13}\text{C-HCO}_3^-$ can replace the radiocarbon method without disrupting long-term time series - thus ensuring the smooth transition of monitoring efforts. As the natural ^{14}C abundance is in the range of 1 part per trillion (ppt, 10^{-12}) and the natural ^{13}C abundance is approximately 1%, ^{13}C incubation concentrations must be considerably higher than with ^{14}C labels. Moreover, as ^{13}C of particulate organic carbon (POC) is measured by mass spectrometry, stopping and preserving incubation samples must be accomplished without introducing additional carbon. A series of methodological experiments and comparisons with standard ^{14}C incubations over one year demonstrates that ^{13}C incubations may serve as an excellent alternative to measuring pelagic primary production in lakes. The approach is cost-efficient and environmentally friendly. Production rates determined along depth profiles over an entire annual cycle show that ^{13}C - and ^{14}C -methods are interchangeable and do not require empirical conversion factors.

P 5 Hillslope-controlled capillary fringe dynamics and subsurface water storage in a mixed broadleaf temperate forest ecosystem

ID: 166

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The increasing frequency and intensity of droughts due to climate change pose a growing threat to temperate forest ecosystems. Our study explores the importance of the capillary fringe that may be vital to the survival of forest species. We evaluated the selective access to, and contribution of, the capillary fringe as a zone capable of mitigating water scarcity along three positions of a hillslope. Specifically, we address: 1) Where is the capillary fringe located? 2) Is the capillary fringe important for supplying water to trees? and 3) What is the contribution of the capillary fringe to tree water uptake across species? We continuously monitored water content at different depths along a topographic gradient (hilltop, slope, and valley). We measured the isotopic composition of soil and xylem water in several species. We found a soil layer with constant water content, dependent of the hillslope position, indicating that the capillary fringe is located above this layer. During dry periods, the capillary fringe was sequentially depleted at all hillslope positions, from 1.5 to 3.0 m at the hilltop from 1.5 to 2.4 m at the slope and from 1.5 to 1.8 m in the valley. From the soil

moisture data alone, it cannot be inferred whether this soil water depletion is due to direct root water uptake or soil water transport. In order to explore this further, we applied an isotopic tracer enriched in deuterium at a depth of 2 m during the dry season at all hillslope positions multiple times; however, no tracer signal was detected in the trees, indicating that they are not directly utilizing water from the capillary fringe. Preliminary analysis of water isotopes of plants and soils suggested water uptake depths up to 1.5 m depending on the hillslope transect. These findings show that hillslope position strongly controls the depth and seasonal dynamics of the capillary fringe. Although soil moisture data revealed sequential drying of the capillary fringe following depletion of shallower layers, the absence of a deuterium tracer signal in xylem water indicates that trees did not directly access water from this deep zone. Instead, deep-soil drying likely reflects a combination of soil water redistribution and slow vertical or lateral subsurface flow. Overall, our results indicate that drought resilience in this temperate mixed forest depends less on direct use of the capillary fringe than on hillslope-controlled subsurface water storage.

P 6 Spatial and temporal patterns of nitrogen isotopes in nitrate and ammonium across precipitation and ecosystem samples

ID: 110

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In Europe, atmospheric nitrogen (N) deposition increased from the 1950s until the 1980s before declining from the 1990s onward, while climate change has continued to accelerate. To assess the consequences of these changes for forest ecosystems, stable nitrogen isotope ratios ($\delta^{15}\text{N}$) in plant and soil samples are widely used as indicators of N availability and the ecological processes governing N cycling. However, spatial and temporal analyses of $\delta^{15}\text{N}$ often overlook potential isotopic variability in atmospheric N inputs, particularly nitrate and ammonium deposited onto forest ecosystems, because of limited observational data.

To improve our understanding of $\delta^{15}\text{N}$ variability in atmospheric N deposition and its propagation through forest ecosystems, we analyzed time series of precipitation and ecosystem samples from a long-term experimental N-addition site in Switzerland and found seasonal $\delta^{15}\text{N}$ variability in nitrate and ammonium. Further, we conducted pan-European sampling campaigns of bulk deposition, throughfall, foliage, and soil. In this poster, we will present the first preliminary results of these efforts.

P 7 Towards improved IRMS analysis of $^{15}\text{N}\text{-N}_2$ and $^{15}\text{N}\text{-N}_2\text{O}$ for denitrification research – lessons learned from an international laboratory intercomparison

ID: 136

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The denitrification products nitrous oxide (N_2O) and dinitrogen (N_2) are major contributors to gaseous nitrogen losses from soils, but N_2 emissions and $\text{N}_2\text{:N}_2\text{O}$ stoichiometry remain the largest uncertainty of the nitrogen cycle due to analytical challenges. The ^{15}N gas flux method, currently standard for in situ and laboratory quantification of N_2 emissions, combines ^{15}N -enriched fertilizer application with a chamber approach and subsequent detection of $^{15}\text{N}\text{-N}_2\text{O}$ and $^{15}\text{N}\text{-N}_2$ enrichment. Accurate ^{15}N determination requires highly sensitive isotope ratio mass spectrometry (IRMS) coupled with appropriate sample preparation systems. Particularly challenging is the detection of the $m/z=30$ ion current, due to the overlap of $^{15}\text{N}^{15}\text{N}$ with $^{14}\text{N}^{16}\text{O}$, which is typically formed in the ion source. Furthermore, no commercially available $^{15}\text{N}\text{-N}_2$ (and only limited $^{15}\text{N}\text{-N}_2\text{O}$) reference materials exist, impeding both calibration in individual laboratories and interlaboratory comparison of analytical results.

To assess current analytical capabilities, we prepared a suite of $^{15}\text{N}\text{-N}_2$ and $^{15}\text{N}\text{-N}_2\text{O}$ gas samples and distributed them to six different IRMS laboratories with targeted equipment. Samples ranged from ambient N_2 and N_2O over headspace air drawn from a chamber incubation to mixtures of ambient air with single ($^{14}\text{N}^{15}\text{N}$, ($^{14}\text{N}^{15}\text{N})\text{O}$) and double labelled ($^{15}\text{N}^{15}\text{N}$, $^{15}\text{N}^{15}\text{NO}$) components. The objective was to evaluate analytical precision, accuracy and the comparability of measurements relevant to the ^{15}N gas flux method.

Instrument precision has been assessed as variability in isotope ratios $^{29}\text{R} = ^{29}\text{N}_2 / ^{28}\text{N}_2$, $^{30}\text{R} = ^{30}\text{N}_2 / ^{28}\text{N}_2$, $^{45}\text{R} = ^{45}\text{N}_2\text{O} / ^{44}\text{N}_2\text{O}$ and $^{46}\text{R} = ^{46}\text{N}_2\text{O} / ^{44}\text{N}_2\text{O}$. Mean values $\pm$ standard deviation reached $^{29}\text{R} = (7.3528 \pm 0.0005) \cdot 10^{-3}$ and $^{30}\text{R} = (1.33 \pm 0.04) \cdot 10^{-5}$ for replicated samples of ambient air, acting as N_2 standard, as well as $^{45}\text{R} = (7.9857 \pm 0.0013) \cdot 10^{-3}$ and $^{46}\text{R} = (2.0998 \pm 0.0004) \cdot 10^{-3}$ for an in-house N_2O working standard. However, some instruments showed severalfold increased variability in individual ratios.

Lab-specific corrections of raw ^{29}R narrowed down interlaboratory variation from $7 \cdot 10^{-7}$ to $5.5 \cdot 10^{-3}$ to $7.348 \cdot 10^{-3}$ to $7.356 \cdot 10^{-3}$ (cf. $^{29}\text{R}_{\text{theoretical}} = 7.3530 \cdot 10^{-3}$), underlining the need for thorough calibration. For ^{30}R , a bias

correction is inevitable to account for NO formation, which constituted 75-99% of the raw value. Bias-corrected ^{30}R was $1.29\text{--}1.38 \cdot 10^{-5}$ among laboratories (cf. $^{30}\text{R}_{\text{theoretical}} = 1.352 \cdot 10^{-5}$). For the two ^{15}N enriched mixtures, laboratories reported $^{30}\text{R} = 1.34\text{--}3.24 \cdot 10^{-5}$ and $1.30\text{--}1.94 \cdot 10^{-5}$, respectively.

Ambient N_2O yielded 0.37-0.58 atom% ^{15}N among laboratories, while two enriched mixtures yielded 9.8-15.3 atom% and 29.6-33.7 atom%.

Overall, this interlaboratory comparison demonstrates that standardized procedures for $^{15}\text{N}\text{--}\text{N}_2$ and $^{15}\text{N}\text{--}\text{N}_2\text{O}$ analysis are currently lacking, resulting in substantial variability among laboratories, particularly for highly enriched samples. The establishment of internationally accepted reference materials, standardized calibration procedures, and harmonized analytical protocols is essential to improve accuracy, reproducibility and comparability of ^{15}N gas flux measurements for denitrification studies.

P 8 Hydraulic Redistribution barely replenishes soil water

ID: 164

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Hydraulic redistribution (HR) has been proven in ecosystems worldwide, but its magnitude and influence on the stand-level water budget are not yet well understood.

In this study, we aimed to identify and quantify the amount of water hydraulically redistributed towards shallow soil in two different environments: i.) a mixed broad-leaved forest in northern Germany and ii.) a tropical dry forest in Costa Rica.

In order to do so, we used a multi-method approach: i.) distributed shallow soil water content and matric potential monitoring; ii.) root-exclusion control plots (roots cut to prevent HR) and iii.) in situ monitoring of diurnal soil water isotope shifts, iv.) targeted isotopic deep-labeling experiments and v.) geophysical monitoring (ERT). With this multi-method approach, we address the methodological shortcomings of isolating HR from other water transport processes, like liquid or vapor water fluxes within the soil or temperature effects on the sensors or the spatial limitation of existing studies on HR.

Over a period of two years, we did not find evidence for a substantial replenishment of shallow soil water via HR at the temperate mixed broad-leaf forest even during most severe droughts; nor release of tracer taken up by the trees in the shallow subsurface. While shallow soil

water isotope values showed a trend towards more depleted isotope values over night in certain periods, this trend was weak and could not be definitely attributed to HR.

At the tropical dry forest, we found HR towards shallow soil by the deep rooting tree species *Sideroxylon capiri* (Tempisque tree). However, the appearance of redistributed water was patchy and no substantial increases in soil water contents on the stand scale were observed.

Based on our results we conclude that HR might be a process that has little relevance on stand-level water budgets and might be primarily a process relevant for plant-plant interactions.

P 9 Microbial, thermogenic, or oxidised? Isotopic characterisation of methane sources in an Arctic permafrost landscape overlying documented oil and gas seeps

ID: 138

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Arctic permafrost landscapes are among the fastest warming environments on Earth, and their changing aquatic systems are increasingly recognised as important, yet poorly constrained, sources of methane (CH_4). Stable isotopes are a powerful tool for classifying CH_4 sources. However, partial CH_4 oxidation shifts the isotope composition, so that microbial CH_4 may be misinterpreted as thermogenic. The Nuussuaq Peninsula, West Greenland, offers a rare opportunity to disentangle these sources, a permafrost landscape whose lakes, ponds and streams overlie documented petroleum bearing rocks and host active gas seeps.

This unique setting allowed us to address whether stable isotopes can distinguish microbial from thermogenic CH_4 in these aquatic systems and how CH_4 oxidation complicates that distinction. To test this, we combined $\delta^{13}\text{C}$ - and $\delta^2\text{H}\text{--}\text{CH}_4$ with Bernard ratio ($\text{CH}_4/[\text{ethane}+\text{propane}]$) analyses in the water, sediment and rising bubbles of ten lakes, ponds and streams.

$\delta^{13}\text{C}\text{--}\text{CH}_4$ ranged from -85 to -36 mUr and $\delta^2\text{H}\text{--}\text{CH}_4$ from -441 to -111 mUr. Unexpectedly, the systems richest in CH_4 , including the strongest seeps, were the most isotopically depleted, suggesting a microbial rather

than thermogenic origin. The systems lowest in CH_4 were isotopically enriched and aligned on a $\delta^2\text{H}$ vs. $\delta^{13}\text{C}$ trend consistent with CH_4 oxidation. As oxidation shifts both isotopes along this slope, we used a novel parameter, $\Delta(2,13) = \delta^2\text{H} - \Lambda \cdot \delta^{13}\text{C}$ ($\Lambda \approx 10$, the hydrogen to carbon isotope fractionation ratio), which removes the oxidation effect so that only the source signal remains. The $\Delta(2,13)$ values showed that water and bubbles shared a common source, distinct from the sediment. A thermogenic isotopic signature appeared at only one site, Gassø, whose seep gas was N_2 dominated and CH_4 poor (1.4 ppmv) despite being the most enriched in $\delta^{13}\text{C}\text{-CH}_4$ (-42 mUr) and $\delta^2\text{H}\text{-CH}_4$ (-265 mUr) of all seeps. Consistently low C_2/C_3 and Bernard ratios across all systems indicated low thermogenic influence or seeps generally depleted in hydrocarbons.

Our data suggest the following: (1) The emitted CH_4 was predominantly microbial. (2) Microbial oxidation in the studied systems likely drove $\delta^{13}\text{C}\text{-}$ and $\delta^2\text{H}\text{-CH}_4$ toward values easily mistaken for thermogenic CH_4 . (3) At Gassø, and likely at the other seeps, both the N_2 rich seep gas and the large bubble volume point to a deep gas source rather than microbial production. Yet on their way up, these bubbles apparently collect microbial CH_4 and transport it to the surface. (4) $\Delta(2,13)$ may help to correct for CH_4 oxidation and could thereby improve source classification.

P 10 Model demonstrating the differences between intrinsic and apparent temperature dependence of nitrification by substrate availability

ID: 146

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The temperature dependence of nitrification has been studied extensively. It is generally assumed that processes based on chemical reactions can be accurately modelled using the Arrhenius function. A Q_{10} value of 2 is often observed or assumed, meaning the conversion rate doubles for every 10°C increase in temperature. However, it should be noted that this is usually an 'apparent' temperature sensitivity, and the underlying intrinsic temperature sensitivity remains unclear.

Using a simple numerical model, we demonstrate how the trends in intrinsic and apparent temperature sensitivity can differ. The model was parameterised using field and laboratory measurements of gross nitrification, which were carried out using the ^{15}N -pool dilution technique. It shows how a saturation curve representing 'apparent' temperature sensitivity can arise from linear intrinsic temperature sensitivity.

P 11 Photosynthesis results in ^2H -depleted carbohydrates, but why?

ID: 154

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When you grow plants in the light, the hydrogen isotopic composition (i.e. d^2H) of plant compounds such as cellulose is ^2H -depleted relative to plants grown in the dark. Therefore, it is logical to assume that photosynthetic reactions (including both light and dark reactions) introduce ^2H -depleted hydrogen atoms into carbohydrates. It is well known that both the acidic splitting of water in PS II and the subsequent synthesis of NADPH by ferredoxin-NADP⁺ reductase (FNR) are associated with significant ^2H isotope effects. In the Calvin-Benson-Bassham cycle this NADPH molecule is introduced by glyceraldehyde-3-phosphate reductase (GAPDH) into position 4 (H-4) of glucose (glc). The enzyme GAPDH is also known to exhibit an ^2H isotope effect. Intriguingly, the H-atom in position 4 of glc tends to be one of the most ^2H -enriched positions of glucose in C_3 plants.

This raises the question of why the combination of several biochemical reactions - some of which exhibit a significant ^2H isotope effect - leads to an ^2H enrichment in the final reaction product (position H-4 in glc).

To address this issue, we examine the stereospecific mechanism of hydride transfer via NADP(H) catalyzed by oxidoreductases (FNR and GAPDH) as a key reason why photoproduced NADPH is not directly the source of ^2H -depletion of autotrophically produced carbohydrates in C_3 plants.

Of further interest in this context is, can we interpret the degree of ^2H -depletion of plant compounds with respect to this key reaction(s)? With the recent resurgence of studies offering hydrogen isotopes as a new proxy for plant central carbon and energy metabolism, such a fundamental question seems pertinent to answer.

P 12 ISOfun - A database for fungal natural abundance of stable isotopes

ID: 126

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The natural abundance of stable carbon and nitrogen isotopes ($\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values) has been used to understand the role of fungi in material cycles, as well as fungal physiology and lifestyles. Meta-analyses of large stable isotope composition datasets capture comprehensive ecological trends across broad spatiotemporal scales, yet they continue to face challenges due to data heterogeneity and inconsistent study documentation.

To overcome this hurdle, we developed a global database of natural abundance data for stable isotopes in fungi: ISOfun. This database provides a uniformly structured organisational scheme, integrating ^{13}C and ^{15}N natural abundance measurements with standardised metadata, e.g. on sample location, collection time, fungal traits, nutritional resources, and the sampling environment. Using a systematic literature search following the PRISMA workflow, we compiled data from 60 studies published up to 2026. The resulting dataset comprises 4,039 fungal sample entries spanning sampling years from 1930 to 2022. We present three distinct case studies to illustrate how the ISOfun database can be leveraged to resolve complex ecological questions at different scales and to generate novel hypotheses.

The ISOfun database compiles published data on stable isotope composition, C and N content and C/N ratios of fungi (fruit body, ectomycorrhizal root tips, intraradical hyphae, extraradical hyphae, peloton, spores, mycelium) and offers a structured framework for the future collection of data, supporting a wide range of ecological and mycological research projects.

P 34 Partitioning of Evapotranspiration in an intensively managed grassland ecosystem

ID: 168

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Partitioning of evapotranspiration (ET) allows the study of field site-specific plant water use and water stress conditions in agricultural ecosystems. ET was partitioned into its component fluxes, soil evaporation (E) and plant transpiration (T) using water stable isotopic measurements ($\delta^2\text{H}$ and $\delta^{18}\text{O}$), lysimeters and eddy covariance. Isotopic data was measured with a mobile water stable isotope laboratory (IsoMobile) in the vicinity of the ICOS-DE-RuR climate station (Rollesbroich, Germany) in an intensively managed temperate grassland ecosystem between 05.05. and 30.09.2025. Isotopic partitioning was calculated at hourly resolution from the isotopic mass balance between ET, E, and T (δ_{ET} , δ_{E} , and δ_{T} , respectively). The Keeling-plot approach was used to model δ_{ET} , using non-destructive measurements of atmospheric water vapor inside and above the plant canopy. δ_{T} was estimated destructively from xylem water extracted from composite grass samples and under the assumption of isotopic steady state transpiration. δ_{E} was modelled from the isotopic composition of *in situ* non-destructive measurements of soil water using semipermeable tubing placed below the root zone and water extracted from soil samples. Additionally, ET was partitioned using lysimeters measuring total water flux and evaporation flux (lysimeter treated with pesticide to stop transpiration). Partitioning results were confronted against time series of environmental variables measured by the climate station. Sub-daily isotopic T/ET responded to daily and seasonal changes of environmental conditions, as well as farming practices applied to the grassland. T/ET decreased significantly after the plants were cut, followed by an increase during the subsequent period of plant regrowth. T/ET estimates range between 52 to 98 % for $\delta^{18}\text{O}$ over the course of the seasons. Lysimeter-based T/ET was underestimated in comparison, ranging from 21 to 82 % between 09.07.-30.09. Prior measurements were not successful, as lysimeter T could not be suppressed fully. Water stress was not identified from the combination of environmental variables and partitioning results. From a technical view, non-destructive soil water vapor sampling was found to be a good alternative to destructive soil water sampling, matching T/ET results using destructive soil sampling with R^2 of 0.86. Meaningful δ_{E} estimations were achieved, reducing fieldwork, laboratory time and resources. Concluding, the partitioning results

presented in this study provide opportunities to investigate sub-field scale water fluxes in agricultural environments, aiding in the representation of changing water fluxes at local scales and potentially enable the tuning of large-scale environmental models.

POSTERS – Hydro(geo)logy including German Isotope Network

P 13 Isotope biogeochemistry of the inorganic carbon system in a subterranean estuary of a temperate high energy beach

ID: 156

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Subterranean estuaries (STE) connect terrestrial water and certain element cycles with the coastal marine environment and represent areas of steep biogeochemical gradients that influence, for example, the transport and transformation of carbon species. The availability of dissolved sulfate in the sediment is of particular significance, alongside with the concentration of reactive carbon compounds. Interactions with the mineral phases in the aquifer and overlying sediment can contribute to the hydrochemical modulation of the solutions that ultimately leave the sediment. Via benthic-pelagic coupling, this has an important impact on the buffer capacity of coastal surface water.

The interdisciplinary research group DynaDeep is dedicated to investigate the deep-seated dynamics in the processes of a STE characterized by permeable sands in the north of Spiekeroog Island (Massmann et al., 2023; Reckhardt et al., 2024). The beach system, in contact with the southern North Sea, represents a unique, highly dynamic STE, enabling the investigation of interactions between freshwater and saltwater with regard to current and future system changes. Boreholes and multi-level wells allow for seasonal observations of porewater composition, besides sediment sampling. In this study we discuss the results of stable isotope (H,C,O,S) analyses of dissolved (water, dissolved C and S species) and solid carbonate phases. The water isotope ratios characterize the mixing fresh groundwater endmember and allow for a comparison with wells in the catchment of the backbarrier island. The C-isotope signature in DIC identifies the dominant role of fresh and salt- water mixing which is superimposed by minor

degradation of DOC, but also the corrosion of marine carbonates. The solid phase carbonate pool consists of a mixture between calcite, mostly biogenic, and dolomite, likely originating from riverine transport.

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P 14 Hochauflösende Langzeit-Isotopenuntersuchung der Uferfiltration für die Bewirtschaftung flussnaher Grundwasserressourcen am Beispiel des LURCH-IsoGW-Pilotstandortes Ofterschwang im Oberallgäu

ID: 113

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Uferfiltration ist eine ökonomische Methode, flussnahe Grundwasserressourcen nachhaltig zu bewirtschaften. Insbesondere die Sicherstellung der Trinkwasserversorgung aber auch die Bereitstellung von Brauchwasser für die landwirtschaftliche und geothermische Nutzung stellen die Wasserwirtschaft vor stetig wachsende Herausforderungen.

Im Rahmen von BMBF-LURCH IsoGW wurden an verschiedenen Pilotstandorten Teilprojekte zur Erarbeitung eines Best Practice Leitfadens (Anwendung von etablierten isotopenhydrologischen Methoden für Wasserversorger und beratende Büros) durchgeführt.

Um die Variabilität der hydrologischen Prozesse bei der Uferfiltration in hoher Auflösung näher zu untersuchen, wurde am Standort Ofterschwang über einen Zeitraum von mehr als 2 Jahren der Beitrag der Iller an der Grundwasserneubildung in hoher zeitlicher Auflösung untersucht. Für die Charakterisierung der Grundwasserneubildungskomponenten, Abstandsgeschwindigkeiten oder Mischungsbilanzen dienen die stabilen Wasserisotope in Verbindung mit hydraulischen, hydrochemischen, Edelgas- und Spurengastracer Messdaten.

Vorgestellt werden die Ergebnisse der gesamten Messkampagne sowie die wesentlichen methodischen Ansätze und Interpretationen auf Grundlage der

optimierten Anpassung des 2-Komponenten-Mischungsmodells (hochvariables Illeruferfiltrat + Grundwasser aus dem tieferen Illertalbecken) vor.

P 15 Class-A-Pan and small pond evaporation experiments in a humid climate – A first step towards quantifying pit-lake evaporation in Lusatia

ID: 152

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Evaporation loss from post-mining pit lakes in the Lusatian mining district are a hot topic of debate. It is still unclear, if evaporation loss occurs in a magnitude that significantly enhances the water scarcity in one of the driest regions in Germany. Stable isotope methods to quantify evaporation loss (Gibson et al. 2017, Skrzypek et al. 2015) have been applied worldwide in numerous studies of natural lakes. Preliminary results from a large-scale sampling campaign 2024 (depth-oriented sampling in 54 lakes, 1-4 per year) in Lusatia show that stable water isotopes are a useful tool for a qualitative analysis and the identification of hydrogeological, hydrological and hydrometeorological processes. But quantification of evaporation loss is difficult as the post-mining landscape is a highly regulated hydrological system. Two distinct local evaporation lines (slope 1: 6.0; slope 2: 4.9) have been identified, suggesting differences between large and smaller lakes as well as pointing towards a still incomplete understanding of the hydrometeorological conditions. Class-A-Pan evaporation experiments are used as a first step to test time variable evaporation using the Craig-Gordon-Model under Lusatian climatic conditions, which are currently transitioning from a humid continental climate towards a temperate oceanic climate, by additionally considering influence through groundwater inputs and precipitation. Regular sampling of precipitation and water in a small pond in an artificial catchment (known and controlled conditions) allows for a next step in upscaling the quantification of evaporative effects to a larger scale.

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P 16 Ergebnisse von Laborvergleichsmessungen für stabile Wasserisotope im Deutschen Isotopennetzwerk (GIN)

ID: 139

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Im Rahmen des Deutschen Isotopennetzes (GIN) wurden zwischen 2018 und 2026 bisher insgesamt sieben Laborvergleiche für stabile Wasserisotope durchgeführt bei denen jeweils zwischen 8 und 23 Labore teilgenommen haben. Teilnehmende wurden hierbei gebeten mehrere unbekannte Wasserproben nach den üblicherweise im Labor verwendeten Methoden zu messen und Werte sowie Messmethoden innerhalb einer vorgegebenen Zeitspanne zurück zu melden. In 2024 wurde zudem ein Vergleich durchgeführt, bei dem alle Labore zusätzlich drei gleiche Arbeitsstandards verwendeten. Im letzten Laborvergleich 2026 (Lbvgl7) wurden zudem alle Labore angefragt, eine Wasserprobe (präpariertes destilliertes Wasser, G7) möglichst oft mit zu messen, um eine langfristige Laborgenauigkeit für das gesamte GIN-Netzwerk abzuschätzen.

Die Ergebnisse der Vergleichsmessungen zeigen generell eine kontinuierliche Verbesserung der Abweichung für die meisten Labore. Die Gesamt-Standardabweichungen bei den letzten drei Laborvergleichen (GIN Lbvgl5-Lbvgl7) waren für verschiedene Proben meist deutlich besser als 0.3 ‰ und 1.5 ‰ für $\delta^{18}\text{O}$ und $\delta^2\text{H}$ -Werte. Eine identische Probe, die über gut ein Jahr von über 20 verschiedenen Labors (insgesamt über 600-mal) gemessen wurde, liegt in einem Fehlerbereich besser als 0.14 ‰ für $\delta^{18}\text{O}$ und 0.6 ‰ für $\delta^2\text{H}$. Zusätzlich zum sehr gut etablierten

internationalen Vergleichstest für Wasserisotope (WICO), der regelmäßig durch die IAEA organisiert wird, ermöglichen Vergleiche auf nationaler Ebene einen fachlichen Austausch der Labore und eine intensivere Diskussion zu Verbesserungen und Herausforderungen für die Messung stabiler Wasserisotope. Auch weiterhin sind GIN-Laborvergleiche geplant, um die Isotopenmessungen auf nationaler Ebene zu verbessern und die Labore miteinander zu verbinden.

P 17 Eine Webseite für das Deutsche Isotopennetz (GIN): Stabile Isotope und Tritium in Niederschlag, Oberflächenwasser und Grundwasser

ID: 147

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Zur Nutzung hydrologischer Isotopendaten in Deutschland wird in Kürze eine neue Webseite zur Verfügung stehen (*isotopes-GIN.de*), durch die Isotopengehalte in Niederschlag, Oberflächenwasser und Grundwasser interessierten Anwendern zugänglich werden. Vergleichbare Webseiten sind das globale Isotopen-Niederschlagsnetz (GNIP-WISER) der IAEA [1] oder auf nationaler Ebene das österreichische Isotopennetz ANIP. Für Deutschland werden Stationen für Niederschlag und Oberflächenwasser auch weiterhin regelmäßig als Monatswerte gemessen. Grundsätzlich ist die hierfür angelegte Datenbank (Aqua, BGR) erweiterbar, sodass zukünftige Daten sowie Messstellen auch aus dem Grundwasser ergänzt werden können. Innerhalb des BMBF LURCH Projektes IsoGW wurden bundesweit bereits vorhandene Isotopendaten aus über 10.000 Grundwassermessstellen der Bundesländer und Wasserversorger zusammengeführt und gut 5.000 Proben neu gemessen. An den Stationen des Niederschlags- und Oberflächenwassernetzes der Bundesanstalt für Gewässerkunde (BfG) und des Deutschen Wetterdienstes (DWD), wo seit den 1970er-Jahren monatlich Isotopendaten erhoben werden, liegen bisher etwa 40.000 Messungen vor (davon ca. 15.000 für Niederschlag und ca. 24.000 für Oberflächenwasser) [2,3].

Für die Erstellung und Nutzung von Isotopenkarten (Isoscapes) werden aus einem IsoGW/GIN Projekt in der Langzeit sicheren SQL DB Daten in ein GIS-Projekt (ESRI, BGR) abgelegt, aus dem ein Web-Feature-Service die Mess- und Metadaten auswertungsfreundlich über das https-Protokoll und als Geopackage den Projektpartnern zur weiteren Verarbeitung und Interpolation übergibt. Datenherkunft und die Daten-Nutzungsrechte sind dokumentiert und bestimmen die Zugänglichkeit zu spezifischen Messstelleninformationen und Analyseergebnissen. Grundsätzlich können die interpolierten Isotopenkarten zur Verfügung gestellt werden. Individuell und regional auswählbare Isotopendaten sind darüber hinaus für eine weitere Verwendung und in Wertsetzung dieses Datensatzes für Forschung und Wirtschaft zugänglich.

[1] Terzer-Wassmuth S., Wassenaar L.I., Welker J.M., Araguás-Araguás L.J. (2021): Improved high-resolution global and regionalized isoscapes of $\delta^{18}\text{O}$, $\delta^2\text{H}$ and d-excess in precipitation. *Hydrological Processes*. DOI:10.1002/hyp.14254.

[2] Schmidt A., Frank G., Stichler W., Duester L., Steinkopff T., Stumpp C. (2020): Overview of tritium records from precipitation and surface waters in Germany. *Hydrological Processes* (2020); DOI:10.1002/hyp.13691.

[3] Koeniger P., Schmidt A., Stumpp C. (2022): Stable isotope patterns of German rivers with aspects on scales, continuity and network status. *Isotopes in Environmental and Health Studies* 58 4-6, 363-379. DOI:10.1080/10256016.2022.2127702.

P 18 Sources and Fate of Carbon and Sulfur in Travertine Formation: A Multi-Isotope Study of the Dreimühlen Waterfall, Eifel

ID: 149

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When hard-water springs reach the surface, they carry water already at the saturation point for CaCO_3 , with CO_2 concentrations far exceeding atmospheric levels. As this water travels downstream, an interplay between two processes, CO_2 degassing and carbonate mineral precipitation, shapes its chemical evolution and ultimately drives travertine deposition. At the Dreimühlen waterfall near Nohn in the Eifel region, this

evolution reaches a tipping point: travertine precipitates abruptly across a dense moss substrate, producing a geological feature valued for regional tourism.

This study examines how stable isotopes (C, H, O, N, S) and trace elements distribute and partition as the Nohn hard-water creek transforms into travertine downstream. We combined field measurements of water chemistry (alkalinity, major and trace element concentrations, nutrients) with isotopic analysis of both the water and the precipitating solids, also segregating between inorganic and organic carbon and sulfur signatures. Solid-phase textures and compositions were additionally examined using SEM-EDX.

Two distinct stages emerge along the creek's course: an initial phase governed by gradual CO₂ loss, followed by abrupt calcite precipitation at the waterfall that in turn accelerates further degassing. Isotope data trace the origin of dissolved constituents and clarify the mechanisms driving carbonate formation. Process rates may be modulated by local topography and biological activity. Notably, sulfate in the creek water derives from sulfide mineral oxidation within the underlying aquifer, and can become incorporated into the growing carbonate as carbonate-associated sulfate (CAS).

POSTERS – Climate and Atmosphere

P 19 How to investigate short-term carbon turnover and sequestration in paludicultures during the vegetation period?

ID: 129

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Paludicultures, the agricultural or forestry use of rewetted peatlands, is one promising mitigation measure for significant greenhouse gas emissions (GHG) reduction of organic soils. However, the long-term effectiveness and resilience of this measure has not yet been sufficiently studied. Long-term studies are therefore necessary to reliably assess their climate mitigation potential. Thus, there is an urgent need for long-term investigations and in depth understanding of the carbon (C) cycle and mechanisms involved in C sequestration across a broad spectrum of paludicultures. The objective of this study is to determine the fate of newly assimilated atmospheric carbon dioxide (CO₂) within the different C pools, and to assess the stability and potential risk of remobilization of recently sequestered C across three different paludiculture species: *Carex acutiformis*, *Phalaris*

arundinacea, *Typha latifolia*. We aim to quantify plant CO₂ uptake, C transfer and metabolism within the plant-soil-atmosphere continuum at different time scales under field conditions. To achieve this, three different paludiculture species will be exposed up to nine times to ¹³C-enriched CO₂ for a short time period during the vegetation period in 2026. All field experiments will be conducted at a fully equipped, permanent peatland research site of the HSWT-PSC using a novel robotic chamber GHG measurement system equipped with high-frequency GHG and high-precision analyses of ¹³CO₂ and ¹³CH₄. In addition to gaseous losses, samples of plant biomass, dissolved organic carbon, dissolved CO₂ and CH₄, soil organic carbon, microbial C, and biochemical fractions of plant biomass and soil will be analyzed for δ¹³C isotopic signatures. The experimental set-up and first results will be presented.

P 20 Four-year precipitation isotope monitoring in the Bale Mountains, Ethiopia, and implications for paleoclimate interpretations of ²H and ¹⁸O records

ID: 157

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Reliable interpretation of stable ²H and ¹⁸O paleoclimate isotope records from sedimentary archives requires a robust understanding of the modern hydrological and atmospheric processes controlling isotopic variability. Here, we present four years (2017–2020) of ²H and ¹⁸O isotopes in precipitation monitoring from the Bale Mountains, Ethiopia, as a follow-up study of Lemma et al. (2020) and/or Rozanski et al. (1996).

While our dataset corroborates the well-known altitude effect, it does interestingly not show a clear and originally expected seasonal pattern that could be interpreted in terms of a temperature or an amount effect. The same holds true for respective interannual relationships. Back-trajectory analyses identify four dominant moisture transport pathways supplying precipitation to the Bale Mountains, with no evidence for Atlantic moisture contributions. The varying moisture sources are strongly controlled by seasonal atmospheric circulation, moisture mixing, and regional climate conditions. The most striking feature of our dataset is the skipping of the dry season in 2019–2020. This event resulted in extremely low δ²H and δ¹⁸O values over weeks. Given that such events were already reported by Rozanski et al. (1996) and assuming that the recurrence of such events was variable in the past, our finding suggests caution when interpreting Ethiopian, possibly even East African, classical ²H and ¹⁸O paleoclimate records from

sedimentary archives. We suggest that robust (paleo-)hydrological interpretations are, however, still feasible, namely when lake evaporation rather than precipitation is the dominant controlling factor for sedimentary isotope records (Chernet et al., 2025).

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P 21 SOC content of paddy soils under different residue management as a driver for CO_2 and CH_4 emissions

ID: 134

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The use of rice straw after harvest is an important management decision in paddy rice cropping systems. Incorporating rice straw into the soil returns nutrients and adds organic carbon, but increases methane (CH_4) emissions compared to straw removal. Stabilisation of rice straw via pyrolysis to biochar is considered a promising option for long-term carbon stabilization in paddy soils, and has been shown to reduce CH_4 emissions in mineral paddy soils with low soil organic carbon (SOC) content. However, higher SOC contents, as occurring in degrading organic soils, may affect how residue management influences CH_4 fluxes during the vegetative season in paddy rice cropping. In addition, during paddy drainage in the fallow season, CO_2 fluxes from the soil may be affected by said parameters with the risk of SOC loss through mineralization. Due to increasing interest in paddy rice cultivation for greenhouse gas mitigation on degrading organic soils, knowledge about possible SOC-dependent management implications is needed. In this study, we

investigate the impact of ^{13}C -labelled straw and biochar addition on CO_2 and CH_4 emissions from paddy soils with different SOC contents.

Four rice paddy soils representing an SOC gradient from 1.6 to 27.5% are amended with ^{13}C -labelled rice straw ($\delta^{13}\text{C}$ 750‰; equivalent to application of 4t/ha), biochar (equivalent to application of 20t/ha) or a combination of both substrates. First, soils are aerobically incubated under controlled conditions. In a second phase, the incubation is shifted to an anaerobic atmosphere, and water is added to simulate flooded conditions. Both CO_2 and CH_4 exchange rates and isotopic composition, to differentiate the sources, are regularly measured on headspace samples using a Picarro G-2201i. We hypothesize increased CO_2 emissions from all treatments relative to a no-addition control. Furthermore, we expect a reduction in CH_4 emissions in the biochar treatment during the anaerobic incubation phase. Soils containing more SOC are predicted to have higher CO_2 and CH_4 emissions, and simultaneously a bigger impact of straw and biochar addition with a larger fraction of SOC-derived carbon is expected in these soils. Results will reveal to what extent CO_2 and CH_4 emissions are influenced by SOC content and if SOC content needs to be taken into account when deciding on rice straw management for greenhouse gas mitigation.

POSTERS – Paleoclimate, Sedimentology and Soil

P 22 Isotope signatures along high-resolution soil moisture release curves in natural soils: coupling Cavity Ring-down Spectroscopy with HYPROP-systems

ID: 105

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The soil matrix may have impacts on the isotopic signature of soil water, e.g. may induce fractionation effects at different soil tensions. If neglected, this may lead to erroneous estimations of seepage and/or recharge rates, the extent of which is not known yet. Also, the conditions under which implications occur, and their relations to different soil types, are still unclear. For a systematic investigation, we conduct experiments that examine the relation between soil water tension and stable isotope signatures ($\delta^2\text{H}$, $\delta^{18}\text{O}$) in soil water of natural soils. For this, we record high-resolution soil moisture release curves on soil samples in the lab via the evaporation method using a HYPROP system. We conduct concurrent $\delta^{18}\text{O}$ and $\delta^2\text{H}$ measurements on the

water vapor throughout the experiment in order to be able to (quantitatively) better assess water movement in soil though the unsaturated zone into the groundwater. We show the experimental setup, challenges and first results.

POSTERS – Physiology, Metabolism, Forensics, Food

P 23 Isotopic fluxes in pine - disentangling assimilate transfer and phloem loading in conifer trees

ID: 125

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Leaf assimilate transport and phloem loading are less understood in conifers than in angiosperms. Among other peculiarities, we would like to highlight the presence of a semi-permeable endodermis bundle sheath in Pinaceae species. This impermeable cell layer acts as a bottleneck for assimilate transport, when mass flow of water from the xylem opposes diffusion of assimilates towards the phloem. We propose that transitory starch storage in the endodermis and transfusion parenchyma tissues from the needle veinlet may facilitate steady carbohydrate supply for phloem loading, especially during periods of high transpiration. ¹³C labelling and temporally resolved localization of labelled starch with high-resolution Secondary-ion mass spectrometry (SIMS) imaging were used in our endeavour to shed light on the mechanisms of assimilate storage and transport.

POSTERS – Analytics, Methods, Quality Assurance

P 24 Isotope signature as an assessment method for contamination cases involving trifluoroacetic acid (TFA) and short-chain PFAS in drinking water and groundwater

ID: 111

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Per- and polyfluoroalkyl substances (PFAS) – so called forever chemicals due to their tremendous persistence – are found almost everywhere by now, including most water sources. The EU is currently considering far-reaching restrictions on the use of this substance

class across many sectors and applications. Trifluoroacetic acid (TFA), may be formed from degradation of cooling agents in the atmosphere and subsequent rainout, from decomposition of fluorinated pesticides in soil, from degradation of fluorinated pharmaceuticals in wastewater, or from direct industrial release.

A dossier on the hazard classification of TFA has been submitted by multiple German authorities to the European Chemical Agency (ECHA) last year due to the long persistence, reproduction toxicity and high environmental mobility of TFA. The Committee for Risk Assessment (RAC) at ECHA has now followed this assessment and proposes classifying TFA as probable reproductive toxicant (Category 1B). According to media reports, the European Food Safety Authority (EFSA) is also working on a guideline value for TFA in food emphasizing the importance of restricting the use and release of PFAS into the environment.

Due to the great current relevance of PFAS and TFA in particular, an understanding of the different complex TFA formation and entry pathways into comestible goods and water is of outmost importance. Perfluoroalkyl acids (PFAAs) in general, can have distinctively different synthetic sources of carbon (crude oil, methane, carbon monoxide) and oxygen (water, oxygen, hydroxy radicals). Therefore, the formation pathway of PFAA should define $d^{13}C_{bulk}$ and $d^{18}O_{bulk}$ values as well as position specific $d^{13}C$ values. Hence, different isotope ratios of four groups should exhibit a different pattern for every PFAA and its respective formation pathway.

Group 1 $d^{13}C$ value of $C_xF_{2x+1}CO_2H$ ($x=1$ for TFA) (EA/GC-IRMS)

Group 2 $d^{18}O$ value of the $R-CO_2H$ (EA/GC-IRMS)

Group 3 $d^{13}C$ value of $C_xF_{2x+1}CO_2H$ (PSIA)

Group 4 $d^{13}C$ value of $R-CO_2H$ (PSIA)

Initial analyses performed by EA-IRMS and GC-IRMS reveal distinctively different isotope ratios for the different groups :

Group 1 shows a big range of $d^{13}C$ values of PFAAs: from -24,7 mUr and -52,6 mUr. The spread for $d^{18}O$ values of PFAA in group 2 ranging from -8,4 mUr_{VSMOW} to +16,6 mUr_{VSMOW} is pronounced. Similar effects could be observed for the $d^{13}C_{C_xF_{2x+1}}$ and $d^{13}C_{CO_2}$ values of different PFAAs: The range is between -60,5 mUr to -42,7 mUr ($d^{13}C_{C_xF_{2x+1}}$) and -58,2 to +24,9 mUr ($d^{13}C_{CO_2calculated}$) respectively.

Isotope analysis thereby is a valid method identifying and determining different formation pathways.

P 25 Carbon and Nitrogen Stable Isotope Analysis of Sulfamethoxazole During Abiotic Degradation Processes

ID: 132

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The extensive use of synthetic chemicals has led to their widespread occurrence in the environment due to limited or inefficient removal processes. Antibiotics are of particular concern because their environmental persistence may promote the development of antimicrobial resistance. Among these compounds, sulfamethoxazole (SMX) is frequently detected in European surface waters due to its broad use in human medicine, aquaculture, and livestock production. Despite its widespread occurrence, the transformation pathways and environmental fate of SMX remain insufficiently understood. Under such circumstances, compound-specific isotope analysis (CSIA) can help trace ongoing degradation and even distinguish among different degradation pathways. Enabled by gas chromatography hyphenated with isotope ratio mass spectrometry (GC-IRMS), it monitors subtle changes in isotope ratios of the entire target compound (e.g., $^{13}\text{C}/^{12}\text{C}$, $^{15}\text{N}/^{14}\text{N}$) during a reaction. Carbon and nitrogen isotope fractionation was investigated in two distinctly different abiotic transformation pathways: with Fe(II)-amended goethite suspensions under anoxic conditions and with d-MnO₂ under oxic conditions. Reductive degradation of SMX by surface-bound Fe(II) showed significant carbon isotope fractionation ($\epsilon\text{C} = -3.6\text{‰} \pm 0.1\text{‰}$ / $\epsilon\text{C} = -2.9\text{‰} \pm 0.2\text{‰}$, with and without buffer, respectively), nitrogen isotope fractionation ($\epsilon\text{N} = -12.8\text{‰} \pm 0.6\text{‰}$ and $\epsilon\text{N} = -13.0\text{‰} \pm 0.2\text{‰}$, with and without buffer, respectively), and transformation products that align with the initial reductive N-O bond cleavage. Oxidation by d-MnO₂ resulted in minor normal carbon isotope fractionation and inverse nitrogen isotope fractionation ($\epsilon\text{C} = -1.7\text{‰} \pm 0.1\text{‰}$ / $\epsilon\text{C} = -2.7 \pm 0.2\text{‰}$, with and without buffer, respectively, and $\epsilon\text{N} = +1.9\text{‰} \pm 0.2\text{‰}$ without buffer), a fractionation pattern characteristic of an electron-transfer-driven oxidation pathway. Although carbon isotope enrichment alone did not allow clear differentiation between oxidative and reductive degradation, dual-element isotope analysis provided a robust distinction ($\Delta\text{Fe(II)}/\text{goethite} = 4.6 \pm 0.1$, $\Delta\text{MnO}_2 = -0.4 \pm 0.1$), demonstrating the ability of combined carbon and nitrogen isotope analysis to identify specific degradation pathways. Oxidation products were not easily identifiable through high-resolution mass spectrometry, demonstrating the potential of CSIA to identify transformation processes when concentration-based measurements and transformation product analysis alone are insufficient,

thereby enabling clear differentiation between oxidative and reductive pathways of SMX.

P 26 How Well Do We Know VPDB—Part 2: Interlaboratory Assessment of Existing $\delta^{13}\text{C}_{\text{VPDB}}$ Reference Materials

ID: 131

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The two internationally accepted scales on which $\delta^{13}\text{C}$ measurements are reported are the VPDB and VPDB-LSVEC scales. Calcium carbonates represent the highest level of the metrological traceability chain available for realizing both scales. For high-precision dual-inlet isotope ratio mass spectrometry (DI-IRMS), these carbonates are converted to CO₂ gas via phosphoric acid digestion. Here, we present an interlaboratory comparison study evaluating the comparability of this acid reaction and the subsequent isotope measurements across three expert facilities: the International Atomic Energy Agency, the Centre for Isotope Research at the University of Groningen, and the BGC-IsoLab of the Max-Planck-Institute for Biogeochemistry.

A key finding is that the parameters of the phosphoric acid reaction require clearer definitions to achieve optimal interlaboratory comparability; particularly, the method of CO₂ extraction following reaction completion demands closer attention. In this study, the IAEA-610, -611, and -612 calcium carbonates are value-assigned for the first time alongside USGS44. The reported values on the $\delta^{13}\text{C}_{\text{VPDB}}$ scale are $-9.114 \pm 0.011 \text{‰}$ (IAEA-610), $-30.815 \pm 0.011 \text{‰}$ (IAEA-611), $-36.739 \pm 0.020 \text{‰}$ (IAEA-612), and $-42.073 \pm 0.015 \text{‰}$ (USGS44). While the values for IAEA-612 and USGS44 deviate slightly from previously published data, the differences are statistically insignificant within the reported measurement uncertainties. Nevertheless, these minor discrepancies can have adverse effects, for example on achieving World-Meteorological-Organization-Global Atmospheric Watch (WMO-GAW) network compatibility goals.

P 27 Fully integrated TOC and TNb analysis of estuarine and sea water samples with the Elementar iso TOC cube®

ID: 109

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Identifying and quantifying the processes that control the carbon and nitrogen cycling in aquatic systems is important for mitigating urban and agricultural pollution, optimizing environmental policy and understanding global nutrient cycles. The isotopic analysis of dissolved organic carbon (TOC) and total bound nitrogen (TNb) are particularly important to elucidate the different sources, track nutrient cycling processes and help contamination identification.

Here, we present the $\delta^{13}\text{C}$ performance of the Elementar iso TOC® cube for <5 mg/L carbon TOC concentrations in estuarine river water samples, highlighting a salinity gradient from 2g/L to 25g/L. We also present determination of TOC concentration and $\delta^{13}\text{C}$ TOC in seawater, demonstrating the performance of the iso TOC® cube for the analysis of seawater samples.

The iso TOC cube® elemental analyser has been developed for fully integrated TOC/TNb isotope ratio analysis. Optimised for precise measurements of TC, TOC, TIC and TNb isotope ratios covering a wide range of applications areas. All types of liquids from drinking water, industrial wastewater, soil leachates, or marine samples are determined reliably and with the highest isotopic precision.

P 28 Open source hard- and software for in situ sampling of water vapor

ID: 165

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Stable water isotopologues can be a very useful tool to trace water through soils and plants. However, established destructive sampling techniques (such as the extraction of soil cores or twig sampling) may be to damaging and/or labor intensive to allow for higher sampling frequencies. Recent developments of different in situ sampling techniques offer great opportunities to overcome these limitations, but the relative novelty of this branch of research in conjunction with the rather limited circle of potential users severely limits the commercial availability of systems that are specifically suited for the in situ sampling of water vapor for subsequent analysis of stable water isotopologues.

Consequently, research groups in that field often work with self-developed in situ sampling systems.

Developing such systems from scratch requires technical knowledge that is typically not part of environmental researchers' scientific training. That can be solved by a) hiring a capable technician and establishing a way of communication between technician and scientist or b) improvisation and learning many things the hard way. Either of these two options could be facilitated by sharing the lessons learned and the developed products of already completed projects.

On this poster I want to present the open source hard- and software of IsWISaS, the (I)n-(s)itu (W)ater (I)sotope (Sa)mpling (S)ystem, which has been essential to many previous in situ sampling projects. This contribution is also intended to act as a catalyst for lively discussions around the topics of sharing and documenting technical developments that may not always find their way into scientific publications.

P 29 Improving detection limits for carbon isotopic analysis of BTEX by GC-IRMS using headspace SPME Arrow sampling

ID: 160

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Benzene, toluene, ethylbenzene, and xylenes (BTEX) are hazardous environmental contaminants associated with fuel releases and industrial activities. Concentration data alone may not distinguish contaminant sources or demonstrate in situ transformation. Compound-specific stable carbon isotope analysis can provide complementary evidence, but its application at environmentally relevant concentrations is often limited by the analyte mass required for precise isotope-ratio measurements. We optimized headspace solid-phase microextraction Arrow method coupled to GC-IRMS for carbon isotope analysis of BTEX in water.

Chromatographic conditions, fiber conditioning, sample preparation, and conversion reactor setup were optimized to improve analyte transfer, minimize carryover, and preserve isotope-ratio accuracy. Method performance was evaluated with BTEX standards and an isotopically characterized benzene-toluene-m-xylene mixture. At 50 ppb, replicate measurements of BTX mix show excellent data reproducibility ($\text{SD} \leq 0.08 \text{ ‰}$) for $\delta^{13}\text{C}$. Across three fibers and different measurement days, offsets from certified values were 0.02 ‰ for benzene, -0.01 ‰ for toluene, and 0.05 ‰ for m-xylene, with standard deviations of 0.07-0.08 ‰. Isotope ratios remained stable and independent of concentration from 12.5 to 100 ppb.

Application to an industrially contaminated water sample demonstrated BTEX detection in a complex

matrix containing phenols, cyclopentanes, and polycyclic aromatic hydrocarbons. The results show that headspace SPME Arrow-GC-IRMS can extend reliable carbon-isotope measurements of volatile aromatic contaminants to low-ppb levels, enabling isotope fingerprinting at environmentally relevant concentration levels.

P 33 Sealing Samples in the Field: An Evaporation-Proof Autosampler Benchmarked Against Standard Practice

ID: 167

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Stable water isotopes enable hydrologists to trace the origin of water, the paths it takes and how long it remains in a catchment area. However, every step between collection and analysis can corrupt this signal: water left standing in a sample bottle evaporates, which fractionates what remains. Commercial autosamplers do little to prevent this. Their bottles remain open in the field for days or weeks, and their cost means that most studies are confined to one or two sampling points — too few to determine how precipitation input varies across a catchment.

We built the Portable Autosampler for Liquids (PAUL), which seals each bottle as soon as it is filled, and investigated how much isotopic alteration this prevents. We placed PAUL and a Teledyne ISCO autosampler side by side on a roof in Freiburg, Germany, which was exposed to the sun, for one month. During this time, the air temperature fluctuated between 20 and 40 °C. All bottles received water from a single batch. Ten replicates went into PAUL. The ISCO had ten bottles: five left open and five covered with Styrofoam beads — the workaround that many groups rely on. Aliquots of the same batch, stored in a cool, dark place, served as unevaporated controls. We measured every sample using cavity ring-down spectroscopy.

We report how far each treatment drifted from its control in terms of $\delta^2\text{H}$ and $\delta^{18}\text{O}$ values, as well as how the deuterium excess shifted in response.

POSTERS – Further Topics

P 30 ^{13}C pulse branch bag labelling in mature stands of European beech and Norway spruce in a long-term drought experiment

ID: 158

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With multiplying heatwaves and dry spells, diebacks are increasingly observed in our temperate European forests. However, the physiological processes occurring in the rhizosphere under drought are still understudied in comparison to aerial tree parts, while being the center of water and nutrient uptake. Which leads to an incomplete big picture of the tree carbon allocation under drought.

This study tries to improve our existing ^{13}C labelling method, as a way of tracing carbon allocation specifically in the fine root system of European beech and Norway spruce in our long-term drought experiment, KROOF. A pulse labelling was performed by bagging about 10% of the tree's sunlit canopy for 2 hours and filled with 120-240mL of 99% $^{13}\text{CO}_2$. Regular sampling of leaves and fine root tips and soil respiration measurements were performed, from 3 days to 14 days after sampling.

Isotope-ratio mass spectrometry (IRMS) analyses were conducted on plant material and CO_2 efflux from soils. The ^{13}C tracer was found in the fine root systems around 10 days after labelling but already perceivable in soil respiration 7 days after labelling. More trees are planned to be labelled in the following growing year, and an improvement of the technique is to be determined.

P 31 Development of an information and eLearning portal for stable isotope applications

ID: 106

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The Laboratories for Stable Isotopes (LSI) are an association of UFZ research laboratories that build on a long-standing expertise in the analysis of stable isotopes (e.g., H, C, N, O, S, Cl), respective concepts and applications, and thus forming a unique center of competence in isotope analytics. In the context of environmental (microbial) process investigations, these methods are applied for e.g. monitoring of biogeochemical element cycles in relation to climate

change adaptation and energy storage, pollutants/nutrients transport and turnover in terrestrial and freshwater ecosystems or the characterization of pathways and quantification of biotransformation of organic groundwater pollutants. Although these stable isotope applications are established as scientifically valuable methods, their implementation falls far short of their expected potential, presumably due to their highly specialized nature and, more critically, the lack of effective knowledge transfer to potential key stakeholders. To fully utilize the potential of stable isotope methods, a diverse range of users must thus develop a basic understanding of those methods and their benefits. To bridge this gap and unlock the full potential of stable isotope applications, we intend to build an open-access, centralized web platform providing user-customized knowledge on stable isotope applications. This platform is proposed to provide tailored information, training, and resources for two key target groups: stakeholders i.e. commercial users, and local and regional authorities, to support decision-making and facilitate real-world implementation as well as the academic community, incl. students, who represent the next generation of stable isotope experts and exploiters.

Here, we present the prototype of our portal, created in cooperation with the SME Isodetect GmbH and the UFZ-knowledge and technology transfer office. We invite you to share your views, experiences, and requirements by reflecting on questions such as i) would such a website be useful for your work, and what would increase its usefulness for you, ii) what additional information, examples, or media formats would help your users, colleagues or students better understand and apply stable isotope techniques, iii) would you recommend this type of resource to your collaborators and colleagues, and iv) are you interested to join us as partner in this endeavour? Your feedback will help us to develop an accessible, user-oriented, web-based information and eLearning portal.

P 32 Methane Hydrogen Isotope Signatures ($\delta^2\text{H}-\text{CH}_4$) as an Early-Warning Indicator for Process Instability in Anaerobic Digestion

ID: 142

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Anaerobic digestion (AD) is an established renewable energy technology whose economic viability depends on stable operation at high organic loading rates

(OLRs). Operating close to the maximum OLR increases methane (CH_4) productivity but also the risk of volatile fatty acid accumulation, acidification, and reactor failure, making reliable early-warning indicators essential for process control. Conventional monitoring parameters, such as pH, the ratio of volatile organic acids to total inorganic carbonate (VOA/TIC), hydrogen (H_2) concentration, and CH_4 yield, often respond only after process deterioration has already progressed. Stable isotope analysis has recently emerged as a promising approach for investigating methanogenic pathways and detecting process alterations, yet the potential of methane hydrogen isotope signatures ($\delta^2\text{H}-\text{CH}_4$) for process monitoring has remained largely unexplored.

In this study, long-term continuously operated AD experiments were conducted using maize silage, sugar beet molasse pellets, and alfalfa as substrates under stepwise increasing OLRs. Conventional process stability parameters were monitored alongside stable isotope measurements ($\delta^{13}\text{C}-\text{CH}_4$, $\delta^{13}\text{C}-\text{CO}_2$, and $\delta^2\text{H}-\text{CH}_4$ values) and molecular biological characterization of the methanogenic community. Carbon isotope signatures exhibited distinct substrate-specific patterns, while isotopic fractionation and microbial analyses consistently indicated acetoclastic methanogenesis as the dominant CH_4 formation pathway under stable operating conditions across all substrates. Among all investigated parameters, $\delta^2\text{H}-\text{CH}_4$ values proved to be the most sensitive indicator of changing process conditions. Across all substrate systems, $\delta^2\text{H}-\text{CH}_4$ values increased progressively by approximately 10–15 mUr with increasing OLRs, consistently preceding detectable changes in conventional monitoring parameters. As reactor instability developed, the $\delta^2\text{H}-\text{CH}_4$ trend plateaued or reversed before process failure, which was subsequently characterized by decreasing pH, increasing VOA/TIC and H_2 concentrations, and declining CH_4 yields. In contrast, $\delta^{13}\text{C}-\text{CH}_4$ values primarily reflected substrate-specific characteristics and methanogenic pathway dynamics but showed lower sensitivity as early-warning indicators. The observed $\delta^2\text{H}-\text{CH}_4$ shifts likely result from a combination of microbial and process-related effects, including an increasing contribution of methylotrophic methanogenesis, rather than reflecting changes in hydrogenotrophic methanogenesis alone. These findings demonstrate that methane $\delta^2\text{H}-\text{CH}_4$ signatures provide earlier information on process destabilization than established monitoring parameters. Integrating $\delta^2\text{H}-\text{CH}_4$ measurements into AD monitoring strategies therefore represents a promising approach for improving process stability, enabling operation at higher OLRs, and enhancing the economic performance and operational flexibility of biogas production systems.

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Stable Isotopes

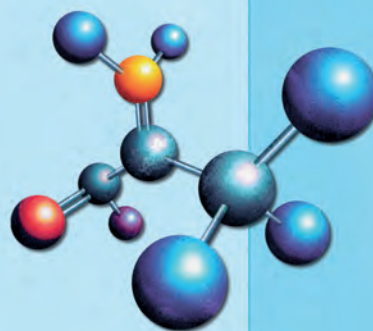
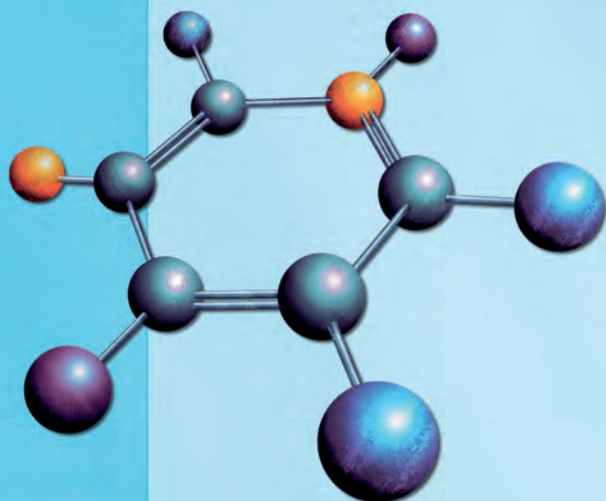
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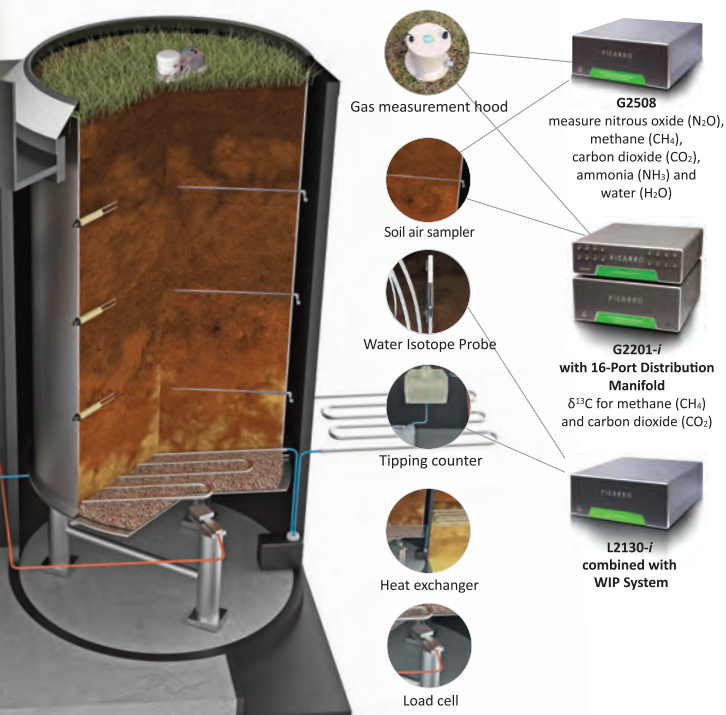
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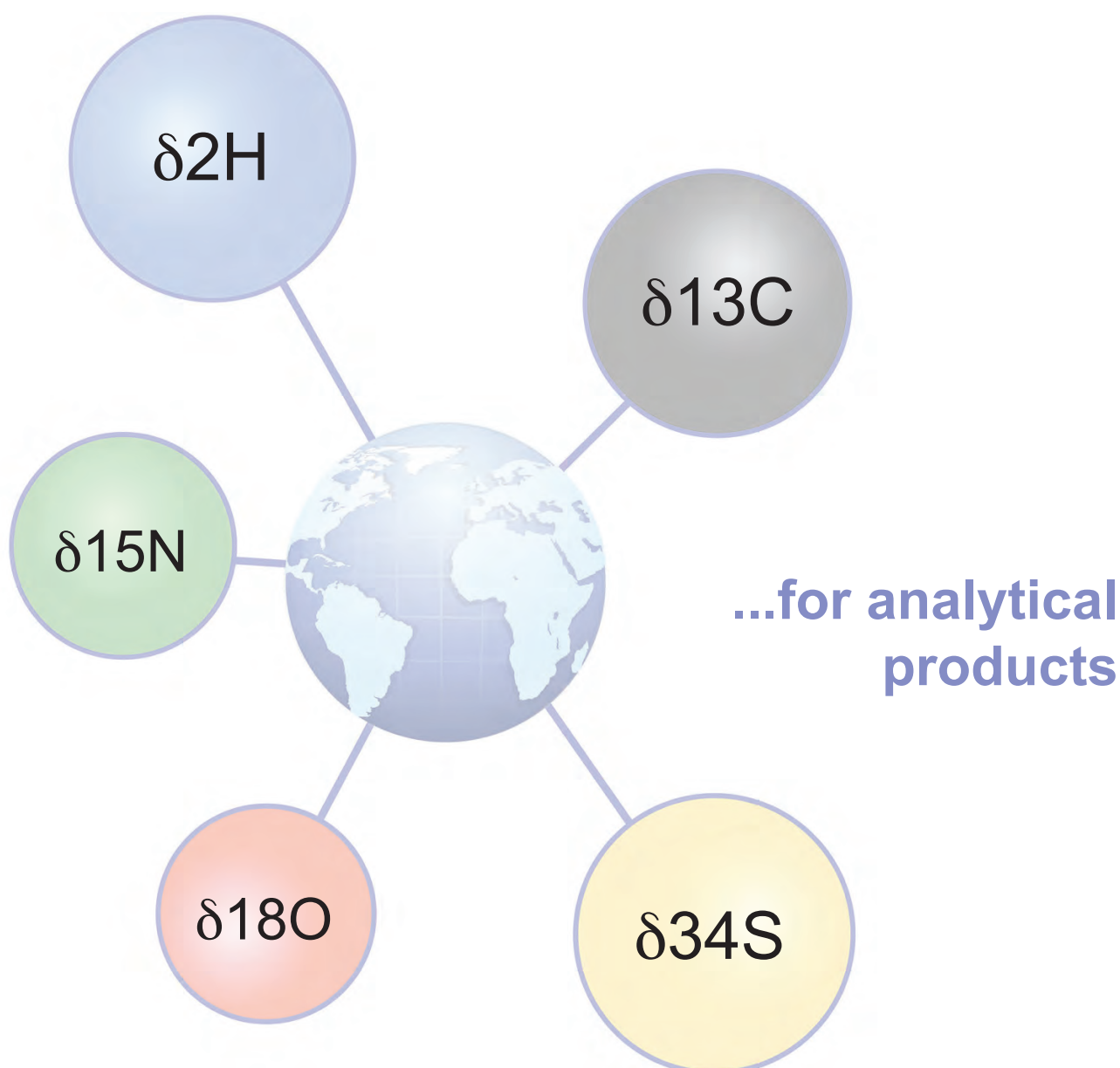
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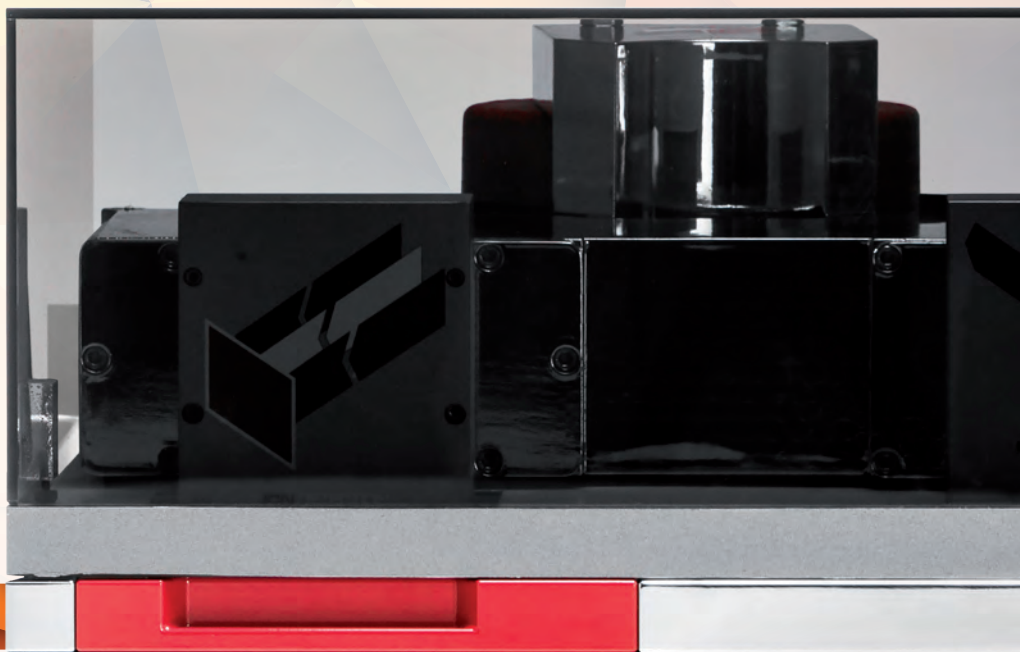
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