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Sub-daily stable water isotope dynamics of urban tree xylem water and ambient vapor

Ann-Marie Ring et al.

Correspondence to: Dörthe Tetzlaff (doerthe.tetzlaff@igb-berlin.de)

Supplementary Material

Table S1. Details of the monitored parameters with location, sampling intervals and logger, sensor and sampling details, respectively.

Parameter	Location	[∞]	Logger and Sampling Details
Temperature [C°] Precipitation [mm] Windspeed [m/s] Relative Humidity [%] Net Radiation[W/m²]	Leibniz Institute of Freshwater Ecology and Inland Fisheries (IGB) Weather Stations ~325 m distance to study site	5 min	Pt100, Thies GmbH; cup anemometer, Thies GmbH; hair tension dial hygrometer, Thies GmbH; Albedometer CMP6, Kipp&Zonen
Precipitation [mm]	Study site; open grassland	15 min	tipping bucket raingauge, 0.2 mm/tip, precision ±3% of total rainfall; AeroCone® Rain Collector, Davis Instruments, Hayward, USA; CR800 Datalogger (Campbell Scientific, Inc. Logan, USA)
Temperature [C°] δ_v	At δ_v tube inlets		CR300 Datalogger (Campbell Scientific, Inc. Logan, USA)
Temperature [C°] δ_{xyl}	Inside borehole membranes		fine PFA-sealed resistance thermometers (Pt100, HSRTD, Omega Engineering, Norwalk, USA; tolerance: ±0.15 to 0.35 C (over 0 to 100 °C); CR800 Datalogger (Campbell Scientific, Inc. Logan, USA)
Stable water isotopes			cavity ring-down spectroscopy (CRDS; L2130-i, PICARRO, INC., Santa Clara, CA)
Precipitation [‰]	Study site	24 h – 72 h	sampled manually with HDPE deposition sampler (100 cm2 opening; Umwelt-Geräte-Technik GmbH, Müncheberg, Germany); analysed with CRDS
Precipitation [‰]	IGB grounds; 350 m distance to study site	24 h	autosampler (ISCO 3700, Teledyne Isco, Lincoln, USA); autosampler bottles were filled with a paraffin oil layer that was more than 0.5 cm thick (per IAEA/GNIP, 2014); analysed with CRDS
Groundwater [‰]	IGB grounds; 350 m distance to study site	7 d	submersible pump (COMET-Pumpen Systemtechnik GmbH & Co. KG, Pfaffschwende, Germany); analysed with CRDS
δ_v (ambient water vapor) [‰]	Study site; below *A. platanoides* canopy, above grassland	~ 3.5h	Measured *in-situ* real time sequentially; connected to CRDS with polytetrafluoroethylene (PTFE) tubing (1.6 mm x 3.2 mm); sample flow rate 0.04 L min^{-1} in 1 Hz resolution; calibration every 3rd monitoring sequence
δ_{xyl} (tree xylem water) [‰]	Study site; *A. platanoides; B.pendula*		
Soil water [‰]	Below *A. platanoides* canopy & grassland; five depths (0-5, 5-10, 10-20, 20-40 and 40-70 cm)	30 d	Destructive sampling; sampling ring up to 10 cm depth, below 10 cm soil auger (diameter 4 cm); 3 replicates; stored in stable bags (CB400-420siZ, WEBER Packaging GmbH, Güglingen, Germany); Los Gatos off-axis integrated cavity output spectroscopy (OA-ICOS) triple water-vapour isotope analyser (TWIA-45-EP, Los Gatos Research, Inc., San Jose, CA, USA)
Ecohydrology			
Sap flow [L/h]	Study site; “breast height” 1.3 m at stem of *A. platanoides, B. pendula*	15 min	• SFM-4, Umwelt-Geräte-Technik GmbH, Müncheberg, Germany; ±0.1 cm/hr heat velocity precision: *A. platanoides* north & south • SFM1 instrument, ICT International, Australia: *A. platanoides* (northwest), *B. pendula* (north, northwest and south) • CR800 Datalogger (Campbell Scientific, Inc. Logan, USA)
Stem growth [µm]			DR Radius Dendrometer, Ecomatik, Dachau, Ger170; accuracy max. ± 4.5% of the measured value (stable offset); CR800 Datalogger (Campbell Scientific, Inc. Logan, USA)
Soil moisture; VWC [%]	Below *A. platanoides* canopy & grassland; 5 depths (5-70 cm), 3 replicates per depth		SMT-100, Umwelt-Geräte-Technik GmbH, Müncheberg, Germany; factory calibration precision ±3% vol in mineral soils; median value of 3 replicates was calculated per depth; CR800 Datalogger (Campbell Scientific, Inc. Logan, USA)
Twig water potential [MPa]	*A. platanoides, B. pendula*	14 d	9 am and 12:30 pm; samples from lower canopy; Scholander pressure chamber instrument (Model 1000, PMS Instrument Company, Albany, OR, USA; 0.5% accuracy)
Leaf Area Index (LAI)			Plant canopy analyser (LAI 2000, Li-cor, Inc., Lincoln, NE, USA); 3 replicates; constant point under canopy
Groundwater level [m]	IGB grounds	7 d	Water level meter

Additional information to Eq 1.(Majoube, 1971)

Parameter	$\delta^{18}O$	$\delta^{2}H$
a	1.137	24.844
b	-0.416	-76.248
c	-2.067	52.612

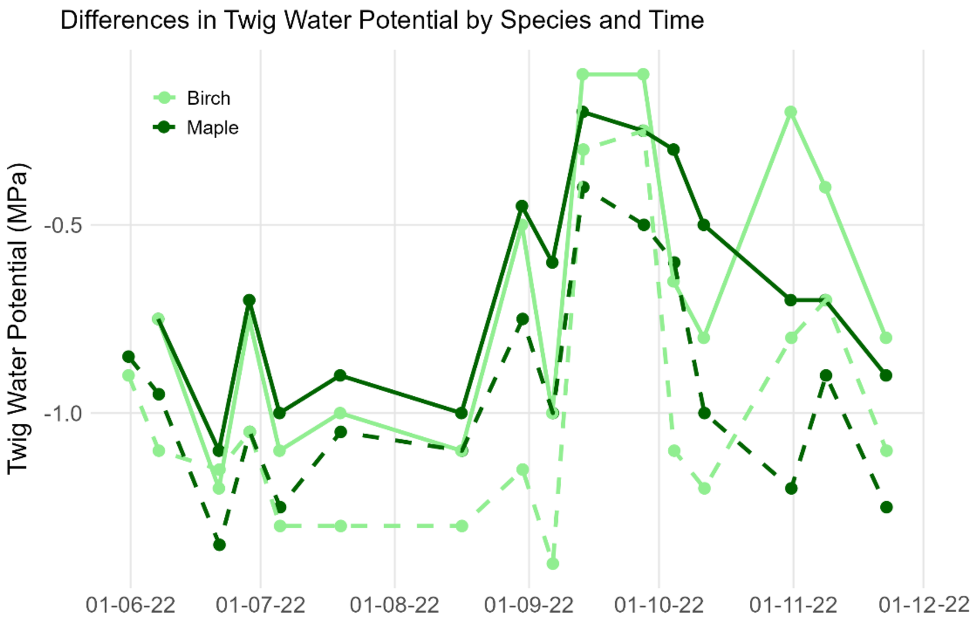

Figure S1: Timeseries of morning (~9:00 am, solid lines) and midday (~12:30 pm, dashed lines) twig water potential of *A. platanoides* (dark green) and *B. pendula* (light green) measured weekly from 31.05.-22.11.2022 with samples taken from lower canopy.

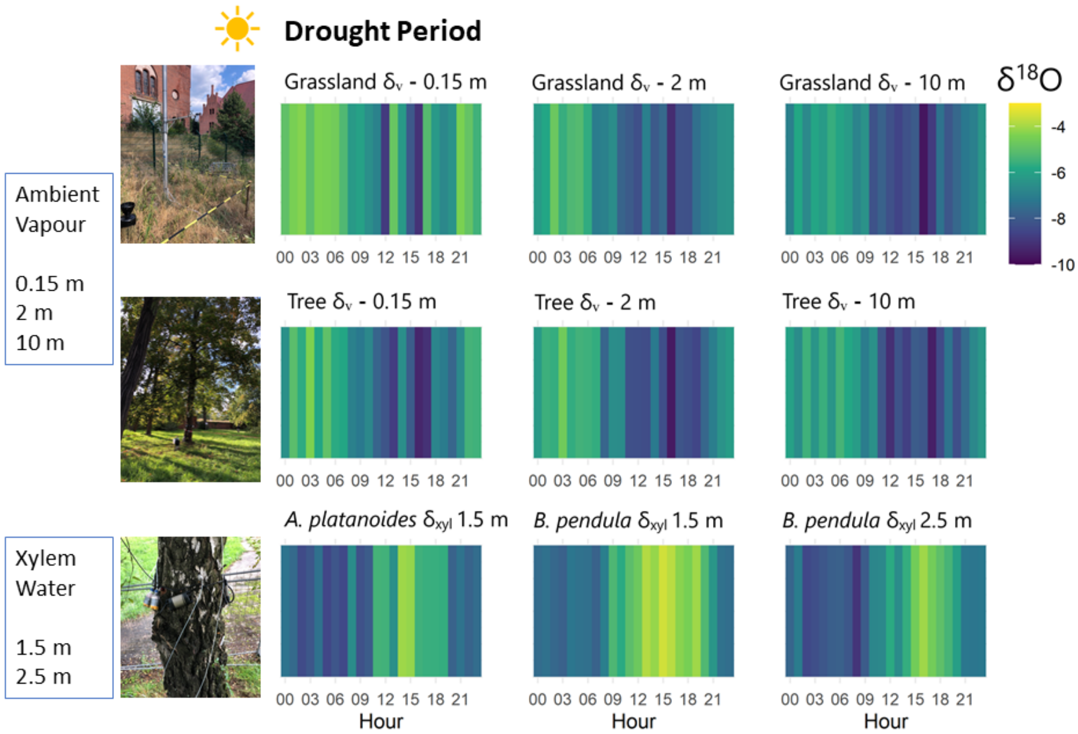

Figure S2: 24-h cycle heatmap of hourly median δ^{18}O data of tree xylem water (δ_{xyl}) and atmospheric vapor (δ_v) during summer drought period 01.07.-14.08.2022. One in situ measurement loop took ~3.5 h and unstable measurements were ruled out (cf. Method section). The hourly median shown for each hour of the day was calculated based on ~8.6 measurements.

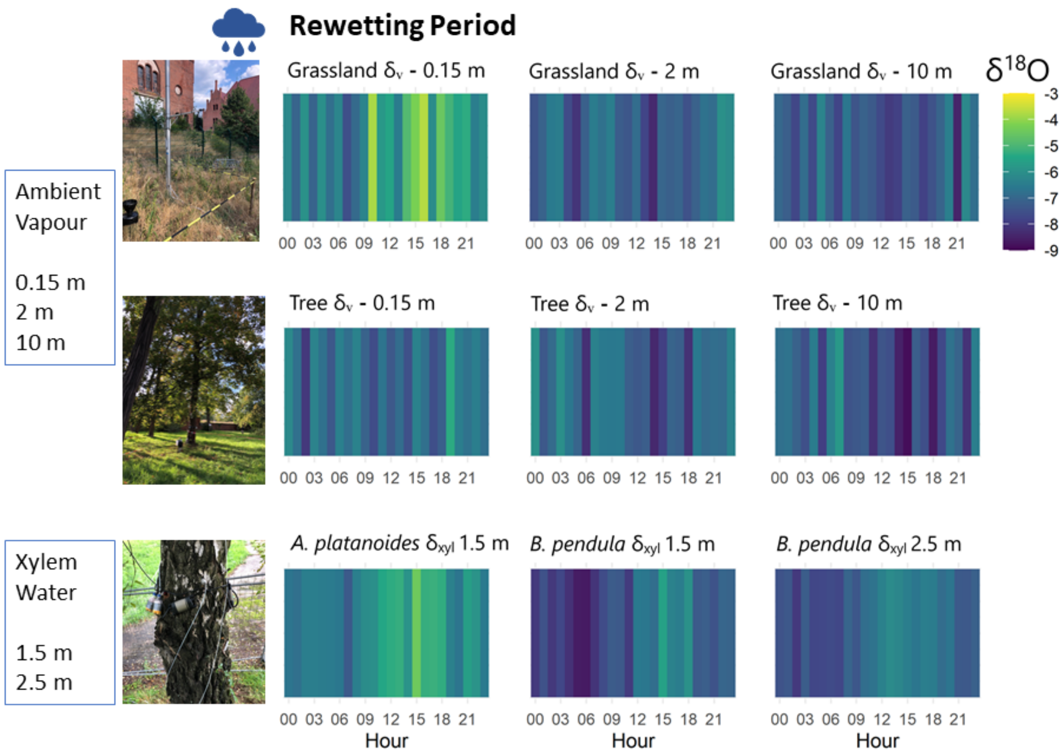

Figure S3: 24-h cycle heatmap of hourly median δ^{18}O data of tree xylem water (δxyl) and atmospheric vapor (δv) during rewetting period 15.08.-30.09.2022. One in situ measurement loop took ~3.5h and unstable measurements were ruled out (cf. Method section). The hourly median shown for each hour of the day was calculated based on ~9.2 measurements).

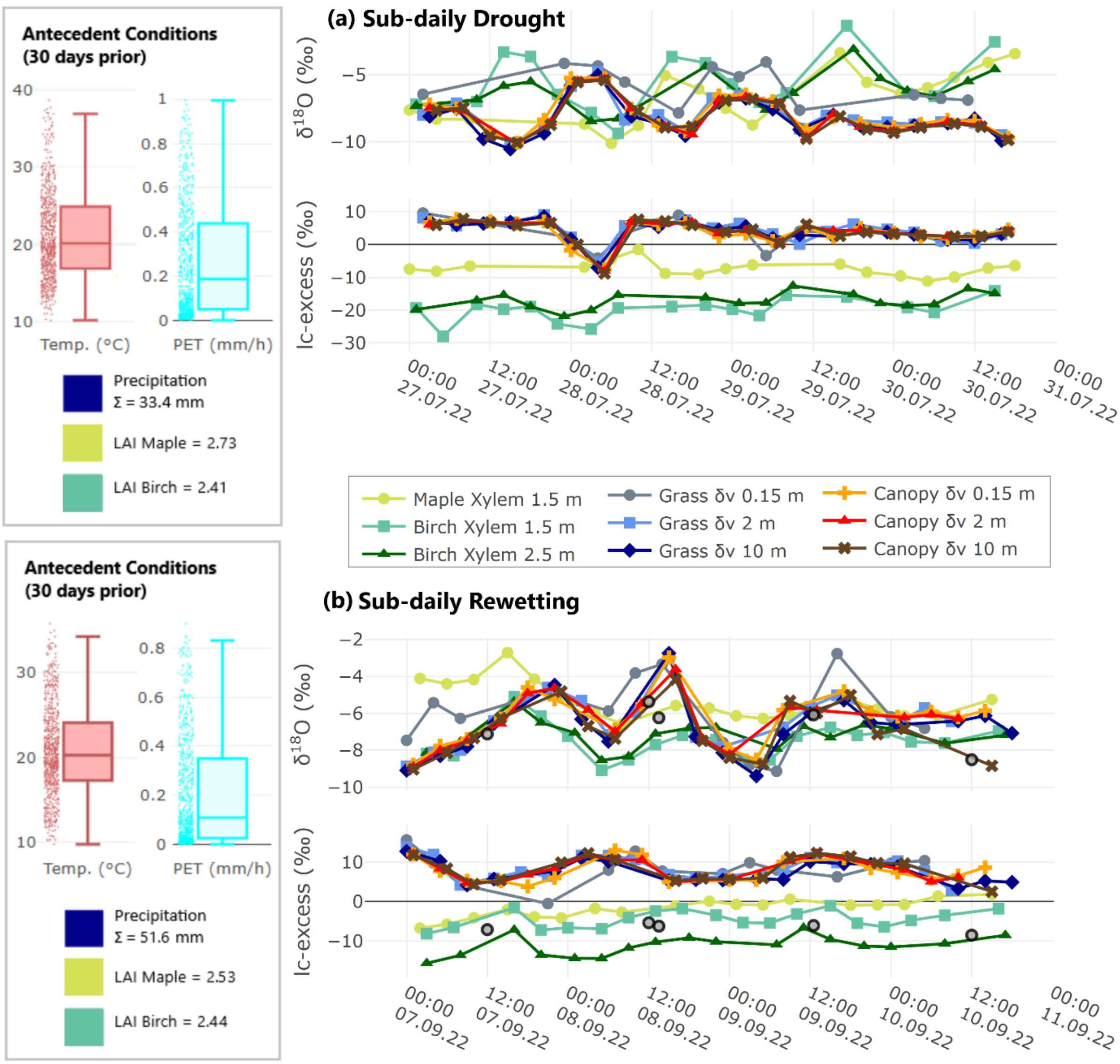

Figure S4: Sub-daily timeseries displaying diurnal variation of tree xylem water (δ_{xyl}) and atmospheric vapor (δ_v) and measured ecohydrological variables during (a) drought conditions and (b) rewetting. The boxes show on the left show antecedent conditions 30 days prior the timeseries: hourly data of temperature and PET, precipitation as 30-day sum and mean LAI of each tree.

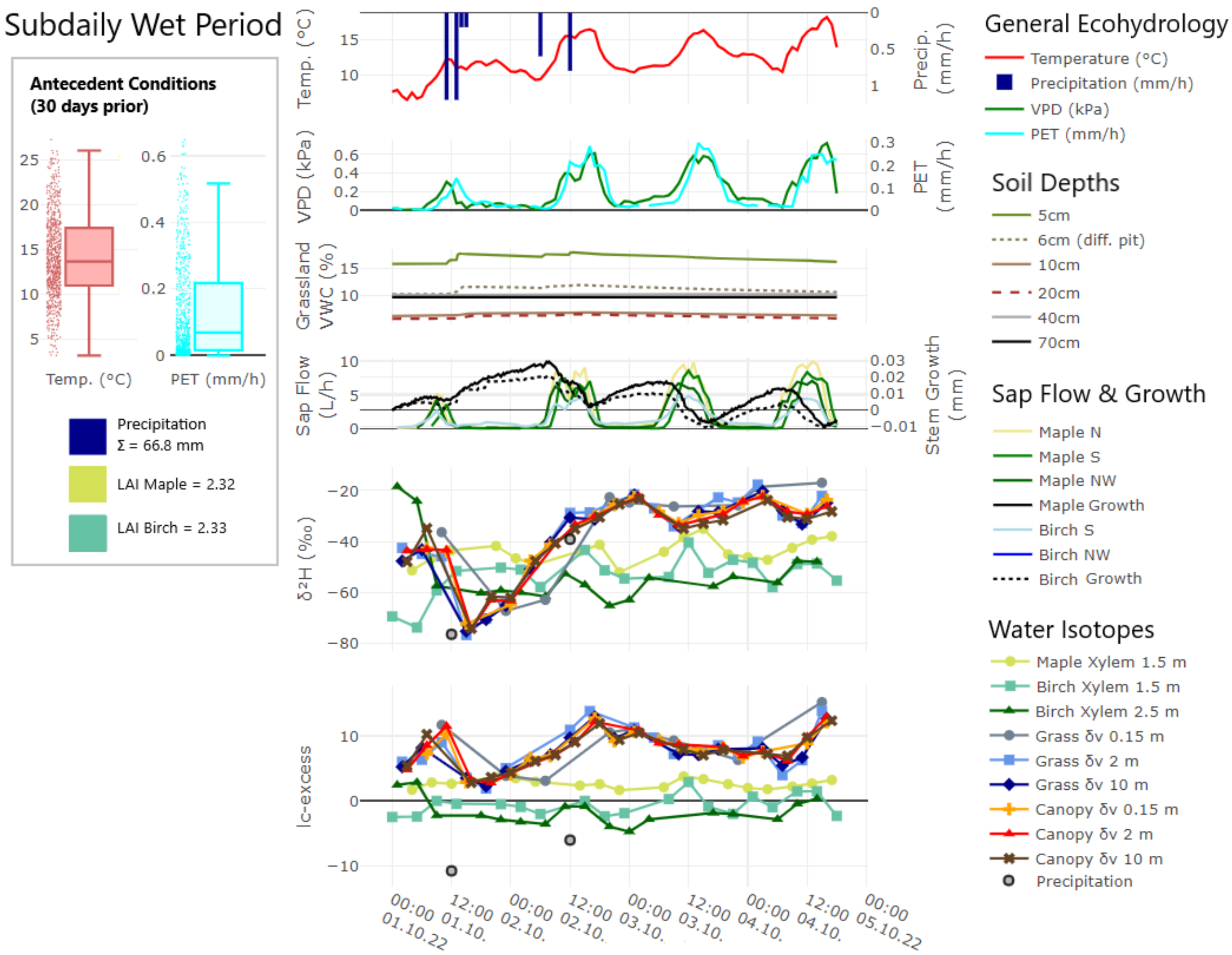

Figure S5: Wet conditions, after completed rewetting: Exemplary sub-daily timeseries displaying diurnal variation of tree xylem water (δ_{xyl}), atmospheric vapour (δ_v), precipitation water isotopes and measured ecohydrological variables. The top-left box shows antecedent conditions 30 days prior the timeseries: hourly data of temperature and PET, precipitation as 30-day sum and mean LAI of each tree.

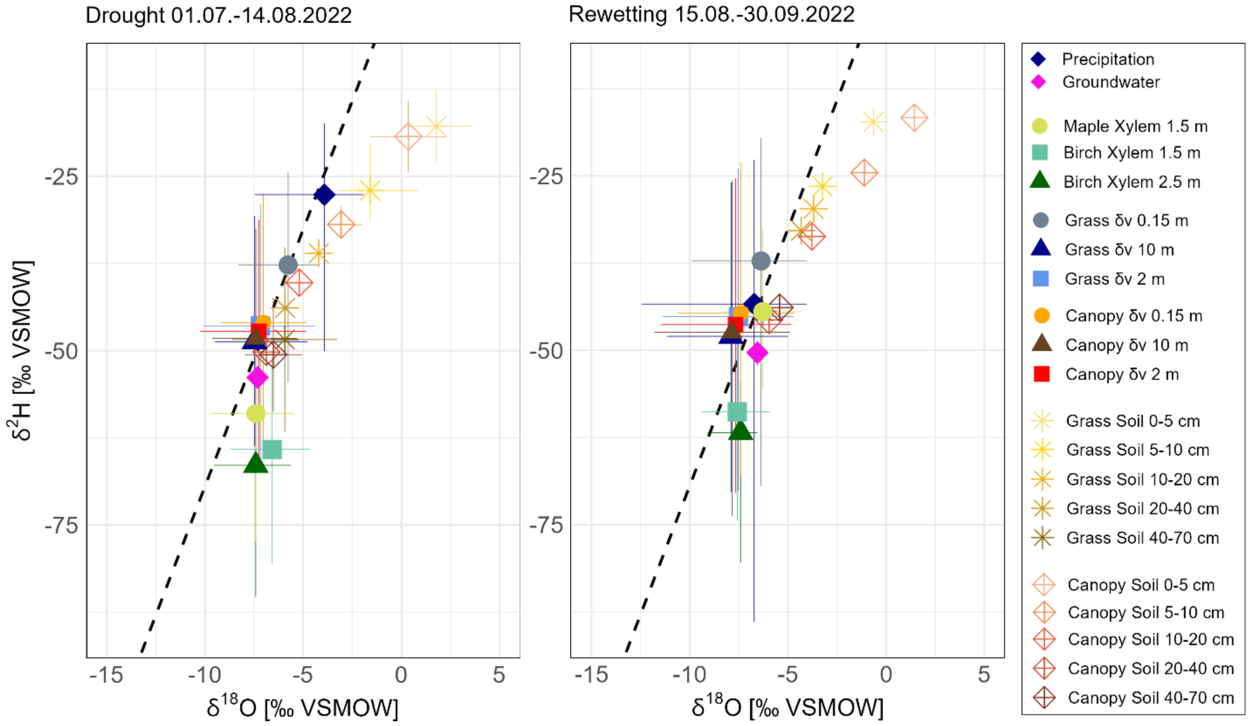

Figure S6: Dual isotope plot of all measured waters (mean with outliers) during drought 01.07.-14.08.2022 and rewetting period 15.08.-30.09.2022. LMWL derived from 2022 precipitation isotopes measured at the study site in Berlin-Friedrichshagen as dashed line. (For summary statistics see Tables S2 & S3)

Table S2 Summary statsistics of dual isotopes in ‰ during drought period 01.07.-14.08.2022

Drought	**Mean δ^{18}O**	**Mean δ^2H**	**Min δ^{18}O**	**Max δ^{18}O**	**Min δ^2H**	**Max δ^2H**
Groundwater	-7.32	-53.84	-7.42	-7.13	-54.38	-52.15
Precipitation	-3.92	-27.64	-7.47	-1.92	-50.1	-17.38
Grass δ_v 0.15 m	-5.77	-37.7	-8.3	-4.17	-54.5	-24.47
Grass δ_v 2 m	-7.18	-46.45	-10.09	-4.41	-66.09	-28.99
Grass δ_v 10 m	-7.48	-48.72	-9.49	-4.79	-63.71	-30.71
Canopy δ_v 0.15 m	-7.03	-45.98	-9.18	-4.82	-63.42	-27.49
Canopy δ_v 2 m	-7.26	-47.23	-10.24	-4.86	-67.15	-31.24
Canopy δ_v 10 m	-7.41	-48.26	-9.63	-5.31	-65.21	-32.54
Maple δ_{xyl} 1.5 m	-7.41	-59.01	-9.77	-5.48	-77.31	-46.01
Birch δ_{xyl} 1.5 m	-6.59	-64.16	-8.7	-4.69	-80.48	-50.97
Birch δ_{xyl} 2.5 m	-7.41	-66.45	-9.54	-5.62	-85.28	-51.19
Grass Soil 0-5 cm	1.78	-17.82	0.04	3.52	-23.05	-12.6
Grass Soil 5-10 cm	-1.59	-27.03	-3.2	0.83	-31.48	-20.35
Grass Soil 10-20 cm	-4.21	-36.04	-4.4	-3.93	-36.56	-35.7
Grass Soil 20-40 cm	-5.92	-43.87	-5.96	-5.88	-45.17	-42.56
Grass Soil 40-70 cm	-5.94	-48.41	-8.61	-3.26	-61.62	-35.2
Canopy Soil 0-5 cm	0.35	-19.29	-1.59	2.29	-24.45	-14.12
Canopy Soil 5-10 cm	-3.07	-31.91	-3.8	-1.98	-33.73	-29.18
Canopy Soil 10-20 cm	-5.2	-40.25	-5.31	-5.13	-40.59	-40.03
Canopy Soil 20-40 cm	-6.87	-50.2	-6.87	-6.87	-51.55	-49.3
Canopy Soil 40-70 cm	-6.52	-50.58	-7.97	-5.07	-58.75	-42.41

Table S3 Summary statsistics of dual isotopes in ‰ during rewetting period 15.08.-30.09.2022

Rewetting	**Mean** $\delta^{18}O$	**Mean** $\delta^{2}H$	**Min** $\delta^{18}O$	**Max** $\delta^{18}O$	**Min** $\delta^{2}H$	**Max** $\delta^{2}H$
Groundwater	-6.55	-50.33	-6.96	-6.2	-52.22	-48.67
Precipitation	-6.72	-43.37	-12.45	-4.05	-88.97	-22.72
Grass δ_v **0.15 m**	-6.37	-37.2	-9.92	-4.02	-69.5	-19.58
Grass δ_v **2 m**	-7.52	-45.18	-11.39	-4.71	-70.13	-23.95
Grass δ_v **10 m**	-7.9	-48	-11.15	-5	-70.31	-25.98
Canopy δ_v **0.15 m**	-7.4	-44.66	-10.66	-4.66	-67.86	-23.12
Canopy δ_v **2 m**	-7.66	-46.32	-11.47	-4.83	-70.46	-25.31
Canopy δ_v **10 m**	-7.85	-47.44	-11.8	-4.9	-73.78	-25.69
Maple δ_{xyl} **1.5 m**	-6.28	-44.45	-8.23	-4.36	-55.57	-32.65
Birch δ_{xyl} **1.5 m**	-7.58	-58.82	-9.39	-5.91	-74.43	-46.8
Birch δ_{xyl} **2.5 m**	-7.41	-61.8	-9.09	-6.56	-80.43	-54.32
Grass Soil 0-5 cm	-0.65	-17.26	-0.65	-0.65	-17.26	-17.26
Grass Soil 5-10 cm	-3.24	-26.49	-3.24	-3.24	-26.49	-26.49
Grass Soil 10-20 cm	-3.69	-29.71	-3.69	-3.69	-29.71	-29.71
Grass Soil 20-40 cm	-4.32	-32.85	-4.32	-4.32	-32.85	-32.85
Grass Soil 40-70 cm	-6.28	-44.42	-6.28	-6.28	-44.42	-44.42
Canopy Soil 0-5 cm	1.44	-16.66	1.44	1.44	-16.66	-16.66
Canopy Soil 5-10 cm	-1.11	-24.53	-1.11	-1.11	-24.53	-24.53
Canopy Soil 10-20 cm	-3.78	-33.68	-3.78	-3.78	-33.68	-33.68
Canopy Soil 20-40 cm	-5.96	-45.65	-5.96	-5.96	-45.65	-45.65
Canopy Soil 40-70 cm	-5.42	-43.89	-5.42	-5.42	-43.89	-43.89

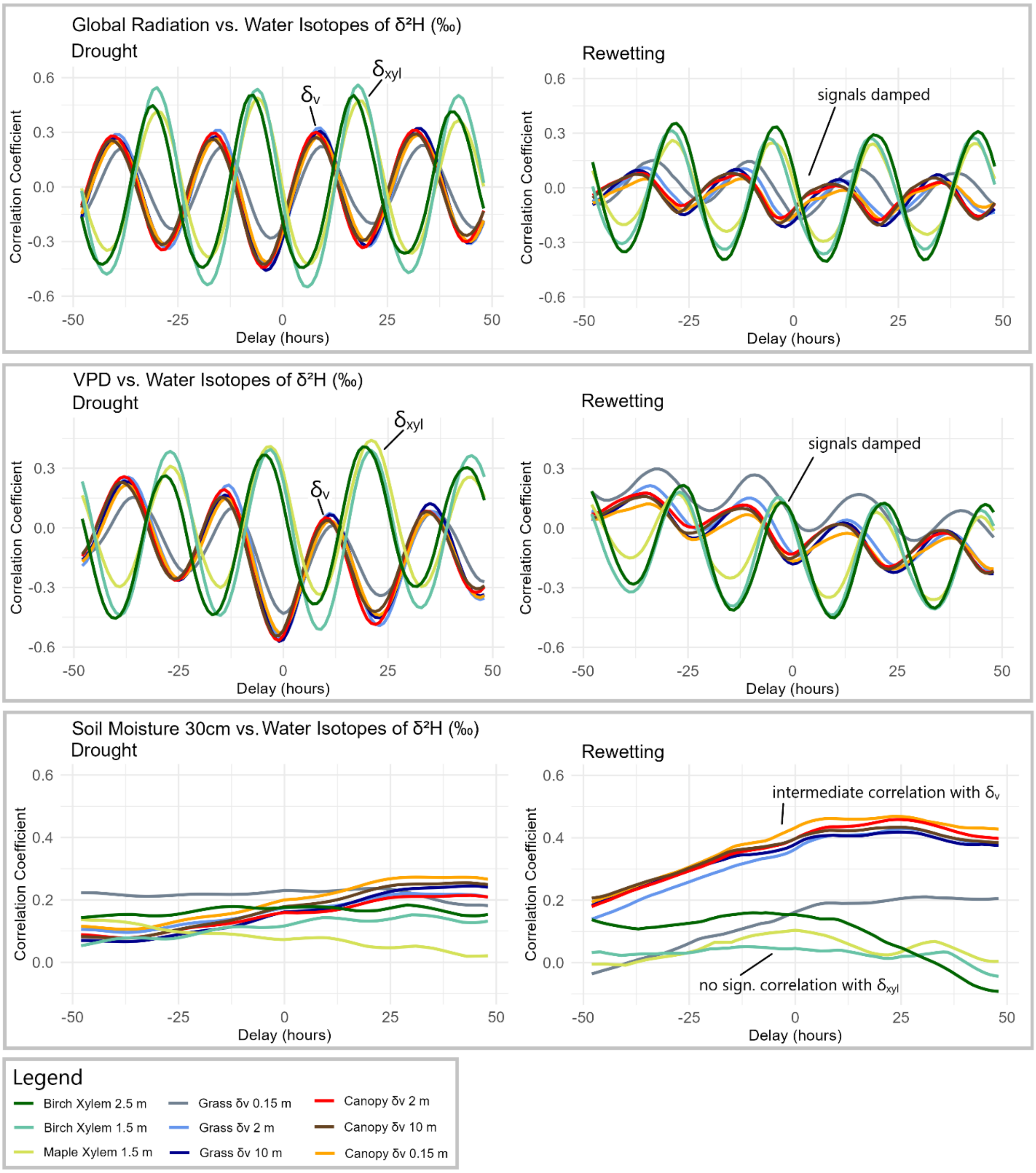

Figure S7: Cross correlation analysis between in situ measured δ^2H data (tree xylem water (δ_{xyl}) and atmospheric vapor (δ_v)) and global radiation, VPD and soil moisture at 30 cm depth underneath canopy comparing the two focus periods of drought (01.07. - 14.08.2022) and rewetting (15.08.2022 - 30.09.2022).

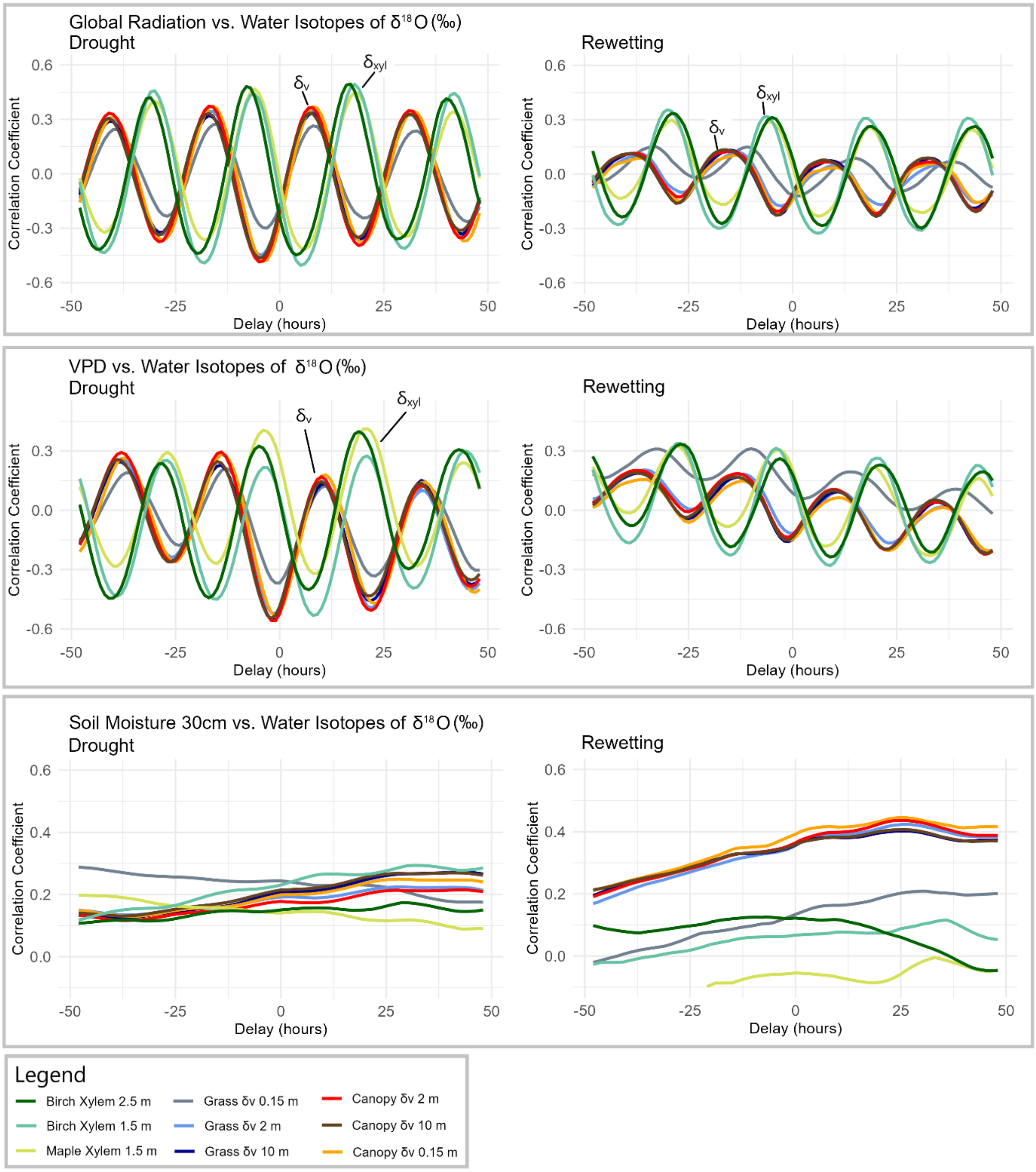

Figure S8: Cross correlation analysis between in situ measured $\delta^{18}O$ data (tree xylem water (δ_{xyl}) and atmospheric vapor (δ_v)) and global radiation, VPD and soil moisture at 30 cm depth underneath canopy comparing the two focus periods of drought (01.07. - 14.08.2022) and rewetting (15.08.2022 - 30.09.2022).

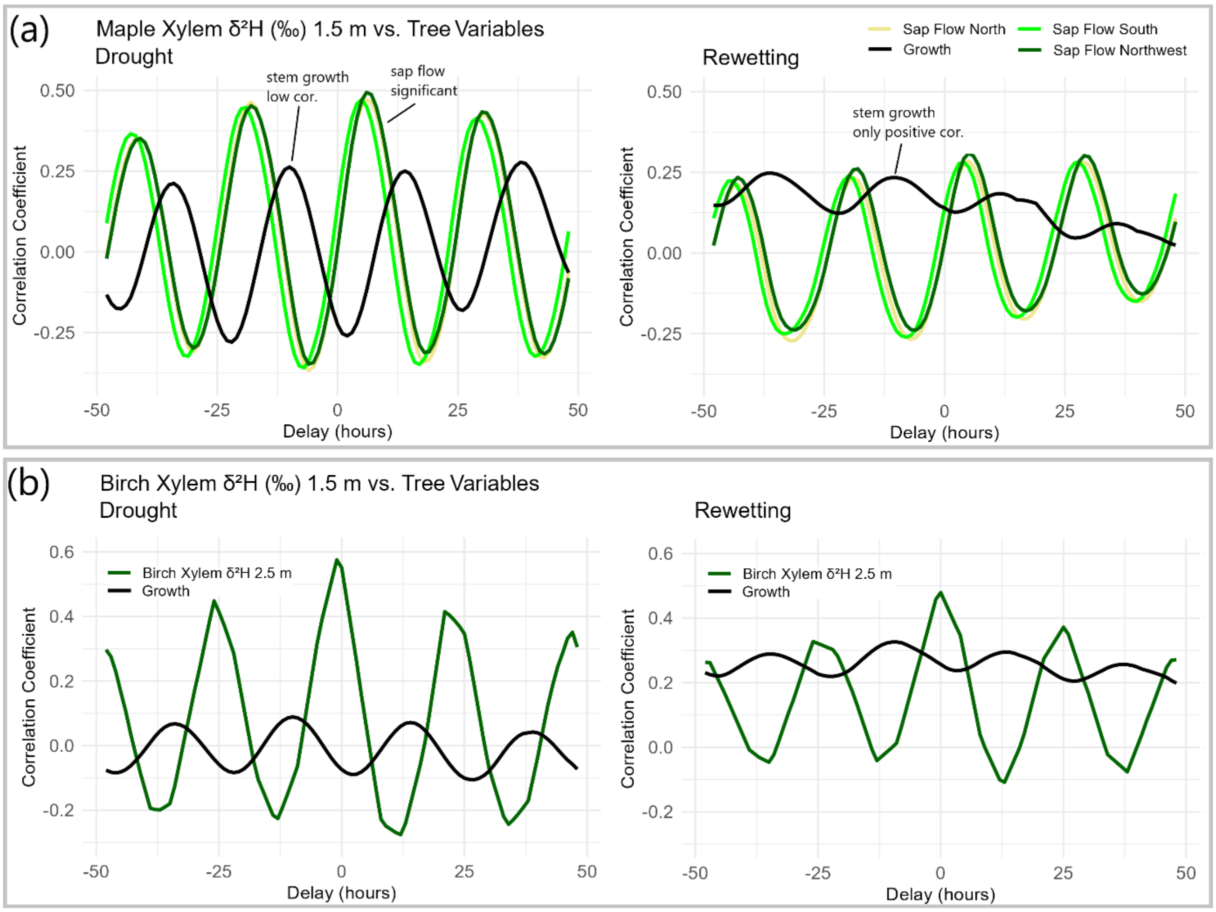

Figure S9: Cross correlation analysis between: (a) δ^2H of Maple xylem water (1.5 m borehole) and measured sap flow and stem growth comparing the two focus periods of drought (01.07. - 14.08.2022) and rewetting (15.08.2022 - 30.09.2022); (b) δ^2H of Birch xylem water (1.5 m borehole) and δ^2H of Birch xylem water (2.5 m borehole) plus stem increments comparing the two focus periods of drought (01.07. - 14.08.2022) and rewetting (15.08.2022 - 30.09.2022).

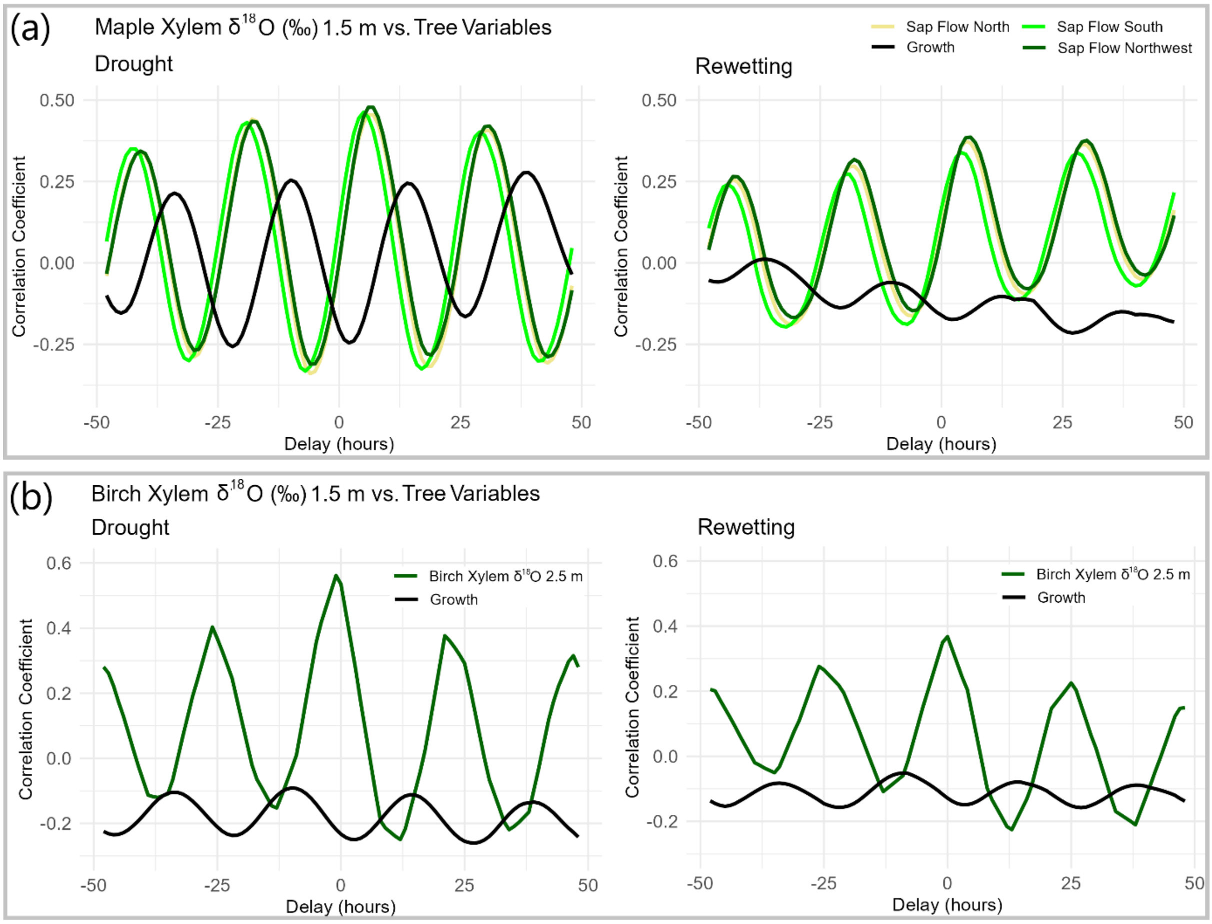

Figure S10: Cross correlation analysis between: (a) $\delta^{18}O$ of Maple xylem water (1.5 m borehole) and measured sap flow and stem growth comparing the two focus periods of drought (01.07. - 14.08.2022) and rewetting (15.08.2022 - 30.09.2022); (b) $\delta^{18}O$ of Birch xylem water (1.5 m borehole) and $\delta^{2}H$ of Birch xylem water (2.5 m borehole) plus stem increments comparing the two focus periods of drought (01.07. - 14.08.2022) and rewetting (15.08.2022 - 30.09.2022).

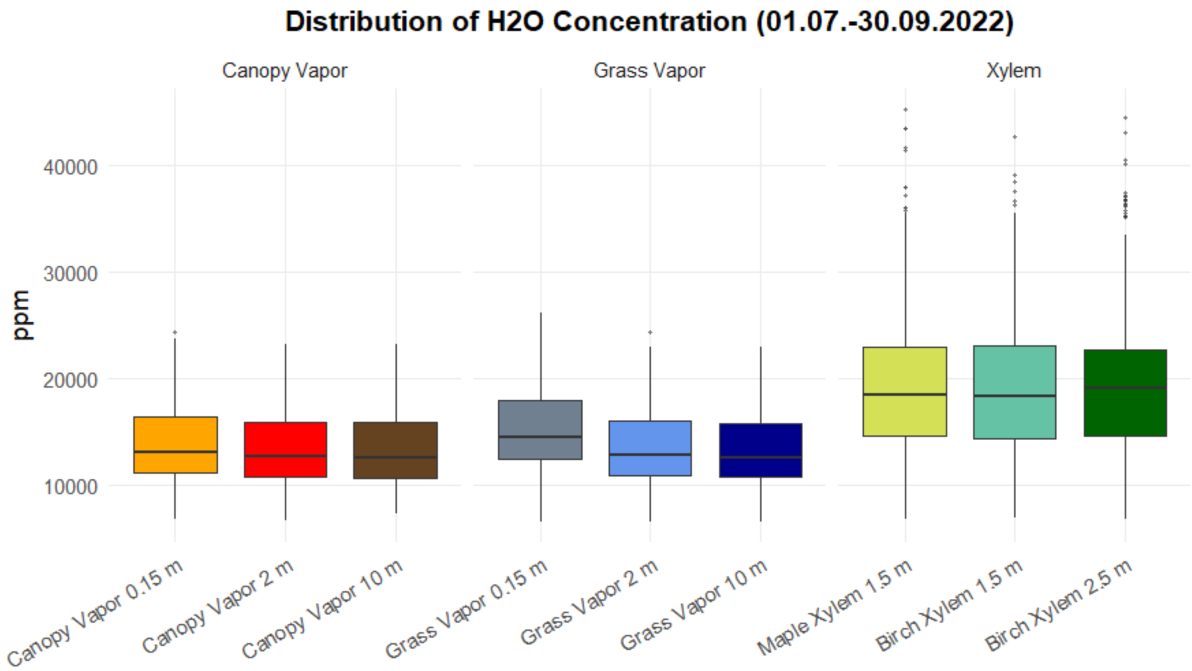

Figure S11: Water vapor concentration range of the analyzed SWI samples (tree xylem water (δ_{xyl}) and atmospheric vapor (δ_v)) covering the whole drought and rewetting period (01.07-30.09.2022).