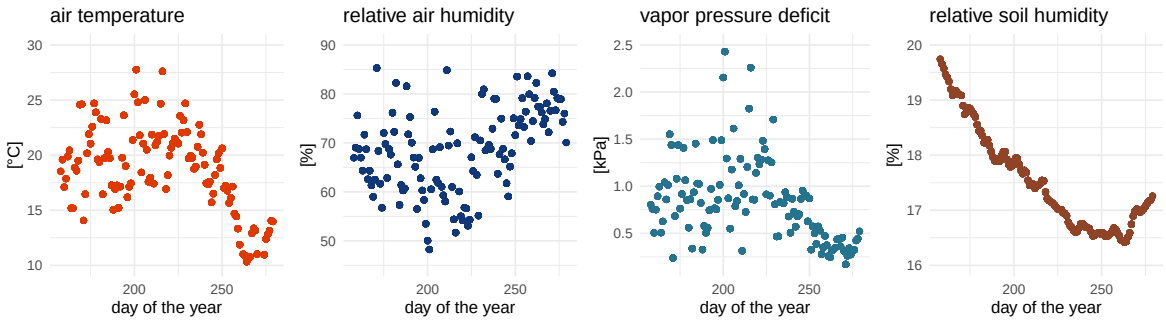
Supplementary information: Temporal dynamics in vertical leaf angles can confound vegetation indices widely used in Earth observations

Authors: Teja Kattenborn, Sebastian Wieneke, David Montero, Miguel D. Mahecha, Ronny Richter, Claudia Guimarães-Steinicke, Christian Wirth, Olga Ferlian, Hannes Feilhauer, Lena Sachsenmaier, Nico Eisenhauer, and Benjamin Dechant



Supplementary Figure 1: Temporal dynamics of environmental drivers monitored at the MyDiv experimental site. Air temperature and vapor pressure deficit have a pronounced short-term variability, while soil moisture varies with very smooth transitions. With these environmental drivers, mixed effect models explain 27% and 47% of the variation of average leaf angles at the level of species and individuals, respectively (Supplementary Figure 2).

Supplementary Table 1: Correlation of average leaf angles [deg.] per species with air temperature [°C].

Species	**r**
Fagus sylvatica	0.38
Quercus petraea	0.06
Acer pseudoplatanus	-0.18
Tilia platyphyllos	0.32
Betula pendula	0.51
Prunus avium	0.59
Aesculus hippocastanum	0.25
Fraxinus excelsior	0.5
Sorbus aucuparia	0.57
Carpinus betulus	0.63

Supplementary Table 2: Correlation of average leaf angles [deg.] per species with relative soil moisture [%] (0.05 m depth).

Species	**r**
Fagus sylvatica	0.46
Quercus petraea	-0.01
Acer pseudoplatanus	-0.5
Tilia platyphyllos	0.03
Betula pendula	0.37
Prunus avium	0.13
Aesculus hippocastanum	0.38
Fraxinus excelsior	0.51
Sorbus aucuparia	0.6
Carpinus betulus	0.18

Supplementary Table 3: Correlation of the average leaf angle [deg.] per species with vapor pressure deficit [kPa].

Species	**r**
Fagus sylvatica	0.42
Quercus petraea	0.08
Acer pseudoplatanus	-0.19
Tilia platyphyllos	0.37
Betula pendula	0.55
Prunus avium	0.57
Aesculus hippocastanum	0.31
Fraxinus excelsior	0.48
Sorbus aucuparia	0.58
Carpinus betulus	0.64

Supplementary Table 4: Quantile ranges (0.01 and 0.99) of traits used for radiative transfer modelling with PROSAIL, simulated reflectances of Sentinel-2 bands (B2-B12), and resulting vegetation indices (VIs). CHL = Chlorophyll, CAR = Carotenoids, ANT = Anthocyannins, EWT = Equivalent water thickness, LMA = Leaf mass per area, LAI = Leaf Area Index. The full names and references for the vegetation indices can be found in [2].

Trait / Band / VI	**0.01 quantile**	**0.99 quantile**
CHL	27.369	67.549
CAR	2.515	10.87
ANT	0.311	2.27
EWT	0.008	0.025
LMA	0.001	0.013
LAI	1.036	4.972
B2	0.019	0.106
B3	0.039	0.161
B4	0.017	0.105
B5	0.056	0.194
B6	0.325	0.472
B7	0.45	0.647
B8	0.461	0.676
B8A	0.465	0.688
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VI	0.01 quantile	0.99 quantile
B11	0.162	0.389
B12	0.046	0.235
AFRI1600	0.373	0.643
AFRI2100	0.647	0.909
ARI	0.918	7.976
ARI2	0.473	4.574
ARVI	0.659	0.94
ATSAVI	0.525	0.77
AVI	0.563	0.758
BCC	0.197	0.3
BNDVI	0.659	0.94
BWDRVI	-0.345	0.525
CIG	2.151	13.706
CIRE	1.634	9.33
CVI	1.354	6.449
DSI	0.329	0.692
DSWI1	1.446	3.041
DSWI2	1.73	7.648
DSWI3	2.799	19.245
DSWI4	1.318	4.22
DSWI5	1.451	3.089
DVI	0.399	0.657
DVIplus	0.175	0.284
EVI	0.737	1.019
EVI2	0.575	0.955
ExG	0.041	0.151
ExGR	0.053	0.219
ExR	-0.069	-0.001
FCVI	0.381	0.644
GARI	0.994	1.048
GBNDVI	0.323	0.817
GCC	0.398	0.646
GDVI	0.921	0.999
GEMI	0.852	1.073
GLI	0.139	0.571
GM1	2.711	8.953
GM2	2.272	6.305
GNDVI	0.518	0.873
GOSAVI	0.422	0.704
GRNDVI	0.327	0.823
GRVI	3.151	14.706
GSAVI	0.418	0.721
GVMI	0.435	0.798
IAVI	0.666	0.958
IKAW	-0.173	0.007
IPVI	0.831	0.974
IRECI	0.926	3.627
MCARI	0.069	0.539
MCARI1	0.629	1.017
MCARI2	0.552	0.982
MCARI705	0.436	1.586
MCARIOSAVI	0.1	0.642
MCARIOSAVI705	1.201	2.569
MGRVI	0.269	0.894
MNDVI	0.4	0.826

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VI	0.01 quantile	0.99 quantile
MNLI	0.222	0.593
MRBVI	-0.337	0.013
MSAVI	0.553	0.915
MSI	0.329	0.692
MSR	1.61	5.857
MSR705	0.703	1.963
MTCI	2.349	7.768
MTVI1	0.629	1.017
MTVI2	0.552	0.982
ND705	0.389	0.726
NDDI	6.454	26.072
NDGI	0.47	0.884
NDII	0.182	0.505
NDMI	0.182	0.505
NDPI	0.222	0.539
NDREI	0.45	0.823
NDVI	0.662	0.948
NDVI705	0.389	0.726
NDYI	0.141	0.531
NGRDI	0.137	0.617
NIRv	0.333	0.64
NIRvH2	0.399	0.657
NLI	0.429	0.923
NMDI	0.515	0.627
NRFIg	-0.565	0.251
NRFIr	-0.804	-0.211
NormG	0.062	0.209
NormNIR	0.664	0.911
NormR	0.024	0.136
OCVI	1.085	5.698
OSAVI	0.525	0.77
PSRI	-0.024	0.003
RCC	0.153	0.302
RDVI	0.516	0.789
REDSI	25.005	518.724
RENDVI	0.389	0.726
RGBVI	0.272	0.863
RGRI	0.237	0.759
RI	-0.617	-0.137
RVI	4.103	22.946
S2REP	719.452	732.311
SARVI	0.499	0.771
SAVI	0.499	0.776
SAVI2	4.918	37.194
SEVI	10.521	70.379
SI	0.877	0.975
SR	4.918	37.194
SR2	3.151	14.706
SR3	16.416	258.33
SR555	2.711	8.953
SR705	2.272	6.305
SeLI	0.452	0.826
TCARI	0.083	0.275
TCARIOSAVI	0.098	0.408
TCARIOSAVI705	-0.491	0.996

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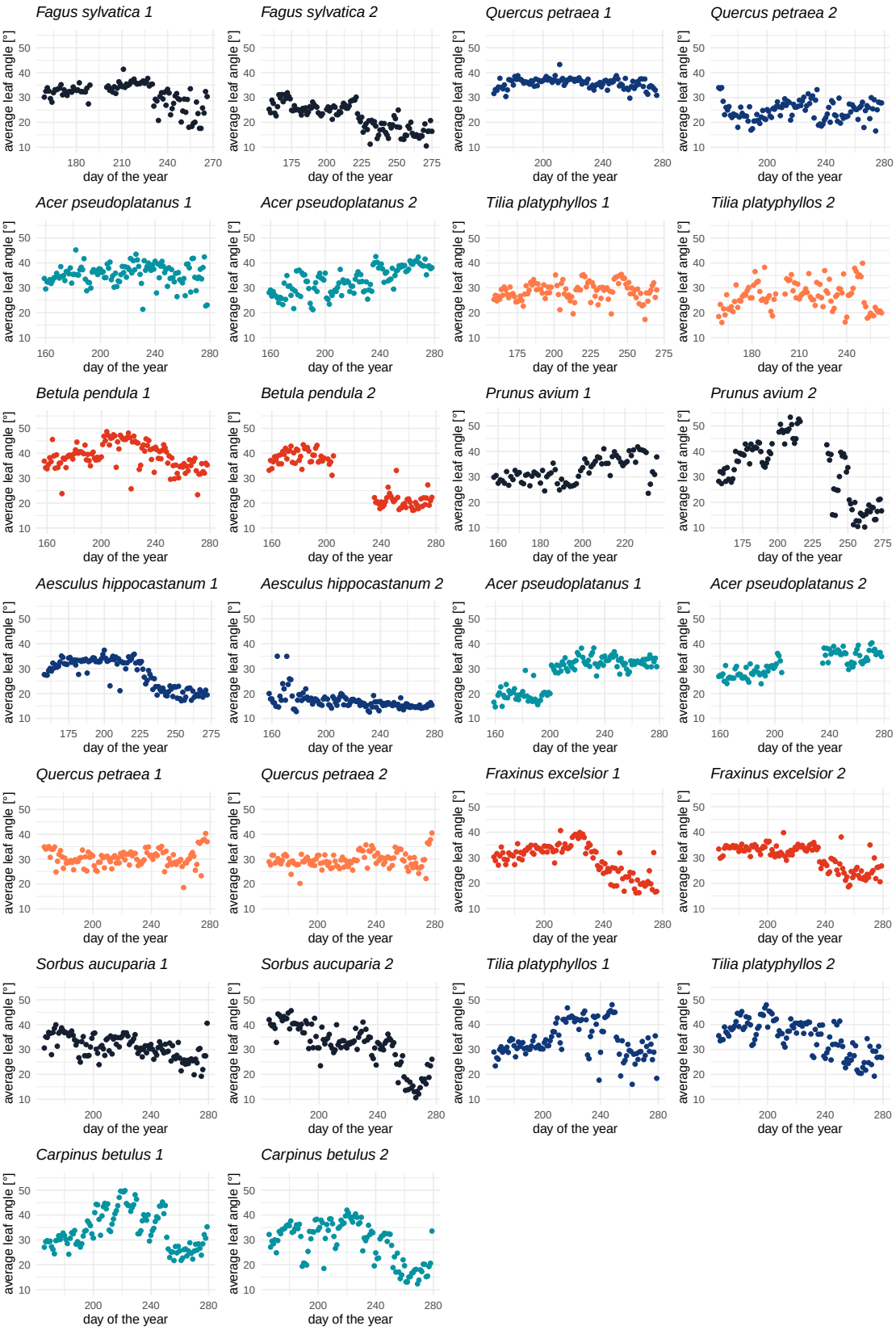
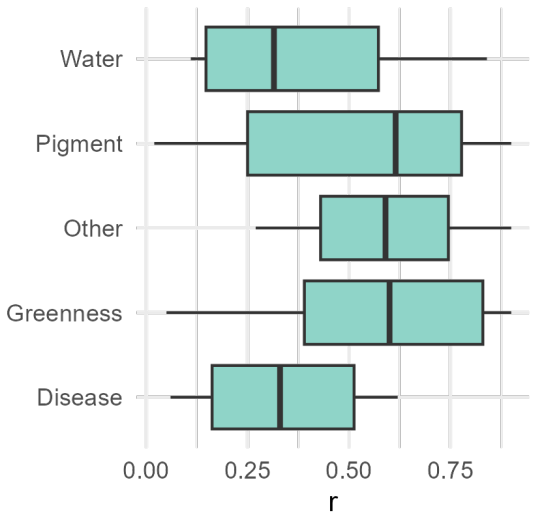
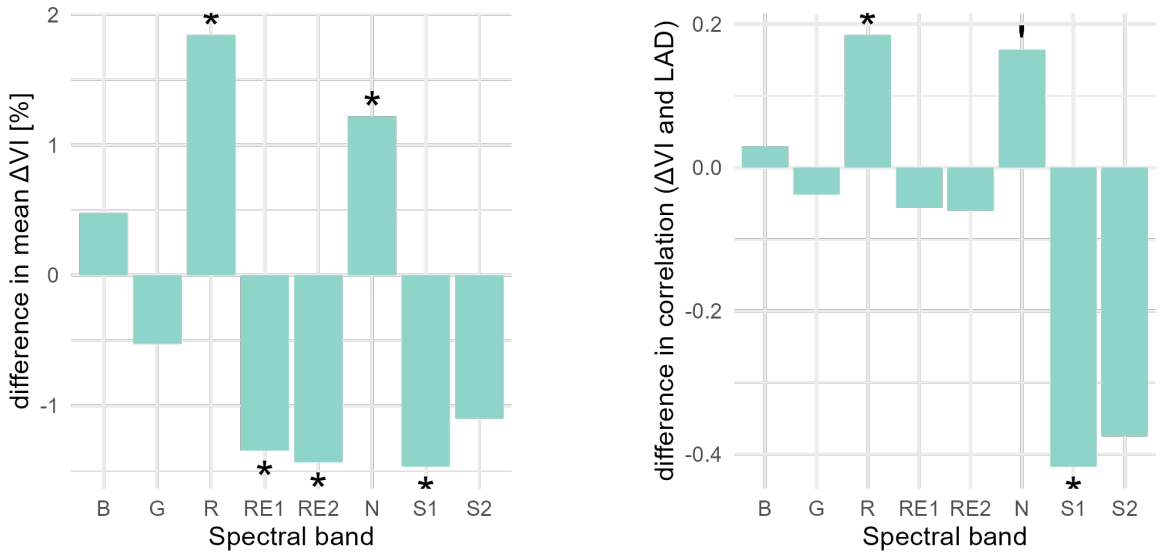
VI	0.01 quantile	0.99 quantile
TCI	0.073	0.298
TDVI	0.65	0.998
TGI	1.908	7.1
TRRVI	0.365	0.471
TSAVI	0.662	0.948
TTVI	2.326	8.413
TVI	1.078	1.203
TriVI	25.458	41.126
VARI	0.239	0.839
VARI700	0.353	0.966
VI700	0.22	0.693
VIG	0.137	0.617
WDRVI	-0.341	0.576
WDVI	0.399	0.657
NDWI	-0.873	-0.518
kNDVI	0.449	0.864



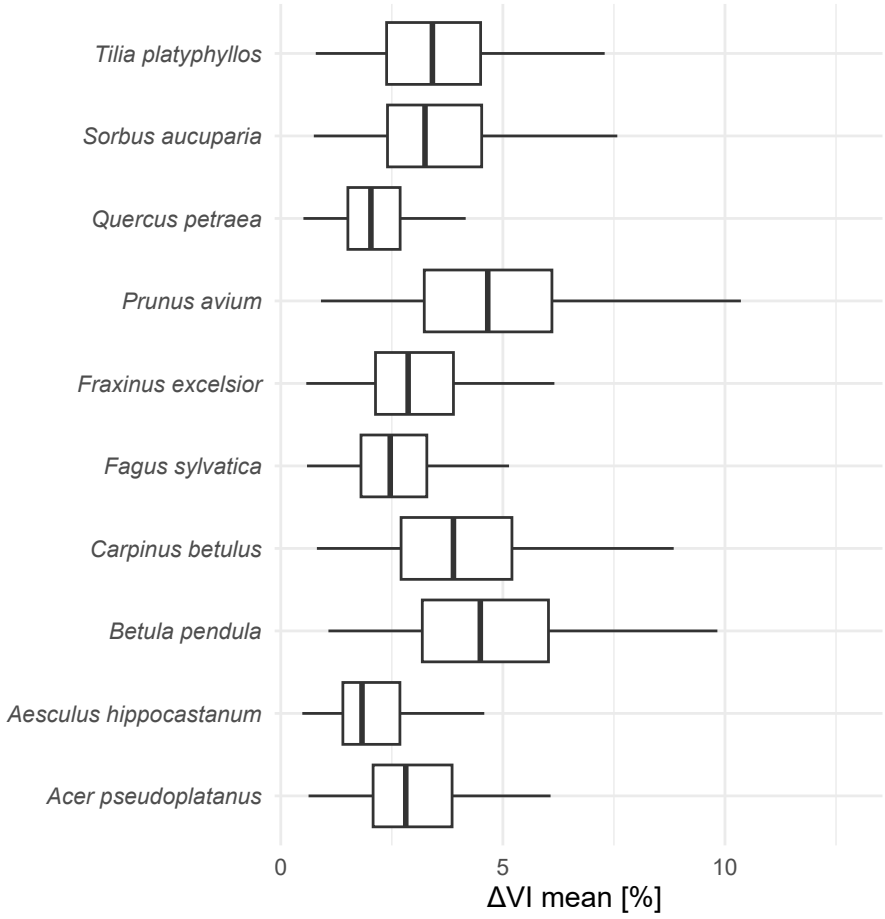
Supplementary Figure 2: Short and long-term dynamics of leaf angles at satellite overpass times. Leaf angles were obtained using AngleCam [1] and visualized as average leaf angles derived from the predicted leaf angle distributions to ease the visualization. The two individuals per species (see colors) show similar leaf angle dynamics, underlining both the robustness of the AngleCam method and the species-specific leaf angle behavior.



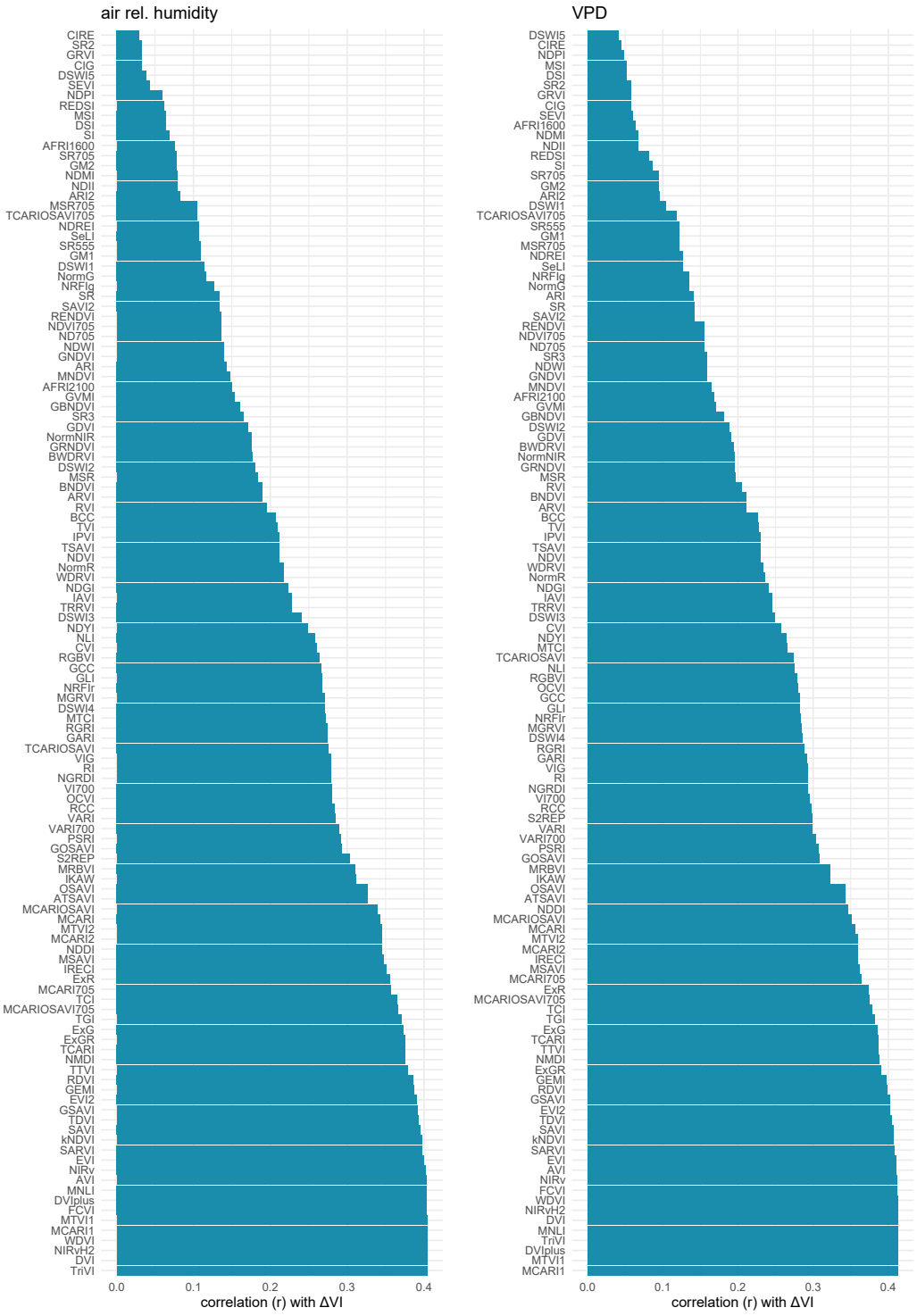
Supplementary Figure 3: Effect of leaf angle dynamics grouped by vegetation index application types (Water, Structure, Pigment, Greeness, Disease). The effect is measured as the correlation of ΔVI with leaf angle dynamics. Leaf angle dynamics are measured as difference of actual and species-mean leaf angle. The boxes show the interquartile range (IQR) and median, while the whiskers extend to the smallest and largest values within 1.5 times the IQR.



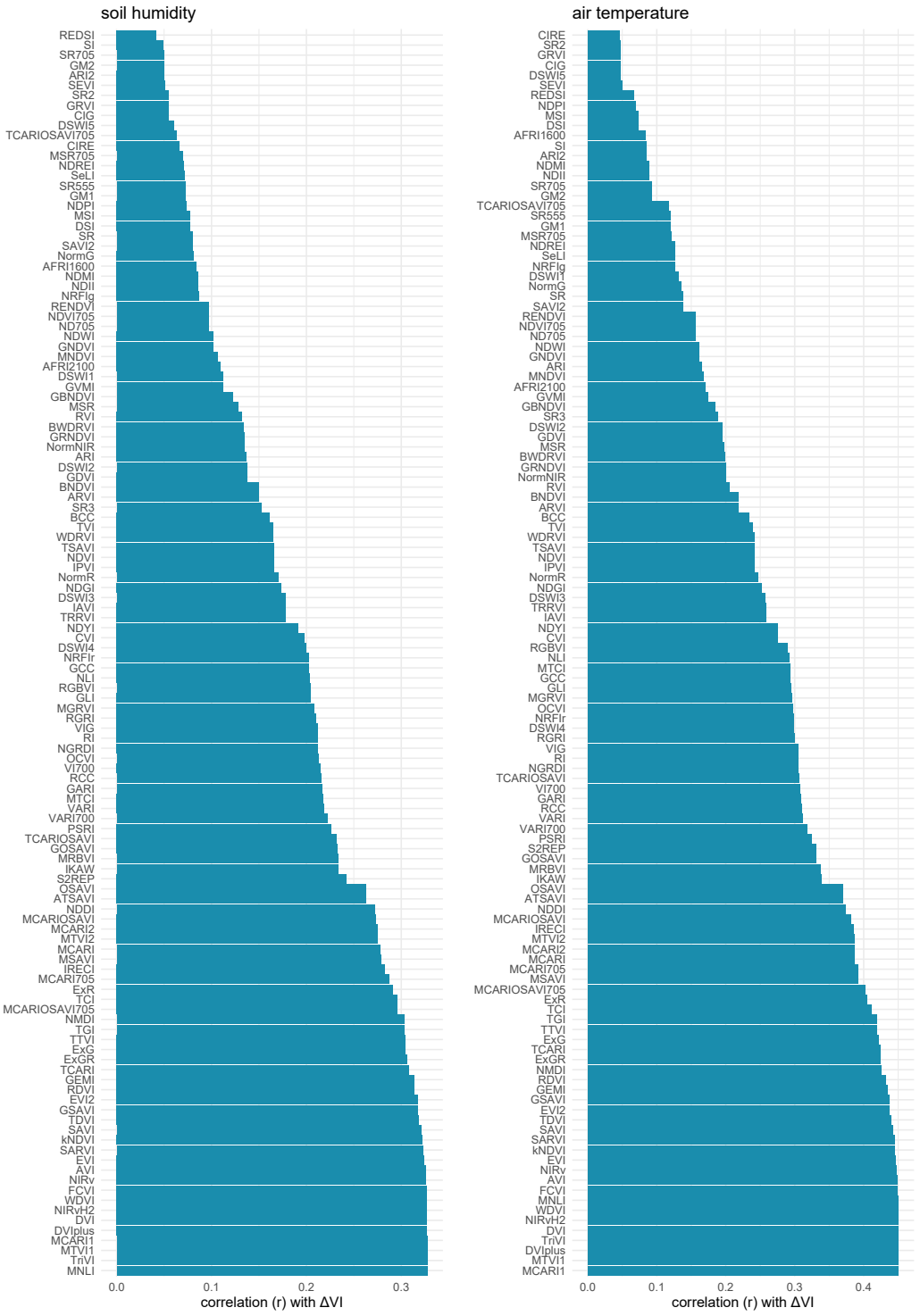
Supplementary Figure 4: The average confounding effect of leaf angle dynamics averaged across all VIs grouped by spectral bands; a) the difference in ΔVI% and b) the difference in the correlation of ΔVI% and leaf angle dynamics. Leaf angle dynamics are measured as difference of actual and species-mean leaf angle. Spectral bands correspond to Sentinel-2 bands with B = Blue, G = Green, R = Red, R1 = RedEdge-1, R2 = Rededge-2, N = Near Infrared, S1 = Short wave infrared-1, S2 Short wave infrared-2. Significant effects are marked with '*' for p-values ¡ 0.05 and '-' for p-values ¡ 0.10.



Supplementary Figure 5: ΔVI% mean by tree species. The boxes show the interquartile range (IQR) and median, while the whiskers extend to the smallest and largest values within 1.5 times the IQR.



Supplementary Figure 6: The averaged species-wise correlation of ΔVI% with relative air humidity [%] and vapour pressure deficit (VPD) [kPa].



Supplementary Figure 7: The averaged species-wise correlation of ΔVI% with soil humidity [%] and air temperature [°C].

References

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