Vegetation controls spatial patterns of soil water isotopes in a tropical dry forest and UAV's can help to predict them

Matthias Beyer, Malkin Gerchow, Alberto Iraheta, Kathrin Kuehnhammer, Paul Koeniger, Ricardo Sanchez-Murillo, David Dubbert, Maren Dubbert, Ana Claudia Callau-Beyer, and Christian Birkel

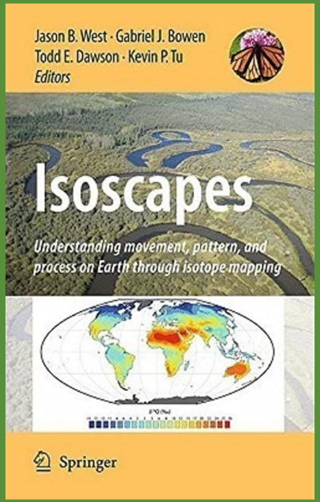
ISODRONES

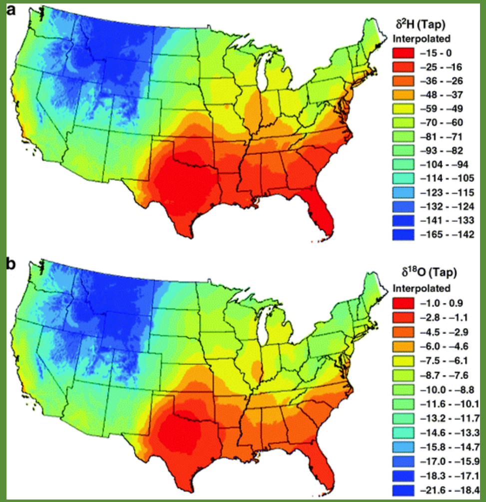
isodrones.com

Isodrones Project

@Isodronesproject

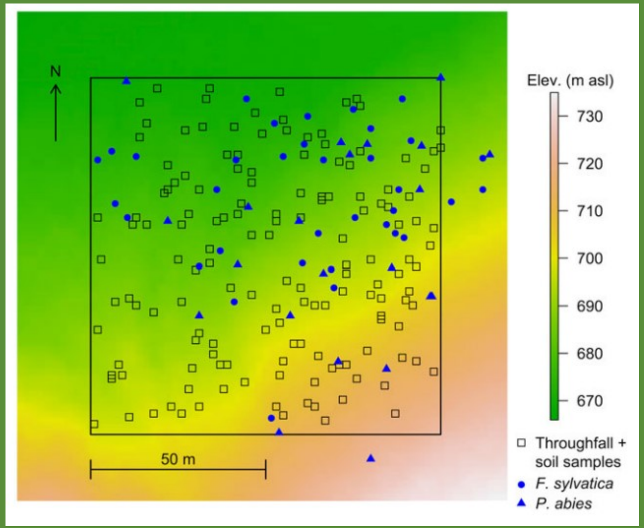
Motivation

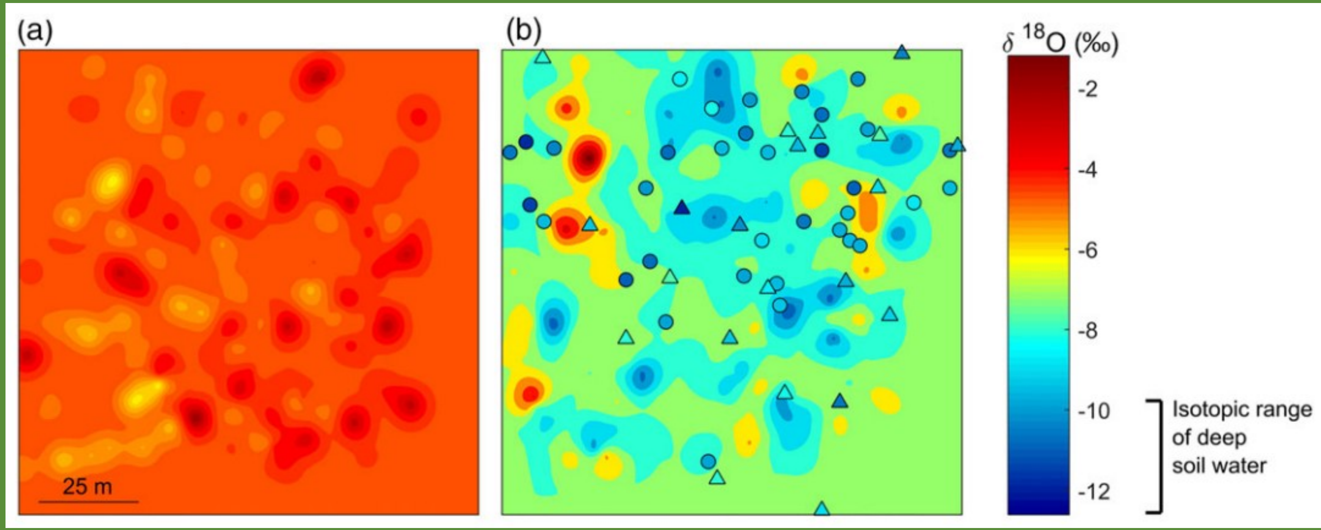




- Rainfall isoscapes are great → spatio-temporal investigations
- Very few studies investigate spatial patterns of soil and plant water isotopes

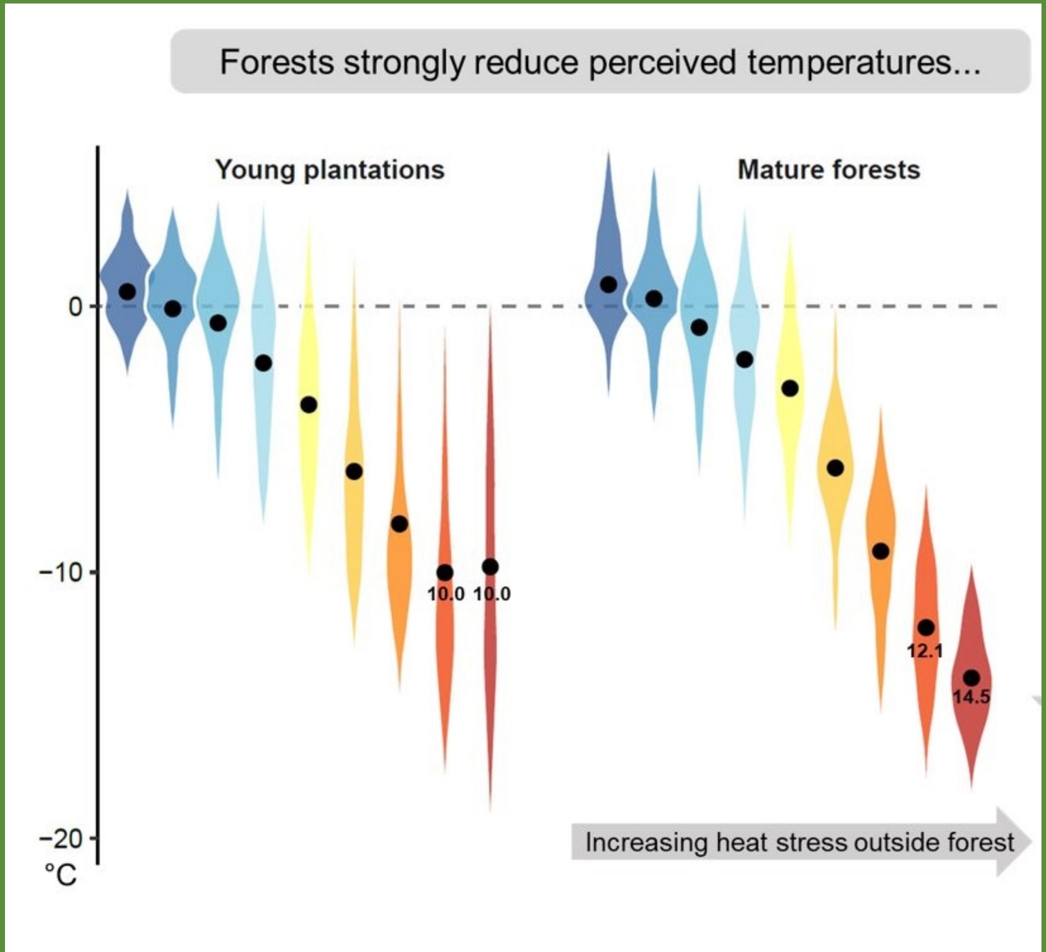
[Goldsmith et al., 2018, Oerter et al., 2019]

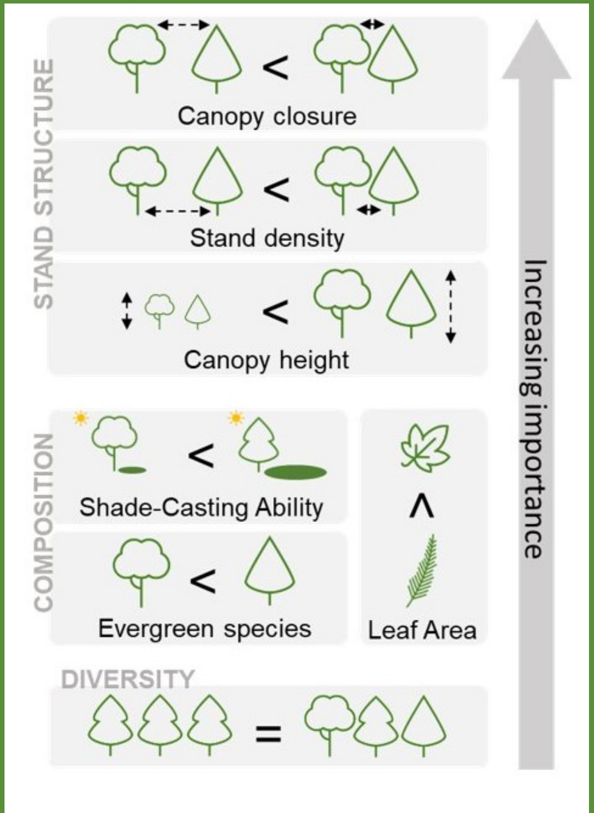




[Goldsmith et al., 2018]

Canopy structure affects temperatures…



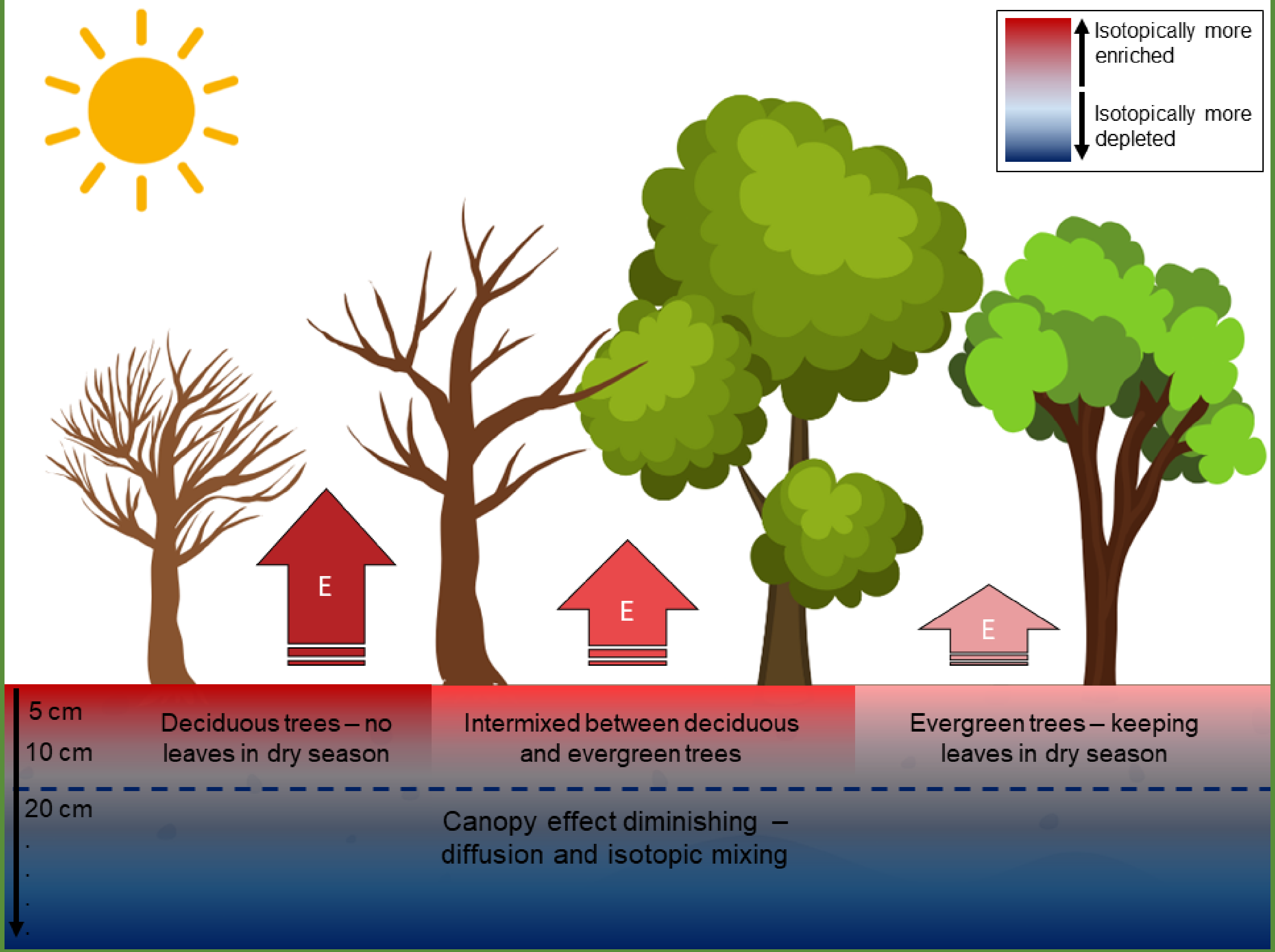


[Gillerot et al., 2022]

- canopy structure affects air and soil temperatures

- soil temperature affects evaporation & isotope fractionation

…we should see this in heterogeneous systems!

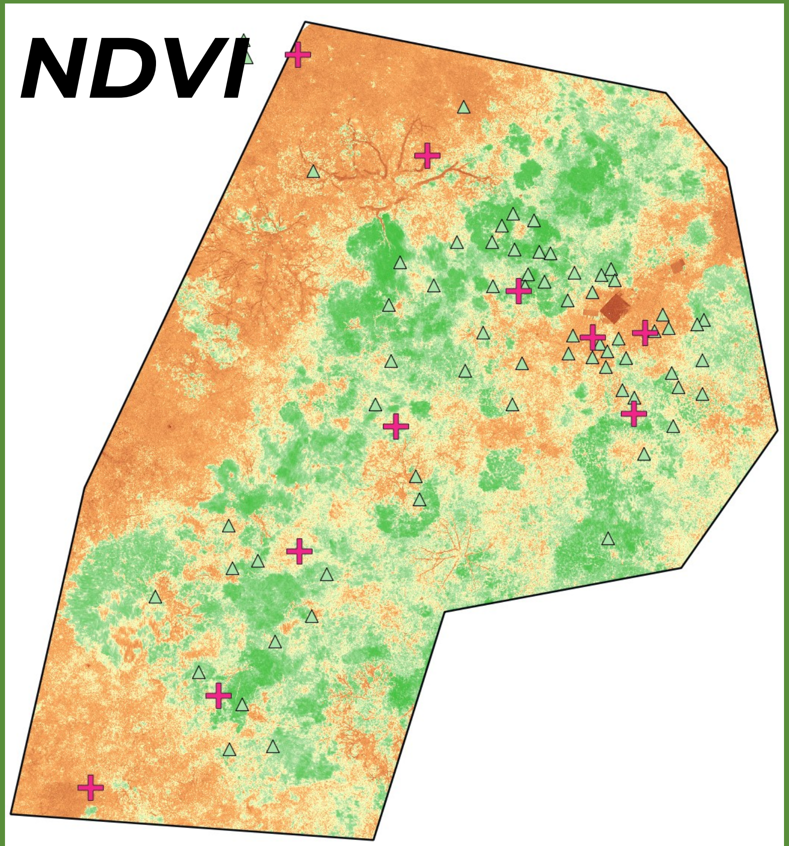


Hypothesis:

Substantial variations of soil water content and isotope values exist in heterogeneous systems.

- Is this relevant?
- What affects the spatial distribution of soil water isotopes?
- How does this relate to water uptake depths and water partitioning?

Study site



- Tropical-dry, no rain Jan-May
- P ~ 1800 mm y^{-1}

Methods

I. Collection and analysis of **10 soil water isotope-depth profiles** and spatially distinct xylem sampling

- peak of dry season, March 2019
- 0-150cm soil depth
- CVE [Koeniger et al., 2011]

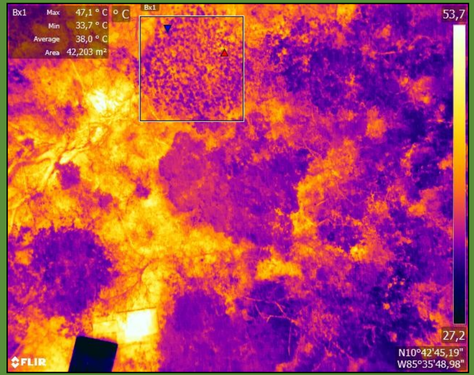
II. UAV overflights and analysis
(DJI Matrice 210, 2xmultispec, 1xthermal cameras)

III. UAV-derived temperature under canopy vs. soil water isotope values

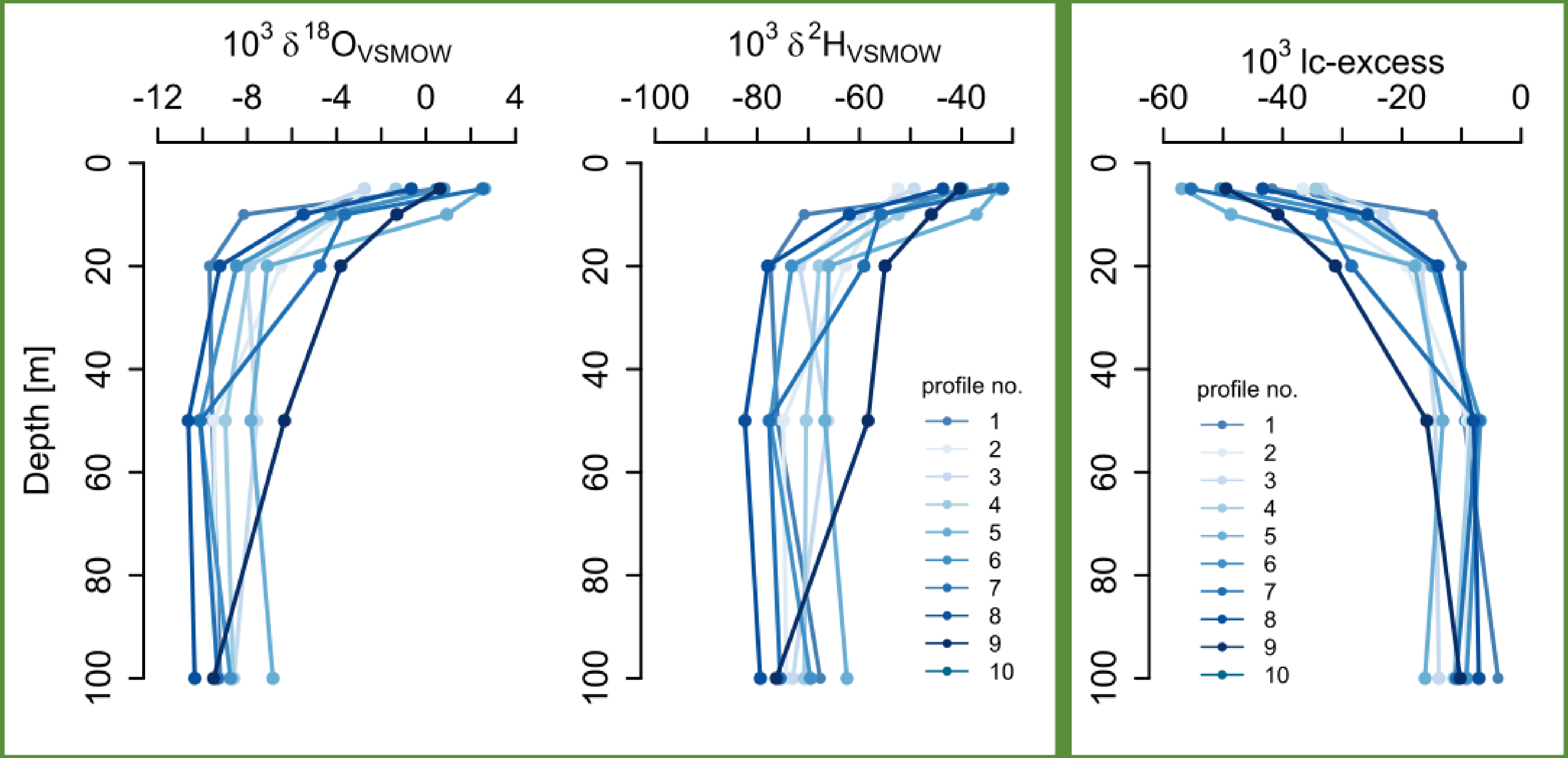
IV. Analysis of UAV-derived vegetation indices vs. soil water content & soil water isotopes [different resolutions]

V. Interpolation (EDK,OK,ID, LR)/Cross-validation using best relationships → soil water isoscapes



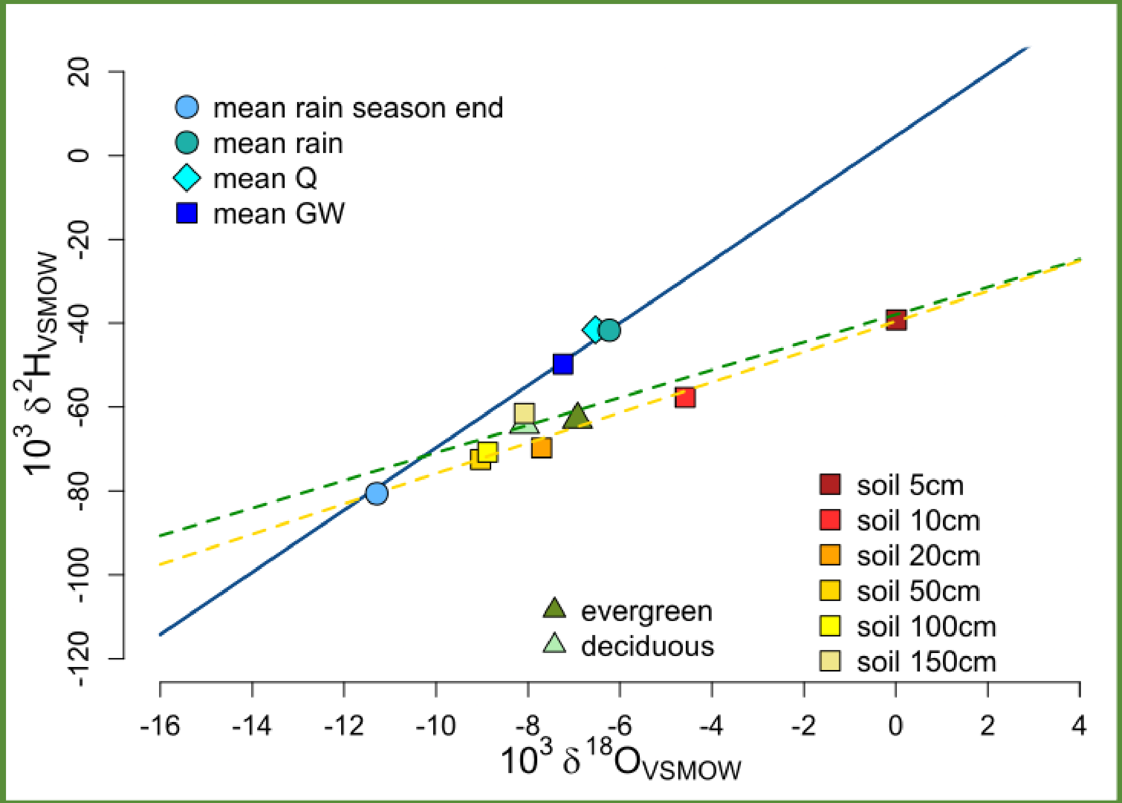



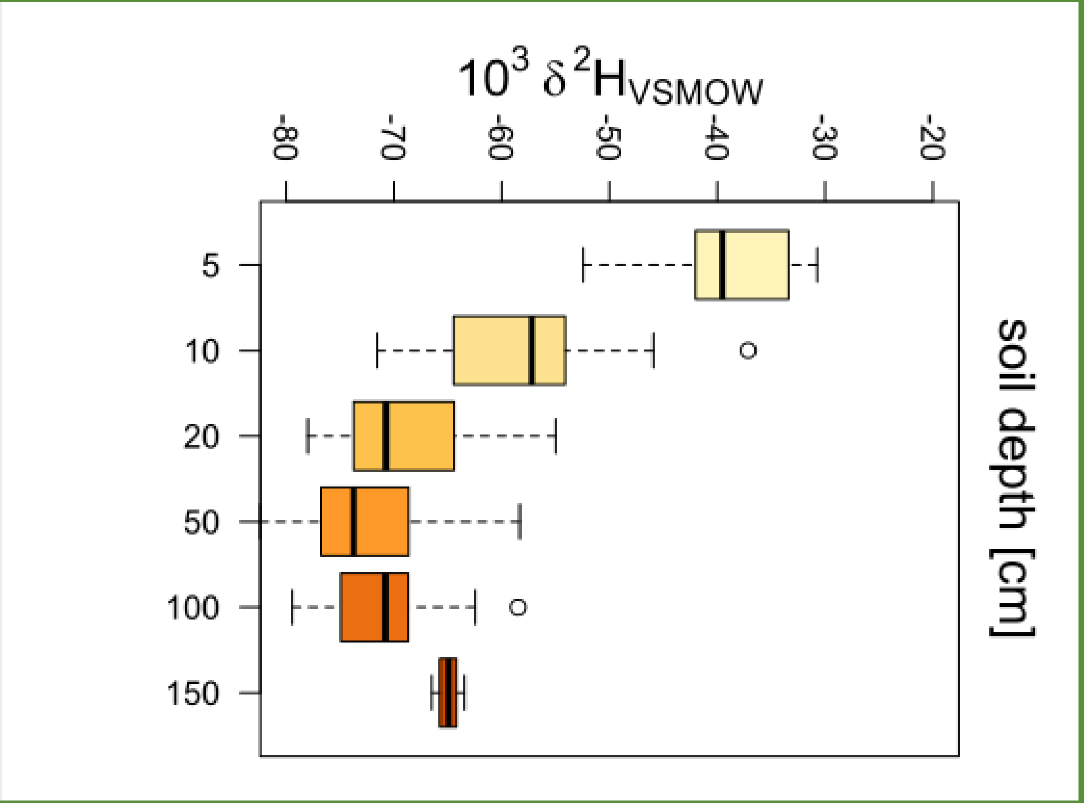
Results: soil water isotope heterogeneity



ISODRONES VolkswagenStiftung Technische Universität Braunschweig

Results: Soil water isotope heterogeneity





- Strong surface enrichment of soil isotopes
- Enrichment down to 100 cm, source: late rainy season rainfall

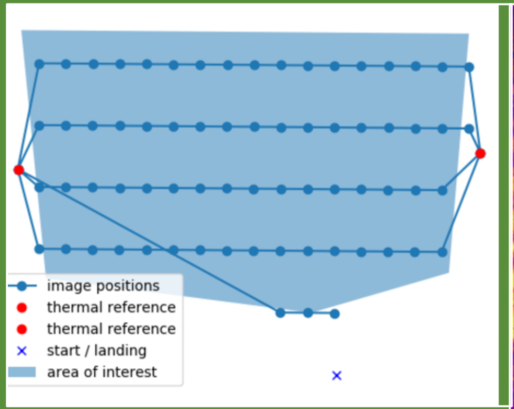
- Range of δ^2H highest at 10 cm, but large range throughout

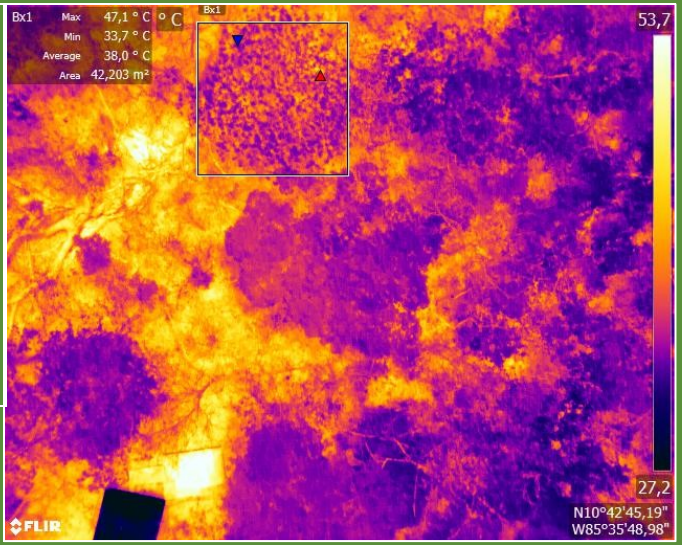
H1: soil water isotopes vs. soil temp.

- Soil temp at each plot extracted from calibrated thermal image

	R^2/correl.				
soil depth [cm]	5	10	20	50	100
T_{soil} vs. $\delta^{18}O$	**0.65 / 0.80**	0.14 / 0.38	0.02 / 0.14	0.01 / -0.02	0.04 / -0.2
T_{soil} vs. $\delta^{2}H$	**0.57 / 0.76**	0.13 / 0.35	0.01 / 0.11	0.002 / -0.05	0.004 / 0.06
T_{soil} vs. lc	**0.45 / -0.67**	0.16 / -0.40	0.03 / -0.17	0.001 / -0.03	0.18 / 0.42
T_{soil} vs. wc	0.001/-0.03	0.04/-0.19	0.004/0.07	0.11/0.33	0.001/-0.02

- highest R^2/correlation at surface
- no correlation for water content





A novel method for calibration and flight planning for thermal data aquisition

[Gerchow et al., in prep.]

Vegetation indices vs. isotopes/wc

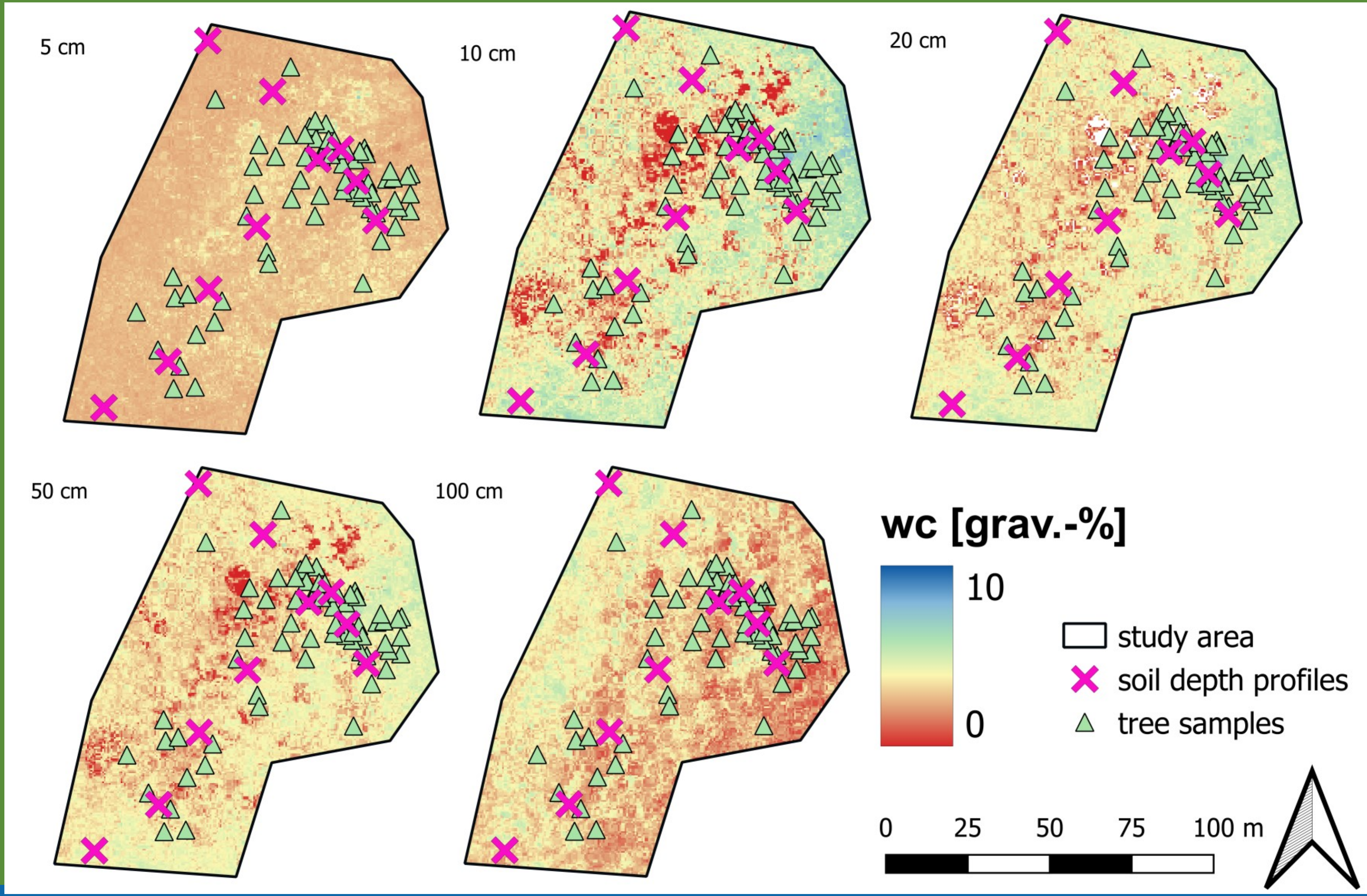
- R^2 with different resolutions: **0.5m** > 0.03m (orig) > 1m=2m=5m

	Highest-correlated veg. index	R^2	correl
water content			
5	**sr_edge**	**0.67**	**0.82**
10	**rvi**	**0.82**	**-0.91**
20	rvi	0.57	-0.76
50	rvi	0.56	-0.75
100	**cir**	**0.73**	**-0.85**
^{18}O			
5	**ndvi**	**0.69**	**-0.83**
10	**rvi**	**0.62**	**0.82**
20	sr_edge	0.42	0.65
50	cir	0.49	-0.7
100	**cir**	**0.76**	**-0.84**
^{2}H			
5	**evi2**	**0.48**	**-0.69**
10	**rvi**	**0.79**	**0.89**
20	cir	0.63	-0.79
50	cir	0.69	-0.83
100	**rvi**	**0.81**	**-0.9**

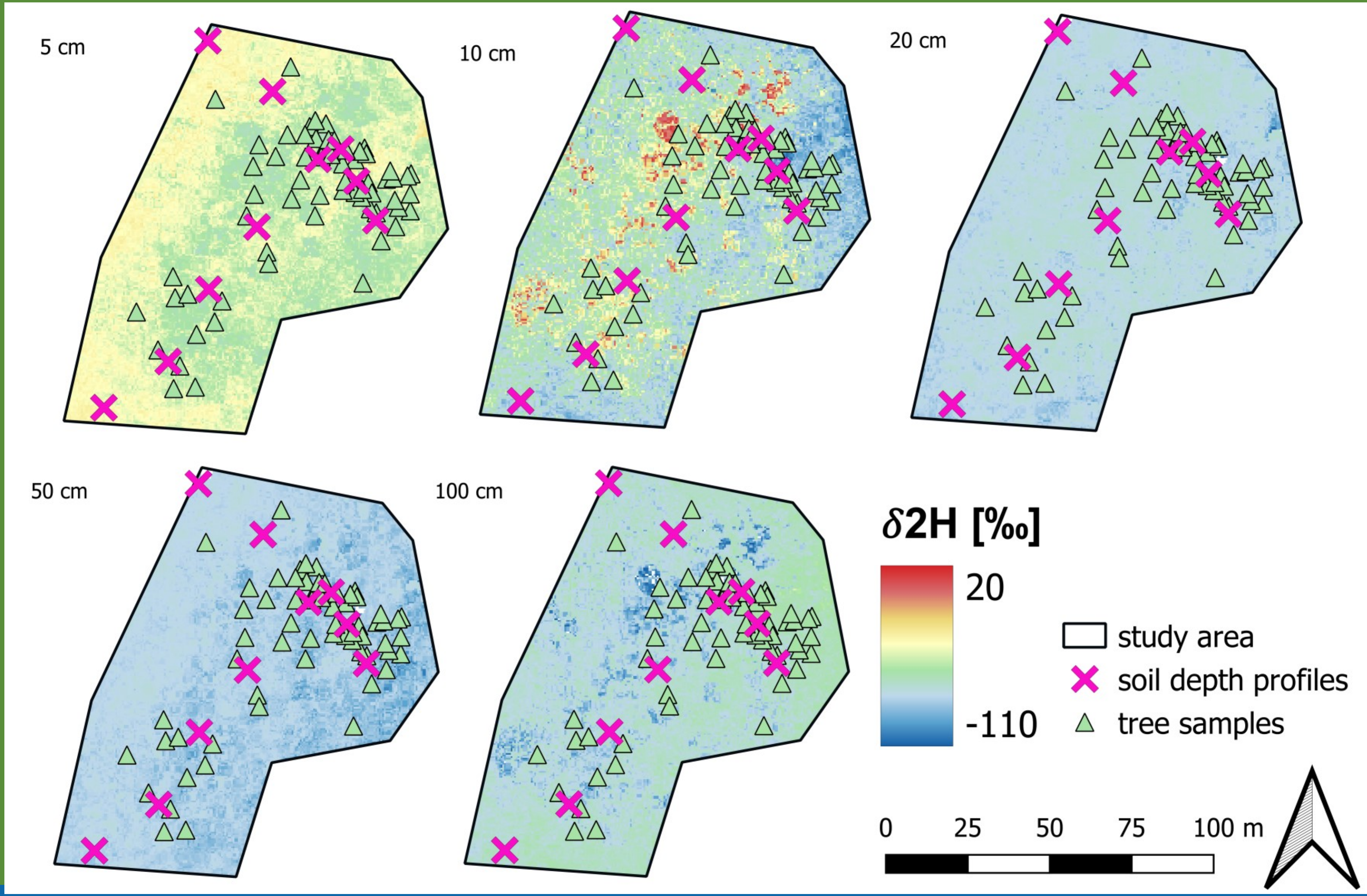
- Acceptable relationships for all depths
- 10cm depth is an exception → super low water contents where vegetation is still green
- 100 cm?

sr_edge – red edge simple ratio
rvi - ratio vegetation index
cir - color infrared
ndvi - normalized difference vegetation index
evi2 - enhanced vegetation index 2

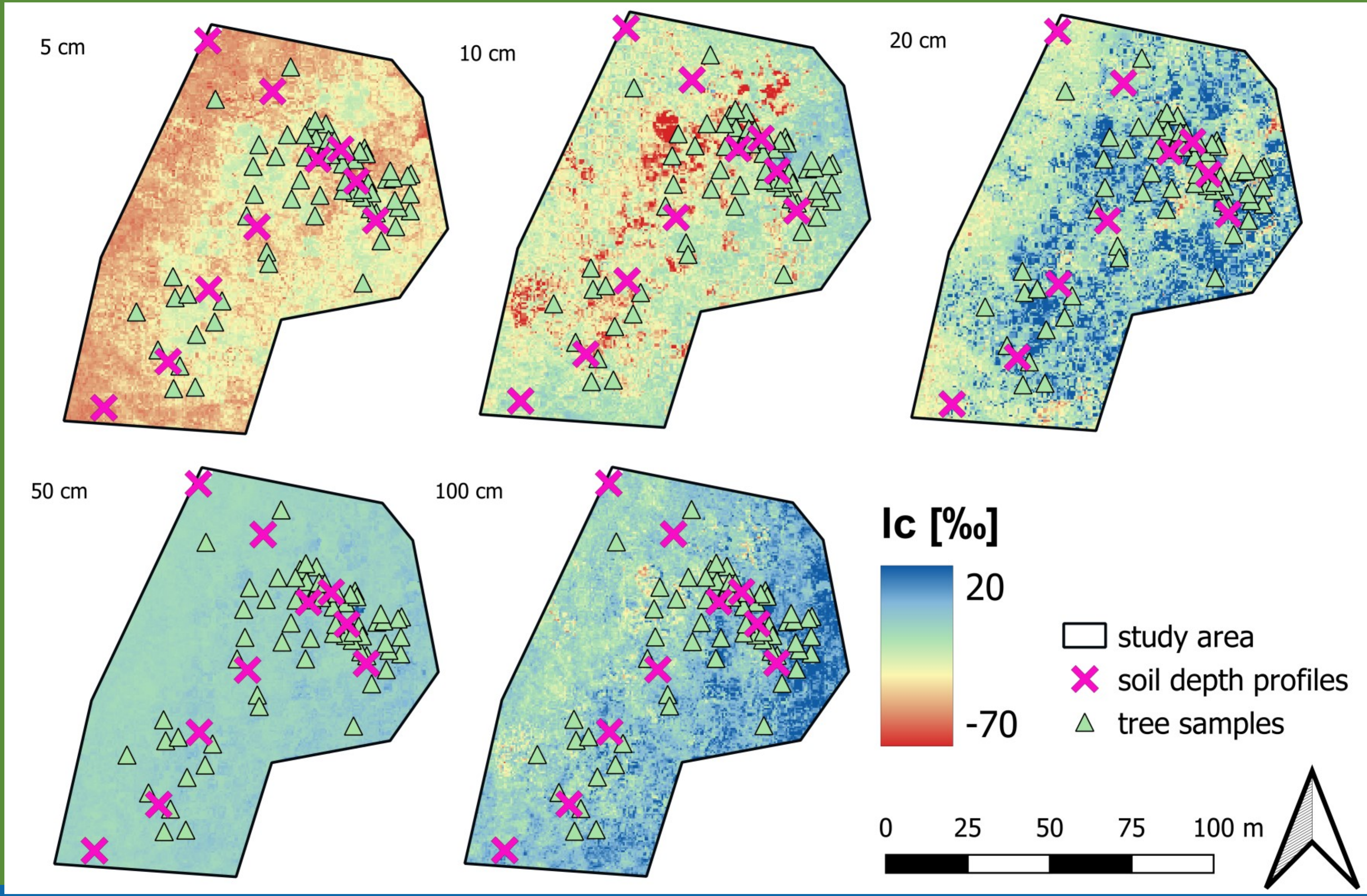
Soil water isoscapes – water content



Soil water isoscapes – δ^2H



Soil water isoscapes – lc-excess



ISODRONES VolkswagenStiftung Technische Universität Braunschweig

Wrap-up

- Canopy structure and 'degree of greenness' does affect soil water isotopes under steady-state dry conditions
- Higher 'degree of greenness' > lower soil temperature > less isotopic enrichment
- Surprising: acceptable correlations of vegetation indices vs. isotope values & water content for all depths!
- Isoscapes as baseline for water uptake depth estimations?
- Consequences for water uptake depth estimations?
  - Highlights necessity of sampling multiple profiles and cover different canopy covers
  - Likely increases uncertainty of water uptake depth estimations

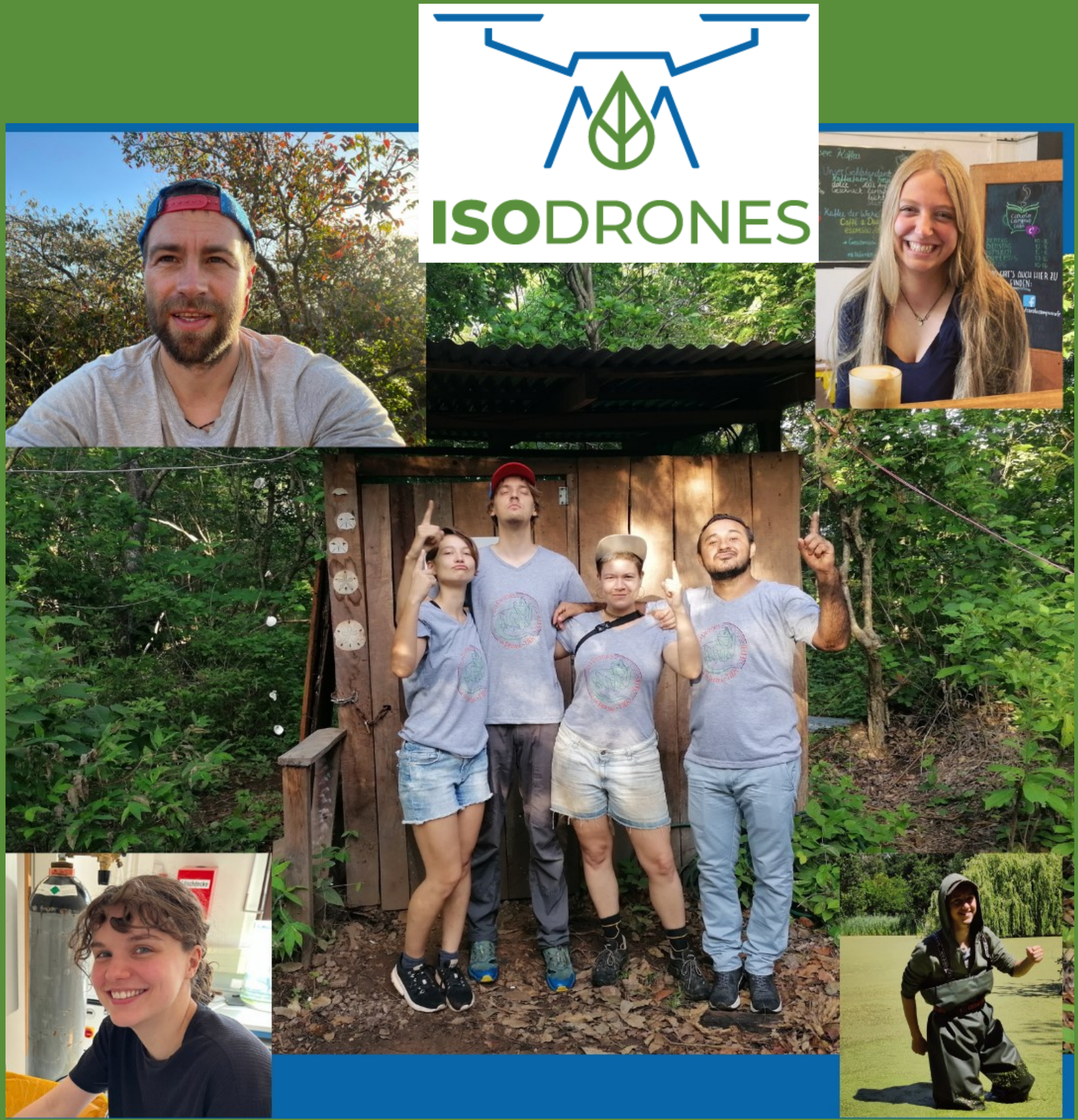
"Just don't do it!!!???"

Thank you!

isodrones.com

Isodrones Project

@Isodronesproject



Vegetation Indices

The **RVI** (Ratio Vegetation Index) is a vegetation index that is derived from remote sensing data, which is widely used in agriculture and environmental monitoring applications. The RVI is a ratio-based index, which is calculated as the ratio of the near-infrared (NIR) and red spectral bands of the remote sensing data.

The RVI is similar to the Normalized Difference Vegetation Index (NDVI) in that it uses the red and NIR bands, but the RVI does not subtract the red band from the NIR band as in the NDVI. Instead, the RVI simply divides the NIR band by the red band. The formula for the RVI is:

RVI = NIR / Red

The RVI is useful for monitoring vegetation in areas with high soil brightness or variable soil backgrounds, as it is less sensitive to soil reflectance than the NDVI. It is also useful in monitoring vegetation in areas with sparse vegetation or for detecting vegetation changes in disturbed areas.

Like other vegetation indices, the RVI can provide valuable information on vegetation health, biomass, and photosynthetic activity, which can be used for crop management, land-use planning, and environmental monitoring.

Vegetation Indices

The **CIR** (Color Infrared) Vegetation Index is a vegetation index that is derived from remote sensing data, which is widely used in agriculture and forestry applications. The CIR vegetation index is calculated using the near-infrared (NIR) and red spectral bands, as well as the blue or green spectral bands.

The formula for the CIR Vegetation Index is:

CIR = (NIR - Red) / (NIR + Red + Blue or Green)

The CIR index uses the fact that healthy vegetation reflects more near-infrared (NIR) radiation and less red and blue or green radiation, compared to non-vegetated areas. By calculating the ratio of NIR to red and blue or green reflectance, the CIR index can provide information on the health and vigor of vegetation in a given area.

The CIR index is particularly useful in areas with dense vegetation cover, where other vegetation indices such as the Normalized Difference Vegetation Index (NDVI) may saturate. The CIR index can also be used to detect changes in vegetation health and biomass, as well as to assess land-use and land-cover changes.

In summary, the CIR Vegetation Index is a useful tool for monitoring vegetation health and dynamics, particularly in areas with dense vegetation cover or in agricultural and forestry applications.

Vegetation Indices

The Red Edge Simple Ratio (**SR_EDGE**) Index is a vegetation index that uses the red edge spectral region of the electromagnetic spectrum, which is sensitive to vegetation chlorophyll content and structure. The index is calculated using remote sensing data, usually obtained from satellite or aerial imagery.

The formula for the RESR Index is:

RESR = NIR / Red Edge

where NIR represents the near-infrared spectral band and Red Edge represents a spectral band located within the red edge region of the spectrum.

The RESR Index is a simple and effective way to estimate vegetation health and biomass, as it measures the ratio of near-infrared to red edge reflectance, which is strongly correlated with chlorophyll content and vegetation structure. The index is particularly useful for monitoring vegetation health and dynamics in agricultural and forestry applications, where rapid and accurate assessments of vegetation biomass and stress are important.

Compared to other vegetation indices that use the red edge region, such as the Red Edge Normalized Difference Vegetation Index (RENDVI), the RESR Index is simpler to calculate and is less sensitive to atmospheric and other sources of noise. However, the index may saturate in areas with high vegetation cover or may not be suitable for certain types of vegetation, so it is important to consider the limitations and assumptions of the index when interpreting the results.

Vegetation Indices

The **CIR** (Color Infrared) Index is a vegetation index that is commonly used in remote sensing applications for monitoring vegetation health and vigor. The CIR index is calculated using three spectral bands: red, near-infrared (NIR), and blue or green.

The formula for the CIR Index is:

CIR = NIR / Red

The CIR index takes advantage of the fact that healthy vegetation reflects more near-infrared (NIR) radiation and less red radiation than non-vegetated areas. By calculating the ratio of NIR to red reflectance, the CIR index can provide information on the density and health of vegetation in a given area.

The addition of a blue or green band in the calculation of the CIR index helps to improve the contrast between vegetation and non-vegetated areas. In some cases, the blue band may be used to correct for atmospheric effects and to improve the accuracy of the index.

The CIR index is widely used in agriculture, forestry, and environmental monitoring applications, as it can provide valuable information on vegetation biomass, stress, and productivity. However, like other vegetation indices, the CIR index has limitations and assumptions that should be considered when interpreting the results. For example, the index may saturate in areas with dense vegetation cover or may not be suitable for certain types of vegetation.

Vegetation Indices

The Enhanced Vegetation Index 2 (EVI2) is a vegetation index that is commonly used in remote sensing applications to assess vegetation health and vigor. It is an improvement over the original Enhanced Vegetation Index (EVI) that reduces the noise and improves the sensitivity to vegetation changes in areas with low to moderate vegetation cover.

The formula for the EVI2 index is:

$$EVI2 = 2.5 * ((NIR - Red) / (NIR + 2.4 * Red + 1))$$

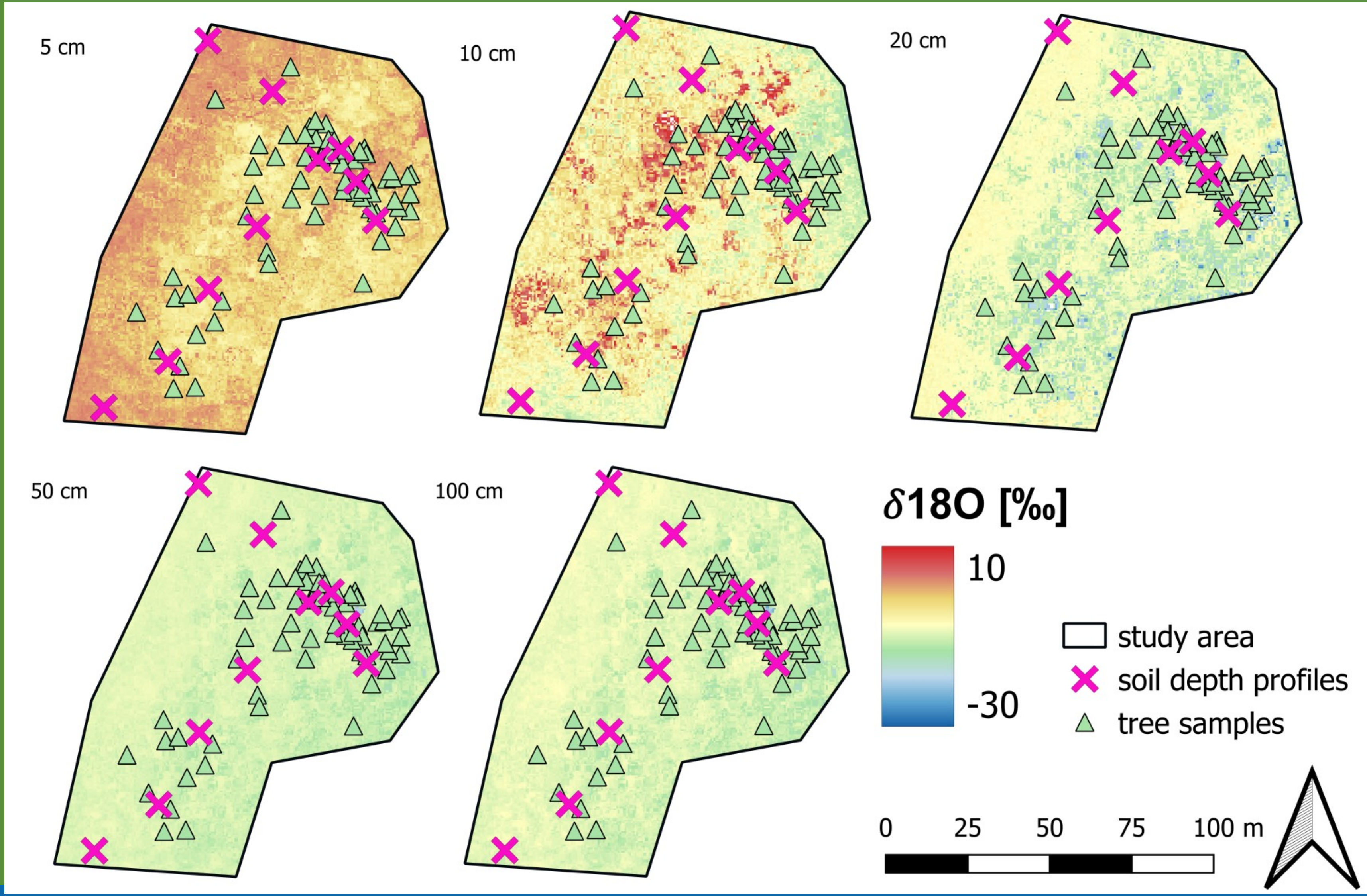
where NIR represents the near-infrared spectral band, and Red represents the red spectral band.

The EVI2 index takes into account the red and near-infrared spectral bands, which are sensitive to vegetation changes, as well as the blue spectral band, which helps to reduce the impact of atmospheric noise. The index ranges from -1 to 1, with higher values indicating healthier vegetation.

The EVI2 index is particularly useful in monitoring vegetation health and productivity in areas with low to moderate vegetation cover, such as croplands, grasslands, and shrublands. It can provide valuable information on vegetation stress, biomass, and productivity, and can be used to detect changes in land use and land cover over time.

Overall, the EVI2 index is a useful tool for vegetation monitoring and management, and has been used in a wide range of applications, including precision agriculture, land use planning, and ecosystem monitoring.

Soil water isoscapes – $\delta^{18}O$



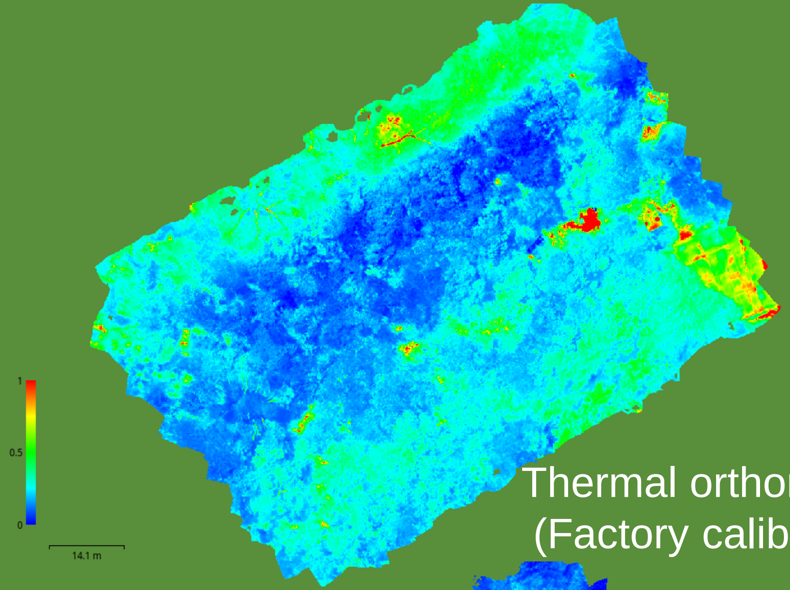
Drones (UAV)

- Thermal camera poses are estimated from RGB photos to form the thermalorthomosaic (dual sensor)
- Comparison of different calibration methods

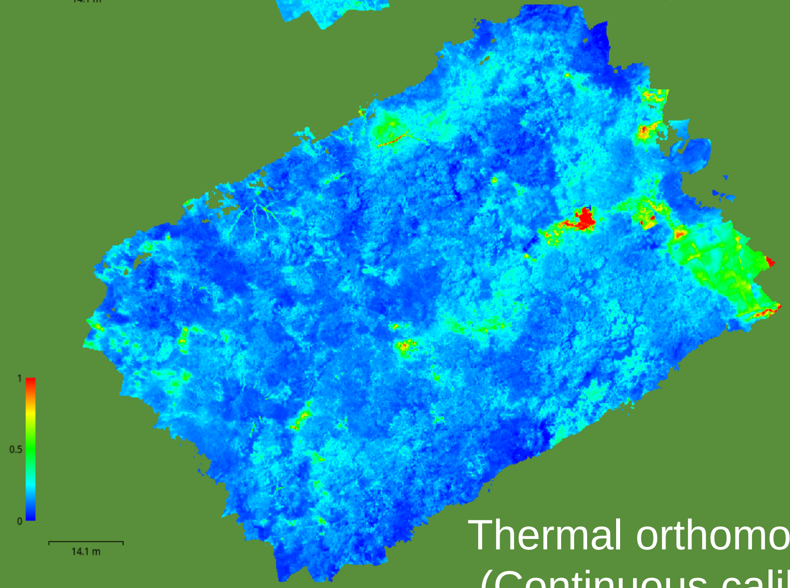
Most accurate

Calibration accuracy (mean ± std)

Flight Conditions	1) Factory Calibration (°C)	2) Empirical line method (°C)	3) Factory Calibration + Drift correction (°C)	4) Continuous empirical line method (°C)
Cloudy	4.3 ± 1.8	1.7 ± 1.2	0.9 ± 1.2	**0.9 ± 0.6**
Sun	6.2 ± 1.7	5.8 ± 2.3	3.5 ± 2.4	**1.5 ± 1.9**
Partly Cloudy	2.9 ± 3.3	2.9 ± 2.9	2.5 ± 3.3	**2.3 ± 3.0**
Overall	4.5 ± 2.4	3.5 ± 2.2	2.3 ± 2.5	**1.6 ± 2.1**



Thermal orthomosaic (Factory calibration)



Thermal orthomosaic (Continuous calibration)