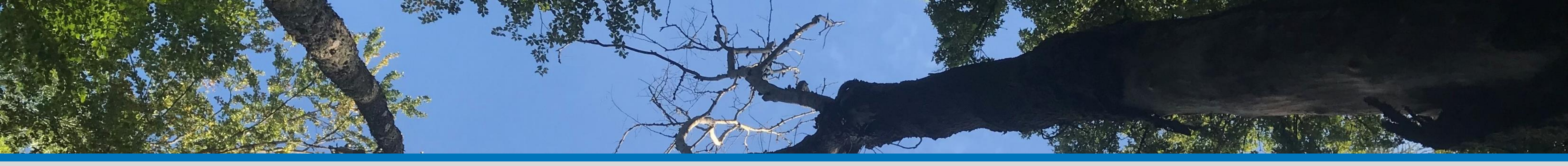

Analyzing Enhanced Forest Structural Complexity from In-Situ and Spaceborne Remote Sensing

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MOTIVATION

- **Forests cover** about **30 %** of **Germany** and are characterized by **age-class** structures, **low deadwood** amount, and **high shares of spruce and pine**.
- **Enhanced structural complexity (ESC)** of forests is needed to **improve biodiversity** and strengthen the **resilience** towards disturbance events.

AIM

Assess the **monitoring potential** of **in-situ and spaceborne remote sensing** to **characterize enhanced structural complexity (ESC)**.

EXPERIMENTAL DESIGN

- **Silvicultural treatments** (n=84) **enhancing structural complexity** (diversification of deadwood structures and spatial arrangements of cuttings) were implemented in **German broad-leaved forests**.

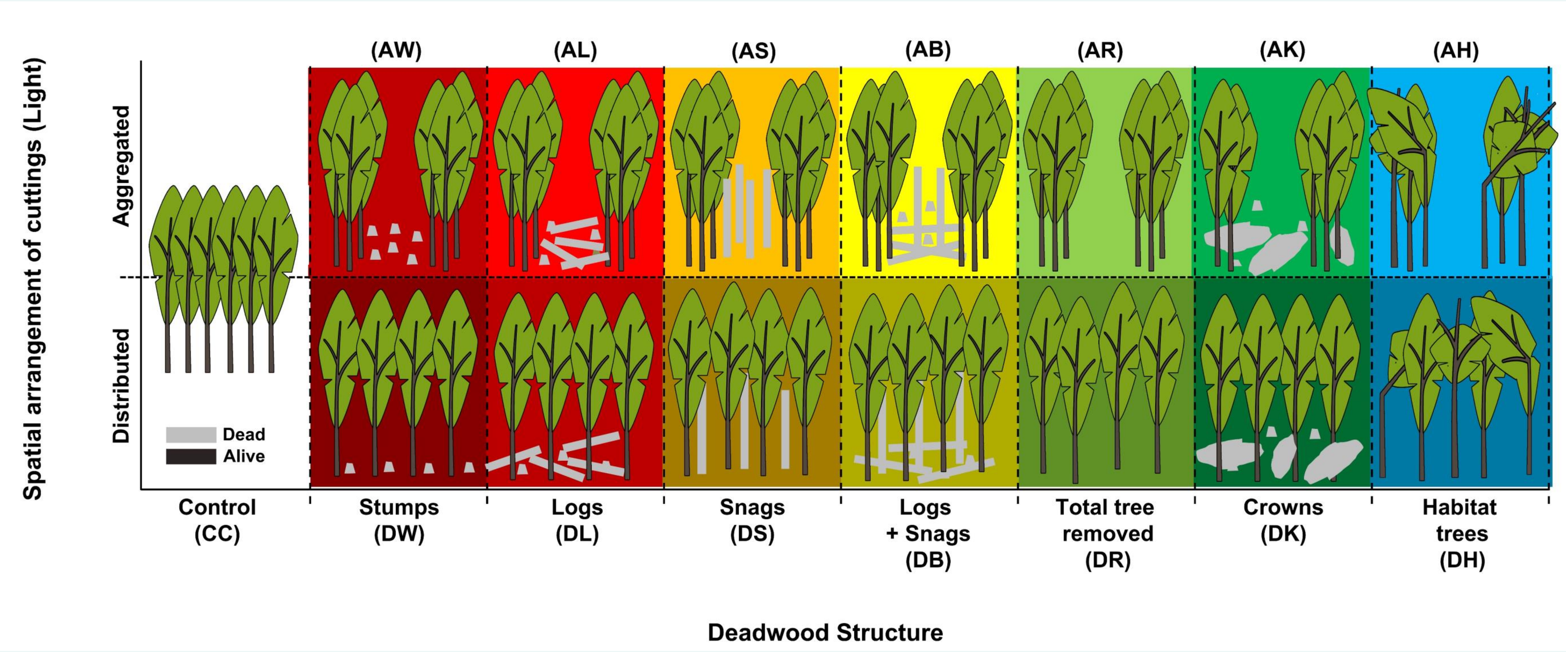

Fig. 1: **Experimental silvicultural treatments** (n=84) **enhancing structural complexity** were implemented in **Nov.-Dec. 2018** within the context of a **research-patch-network** of the **BETA-FOR project**.

METHODS – SATELLITE TIME-SERIES

- **Sentinel-1** (radar) and **Sentinel-2** (multispectral) **time-series metrics** at **patch-level** in order to **assess the potential towards the identification of the treatment implementation event** (Nov.-Dec. 2018).
- **Sentinel-1** (n=12) and **Sentinel-2** (n=129) **spectral indices** were calculated based on Montero et al. 2023 with **per time-step aggregation as patch-level statistics** (n=7: min, max, mean, median, std, var, cv).
- The **original time-series** were **decomposed into additive seasonality and trend components** based on the BEAST algorithm (Zhao et al. 2019). **Change point probabilities** and **dates** are analyzed in order to identify high probability changes (probability > 90 %, date within the treatment implementation period)

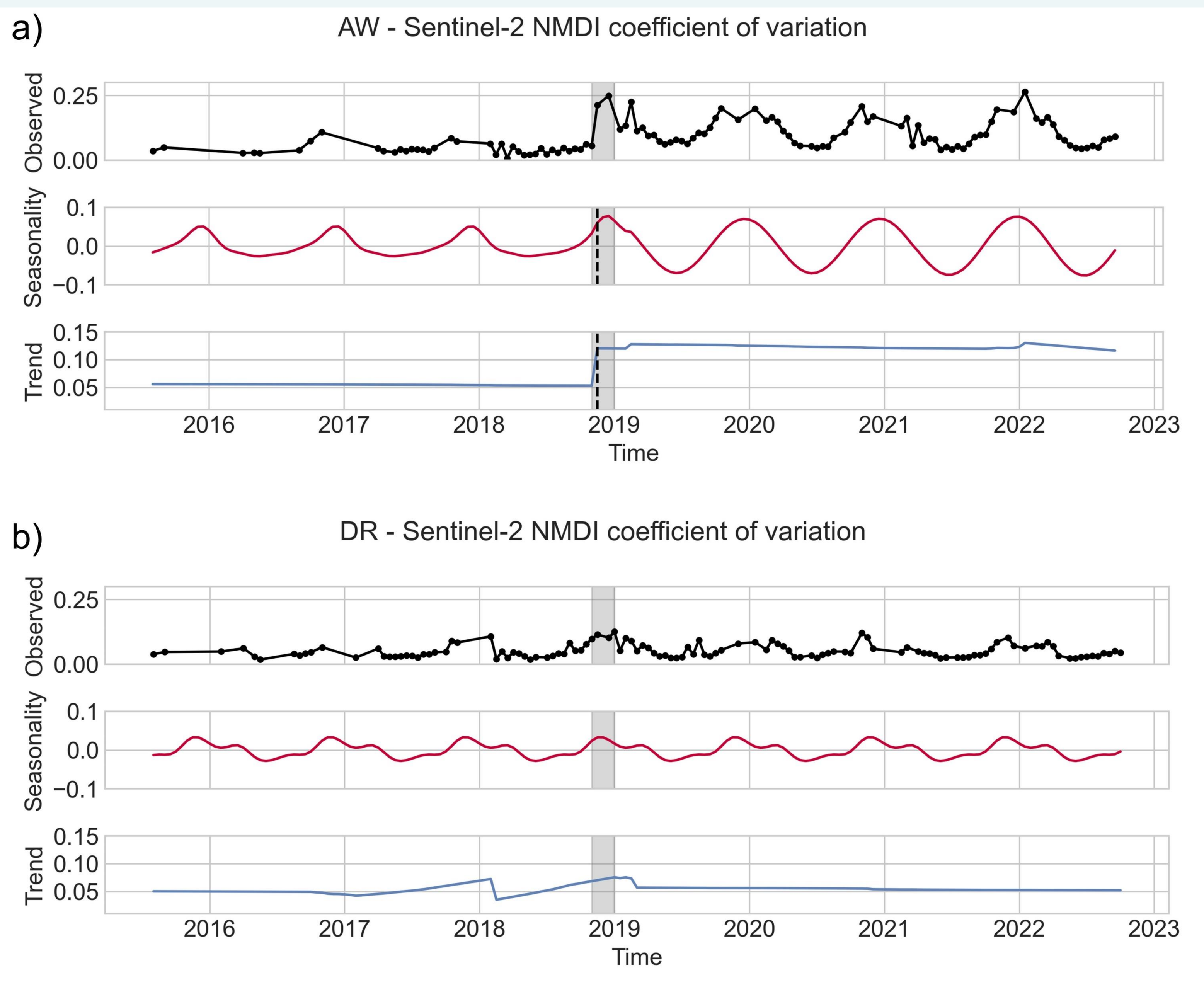

Fig. 2: **Sentinel-2 Normalized-Multi-Band-Drought-Index (NMDI)** cv at **patch-level** for the following treatments: **aggregated stumps remaining** (a, AW)**,** and **distributed complete tree removal** (b, DR).

METHODS – CORRELATION

- **Correlation analysis** of **forest structural complexity metrics**:
  - **MLS** (mobile laser scanning), July 2023: box dimension, canopy cover
  - **TLS** (terrestrial laser scanning), August 2023: Canopy-Openness-Index (COI), Stand-Structural-Complexity-Index (SSCI), Understory-Complexity-Index (UCI)
  - **Sentinel-1** (radar satellite), July-Sept. 2023: cross-polarized VH coefficient of variation (cv)
  - **Sentinel-2** (multispectral satellite), July-Sept. 2023: Normalized-Multi-Band-Drought-Index (NMDI) cv
  - **Modelled GEDI** (Global Ecosystem Dynamics Investigation, spaceborne LiDAR), June-August 2023: canopy height (rh95) cv, total canopy cover (cover) cv, above-ground biomass density (agbd) cv

RESULTS – SATELLITE TIME-SERIES

- Treatment implementation events of **aggregated treatments** are **better assessed**.
- Changes in structural complexity of **aggregated treatments with and without standing deadwood structures are detected**.

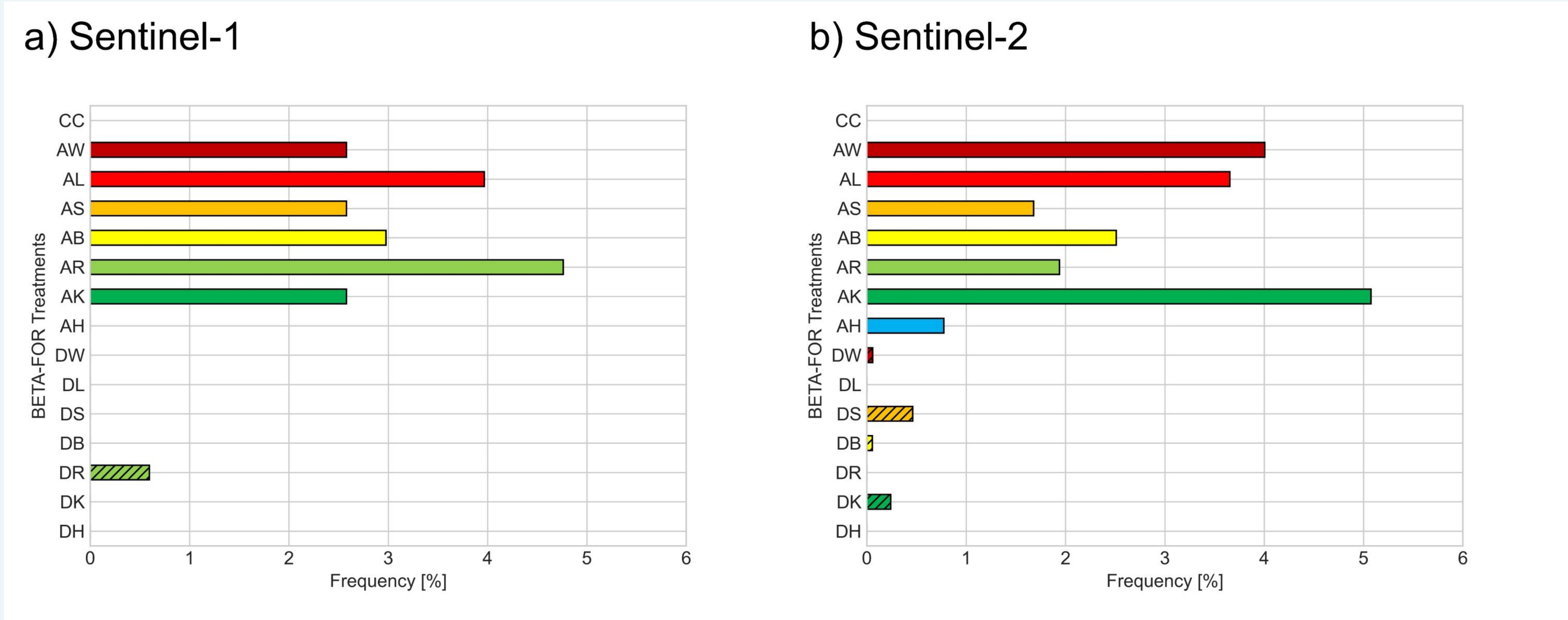

Fig. 3: **Comparative statistics** of **Sentinel-1** (a) and **Sentinel-2** (b) metrics assessing **accurate change points grouped by treatment**. Percentage values on the x-axis are calculated as **grouped statistics** per individual treatment type accounting for all metrics (Sentinel-1: n=84, Sentinel-2: n=903) and change point types (n=2).

- **Sentinel-1 VH** time-series identify most treatment implementation events of all Sentinel-1 metrics.
- Most treatment implementation events are assessed through **Sentinel-2 NMDI time-series**.

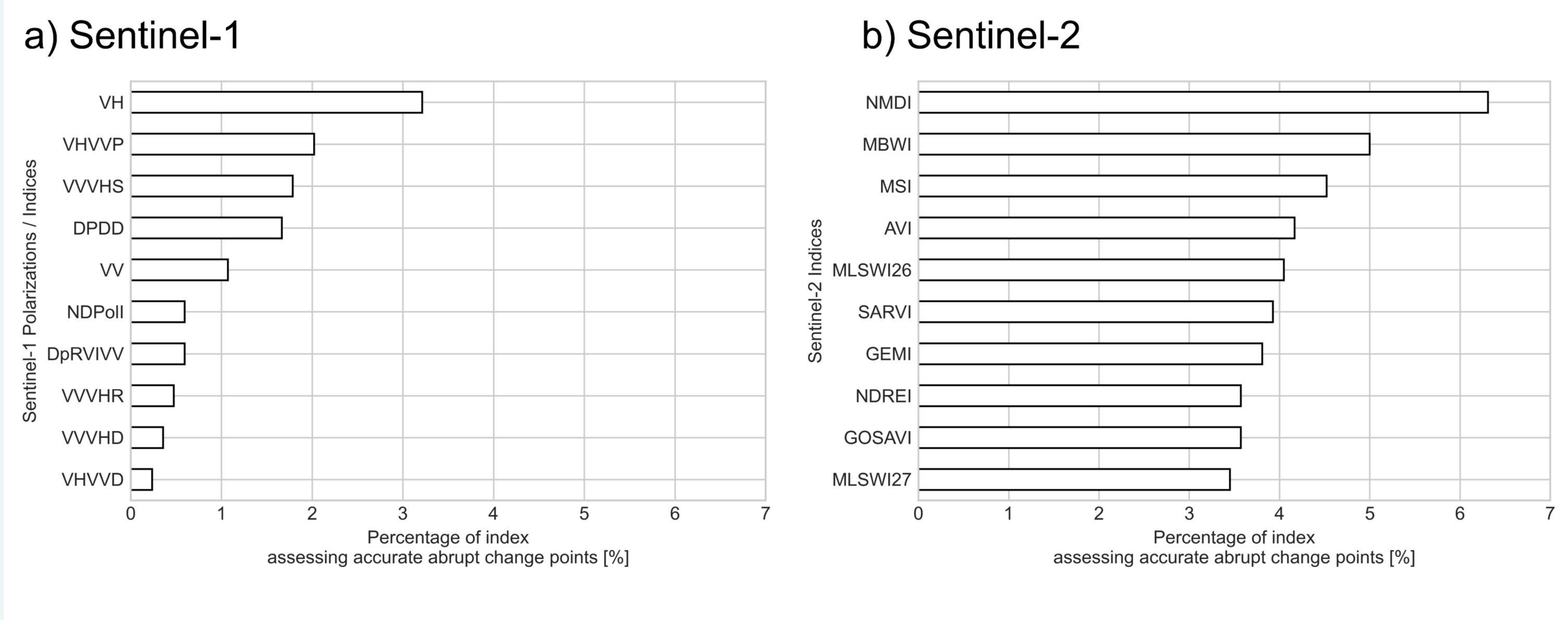

Fig. 4: **Comparative statistics of Sentinel-1** (a) and **Sentinel-2** (b) **indices** assessing **accurate change points** depicting ten spectral indices each **best assessing the treatment implementation event**. Percentage values on the x-axis are calculated per spectral index accounting for theoretically possible change points for all treatment patches (n=60), change point types (n=2) and spatial statistics (n=7).

RESULTS – CORRELATION

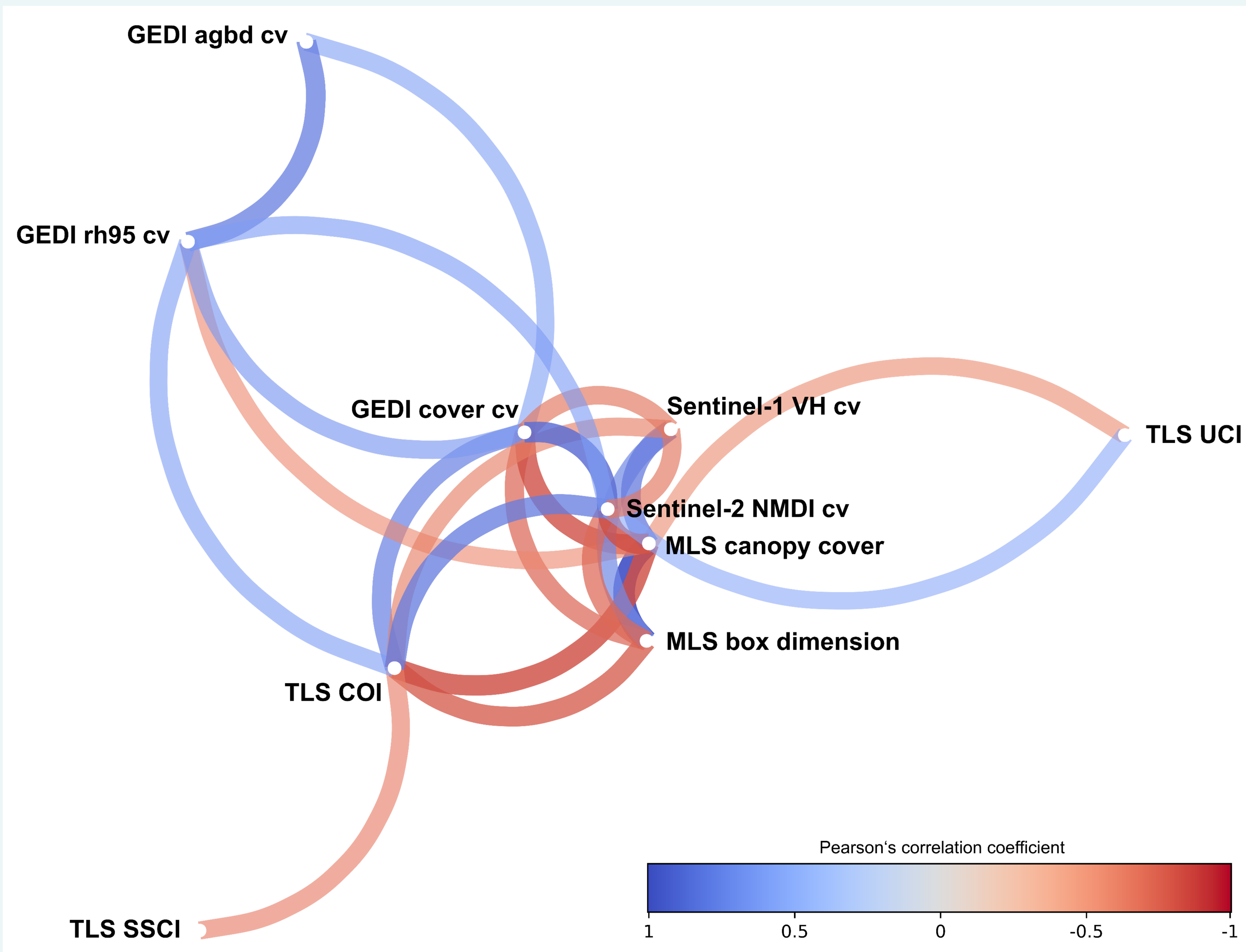

Fig. 5: **Strong inter-platform correlations among structural complexity metrics (|r| >= 0.6)** between MLS, TLS, Sentinel-1, Sentinel-2, and GEDI were identified. All metrics represent summer conditions of 2023.

CONCLUSIONS

- **Satellite time-series** have the potential to assess major **enhancement of structural complexity** through **aggregated treatments**.
- **Sentinel-1 VH** and **Sentinel-2 NMDI metrics** best assess changes in forest structural complexity independent of the presence of standing deadwood.
- Forest structural complexity metrics of different **spaceborne sensors** are **reliable surrogates** of in-situ metrics derived from **MLS and TLS**.
- We suggest a **deeper integration of spaceborne remote sensing into operational forest structure monitoring**, e.g. to
  - **extrapolate in-situ measurements** (in-situ remote sensing estimates and biodiversity sampling) **over space and time** for **continuous coverage**,
  - to **assess potential resilience of forests** based on structural properties,
  - and to **monitor management efforts targeting enhanced structural complexity**.

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BETA-FOR

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Kacic et al. 2024

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