Continuous spectral monitoring below forest canopies

an IoT-based approach

PRESENTER:

Davide Andreatta

davide.andreatta@fmach.it

BACKGROUND

Although Remote Sensing (RS) is an efficient tool to **monitor** and upscale **forest responses to global change**, a reliable in-situ forest monitoring reference network is still lacking (Fu et al. 2023; Ryan 2023; Valentini et al. 2019). While **canopy reflectance** is very well represented in the literature and a number of works described the potential of **episodical transmittance** measurements at the leaf scale (Woolley 1971) or at canopy scale (Dengel, Grace, and MacArthur 2015; Rautiainen et al. 2024**), the IOT-device continuous monitoring** approach represents an unexplored revolution for forest monitoring.

NOVELTY

- Compared to RS, this approach enable the study of vegetation at **finer spatial scales, while also capturing both daily and seasonal variations**.
- Unlike manual measurements with handheld instruments, IoT sensors can provide **continuous canopy monitoring** simultaneously across much **broader areas**.
- Compared to radiation measurements integrated in the PAR region, multi-band spectral measurements offer **a wider range of vegetation indices**

EXAMPLES OF POTENTIAL APPLICATIONS

- **Single-tree resolution phenological response to climate**. Examining how the phenology of trees differing by age, size, hierarchical position and microhabitat inside the same forest stand respond to climate extremes (Vaglio Laurin, 2024; Fig. 1a).
- **Diurnal variation in below canopy radiance** (Fig.1b).
- **Light quality analysis.** Understand its complex role as environmental cue regulating plant's developmental stages (Riikonen et al., 2016; Fig.1c).
- **Canopy responses to biotic and abiotic stresses** (e.g., drought, heatwaves, frost). By analysing time series of transmittance-based vegetation indices acquired with a bi-hemispherical dual field of view (Serrano and Peñuelas, 2005).
- **Satellite products validation.** Estimating LAI and fAPAR. (Fig. 2, Rogers et al. ,2021).

Transmitted light continuous measurement as a new element in the ecologists' toolbox to better understand forest processes.

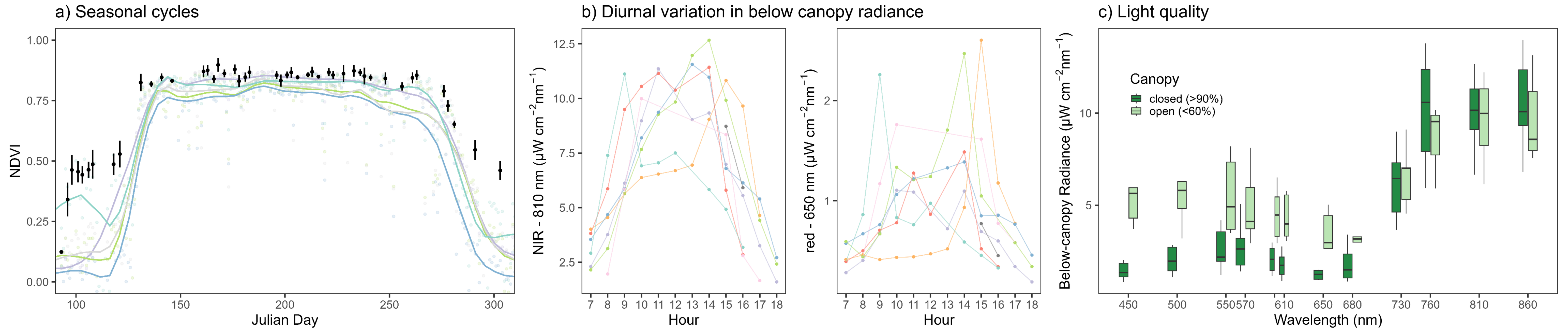

Figure 1. Below canopy transmitted light measurements acquired in a mixed European beech (Fagus sylvatica L.) - Spruce (Picea abies (L.) H.Karst.) - Silver fir (Abies alba Mill.) forest in the Italian Alps (46.203°N, 11.209°E, Cembra site) using a single conical field of view configuration. Panel a): Each color represents measurements from a single spectrometer. Black points and error bars show the mean ± standard deviation of reflectance-based NDVI derived from Sentinel-2 imagery over each spectrometer location. Panel b) Radiance measurements acquired on 2022-07-20, under clear-sky conditions. Panel c): Radiance measurements acquired on 2022-07-20 at 14:00, under clear-sky conditions.

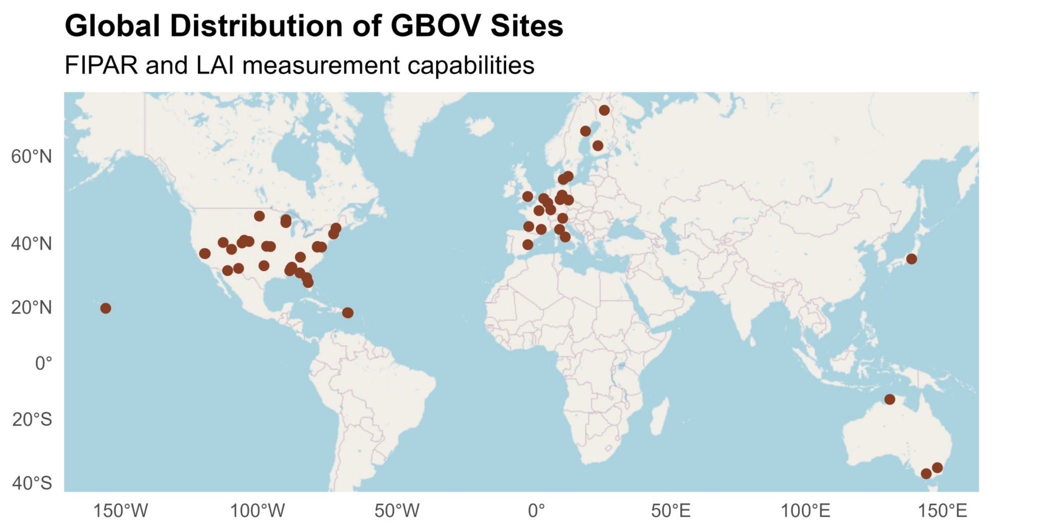

Figure 2. The Copernicus Ground Based Observations for validation is lacking vegetation monitoring sites for Asia and South-America (Bai et al., 2022) . Data: gbov.land.copernicus.eu

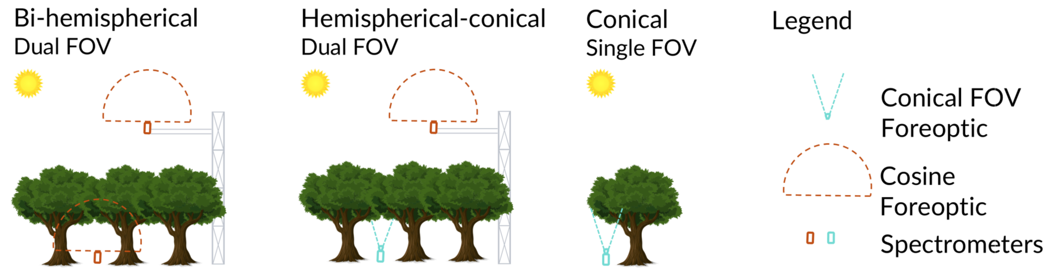

Figure 3. Main instrument configurations for measuring transmitted light in forest.

Table: Advantages, disadvantages, and potential applications of different configurations

Setup	Measured variable	Advantages	Disadvantages	Examples of potential applications
a	Transmittance = ratio between below-canopy downwelling irradiance and above-canopy downwelling irradiance	– Wider sampling area – Less impacted by cloud cover and sun elevation – Smaller changes in canopy status are detectable – Possibility to compute direct to total radiation to estimate cloud cover	– Single tree scale not available – Need to install towers or to find a neighbor area with a wide canopy gap for upward spectrometer installation	– Analysis of canopy response to environmental stresse – Validation of satellite products: radiance, reflectance, fAPAR and LAI – Analysis of light quality – Analysis of diurnal cycles
b	Transmittance = ratio between below-canopy downwelling irradiance and above-canopy downwelling radiance, corrected with empirical cross-calibration factors accounting for the different foreoptics (Gamon et al., 2015)	– Less impacted by cloud cover and sun elevation – Single tree – Possibility to compute direct to total radiation to estimate cloud cover	– Narrower sampling area – Need to install towers or to find a neighbor area with a wide canopy gap for upward spectrometer installation	– Analysis of individual tree response to environmental stresses – Analysis of diurnal cycles
c	Below canopy radiance	– Single tree – No need to install towers or to find canopy gaps for upward spectrometer installation – Lower cost compared to DFOV	– Narrower sampling area – Not normalized on upcoming radiance→ heavily impacted by cloud cover and sun elevation – No possibility to compute direct to total radiance to estimate cloud cover	– Analysis of the effect of stand species richness on phenology – Analysis of the effect of tree age / size / species / hierarchical position / genetics / micro habitat on single tree phenology

Extended bibliography

Davide Andreatta, Luca Belelli Marchesini, Loris Vescovo, and Damiano Gianelle

FONDAZIONE EDMUND MACH dal 1874

RemoTrees

Funded by the European Union

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union. Neither the European Union nor the granting authority can be held responsible for them.