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Passive retrieval of chlorophyll sun-induced fluorescence (Fs) has been referred as a new powerful tool with the ability to track photosynthesis remotely at different vegetation scales. Fs is emitted by the photosynthetic apparatus itself and therefore is closely related to the photochemistry status in plants. Numerous approaches and experiments have succeeded in retrieving Fs using the so called Fraunhofer Line Depth (FLD) principle in those regions of the spectrum where the background solar radiation is diminished by the oxygen of the atmosphere (i.e. O_2A and O_2B bands). Yet the physiological meaning of this feeble signal and the extent in which it is affected by the light distribution in a 3D canopy structure are not fully understood.

With the aim to assess the capacity of Fs to track photosynthesis and for a better understanding of its behavior and distribution within the canopy, highly spatially resolved hyperspectral images (HIS) were used to retrieve Fs at a "close" canopy scale where individual canopy elements could be distinguished. HIS were recorded with a push-broom camera (PS V10E, Specim) at a distance of 3-7 meters above top of canopy over agricultural species subjected to different light and growing conditions. Fs was calculated in the absorption band O_2-A (760 nm) using a modified 3-FLD approach that considers non- fluorescence surfaces as reference.

Measuring at different times of the day and dates we evaluated the diurnal and seasonal variations of Fs in maize, sugar beet and barley. Fs maps were also used successfully to detect different levels of photoinhibition and nitrogen fertilization in the different species. Spatial information of HSI allowed evaluating the contribution of different canopy elements to the overall Fs signal, being of particular interest the contrast in Fs behavior between sunlit and shaded areas. Furthermore, a co-registration with stereo images providing 3D information permitted to evaluate the effect of leaf orientation in the Fs retrieved signal and also in the reflectance spectrum.

In this contribution we draw conclusions on the capacity of Fs to track spatio-temporal variations of photosynthesis and general physiological status of vegetation. We would like to stress, as well, the importance of considering the spatial information when interpreting its meaning.

FLEX/Sentinel-3 Tandem Mission Photosynthesis Study – An investigation of steady-state chlorophyll fluorescence and photosynthesis in terrestrial vegetation

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The FLuorescence EXplorer (FLEX) would be the first space mission optimised for remote observation of steady-state, solar-induced chlorophyll fluorescence (SIF) in terrestrial vegetation. Within the European Space Agency's Phase A/B1 assessment, the Photosynthesis Study considers the potential of SIF for quantifying photosynthesis, vegetation health, and stress status. This presentation gives a broad overview of the main elements and key findings of this study.

The study has two parallel components. One component involves development of a process-based model to quantitatively link steady-state CF yield to photosynthesis. The other evaluates remotely sensed SIF as an indicator of physiological stress, without requiring calculation of photosynthetic rates. This dual approach ensures that the full range of CF capabilities might be exploited in a spaceborne mission.

The modelling activity integrates state-of-the-art modules representative of physiological processes at the molecular, leaf, and canopy levels to feed the Automated SCOPE (A-SCOPE) tool. SCOPE – the Soil Canopy Observation, Photosynthesis Energy balance model, originally developed by C. van der Tol and colleagues – links top of canopy observations of radiance with land surface processes, and includes modules dedicated to chlorophyll fluorescence. A-SCOPE is the Graphic User Interface software package that provides a seamless link between inputs and outputs required for running SCOPE. The SCOPE model has been expanded here to include novel functionalities and features, such as new leaf biochemical routines for C_3 and C_4 species. Outputs include fluorescence and reflectance spectra, among other products. Prediction of photosynthesis from FLEX/S3 observations would be based on inversion of the forward model.

To examine the potential of steady-state fluorescence as an early indicator of stress, we focused on plant water deficit, low or high temperature stress, and nutrient (nitrogen) insufficiency. Following a comprehensive literature review, a random-effects meta-analysis was done for studies of passively (solar-induced) and actively (laser-induced) measured chlorophyll fluorescence in detecting stress. Water stress tends to produce a decline in red and far-red fluorescence at leaf and canopy levels. Chilling causes an increase, whereas heat stress induces a decline. Nitrogen (N) insufficiency yields mixed results, likely reflecting the specific allocation of N with species and circumstances. Results of the meta-analysis were used for an analysis of knowledge gaps and to suggest priorities for future FLEX-based research and applications.

A conceptual framework for the use of space-based SIF in stress detection is proposed. The strategy includes recommendations for tracking the development of photosynthetic strain, recovery, and resilience in terrestrial vegetation; the types of ground-based and other ancillary data required; and the sorts of specialised expertise needed to support accurate interpretations. Consideration is given to factors such as the influence of vegetation type, heterogeneity, and sources of error in fluorescence measurement and interpretation.

Medium Resolution Airborne Spectroscopy to Assess the Relationship between Sun-Induced Chlorophyll Fluorescence and Canopy Photosynthesis

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Approximately 90 % of the gas exchange between the atmosphere and biosphere is mediated by plant photosynthesis, making vegetated ecosystems a critical component of the terrestrial carbon cycle. Photosynthesis is a highly variable process that dynamically adapts to changing environmental conditions. The estimation of actual photosynthetic rates is, hence, difficult and spatial continuous monitoring approaches are required to provide certain information for e.g., carbon budgets. Sun-induced chlorophyll fluorescence (SIF) is a radiation flux emitted from chlorophyll molecules and can be used as remote sensing (RS) observable to be linked to plant photosynthesis. Past and recent field work proved that remotely measured SIF can be used to characterize photosynthetic rates at leaf and canopy level. Newest studies also show a sensitivity of space based SIF measurements to large scale GPP estimates.

In preparation of ESA's potential Earth Explorer "Fluorescence Explorer" (FLEX) that is intended to measure SIF at relevant spatial and temporal scales, airborne based imaging spectroscopy is an available technique to gather insight in spatio-temporal variations of SIF and its functional relationship to plant photosynthesis at ecological relevant scales. Further, airborne spectroscopy is a critical technique to bridge the existing gap between small scale field studies and current and future global observations. The spectral resolution of current instrumentation (e.g., HyPlant 0.26 nm, CASI 2.6 nm, or APEX 5.2 nm) requires the retrieval of SIF using atmospheric absorption bands, e.g., both oxygen bands around 680 nm (O_2-B) and 760 nm (O_2-A). Most critical for accurate SIF retrievals based