DRONE MEASUREMENTS OF SOLAR-INDUCED CHLOROPHYLL FLUORESCENCE ACQUIRED WITH A LOW-WEIGHT DFOV SPECTROMETER SYSTEM

Atherton J[1], MacArthur A[2], Hakala T[3], Maseyk K[4], Robinson I[5], Weiwei L[1,6], Honkavaara E[3], Porcar-Castell A[1]

[1] Optics of Photosynthesis Laboratory, Institute for Atmospheric and Earth System Research/Forest Sciences, University of Helsinki, PO Box 27, 00014 Finland.
[2] School of Geosciences, University of Edinburgh, United Kingdom, EH9 3FF
[3] Finnish Geodetic Institute, Geodeetinrinne 2, P.O. Box 15, 02431 Masala, Finland
[4] Department of Environment, Earth and Ecosystems, Faculty of Science, Open University, Milton Keynes, U.K
[5] Laser Spectroscopy Group, Rutherford Appleton Laboratory, U.K
[6] LREIS, Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, 100101, China

ABSTRACT

Solar induced chlorophyll fluorescence (SIF) emitted from plant canopies is now retrievable from space. In addition,SIF is now also routinely measured from fixed tower platforms. However there is a scale gap between temporally continuous tower measurements and spatially coarse satellite retrievals that is now being bridged by drone technology. Drone retrievals of SIF can be used to help unravel the structural and species component dependencies that occur across space on the scale of meters in heterogeneous vegetation types. Also when flown at sufficient altitude, drones can be used to simulate, and potentially validate satellite retrievals of SIF. We flew a dual field of view spectrometer system, the Piccolo doppio, above a boreal forest with the aim of retrieving SIF. Our flights were designed to assess both spatial heterogeneity of SIF driven by changes in vegetation cover type and to simulate satellite pixels by flying at a relatively high altitude.

Index Terms— Solar induced fluorescence, drone, Piccolo doppio spectrometer

1. INTRODUCTION

Estimating plant photosynthetic performance across space is a key challenge for the global change community. This is because on annual timescales the surface exchange of carbon is driven by biotic processes, namely photosynthesis and respiration. The photosynthetic reactions begin with visible light absorption by chlorophyll molecules; this is the energy that then fuels the conversion of CO_2 and H_20 to sugar molecules. A small fraction of this absorbed light energy is almost immediately re-emitted at longer wavelengths as chlorophyll fluorescence; importantly the yield of this emission is dependent on the state of the photosynthetic reactions at that time [1].

Although only a small fraction of absorbed light is re-emitted as chlorophyll fluorescence, it is detectable remotely as solar-induced fluorescence (SIF) using the Fraunhofer Line Depth/Descriminator (FLD) principle. FLD based methods exploit the fact that fluorescence excited by the sun *fills in* dark telluric or Fraunhofer atmospheric absorption lines, hence the weak signal is amplified (and retrievable) at specific wavelengths. Over the past few years, satellite SIF products based on the FLD principle have offered new insights into plant performance for both crops [2] and forested regions [3].

At present, the highest spatial resolution satellite SIF product is on the order of ~km (NASA's OCO2). However in addition to satellites, proximal systems are also in routine use measuring SIF at fixed sampling locations above forest and crop canopies, and typically operated in tandem with eddy covariance flux towers. Airborne platforms, and drones in particular, offer a 'scaling bridge' between the satellite and canopy scales of current SIF measurements. Accordingly, there are number of interesting scientific questions that fit in this mid-scale niche, which include the impact of small scale (~meters) structural and species changes on SIF, and also the impact of under-story vegetation on the SIF emission in multi-storied forest systems. Further, flown at sufficient altitude drone systems also provide the opportunity to validate satellite retrievals by 'scale-matching' drone observations to satellite pixels.

The aim of our work was to collect measurements of solar-induced fluorescence from a drone platform from multiple forest types. To accomplish this aim, during 2017 we developed and flew a dual field of view (DFOV) spectrometer system specifically designed to measure SIF. The system was successfully mounted on two different platforms, and flown at a boreal forest site, in Finland. We flew 3 different flight plans, which included vertical profiles up to 500 m in altitude in an attempt to simulate satellite pixels. We aim to continue to develop our system and platforms during 2018, and in particular we aim to improve our estimates of solar irradiance.

2. MATERIALS AND METHODS

2.1 Piccolo Doppio spectrometer system and drone platforms

The Piccolo Doppio (referred to as Piccolo from here on) is a dual field of view spectrometer system designed to be mounted on drones or fixed tower locations. (Only a brief review of the system is presented here, for more details see [4]). The Piccolo system consists of three core elements: i/ spectrometers, ii/ control boards and software iii/ fiber optic cables including foreoptics and shutters. The two spectrometers were an Ocean Optics (Ocean Optics Inc.,Florida, USA) Flame and Ocean Optics QEPro. A key requirement of the FLD method is sufficiently high spectral resolution across the features of interest, hence the use of the QEPro which has (an approximate) spectral sampling of 0.1 nm and fwhm of 0.31 nm. The flame on the other hand has a reduced spectral sampling of 0.4 nm and fwhm of 1.3 nm but covered a larger spectral range across the photosynthetically active radiation region, (approximately) from 400 nm to 950 nm in comparison to QEPro's reduced range of 650 nm to 800 nm.

The fiber optic components consisted of a double birfurcated cable, optical shutters, cosine diffuser and fore-optic housing. One cable path is for irradiance collection and one for reflected and fluoresced radiance. The irradiance foreeoptic is mounted above the drone frame and points vertically upwards and has a foreoptic consisting of a cosine diffuser and optical shutter (for dark signal estimation), whereas the radiance foreoptic consists of a shutter housing a cable in bare fiber mode and is mounted below the drone frame in the nadir position. The system is controlled by a raspberry pi as well as an additional hardware control board custom manufactured to control the optical shutters.

2.2 Drone platforms

The majority of flights above the boreal forest, Finland were conducted on a small custom drone platform operated by the Finnish Geospatial Research Institute (Fig. 1). This platform was a custom hexcopter with Tarot T910 frame KDE 4213 motors and pixhawk autopilot. We also conducted a single flight with a custom quadcopter which was based on a Gryphon dynamics frame, and used T-motor U8 100 kv motors and a pixhawk.

Figure 1. Hexacopter platform with Piccolo Doppio spectrometer system in flight. On this platform, the upwards and downwards pointing fore-optics are fixed in place using an aluminum strut, in the skywards and nadir directions respectively.

2.3 Flight plans and sampling sites

Flights were conducted at a forested sites in the boreal forest, Finland on several days from March to July 2017. The boreal forest site was in the vicinity (<10 km) of the Station for Measuring Ecosystem and Atmosphere Relations (SMEARII), Hyytiälä (61.8474N, 24.2948E) and consisted of typical boreal forest vegetation, namely Norway Spruce, Scots pine, silver birch and associated understory vegetation (e.g. berry species). It should be noted that spatially distinct silver birch dominated, Scots pine dominated and Norway spruce dominated stands all existed within the site boundary allowing us to evaluate the effect of species and structure on the SIF emission

Flights were conducted as part of a multi-scale fluorescence measurement campaign (FAST2017, see abstact by Porcar-Castell *et al.* in these proceedings) and a key aim was to attempt to measure fluorescence at a similar spatial scale to a (future) satellite pixel (200 m diameter). We therefore flew vertical profiles, and collected data at 25 m, 80 m, 200 m, and 500 m above ground level where the 500 m measurement step produced the desired pixel size. In addition to the vertical profiles we also flew spatial grid patterns to simulate an (low resolution) image. We flew this pattern at two different heights, 30 m and 200 m above ground level respectively. The 30 m flights were conducted on top of pure stands of Silver birch, Norway Spruce and Scots pine.

3. RESULTS

We collected drone data using three different flights plans on four separate occasions 24th March, 19th April, 26th May, and 24th August. The flights encompassed four different phenological periods (winter dormancy, early spring recovery of evergreen foliage, late spring recovery of evergreen foliage/budburst, and summer). Importantly, during the first flight there was still snow on the ground which challenged the selection of integration time (highly reflective snowy areas vs dark spruce canopy).

At the time of writing this abstract we are developing a complete data processing chain to take us from raw Digital Numbers to processed radiances, and from there to emitted radiances. The impact of snow cover, canopy structure and phenology on the SIF signal will be studied.

4. DISCUSSION

During 2017 we successfully carried out a number of drone flights throughout the season. Of particular note we flew a small lightweight platform to a height of 500 m under blue sky conditions. Although we have not yet processed our data, the potential insights gained by these flights are two-fold. Firstly, once fully processed we can quantify solar-induced fluorescence on a future satellite-like scale. Secondly we can investigate the effect of spatial variability of vegetation type and structure on SIF retrievals.

In tandem to our drone measurements we have also parameterized a 3D radiative transfer model (DART) for our boreal forest measurement site [5]. Our eventual aim is to validate the model predictions using our drone measurements to answer the question, given a model of suitable complexity can spatial variation in SIF be accurately simulated?

5. CONCLUSIONS

Our aim was to collect drone measurements of solar-induced fluorescence. During the course of 2017, we collected several flights worth of measurements which we are currently processing. Our next steps are firstly to complete our processing chain and secondly to improve our estimates of downwelling solar irradiance.

6. REFERENCES

[1] Porcar-Castell, A., Tyystjärvi, E., Atherton, J., van der Tol, C., Flexas, J., Pfündel, E.E., Moreno, J., Frankenberg, C. and Berry, J.A., 2014. Linking chlorophyll a fluorescence to photosynthesis for remote sensing applications: mechanisms and challenges. *Journal of experimental botany*, 65(15), pp.4065-4095.

[2] Guanter, L., Zhang, Y., Jung, M., Joiner, J., Voigt, M., Berry, J.A., Frankenberg, C., Huete, A.R., Zarco-Tejada, P., Lee, J.E. and Moran, M.S., 2014. Global and time-resolved monitoring of crop photosynthesis with chlorophyll fluorescence. *Proceedings of the National Academy of Sciences*, 111(14), pp.E1327-E1333.

[3] Sun, Y., Frankenberg, C., Wood, J.D., Schimel, D.S., Jung, M., Guanter, L., Drewry, D.T., Verma, M., Porcar-Castell, A., Griffis, T.J. and Gu, L., 2017. OCO-2 advances photosynthesis observation from space via solar-induced chlorophyll fluorescence. *Science*, 358(6360), p.eaam5747.

[4] MacArthur, A, Robinson, I, Rossini, M, Davis, N & MacDonald, K 2014, A dual-field-of-view spectrometer system for reflectance and fluorescence measurements (Piccolo Doppio) and correction of etaloning. in *Proceedings of the Fifth International Workshop on Remote Sensing of Vegetation Fluorescence*. European Space Agenccy, Fifth International Workshop on Remote Sensing of Vegetation Fluorescence, Paris, United Kingdom, 22-24 April.

[5] Liu, W., Atherton, J., Mõttus, M., MacArthur, A., Teemu, H., Maseyk, K., Robinson, I., Honkavaara, E., and Porcar-Castell, A.: UPSCALING OF SOLAR INDUCED CHLOROPHYLL FLUORESCENCE FROM LEAF TO CANOPY USING THE DART MODEL AND A REALISTIC 3D FOREST SCENE, *Int. Arch. Photogramm. Remote Sens. Spatial Inf. Sci.*, XLII-3/W3, 107-111, https://doi.org/10.5194/isprs-archives-XLII-3-W3-107-2017, 2017.