Short Term Scientific Mission (STSM)
COST Action OPTIMISE

Interim Science Report:

Project Title Development of a direct and diffuse logging hyperspectral sunphotometer to support FLEX observations

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Purpose of the STSM

Fluorescence, the radiant flux emitted by chlorophyll molecules after excitation by photons, is the most directly measurable reporter of photosynthetic efficiency and hence a key indicator of the health and carbon fixation of photosynthesising organisms. Measurements of fluorescence, at both the leaf and canopy level, can therefore greatly advance our understanding of the dynamics of photosynthesis, gross primary productivity, and ecosystem change over time. The ESA Board and member states have just confirmed that the Fluorescence Explorer (FLEX) has been selected as the sensor system for the Earth Explorer 8 programme. The intention is for FLEX to fly in tandem with Sentinel-3 and the combined sensors provide the necessary measurements to understand vegetation reflectance and fluorescence. A ground validation network will now to be established and instruments and locations selected by ESA to perform this function. This work will begin early in 2016 with a network to be fully established and operational for the launch of FLEX planned for 2022. However, so far no instruments have been developed to measure direct solar radiance and diffuse solar irradiance simultaneously across the spectral range of both Sentinel-3 and FLEX and at sampling interval and band widths which will enable the solar flux in the telluric oxygen A and B bands reaching the Earth's surface to be measured. This is necessary for two reasons. First, to validate the space-based observations of fluorescence it will be necessary to develop models to scale ground-based observations to the sampling size (pixel size) of the space-based observations as both have different measurement supports. Small unmanned aerial vehicles (sUAVs) will be used for this purpose as flying at altitudes above the Earth's surface increases the size of support of these near ground measurements. However, these sUAVs may fly at altitudes of up to 100m and, although some dual-field-of-view systems have been proposed, will not record solar flux at ground level. Knowledge of the solar flux in the telluric oxygen A and B bands reaching the Earth's surface is necessary as not all light is absorbed in these bands and this will have to be accounted for in computations of fluorescence from both the sUAV- and space-based observations. Second, the images acquired by FLEX will require to be corrected for atmospheric effects and ground-based solar flux measurement will enable the computations of the atmospheric correction algorithms to be validated. In addition, as the reflectance of vegetation is grossly effected and spectrally dependent on the direct:diffuse ratio of solar illumination the change in these should be simultaneously recorded to better understand both reflectance and fluorescence from vegetation canopies. The aim of this application is to develop and test an instrument to make these ground-based direct and diffuse radiant solar flux measurements.

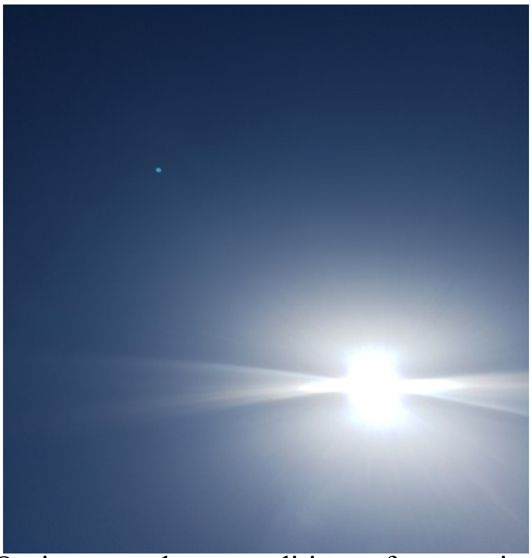
Laboratory for Earth Observation at the U. of Valencia have a CIMEL sunphotometer with an integral sun tracker. The Piccolo fibre with a specially designed fore optic will be attached to the CIMEL and measurements of direct solar flux logged over time. The other fibre will be attached to an integrating sphere with a disc shading the input port, also developed by the author, and hemispherical diffuse irradiance measured by manually and continuously moving the disc to shade the input port while the fibre with fore optic is tracking the sun. By using these dual fibres and making direct and diffuse radiant flux measurements an understanding of a) if it is possible to use the Piccolo to perform these measurement across these spectral ranges, b) if the system can be used to resolve angularly dependent radiant flux i.e in the almucantar, and c) the diurnal relationship of direct to diffuse solar flux in the O_2 A and B bands, will be gained. In addition, to validate the direct VNIR and SWIR observations, the Piccolo/CIMEL system will be deployed alongside another calibrated CIMEL managed by U. of Valencia and part of the AERONET global network of sunphotometers. As the spectral response of the CIMEL is know the hyperspectral measurement can be numerically transformed to match the CIMEL multispectral bands.

Hyperspectral sunphotometer system

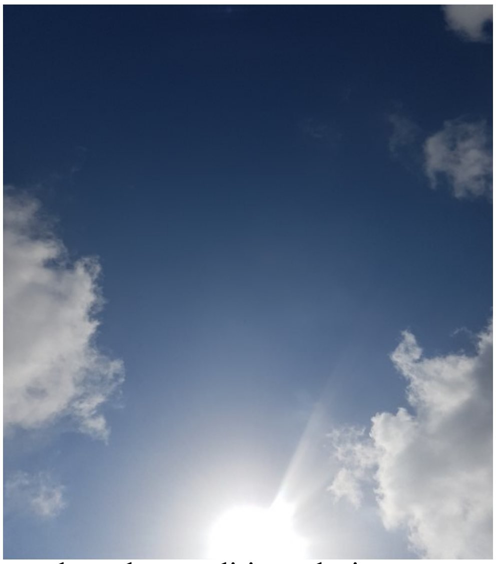
The Piccolo dual-field-of-view multi spectrometer system, currently used to measure visible near infrared (VNIR) reflectance and fluorescence in the telluric O_2 A and B bands was further developed by the author to enable a hyperspectral spectrometer covering the short wave infrared (SWIR) also to be included such that all three spectral regions (visible near-infrared (VNIR), O_2 A and B spectral regions and SWIR) to be measured simultaneously. As the Piccolo system has two input fibre optic channels and the fibre optic for this Piccolo sunphotometer was designed with three output channels. One of the input fibres twas attached to the sun tracker instrument arm and the other to a bespoke integrating sphere. The integrating sphere input port was shaded by the suntracker shading ball such that only diffuse irradiance entered. An EKO STR-22G suntracker < https://eko-eu.com/products/solar-radiation-and-photonic-sensors/sun-trackers/str-22g-sun-tracker > with MB-12-1 shading assembly was used. Unfortunately, QEPro 00114, the 640 nm to 800 nm failed when initial laboratory trials were being conducted. Therefore, only the VNIR QEPro (400 nm to 1,100 nm)could be used to demonstrate the system

Inclement weather

The sky conditions during this STSM visit sky conditions were not optimal for fieldwork to make solar observations. Either complete cloud cover obscured the Sun or, on the days when measurements could be made, scattered cumulus tended to well-up towards midday. The weather therefore severely limited the fieldwork that could be carried out.



Optimum sky condition for testing hyperspectral sunphotometer system



Prevalent sky conditions during most of STSM

Field measurements

Measurements were able to be made on 2 days 24th and 25th July. On the 25th measurements were made from approximately 11:00 to 12:00 UTC and on the 24th from 12:00 to 13:00 UTC

Piccolo measurements are made ‘sequences’ of direct and diffuse pairs and these pairs collected in ‘batches’ which should be averaged to provide a representative mean of the measurement dark current is collected at the start and end of each batch. The dark current is deducted from each measurement then the measurement normalised by its integration time. Microtops measurements were also made during thehyperspectral sunphotometer sampling periods

As the Ocean Optics optical benches used are shallow-well devices multiple measurements have to be made and averaged. 90 measurements (both direct and diffuse) were made with an integration time of 300ms were made in each of the 20 batches. The variance over the period of a typical batch is shown in Figure 3. 1 batch was made every three minutes and teach of the 90 direct and 90 diffuse measurements averaged to provide the 20 sampling periods during the hours of measurement. The means of the data collected at 11:02; 11:17; 11:31; 11:46 and 12:02 are presented below. This shows the hyperspectral sunphotometer system’s ability to track the evolution of direct and diffuse solar irradiance at regular sampling periods in the lead up to solar noon

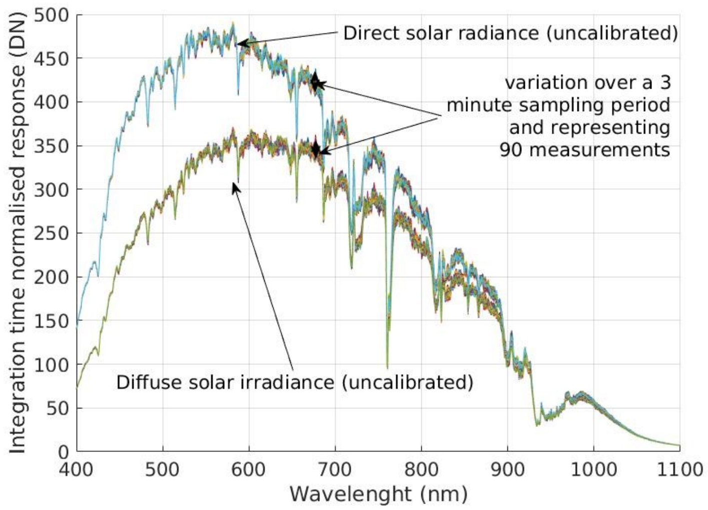


Figure 3 variance in individual measurements during a batch

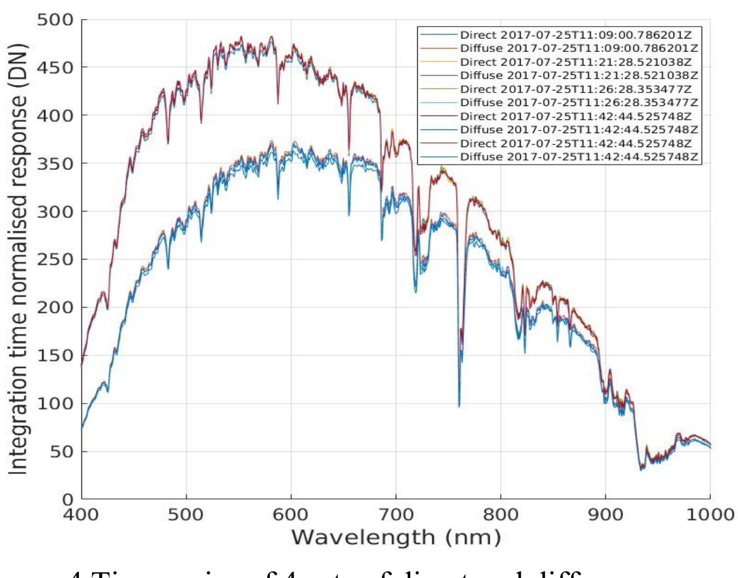


Figure 4 Time series of 4 sets of direct and diffuse measurement means over 1 hour before solar noon

Initial direct solar measurements saturated, even at the spectrometer minimum integration time of 8ms, and the 25µm slit was replaced with a 5µm slit. However, the direct solar measurement still saturated. After some trials, a neutral density filter was then used to reduce the light throughput by a factor of 80%. Measurements could the be made with a integration time of 300ms. However, the use of this slit reduces the band width (FWHM) of the spectrometer to less than its sampling interval. The sampling interval of 0.7nm at both the O_2A and O_2B bands can be seen in Figures 5 a and 5b.

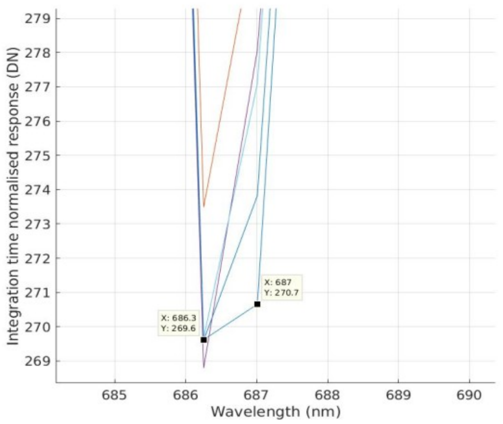


Figure 5a sampling interval at 687nm

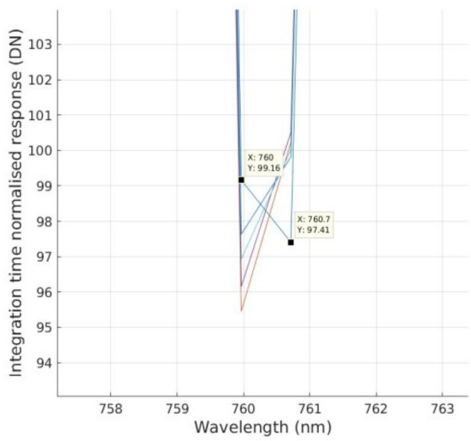


Figure 5b sampling interval at 760nm

Laboratory calibration

Use was made of the LEO optical darkroom and an attempt made to calibrate the hyperspectral sunphotometer. The diffuse channel measurement was reasonably successful, although for an accurate calibration a irradiance source (i.e. and FEL lamp) will be used at a later date. However, the direct channel could not be calibrated, as the intensity of the LEO source (a LabSphere integration sphere See Fig 6) was inadequate when the neutral density filter was in place. The integration time would have been in excess of 60 minutes which is the maximum possible with the Ocean Optics QEPros. Calibration of the direct channel may be possible at the author's laboratory at the U of Edinburgh and both channel twill be calibrated there.

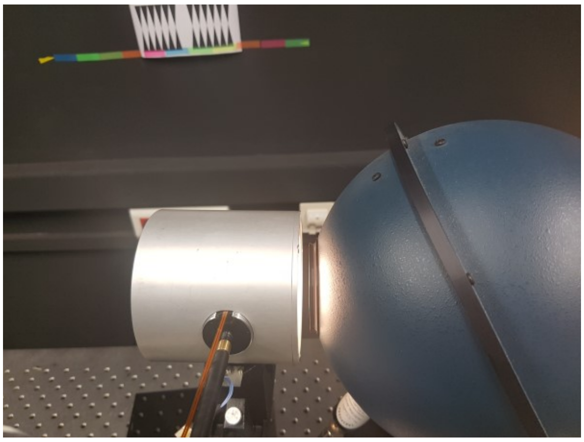


Figure 6 Diffuse channel calibration with LEO integrating sphere

Investigation of O2 band light absorption within sphere

An integrating sphere causes multiple scattering of light within the sphere. It was therefore considered that the absorption of light by oxygen in the atmosphere within the sphere may cause inaccuracies when using this fore optic for sun induced fluorescence measurements. A tungsten halogen (TH) lamp emission spectrum has no absorption features at 687nm or at 760nm. A TH lamp was therefore aligned with the hyperspectral sunphotometer integrating sphere fore optic and 60 measurements made. The mean of these measurements showed no evidence of absorption at either the O2A or O2B bands. The O2A spectral region is shown in Figure 8

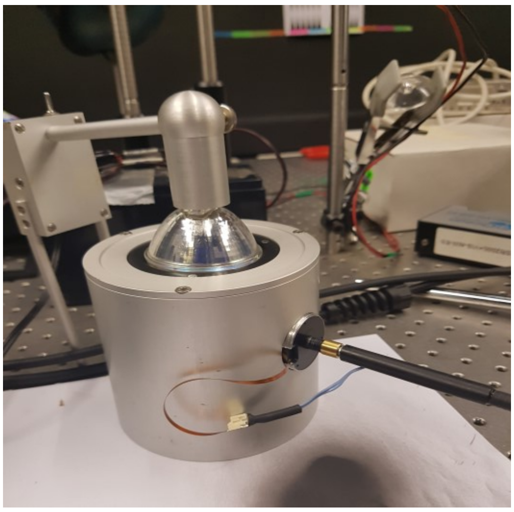


Figure 7 TH lamp aligned with hyperspectral sunphotometer integrating sphere fore optic and with specrtometer fibre optic attached.

Conclusions

This work demonstrated that the Piccolo system could be configured to make hyperspectral solar direct and diffuse

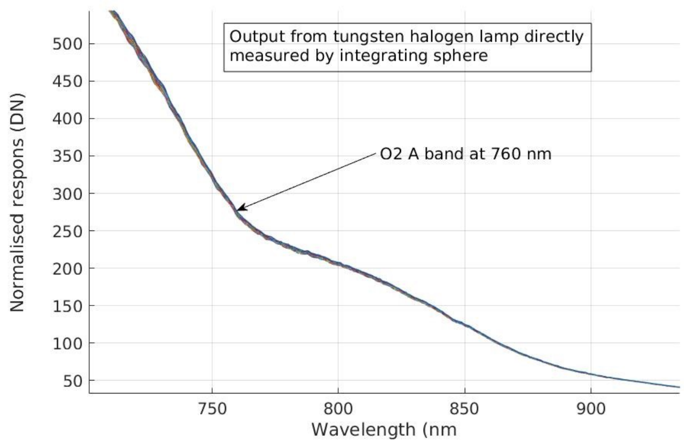


Figure 8 O_2A band spectral region

measurement of solar irradiance. It also demonstrated that the Piccolo system could be mounted on a suntracker so it could be operated as a hyperspectral logging sunphotometer. However, to be of use for validating atmospheric correction models for sun-induced fluorescence, both a VNIR and an O_2 band spectrometer need to be used in tandem. This was not demonstrated due to the spectrometer failure, although the evidence presented here indicated that it will be possible to do so. This work has also demonstrated that an integrating sphere fore optic can be used for irradiance measurements to support sun-induced fluorescence studies. Further work is also needed to determine if the direct channel can be calibrated at the author's facility at the U. of Edinburgh

Note Due to European institute holidays during August Host approval has not yet been received