MODELLING CHLOROPHYLL FLUORESCENCE THROUGH SCOPE AND *IN-SITU* MEASUREMENTS - A CASE STUDY FOR MANGROVE VEGETATION

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ABSTRACT: Fluorescence observations add a new dimension in providing a means to detect vegetation stress before chlorophyll reductions happen. Typically, less than 5% of absorbed photons are re-emitted by plants as fluorescence. Various photosynthesis models are in vogue to simulate field and laboratory measurements of chlorophyll fluorescence at the leaf level. In this paper, the Soil Canopy Observation, Photochemistry and Energy fluxes (SCOPE) model is used for simulation of Solar Induced Fluorescence (SIF). We have simulated SIF using in-situ measurements of biochemical parameters parameters namely; Chlorophyll concentration (C_{ab}), Maximum carboxylation rate (V_{cmax}) for Summer season over Pichavaram, Tamilnadu. For Pichavaram, fluorescence ranged from 1.3 to 3.7 W m^{-2} μm^{-1} sr^{-1}. We have also investigated the sensitivity of fluorescence to biochemical parameters like V_{cmax}, C_{ab}, atmospheric temperature and vapour pressure, visible radiation and Leaf Area Index (LAI). SIF observed to be increased along with increase in LAI. However, it tends to saturate at LAI values greater than 4. The SIF varied between 0.4 and 1.3 W m^{-2} μm^{-1} sr^{-1} for all LAI values ranging from 1 to 2 and V_{cmax} of 50 µmol m^{-2} s^{-1}. it is observed that the sensitivity of SIF is large for V_{camx} less than 150 µmol m^{-2} s^{-1} and above which the fluorescence remains almost saturated. Also Simulation of fluorescence for post monsoon and winter seasons is carried out.

1.0 INTRODUCTION

Photosynthesis is a key factor driving several biochemical pathways and CO_2 exchange occurring between the biosphere and atmosphere. Fluorescence observations add a new dimension in providing a means to detect vegetation stress before chlorophyll reductions happen. Typically, less than 5% of absorbed photons are re-emitted by plants as fluorescence. Solar Induced Fluorescence (SIF) emitted by photosystems I and II is one of the three de-excitation mechanisms of energy captured by light harvesting pigments in plants. SIF emitted by vegetation is seen as a meaningful indicator of instantaneous plant photosynthetic activity at the ecosystem scale (Porcar-castell et al., 2014). A major advantage of the SIF signal is that it is a more physiologically related signal than reflectance, and moreover it originates uniquely from vegetation.

The relationship between fluorescence and photochemistry at leaf level is reasonably understood. Light energy absorbed by chlorophyll molecules has one of the three fates: photosynthesis, dissipation as heat and chlorophyll fluorescence. The peak of the fluorescence spectrum lies between 650 and 850 nm. Under low-light conditions, a negative correlation has been found between fluorescence and photosynthesis light use efficiency (Genty et al., 1989; Rosema et al., 1998; Seaton and Walker, 1990; Maxwell and Johnson, 2000; van der Tol et al., 2009a) while at high-light condition, positive correlation has been observed between fluorescence and photosynthesis (Gilmore and Yamamoto, 1992; Gilmore et al., 1994). Yang et al. (2017) showed good correlation between in-situ steady state fluorescence Canopy SIF. Regarding the water stress, more recently, Lee et al. (2013) showed a negative relation between vapour pressure deficit and SIF. Modelled SIF using FluorMOD model and its comparison with OCO-2 observations which provides SIF at 757 and 771 nm they were lies in the 650-800 nm, we observed that Modelled and observed SIF had good correlation (r = 0.77) at 757nm (Pradhan and Gohel, 2016). Modelled SIF and Photosynthesis using JSBACH biosphere model at local and regional scales in northern Europe, is showed that

Overserved SIF was good taking the seasonal cycle at the forest sites than the modelled SIF and GPP (Thum et al., 2017). Simulated SIF using SCOPE model inferring with GPP, they investigated global and regional means as well as the zonal average of both simulated SIF and GPP, which are in good agreement with satellite-based SIF (Koffi et al., 2015).

The objective of this paper is to model SIF using SCOPE model for summer season from *in-situ* measurements of biochemical and biophysical parameters of major mangrove species from leaf scale to canopy scale of Pichavaram, Tamilnadu. GPP derived using Resourcesat-2 LISS III and MODIS data were compared followed by comparison modelled SIF with Resourcesat-2 LISS III derived GPP for summer season to validate the results.

2.0 MODEL AND DATA

2.1 SCOPE Model and input parameters

SCOPE is a vertical (1-D) integrated radiative transfer and energy balance model (Van der Tol et al., 2009a). The model calculates radiation transport in a multilayer canopy as a function of the solar zenith angle and leaf orientation to simulate fluorescence in the direction of observation. The biochemical component has been updated based on (Collatz et al., 1991,1992) for C3 and C4 plants, respectively. It determines the illumination and net radiation of leaves with respect to their position (distance from the top of canopy in units of leaf area) and orientation (leaf inclination and azimuth angle), and the spectra of reflected and emitted radiation as observed above the canopy in the specified satellite observation geometry. The spectral range (0.4–50 µm) includes the visible, near and shortwave infrared and the thermal domain, with respectively, 1, 10, 100 and 1000 nm resolution. SCOPE requires inputs of meteorological forcing (incoming shortwave and long-wave radiation, air temperature, humidity, wind speed, and CO_2 concentration) and four categories of factors: (1) vegetation structure parameters, such as canopy height, leaf size, leaf angle distribution, and LAI; (2) leaf biophysical parameters: leaf chlorophyll content(C_{ab}), dry matter content(C_{dm}), leaf equivalent water thickness (C_w), senescent material(C_s), and leaf structure (N); (3) optical parameters: reflectance of soil in the visible, near infrared and thermal bands, and vegetation (thermal) emissivity; (4) plant physiological parameters: stomatal conductance parameter (m), and maximum carboxylation capacity, V_{cmax} (Koffi et al., 2015). Output of the model is the spectrum of outgoing radiation in the viewing direction, turbulent heat fluxes, photosynthesis and chlorophyll fluorescence.

2.2 Field data Collection

Pichavaram mangrove forest (Latitude: 11.46° N, Longitude: 79.79° E) which was declared as a Reserve forest in 1987, covers an area about 1471 ha including mangrove forests, mudflats, back waters and sand dunes. The climate is sub-humid with very warm summer and with an annual average rainfall (70 years) of 1310 mm and annual average rainy days up to 56. A total of 14 mangrove species are identified in Pichavaram mangroves, among which *Avicennia marina*, *Avicennia officinals*, *Rhizophora mucronata*, *Excoecaria agallocha*, were considered for the study. *In-situ* measurements of photosynthetic rate (V_{cmax}), and fluorescence measurements were carried out with the instrument LI-COR LI-6400XT- Portable Photosynthesis System. Integrated Pulse amplitude modulation system (PAM) and integrated leaf chamber fluorometer (LCF), has the capability to simultaneously measure the chlorophyll fluorescence and photosynthesis at leaf level with the aid of its LED based fluorescence source accessory. The non-destructive diurnal measurements from morning 5:30 to evening 5:30 were recorded repeatedly at an interval of every 45 minutes. Two leaf samples ('Sun' and 'Shade' leaves) of each species were studied to account the variability within the species. LAI measurements were carried out with the aid of Plant Canopy Imager CI-110. *In situ* measurements of chlorophyll a, and b were carried out on the basis of Arnon's Estimation method.

3.0 METHODOLOGY

The major inputs of SIF map are (I) LAI map, (II) Species Classification map. A total of 18 quadrats, each of 20m x 20m were studied for the in situ measurements of LAI. From near synchronous Resourcesat-2 LISS III data, the corresponding Normalized Difference Vegetation Index (NDVI) values were extracted for each quadrat. A best fit regression was derived between NDVI and LAI, which was used for upscaling LAI map to 24 m resolution. Both the optical and SAR data were used along with limited field observations to derive a classified image of the study area based on certain decision rules. The other important parameter like GPP was derived based on vegetation photosynthesis model (Xiao et al., 2005) wherein ecological scalars such as temperature, water, phenology and salinity were computed to arrive at actual light use efficiency (LUE). Latter, GPP is computed as a product of LUE, PAR and fraction of absorbed PAR (faPAR). Other physical parameters were incident short wave radiation (*www.clearskycalculator.com*), air temperature, air pressure, atmospheric vapour pressure, solar zenith angle and *in-situ* measurements of biochemical parameters like V_{cmax} and C_{ab}. After setting LAI, V_{cmax}, C_{ab}; SCOPE simulations were run for summer season over Pichavaram mangrove site. Modelled SIF radiance at 760 nm were used at different V_{cmax}, C_{ab} and LAI.

4.0 RESULTS AND DISCUSSION

From the sensitivity analysis, it is observed that SIF increases with the increase of LAI. However, it tends to saturate at higher LAI values i.e. greater than 4. The maximum fluorescence observed at high LAI (>4) is attributed to the C_{ab}. Variation of fluorescence is a function of C_{ab} and LAI. For a given LAI, fluorescence was highly sensitivity for C_{ab} less than 20 µg cm^{-2}. For larger C_{ab} values (> 60 µg cm^{-2}) variation in SIF is negligible (Figure 1). The sensitivity is large for V_{cmax} less than 100 µmol m^{-2} s^{-1} and its becomes almost constant for V_{cmax} higher than 150 µmol m^{-2} s^{-1} (Figure 2). We simulated SIF using *in-situ* biochemical parameters for summer season over Pichavaram at 1:30 pm under high light condition which shows good relationship between fluorescence and photosynthesis (Meroni et al., 2009). Similar results were reported by other authors (Gilmore and Yamamoto, 1992; Gilmore et al., 1994). Figure 4 displays modelled SIF at 760 nm and LISS-III derived GPP at 24 m resolution. The modelled SIF ranges from 1.3 to 3.7 W m^{-2} µm^{-1} sr^{-1} at 24 m resolution for Pichavaram Mangroves. A good agreement between modelled SIF at 760 nm and LISS III derived GPP is found (Pearson correlation coefficient r = 0.79) (Figure 3). We observed that *Avicennia marina, Avicennia officinals, Rhizophora mucronata and Excoecaria agallocha* mangrove spices have modelled SIF values are 3.06, 3.12, 3.00 and 2.76 W m^{-2} µm^{-1} sr^{-1} at 760 nm respectively.

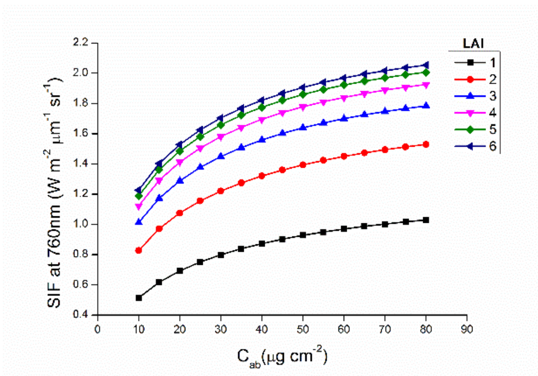

Figure 1. Sensitivity of SIF to C_{ab} at V_{cmax}= 75 µmol m^{-2} s^{-1} R_{in}= 500 W m^{-2}

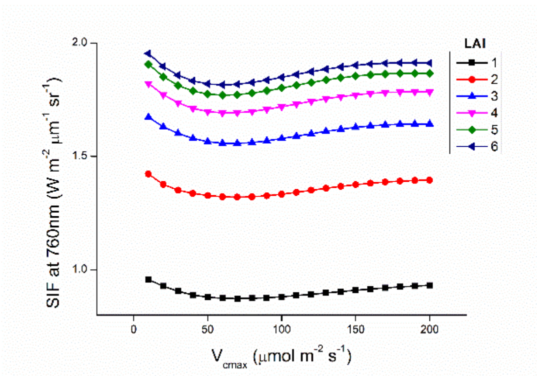

Figure 2. Sensitivity of SIF to V_{cmax} at C_{ab}=40µgcm^{-2} and R_{in}= 500 W m^{-2}

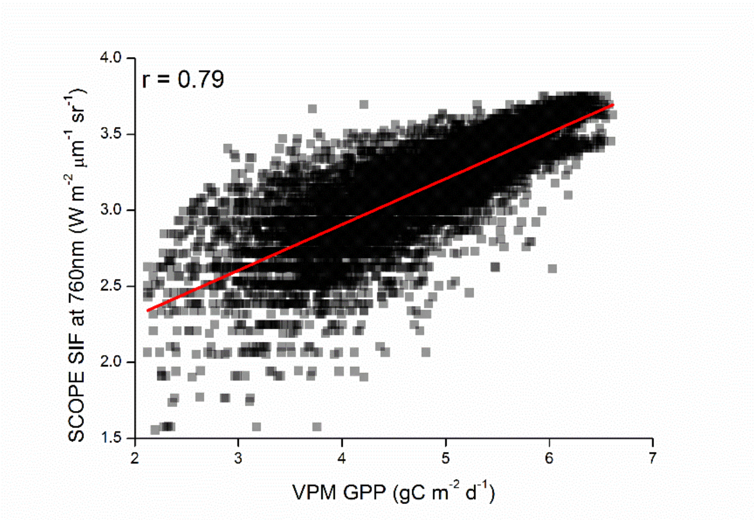

Figure 3. Correlation between SCOPE SIF at 760 nm and VPM GPP over Pichavaram Mangroves, Tamilnadu

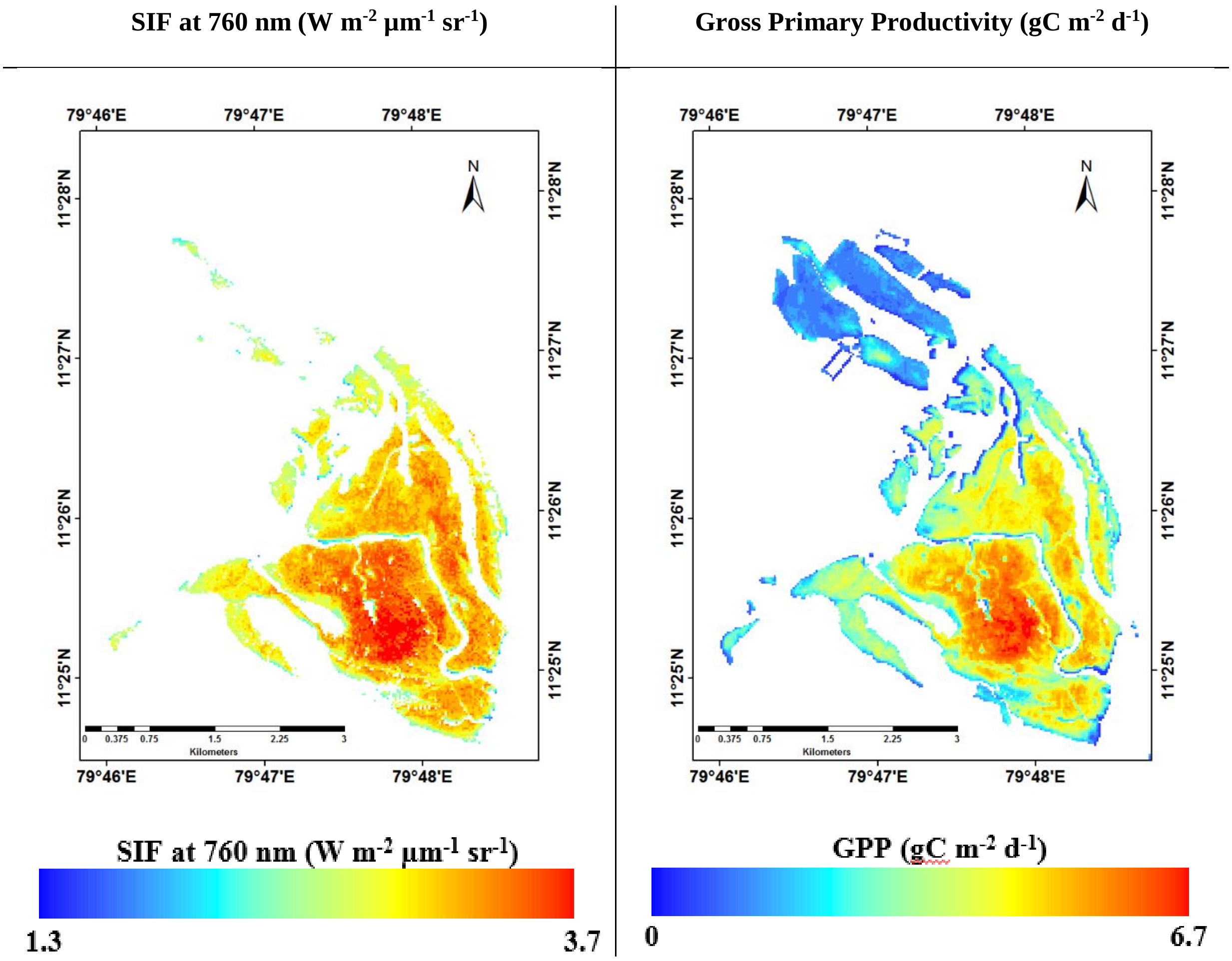

Figure 4. Spatial patterns of SCOPE SIF at 760 nm and VPM GPP at 24 m resolution for Summer Season over Pichavaram, Tamilnadu

5.0 CONCLUSION

SCOPE integrates radiative transfer and energy balance calculations at the level of individual leaves as well as the canopy. Present study relates the *in-situ* biochemical parameters with modelled SIF and reveals the relationship between fluorescence and photosynthesis. SIF appears to be more sensitive to C_{ab} and faintly sensitive to V_{cmax} under high light conditions at different LAI. It is observed that modelled SIF at 760 nm ranges from 1.7 to 3.7 W m^{-2} μm^{-1} sr^{-1}. A significant coherence found between the modelled SIF and GPP ($r = 0.79$) is observed. As an opportunity for future work, the analysis can be extended for the other major seasons like post-monsoon (where the photosynthesis is likely to be at its peak) and winter (where the fluorescence is the least recorded) for other major mangrove sites like Bhitharkanika, Odisha and Chorao Island of Goa.

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