A NEW APPROACH FOR MEASURING PHOTOSYNTHETIC LIGHT-USE EFFICIENCY FROM SPACE USING MULTI-ANGULAR SATELLITE OBSERVATIONS

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Satellite remote sensing of Gross Primary Production (GPP) will greatly enhance our understanding of the terrestrial carbon cycle, as it allows globally continuous estimates of plant CO_2 uptake at regular intervals from space [1]. Remotely sensed GPP can be defined as the product of the incident photosynthetically active radiation (the radiation between 400 and 700 nm wavelength, PAR), the fraction of PAR absorbed by the green canopy elements (f_{PAR}) and the light-use efficiency ε ($gCMJ^{-1}$) with which the absorbed PAR is used to produce biomass [2, 3]. Recent decades have seen considerable progress determining PAR and f_{PAR} from satellite observations [4, 5], remote sensing of ε, however, remains challenging. A possible means to determine ε remotely is the photochemical reflectance index (PRI), a narrow waveband index that measures the photosynthetic activity of leaves using a xanthophyll absorption band at 531 nm. A large number of studies have demonstrated a relationship between ε and PRI over a wide range of species plant functional types[6, 7], the same and other work, however, has also shown that PRI is affected by numerous other factors such as the sun-view geometry, leaf angle distribution, leaf area, canopy structure and pigment pool size, making an upscaling to landscape and global levels difficult [8, 9].

A promising approach to resolve these dependencies is to characterize the anisotropy of the surface reflectance via continuous, multi-angular spectral observations. Using a tower-based, automated, multi-angular spectroradiometer instrument (AMSPEC, Fig. 1), we demonstrated in previous work that stand-level PRI reflectance observed in a Douglas-fir forest can be defined as a function of the sun-observer geometry, the sky condition at the time of measurement and the physiological status of the vegetation canopy observed (i.e. ε) [8, 10]. This physiological component of the reflectance signal can be extracted by stratifying spectra into homogeneous subsets of observations with respect to both sky

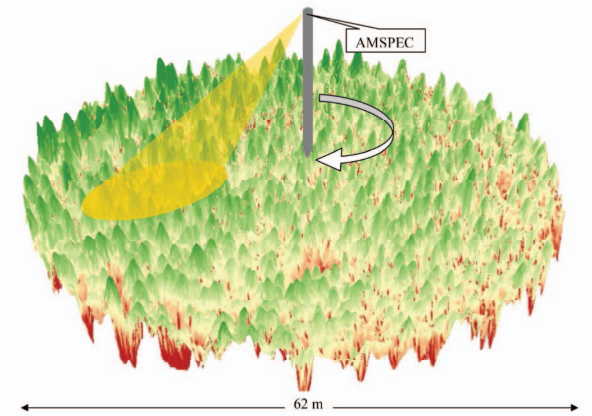

Fig 1: The AMSPEC radiometer system measures canopy reflectance at vertical zenith angles between 32° and 78°, completing a full rotation in 15 min.

conditions and tower measured ε and subsequently modeling the bidirectional reflectance distribution (BRDF) of each of these strata [10]. The approach yielded a highly significant relationship between PRI and ε ($r^2=0.82$; $p<0.01$) throughout the year, and allowed, for the first time, a continuous, year round observation of ε from PRI.

Only a few studies exist that use satellite based estimates of PRI [11-13], and research has focussed on data acquired by the MODerate Resolution Imaging Spectroradiometer (MODIS). Its daily global coverage and its capacity to detect a narrow reflectance band at 531 nm make MODIS a suitable choice for determining ε from space [14]. While some progress has been made relating MODIS observations to eddy covariance (EC) measured ε, a number of key issues still exist. First, the sensor lacks a reference band at 570 nm (which has often been replaced by MODIS Band 12, centered at 551 nm), and Band 11 (531 nm) operates at a fairly coarse spatial resolution of $1km^2$. Second, the differences between the footprint of EC-measurements and the MODIS pixel geometry make a direct comparison between both data sources challenging. Finally, MODIS reflectance is affected by atmospheric scattering effects confounding the relationship between spaceborne PRI and ε.

This study introduces a new approach for a spaceborne acquisition of ε using the MODIS satellite. Instead of comparing MODIS observations to the EC-measurements directly, ungridded, MODIS Level 1B swath data were related to tower-based AMSPEC observations of the same wavelength and viewing geometry, acquired at the time of each satellite overpass. This approach allowed a more spatially explicit comparison between stand level and spaceborne observations and importantly, it facilitated the direct use of the MODIS observations as a multi-angular dataset. A new Multi-Angle Implementation of Atmospheric Correction (MAIAC) algorithm [15], was implemented to correct for atmospheric effects independent of the satellites viewing geometry (Fig. 2). MAIAC features a time series approach which uses an image-based rather than pixel-based processing technique for simultaneous retrievals of atmospheric aerosol and surface bidirectional reflectance (BRDF). The algorithm was tested at a 60 year-old Douglas-fir stand and a 90 year-old Aspen stand located in Coastal British Columbia and Northern Saskatchewan, Canada, respectively. A strong relationship existed between tower-based and spaceborne PRI observations ($r^2=0.74$, $p<0.01$) throughout the vegetation period (Fig. 3a). Swath (non-gridded) observations yielded stronger correlations than gridded data ($r^2=0.58$, $p<0.01$, Fig. 3b) both of which included forward and backscatter observations. The multi-angular implementation of atmospheric correction showed much enhanced results compared to the use of a conventional single orbit atmospheric correction ($r^2<0.36$, $p<0.01$). Spaceborne PRI values were strongly related to canopy shadow fractions and varied with different levels of ε.

We conclude that MAIAC-corrected MODIS observations were able to track the site-level physiological changes from space throughout the observation period. The use of the multi-angular spectro-radiometer as

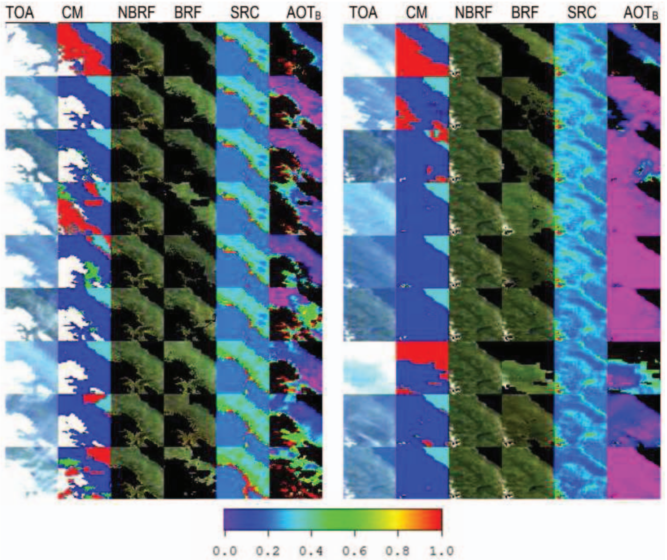

Fig 2: Illustration of the MAIAC algorithm for the BC study area. Shown vertically are 9 consecutive images for two periods, May 25-31, and September 20-25 of 2006. Columns have the following correspondence (scale): 1 - MODIS TERRA TOA RGB, 2 – cloud mask, 3 – RGB Normalized BRDF (computed using retrieved LSRT parameters for fixed view geometry of SZA=45o and nadir view), 4 – RGB BRDF (or surface reflectance), 5 – SRC with scale 0-1 shown by color bar, 6 – retrieved AOT with scale 0-0.6. The cloud mask has the following legend: white, blue and light blue – CLEAR over snow, land and water, respectively; green – possibly clear (AC not performed); red – cloudy. The reflectance scale for RGB images is 0-0.15. The low-left corner is a mountainous area covered by snow, which may persist throughout the summer

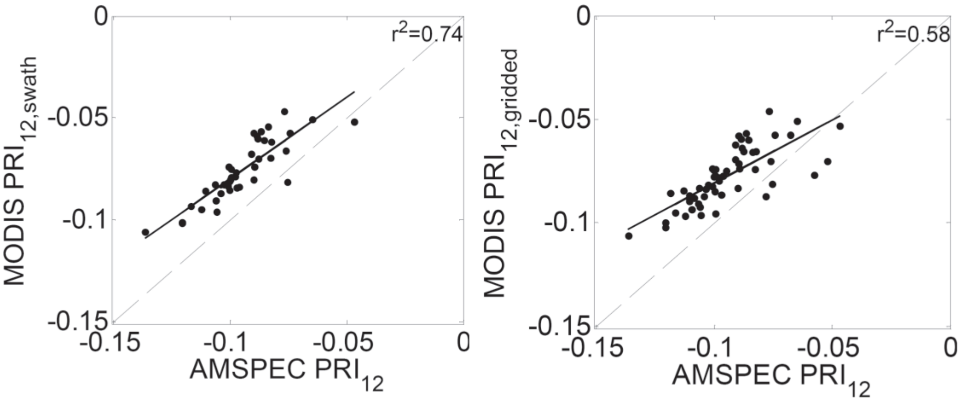

Fig 3: Relationship between MAIAC-corrected MODIS PRI and directionally adjusted AMSPEC PRI. The dashed line represents the 1:1 line. Fig. A shows the non-gridded (swath) data, Fig. B shows the gridded MODIS data. The MODIS gridding process uses series of forward and inverse mapping computational steps to acquire reflectance from multiple adjacent pixel

a tool to “translate” the EC-based ε measurements into a tower-level, PRI signal, significantly enhanced the results over a direct comparison to EC measurements undertaken in previous studies. A proposed network of AMSPEC like spectro-radiometer instruments based on existing flux towers could greatly advance existing upscaling efforts by helping to calibrate coarser scale observations to tower-based measurements and allowing an adjustment for different vegetation and land-cover types.

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