COMBINING OBSERVATIONS IN THE REFLECTIVE SOLAR AND THERMAL DOMAINS FOR IMPROVED MAPPING OF CARBON, WATER AND ENERGY FLUXES

Rasmus Houborg[1,2], *Martha Anderson*[3], *Bill Kustas*[3], *Matthew Rodell*[1]

[1]NASA's Goddard Space Flight Center (GSFC), Greenbelt, MD
[2]Earth System Science Interdisciplinary Center, College Park, MD
[3]USDA-ARS Hydrology and Remote Sensing Laboratory, Beltsville, MD

ABSTRACT

The REGularized canopy reFLECtance (REGFLEC) modeling tool integrates leaf optics, canopy reflectance, and atmospheric radiative transfer model components, facilitating accurate retrieval of leaf area index (LAI) and leaf chlorophyll content (C_{ab}) directly from at-sensor radiances in green, red and near-infrared wavelengths. C_{ab} is particularly useful for monitoring vegetation productivity and is an important indicator of the overall plant physiological conditions. This study investigates the utility of REGFLEC retrievals of LAI and C_{ab} for optimizing CO_2 and energy fluxes simulated by a thermal-based Two-Source Energy Balance (TSEB) model that implements an analytical, light-use-efficiency (LUE) based model of canopy resistance. The LUE model component computes canopy-scale carbon assimilation and transpiration fluxes and incorporates LUE modifications from a nominal (species-dependent) value (LUE_n) in response to variations in environmental conditions. However LUE_n needs adjustment on a daily timescale to accommodate changes in plant phenology, physiological condition and nutrient status. Day to day variations in LUE_n, assessed for a corn crop field in Maryland U.S.A. through model calibration with CO_2 flux tower observations, were found to correlate well with daily changes in C_{ab} derived from aircraft radiance observations, and hourly carbon and energy flux estimation accuracies were significantly improved when using C_{ab} for delineating spatio-temporal variations in LUE_n. The applicability of the established curvilinear relationship between LUE_n and C_{ab} was also tested for an agricultural area near Bushland, Texas. LUE_n was distributed over the modeling domain using C_{ab} retrieved from SPOT and Landsat radiance data whereas the thermal input to TSEB was taken from ASTER and Landsat data. The modeled carbon and energy fluxes were compared with eddy covariance measurements made in stands of cotton and wheat and with fluxes measured by an aircraft flying transects over irrigated and non-irrigated agricultural land and natural vegetation. The results demonstrate utility in combining remotely sensed observations in the reflective solar and thermal domains for estimating carbon and water fluxes within a coupled framework.

1. INTRODUCTION

Remotely sensed data in the reflective solar domain continue to function as a unique source for providing spatio-temporal information on key biophysical and biochemical parameters of land surface vegetation. Leaf area index (LAI) serves as a key vegetation biophysical determinant for variations in land surface fluxes of carbon, water and energy [1]. Leaf chlorophyll content (C_{ab}) is an important indicator of the plant physiological condition; C_{ab} is connected to leaf nitrogen and photosynthetic capacity of the vegetation and has been found useful for detecting vegetation stress [2] and leaf nitrogen deficiency [3]. The benefits of using thermal infrared remote sensing for monitoring land surface fluxes are well documented [4]. Thermal infrared data provide valuable information about the sub-surface moisture status, obviating the need for precipitation input and prognostic modeling of the soil water balance [5]. Radiometric surface temperatures can be an effective substitute for in-situ surface moisture

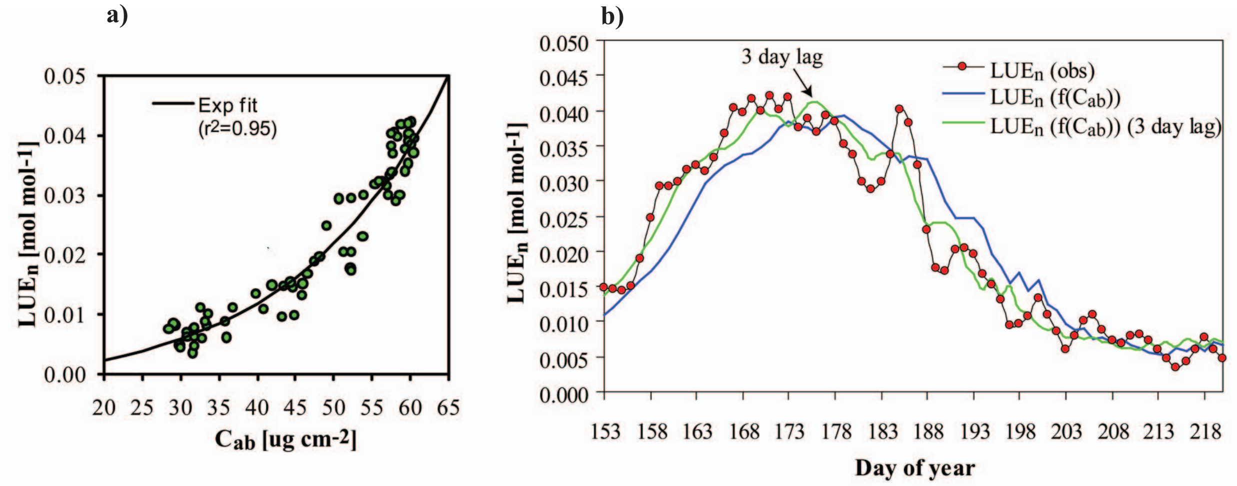

Fig.1 *a) Exponential fit between model calibrated LUE_n and tower footprint weighted aircraft-based C_{ab} estimates when a 3-day lay between LUE_n and C_{ab} is assumed. b)Temporal evolution of model optimized LUE_n and LUE_n estimated as an exponential function of C_{ab} (see left figure). Evidently estimates of C_{ab} can be very useful for describing variations in LUE_n, a key input parameter to TSEB.*

observations [6], and have the ability to capture subtle signatures of soil moisture deficiencies and reduced stomatal aperture [5]. This study aims to use LAI and C_{ab}, retrieved from aircraft and satellite imagery, to parameterize a thermal-based Two-Source Energy Balance (TSEB) model that implements an analytical, light-use-efficiency (LUE) based model of canopy resistance facilitating coupled carbon and water flux simulations.

2. METHODS

Aircraft, satellite and ground-based data were collected in 2007 over a corn crop field located within the USDA-ARS Beltsville Agricultural Research Center, Maryland (39.02° N, 76.85° W), and in 2008 over an agricultural area in and around the Conservation and Production Research Laboratory, USDA-ARS, Texas (35.19° N, 102.06° W) during the Bushland Evapotranspiration and Agricultural Remote Sensing EXperiment (BEAREX08).

2.1. Image-based LAI and Cab retrievals

Spatial estimates of C_{ab} and LAI were derived from aerial and satellite imagery using the REGularized canopy REFLECtance modeling tool (REGFLEC) [7,8]. The REGFLEC tool integrates leaf optics (PROSPECT), canopy reflectance (ACRM), and atmospheric radiative transfer (6SV1) model components, facilitating direct use of at-sensor radiance observations in green (~510-580 nm), red (~610-690 nm), and near-infrared (~800-900 nm) wavelengths. REGFLEC adopts a multi-step look-up table based inversion approach and incorporates a number of image-based techniques to reduce the confounding effects of land cover specific vegetation parameters and soil reflectance. Input parameters to the model include the at-sensor radiance observations, atmospheric state parameters to describe atmospheric scattering and absorption characteristics, solar and sensor view angle geometries, and a land cover and soil map. At the Maryland study site, the image-based LAI and C_{ab} estimates were fused with weekly in-situ measurements in order to generate a continuous spatio-temporal LAI and C_{ab} record spanning the period from day of year 153 to 220, 2007.

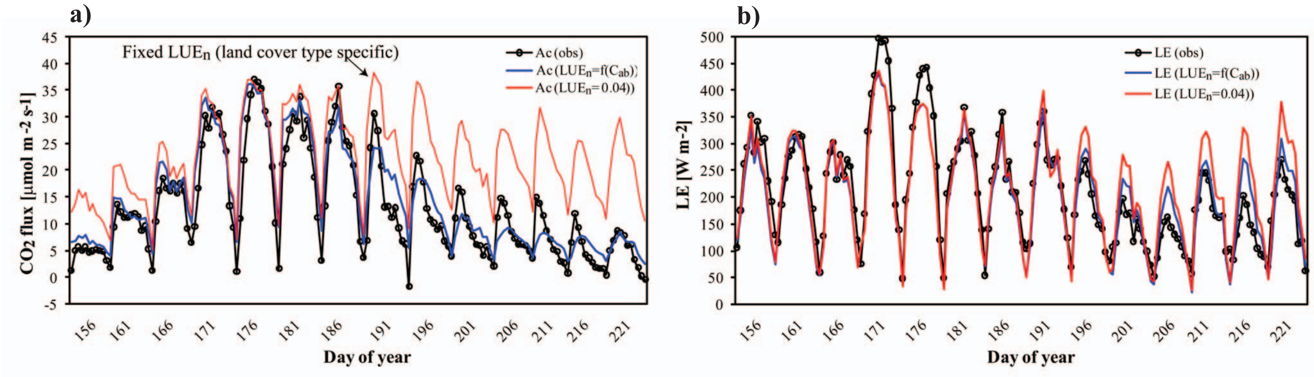

Fig. 2 *Comparison of eddy covariance flux observations (Maryland corn site) against flux estimates derived by running the Two-Source Energy Balance (TSEB) model with a fixed LUE_n, and with a LUE_n that varied seasonally as a function of aircraft-based leaf chlorophyll (C_{ab}) estimates. a) Hourly CO_2 flux estimates optimized using the C_{ab} timeseries see vast improvements especially during green-up and later in the season when drought conditions prevailed. b) A reduced uncertainty is also observed for the latent heat fluxes.*

2.2. Correlating C_{ab} with light-use-efficiencies

A land surface model calibration approach was adopted to generate a daily time-series of nominal light-use-efficiencies (LUE_n) for comparison with the daily C_{ab} estimates (section 2.1). This study uses the thermal-based Two-Source Energy Balance land-surface model (TSEB), which is a two-layer (soil and vegetation) land-surface representation coupling fluxes from the soil, plants, and atmosphere. TSEB implements an analytical, light-use-efficiency (LUE) based model of canopy resistance for computing carbon assimilation and transpiration fluxes. The LUE model component is currently set up to incorporate LUE modifications from a nominal (presumably species-dependent) value (LUE_n) in response to variations in light environment (direct versus diffuse beam fractions), atmospheric humidity, CO_2 concentration, and soil moisture content. However, LUE_n may need further adjustment on a daily timescale to accommodate changes in plant phenology, physiological condition, and vegetation nutrient status. A calibration of TSEB against CO_2 flux tower observations was carried out to test the variability in LUE_n over the study period at the Maryland site (doy 153-220). The temporal evolution of LUE_n was derived by minimizing the root-mean-square (RMS) deviation between the modeled and observed CO_2 fluxes on a daily timescale.

3. RESULTS

Figure 1b plots the daily temporal evolution of nominal LUE values (derived by minimizing the RMS error between model estimated and observed CO_2 fluxes) and corresponding LUE_n values estimated as a function of image-based (aircraft) estimates of C_{ab} within the footprint of the flux tower (Fig. 1a). The C_{ab} estimates are seen to be very useful for tracking the overall trend in LUE_n; specifically the rapid increase during leaf expansion and development (doy 153 - 165), peak values during the early stages of leaf maturity and the fairly rapid decrease initiating around doy 185 and continuing through leaf senescence. The good correlation observed between LUE_n and C_{ab} for the Maryland corn site suggests utility of leaf chlorophyll estimates for optimizing land surface model estimates of carbon, water and energy exchange. Figure 2 compares TSEB model simulations run with a fixed vegetation-specific LUE_n (as typically done) and with a LUE_n that varied seasonally as a function of aircraft-based C_{ab} estimates against eddy covariance flux observations at the Maryland corn site. The result of assimilating the C_{ab} data is a vast improvement in hourly CO_2 flux estimates especially during green-up and later in the season when drought conditions prevailed (Fig. 2a). While C_{ab} is primarily linked to vegetation productivity (i.e. CO_2 exchange), it also has potential for improving estimates of latent heat flux from the LUE-based Two-Source Energy Balance model (Fig. 2b). Similar analysis on the utility of REGFLEC retrievals of LAI and C_{ab} for optimizing CO_2 and energy fluxes simulated by the thermal-based TSEB are currently being done for the Texas study site for a wider range of crop types.

11. REFERENCES

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