Modeling Canopy Water Content for Carbon Estimates from MODIS data at Land EOS Validation Sites

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Abstract - This paper reports on progress made to improve our understanding of the biophysical and ecological processes governing the linked exchanges of water, energy, carbon and trace gases between the terrestrial biosphere and the atmosphere by improving satellite data products for models. The project aims to tests new biophysical data products from MODIS and ASTER EOS sensors and incorporates them into the SiB2 and CASA models. Traditional carbon estimates of such models use NDVI satellite data as inputs, although it is known that NDVI saturates at high LAI values. Radiative transfer models PROSPECT, SAILH and SPRINT were used to study a water-based optical index from MODIS as a measure of canopy water content that potentially improve estimates of LAI, specifically for ecosystems having high LAI (>4). This study shows the validity of the new data product and the potential extent of model improvements for biospheric and atmospheric processes. Validation of the models and the data products is conducted at EOS core land validation sites part of AmeriFlux.

I. INTRODUCTION

State-of-the-art methods for global estimates of CO_2 dynamics rely on ecosystem models such as Simple Biosphere Model, SiB2 [1]-[3] and CASA [4]-[6] that obtain satellite-derived input data from NDVI. This optical index is affected by two factors, pigment absorption, and the scattering of the medium, a function of the canopy structure. Saturation of NDVI at high LAI values is well documented, with such saturation occurring at values substantially below typical LAI in high productivity sites. Limitations of current methods for deriving canopy biophysical (LAI) and leaf biochemical constituents, such as chlorophyll, nitrogen, and water content, limits accuracy when estimating the significance of photosynthetic processes in regulating some components of the carbon cycle. Moreover, no current remote sensing approaches provide reliable estimates of other critically important ecosystem-level properties such as woody, senescent vegetation or changes in canopy structure. Currently, spatially distributed remote sensing data rely only on NDVI as input for such models to simultaneously estimate LAI, evapotranspiration, photosynthesis and primary productivity. A number of studies have shown that the NDVI saturates at LAI of 3-4 [1], while LAI exceeds this for most closed-crown crops and forests. NDVI saturation under-estimates the fluxes of CO_2 and H_2O, and this error feeds back into other physiological processes. One of the key driving variables used by CASA and SiB-2 models is the flux of absorbed PAR, with gross CO_2 uptake, NPP, and canopy conductance all scaled to NDVI. In theory, absorptance of PAR is proportional to NDVI but because both saturate, most of the variability occurs at LAI values < 4. Canopies with a large variations in LAI also exhibit large differences in total photosynthetic capacity and the quantity of nitrogen and other nutrients in the canopy are incorrectly inferred from NDVI. Furthermore, maximum site LAI is often reached at an early stage of growth while non-photosynthetic components of biomass continue accumulation throughout the growing season. The biomass estimates saturate at relatively low levels of biomass, and cause NDVI to markedly under-estimate biomass in woody vegetation.

The accuracy of carbon model predictions in vegetation will improve by estimating canopy biophysical and leaf biochemical parameters using radiative transfer modeling [7]. An optical index of canopy water content derived from MODIS is evaluated through radiative transfer modeling. Linking PROSPECT [8], SAILH [9], and SPRINT [10] leaf and canopy models, the effects of LAI, water thickness, cellulose and lignin, and protein are modeled in R858.5/R1240 optical index calculated from MODIS bands 4 and 5. Core land validation sites of BOREAS SSA (boreal forest), Wisconsin NTL LTER (needle forest canopy), and ARM/CART-Ponca City (wheat canopy) were used.

II. MODELING R858.5/R1240 THROUGH PROSPECT, SAILH, and SPRINT RT MODELS

MODIS band 4 (R858.5, 35nm) and band 5 (R1240, 20nm) are used to build the optical index R858.5/R1240 as an indicator of canopy water content. Location of band 5, on the edge of the liquid water absorption band (Figure 1), and band 4 used for normalization and insensitive to water

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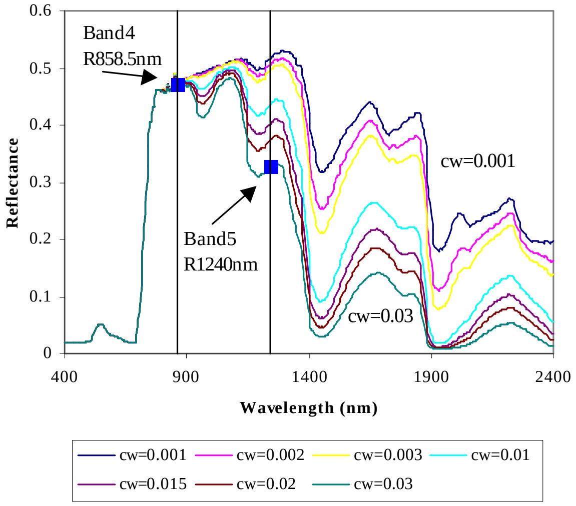

Figure 1. Modeling canopy-level reflectance using PROSPECT+SAILH models for different values of water thickness (cw=0.001 to cw=0.03) showing location of band 4 (R858.5nm) and 5 (R1240nm). PROSPECT parameters used are N=1.5, cp=0.0012 (g/cm^2), cc=0.002 (g/cm^2), and for SAILH LAI=5, plagiophile, θs=35°, θv=0°, ψ=0°.

content changes, make the index potentially suitable for global monitoring of canopy water content from MODIS. The optical index was studied through radiative transfer simulation to account for leaf cellulose, lignin and protein content, and canopy LAI variations (Figure 2). PROSPECT and SPRINT models were used to account for leaf and canopy variables in order to simulate forest canopy characteristics of MODIS core land validation sites such as Wisconsin and BOREAS SSA (boreal forest), and using PROSPECT and SAILH for ARM/CART-Ponca City (wheat canopy) simulations. Nominal canopy parameters used for simulating conifer sites with SPRINT were, tree density at 1100 trees/ha; ellipsoidal crown shape, height of trunk, 8.5 m; height of tree, 15 m; trunk radius, 8.3 cm; crown radius, 2.0 m; shoot area, 0.0008 m^2; canopy effective LAI=5; and leaf area density, 0.4171 /m. Figure 2 (top) shows R858.5/R1240 as a function of LAI and leaf water thickness (cw) for constant LAI=5, N=1.5, protein content (cp) = 0.0012 g/cm^2, and cellulose and lignin content (cc) = 0.002 g/cm^2. Moreover, it shows that the index does not saturate at high LAI as occurs with NDVI after LAI>4 (see Figure 2 (top) for comparison). The effects of variation in other leaf biochemical parameters such as cellulose and lignin, and protein was studied (Figure 2, bottom) as a function of LAI. High, medium and low values of such constituents were used in PROSPECT leaf simulations, varying LAI from 2 to 8. Constituents were changed from low to high over their normal range variation: water thickness (cw_low=0.001; cw_high=0.03), lignin and cellulose (cc_low=0.0004 g/cm^2, cc_high=0.008 g/cm^2), protein (cp_low=0.0002 g/cm^2; cp_high=0.002 g/cm^2), and medium values (cw=0.0155; cc=0.0042 g/cm^2; and cp=0.0011 g/cm^2) were used as inputs for the leaf reflectance simulation. PROSPECT was used as input for SAILH and SPRINT canopy reflectance models. Figure 2 (bottom) shows that water thickness are the main drivers of changes in R858.5/R1240 index (top and bottom boundaries), showing smaller effects due to cellulose and lignin, and protein variation, not saturating at high LAI values.

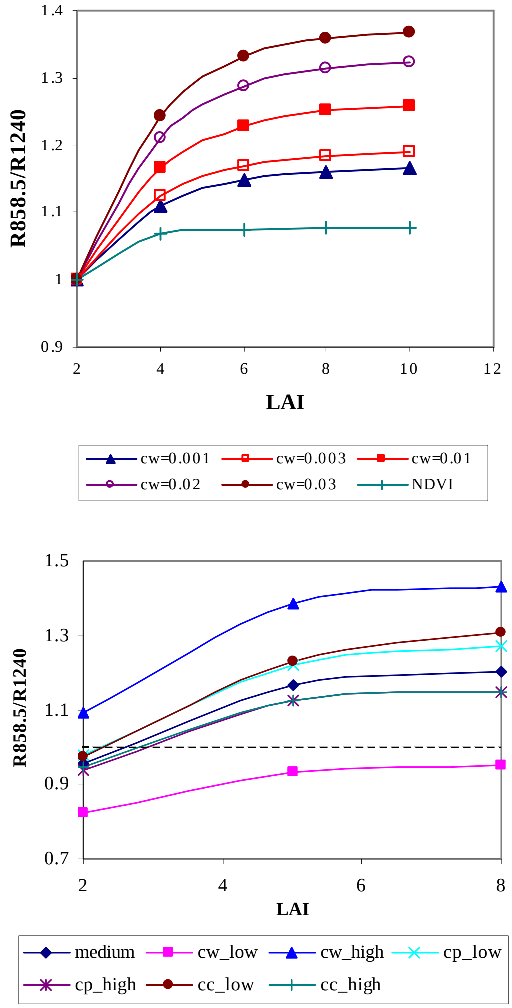

Figure 2. Modeling the effects of LAI (top), and leaf biochemical (cw, cp, cc) and canopy biophysical (LAI) parameters (bottom) in R858.5/R1240 optical index. PROSPECT+SAILH (for wheat) and PROSPECT+ SPRINT (for forest) were used for the simulation of leaf and canopy reflectance.

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III. RESULTS AT EOS LAND VALIDATION SITES

The index R858.5/R1240 was calculated from MODIS MOD09A1 surface reflectance product (500m spatial resolution) starting in June to December 2000. Eight-day composite MODIS surface reflectance data were reprojected from Integerized Sinusoidal ISIN projection, and reflectance extracted. Three core land validation sites were selected due to their different species composition and canopy structure: Wisconsin NTL LTER (-89.6°, 46°) and BOREAS SSA (-105.32°, 53.65°) (boreal forest), and ARM/CART-Ponca (-97.13°, 36.77°) (wheat canopy). Analysis of index variation at different phenological stages (Figure 3) is carried out through model inversion techniques accounting for leaf changes (N, cc, cw, and cp), and canopy structure (LAI) through radiative transfer.

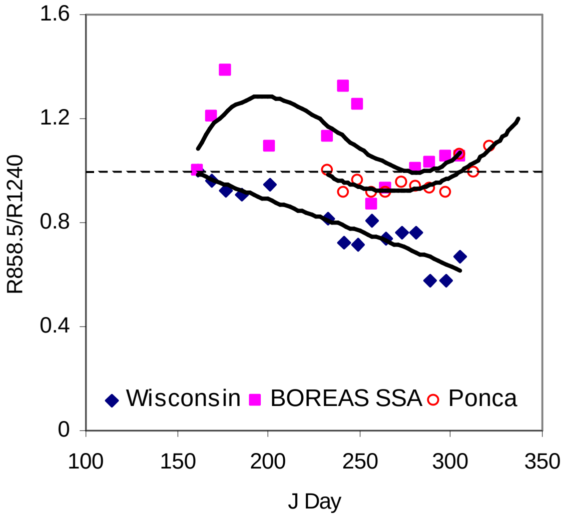

Figure 3. Optical index R858.5/R1240 calculated from MODIS data over Wisconsin (needle leaf forest), BOREAS SSA (boreal forest), and Ponca (wheat) core land validation sites (June-December 2000).

IV. CONCLUSIONS

Modeling methods indicate that R858.5/R1240 index from MODIS reflectance might be potentially used as indicators of canopy water content for global monitoring, and useful for carbon flux estimation. The index does not saturate at high LAI values, potentially improving carbon estimates using SiB2 and CASA models. This ongoing research aims to test carbon estimates from such biogeochemical models using current carbon flux data from the AmeriFlux network and the remotely sensed index discussed in this paper combined with radiative transfer modeling.

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