Regional Mapping of Gross Light-Use Efficiency Using MODIS Spectral Indices

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Introduction

- Estimates of gross primary productivity (GPP) are currently produced at the global scale using a simple light-use efficiency (LUE) approach with model inputs from the MODerate resolution Imaging Spectroradiometer (MODIS) and meteorological databases.
- The LUE model relates vegetation productivity, gross or net, to the amount of absorbed photosynthetically active radiation (APAR) and a LUE term, which describes the plant efficiency in using radiation to fix carbon through photosynthesis (e.g., gross LUE = GPP/APAR, in units of C per unit photons absorbed).
- However, errors in GPP estimates occur, in part, because of the difficulty in capturing the spatial and temporal variations in LUE. A combination of flux tower measurements with remote sensing data (e.g., MODIS) constitutes a potential means by which LUE estimates can be improved.
- Figure 1 shows the interannual variation in annual means of 30-minute periods of LUE (LUE_{30a}) for eight flux measurement sites in Saskatchewan. Figure 2 shows the interannual variation in annual means of three consecutive 30-minute periods of LUE (LUE_{90a}) concomittent with clear MODIS observations of the flux towers.
- In these figures, each site is associated with its MODIS land cover class, which is currently used in the MODIS GPP algorithm: Evergreen Needleleaf Forests (ENF), Mixed Forests (MF), and Open shrublands (Oshrub). Also shown are biome-specific maximum LUE values used in the MODIS GPP algorithm.

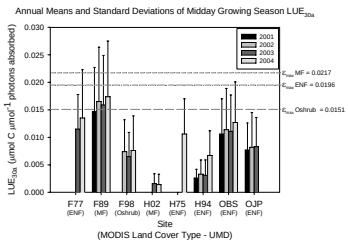

Figure 1. Annual means and standard deviations of 30-minute periods of growing season midday LUE (LUE_{30a}) for eight flux tower sites. F77, F89, and F98 are forest stands that burned in 1977, 1989, and 1998, respectively. H75, H94, and H02 are jack pine sites *(Pinus banksiana)* harvested in 1975, 1994, and 2002, respectively. OBS and OJP are mature black spruce (*Picea mariana*) and jack pine sites, respectively

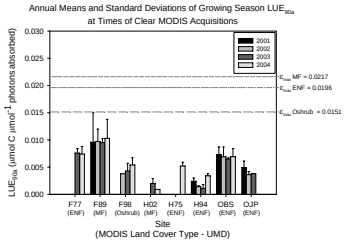

Figure 2. Annual means and standard deviations of growing season 90-minute LUE (LUE_{90a}) at times of clear MODIS overpasses.

Analyses

- Figures 1 and 2 above show that, when averaged over the growing season, the variability in tower LUE is greater between sites than between years at a given site. Moreover, annual means and variability of LUE are significantly reduced when only data at times of MODIS overpasses are used (LUE_{90a}) , suggesting that the use of satellite optical remote sensing data to monitor LUE will be limited to only a small range of minimum LUE values.
- For clear MODIS observations, surface reflectance data were extracted for pixels (1 km^2) corresponding to the tower locations and spectral indices were calculated.
- The Photochemical Reflectance Index (PRI), a physiologically-based index related to LUE, was calculated using:

  -a detection band centered at 531 nm (ρ_{531})

  -three reference bands (ρ_{ref}): 488, 551, 678 nm

$$PRI = (\rho_{531} - \rho_{ref})/(\rho_{531} + \rho_{ref})$$

- The normalized-difference vegetation index (NDVI) was also computed as a comparison.

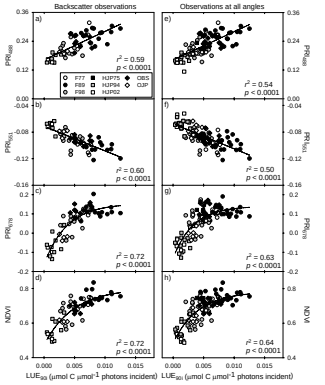

Figure 3. Relationships between MODIS indices and averages of three 30-minute periods of LUE (LUE_{90a}) centered on the time of the satellite overpass, using only MODIS observations closer to the backscatter direction (a-d) and using all observations (e-h).

- Figure 3 shows the relationships between the different PRIs and NDVI, and tower LUE calculated from averages of three 30-minute periods of flux measurements and incident radiation, because of the uncertainties associated with the f_{APAR} estimates.
- While these relationships do not allow us to detect variations in LUE for specific sites, they do allow the detection of between-site differences in LUE at the regional scale. The relationships are improved when only MODIS data closer to the backscatter direction are used.
- The models using PRI_{678} and NDVI are similar, suggesting that variations in PRI_{678} are likely due to changes in the reference band (red band), reflecting variations in canopy chlorophyll content.
- Figure 4a shows the three land cover classes corrresponding to three maximum LUE values of the current MODIS algorithm that would be scaled-down, using a limited set of environmental variables, for estimating LUE.
- Our model using PRI_{551} was used to derive a map of LUE for the same region as Fig. 4a. This figure demonstrates the greater spatial variability of LUE (Fig. 4b) compared to the MODIS GPP approach.

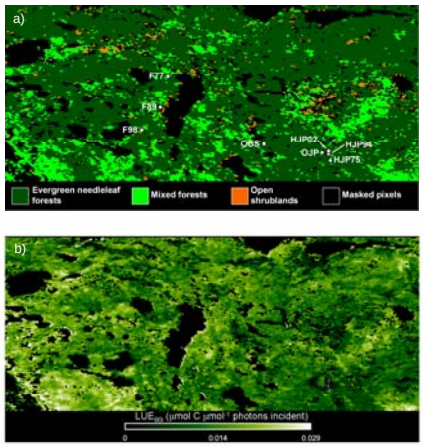

Figure 4. a) MODIS land cover classification (MOD12Q1) for a region encompassing the eight flux tower sites. b) LUE_{90} map derived from the model using PRI_{551}, for day 215 of 2001. All pixels classified as water or other land cover classes than those used in the study were masked.

- One of our hypotheses was that differences in PRIs across the flux tower sites resulted from differences in the relative amounts of canopy shadow fraction between the different canopies.
- To test this hypothesis, we used a geometric-optical canopy model (5-scale) to estimate the relative amount of shaded canopy fraction for every MODIS tower pixel.
- Figure 5 shows that the pixels with higher shaded canopy fractions are associated with higher PRIs (or lower, depending on the formulation of the PRI).
- Pixels with higher shaded canopy fractions correspond to the more developed canopies (i.e., more dense). They also correspond to the canopies with higher LUE.

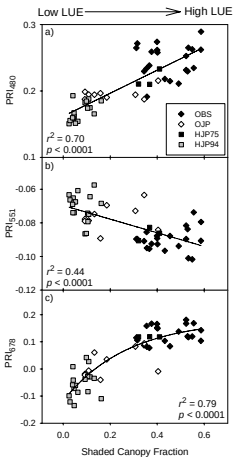

Figure 5. Relationships between three formulations of the PRI from MODIS and pixel shaded canopy fraction estimated using 5-scale.

Conclusions

- The use of data from the MODIS sensor for estimating LUE is restricted to only those observations where LUE variability is low and values are at minima. This is a result of the low LUE values that occur around midday on clear days.
- At the regional scale, relationships between different formulations of the PRI derived from MODIS reflectance data, and tower LUE, allowed the detection of inter-site variations in LUE. However, it did not allow the detection of within-site temporal variations in LUE. This can be due to such factors as:
  1. Variations in pixel footprint size and locations, and hence in pixel spectral composition;
  2. Use of different reference bands than the one used previously in PRI studies (i.e., 570 nm) because this band is not on the MODIS sensor;
  3. Variations in viewing and illumination conditions between MODIS observations and the quality of the atmospheric correction of reflectance data;
  4. Calculation of tower LUE: Other studies showed that the relationship between productivity and LUE is increased when the fraction of PAR absorbed (f_{APAR}) by the chlorophyll is used, compared to when using total canopy f_{APAR} in calculating LUE.
- Between-site variations in PRI and LUE are related to the relative proportions of pixel shaded canopy fraction as this allows remote sensing- based estimates of LUE at regional, and possibly global, scales.

Pertinence to Fluxnet-Canada Objectives

The research activities presented here are aimed at improving our understanding of the long-term and combined effects of climate change and disturbances such as fire and logging on canadian forest productivity.

To achieve these goals, long term records of LUE derived from ecosystem fluxes made at several flux towers representative of various forest ecosystems are combined in a unique way with multi-temporal spectral data from Earth-orbiting satellite platforms.

The synergy between flux tower measurements and remote sensing data represents a unique means by which we will improve our estimates of the total potential for carbon uptake, emission and sequestration by Canadian forests and wetlands on regional and national scales.

This research was supported by: NSERC, CFCAS, Biocap, Environment Canada and NASA.