Monitoring Net Carbon Exchange over Agricultural Landscapes with a Remote Sensing-Based Model

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Introduction

New generation carbon-flux-monitoring campaigns are recognizing the need to establish connectivity between intensive surface observations, typically collected at a point or a distributed set of points, by placing them within a regional context using modeling supported by remote sensing. The North American Carbon Program (NACP), for example is adopting a multi-tiered sampling scheme, where general surface biophysical and land-use properties will be monitored over continental scales using remote sensing, with more intensive sampling of carbon stores and fluxes occurring on the ground at sites selected to represent the endemic range in spatial variability. Large-scale carbon flux networks, such as AmeriFlux and EuroFlux, will require robust methodologies for upscaling and integrating observations made at individual towers to be able to draw regional inferences regarding terrestrial carbon cycles.

Here we describe a nested remote sensing scheme, designed for mapping surface water, energy, and carbon flux distributions at spatial resolutions from 10^0-10^4m, which incorporates an analytical light-use efficiency (LUE) sub-module for modeling bulk canopy conductance and carbon uptake. Preliminary studies show that the LUE module performs well in the context of a two-source thermal remote-sensing model, using surface temperature information as a means to detect vegetation stress and simulate stomatal closure.

Model Description

The LUE sub-module was distilled out of a more detailed soil-plant-atmosphere model (Cupid; Norman and Polley, 1989) for purposes of practical application, and has been demonstrated to provide good predictions of coupled transpiration and carbon assimilation fluxes using only a modest amount of input data (Anderson et al., 2000).

Instead of using a scaled numerical solution to several leaf-level photosynthetic equations, canopy resistance is computed using a second-order analytical expression parameterized in terms of the canopy LUE and the absorbed photosynthetically active radiation (APAR). This analytical solution agrees well with numerical solutions, but is computationally more efficient and stable and uses fewer tunable parameters. And since it is tied to a stand-level measurement – the canopy LUE – the solutions are constrained to lie within the realms of observation.

The LUE module obtains required information about vegetation temperature and in-canopy humidity in iteration with a land-surface energy balance model. The form and boundary conditions of the model used depend on the intended scale of application, but all forms share a common two-source (plant+soil) surface representation. The Atmosphere-Land Exchange (ALEX; Anderson et al, 2000) model, used for local-scale applications, incorporates a multi-layer numerical soil model (Fig 1).

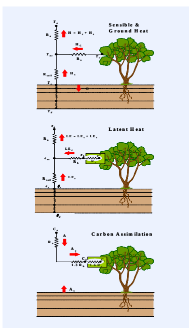

Figure 1: Schematic diagram of LUE canopy resistance sub-module as embedded in the ALEX surface energy balance model.

Local-Scale Validation

The effective LUE diagnosed by the analytical model is typically near the nominal stand-level measurement (an input parameter, indexed by vegetation class), but responds to varying environmental conditions in humidity, temperature (ambient and leaf), wind speed, and CO2 concentration through a system of micrometeorological flux-gradient equations. Stomatal closure in response to water stress and extreme temperatures is simulated through incorporation of empirical stress functions

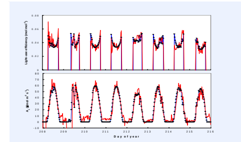

Figure 2: A time-course of measurements of effective light-use efficiency and carbon assimilation (A_C) measurements made in corn over eight consecutive days (red). Also plotted are simulated values of LUE and *Ac* generated by the ALEX model (blue).

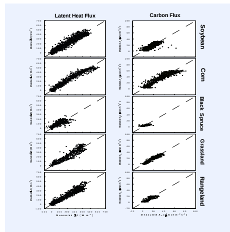

Figure 3: Comparison of hourly measurements of system latent heating and canopy carbon assimilation made in five different vegetative stands with estimates generated by the ALEX model.

Light-use efficiency is also known to depend on light composition (diffuse vs. direct beam fractions); LUE increases under more diffuse lighting conditions, where light is more uniformly and efficiently distributed over the canopy leaf area. When this behavior is incorporated using a linear function of diffuse PAR fraction, the analytical model reproduces subtle diurnal variations in LUE, including enhancement at dusk and dawn when lighting is more diffuse (Anderson et al., 2000; see Fig. 2).

Hourly and daily estimates of evapotranspiration and carbon assimilation from the ALEX model agree well (to within 15%) with micrometeorological measurements made in six different vegetative stands (see Fig. 3). This accuracy is comparable to the 10-20% instrumental variation typically associated with micrometerological flux measurements.

Remote-Sensing Applications

Over larger spatial scales, the detailed soil profile information needed by ALEX will not generally be available. Norman et al. (1995) developed a remote-sensing version of the two-source energy balance model (TSEB; Fig. 4), in which lower boundary conditions in surface temperature are prescribed by thermal infrared imagery. The model partitions surface temperature and fluxes into soil and canopy contributions given an estimate of the fractional vegetation cover within the scene. For application at large scales (5-10km), the TSEB is coupled with an atmosphere boundary layer (ABL) model to form the Atmosphere-Land Exchange Inverse (ALEXI; Anderson et al, 1997) model. ALEXI fluxes can be disaggregated to finer scales using high-resolution thermal and visible/NIR imagery (DisALEXI; Norman et al, 2003).

The LUE module can be embedded within the TSEB to predict canopy transpiration and assimilation fluxes, while the soil evaporation flux is computed as a residual to the system energy budget.

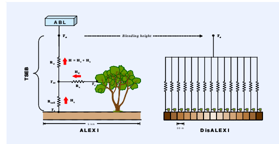

Figure 4: Schematic diagram representing the coupled ALEXI/DisALEXI modeling scheme, built around the TSEB land-surface representation.

Comparison with Aircraft Fluxes

The LUE module as implemented in the ALEXI/DisALEXI remote sensing framework has been tested using tower and aircraft data collected during SGP97 over rangeland, wheat and bare soil, and preliminary results are promising.

Figure 5 shows a 24-m resolution map of net ecosystem CO2 exchange (canopy assimilation + soil respiration) on 2 July 1997 near El Reno, OK, generated with the coupled DisALEXI – LUE model. Soil respiration was estimated using an empirical relationship depending on soil temperature and moisture content and leaf area index.

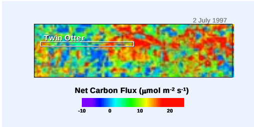

Figure 5: Map of net carbon flux over El Reno study area during SGP97. Twin Otter transect is demarcated.

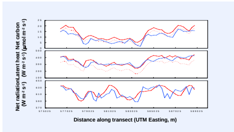

Figure 6: Profiles of modeled (blue) and measured (red) net carbon flux, latent heating, and net radiation. Dotted red lines are original data, solid red show fluxes with forced energy budget closure (carbon corrected by same % as latent heat).

The subregion demarcated in Fig. 5 was overflown several times on 2 July by a Twin Otter aircraft, sampling carbon and energy fluxes along a 10-km transect at a height of 35 m. These fluxes have been segmented into 250-m partitions, and are compared in Fig. 6 with net flux estimates from DisALEXI, averaged over the aircraft footprint as estimated by a stability-corrected form of an analytical footprint model. DisALEXI picks up the large scale trends well, including the depression in carbon fluxes over the senescent wheat and bare fields near the center of transect.

Conclusions

A scalable (10^0-10^4m resolution) remote-sensing-based carbon, energy, and water flux mapping technique has been described, suitable for routine monitoring applications. This technique utilizes a simple analytical model for estimating canopy resistance based on stand-level measurements of canopy LUE. Model predictions of latent heating and net carbon flux compare well with measurements acquired with towers and aircraft over a variety of landcover conditions. Further validation will be conducted in comparison with tower and aircraft CO_2 flux measurements collected during SMEX02 and as part of SMEX05 and the Mid-Continent Intensive Campaign of the NACP.

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