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Assimilating LANDSAT data in an ecosystem model for multi-year simulation of grassland carbon, water and energy budget

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ABSRACT

In this study, a spatially explicit hydro-ecological model (SEHEM) has been developed and validated over a semi-arid grassland sub-watershed in Arizona. The model combines a plant growth sub-model to simulate the seasonal dynamics of root and aboveground biomass, and a hydrological sub-model to simulate soil moisture and temperature dynamics, energy and water budgets for the soil and the vegetation. In addition, the model has been coupled to radiative transfer models (RTMs) in the visible, near infrared and thermal infrared (TIR) bands so that canopy reflectance and directional radiative surface temperature are simulated. Landsat Thematic Mapper (TM) images obtained during a six year period were used to adjust some spatially variable model parameters by minimizing the difference between model simulations and remotely sensed data. Comparisons between observations and model estimates of above ground biomass, net radiation, sensible and latent heat flux, component temperatures are presented.

Keywords: plant growth and hydrological model, grassland, assimilation, radiometric data.

INTRODUCTION

Accurate description of surface processes and their interactions is crucial for the interpretation of consequences of natural and human induced changes in terms of impacts on natural resources. Simulation models are powerful tools for providing much-needed insights on the interactions between terrestrial ecosystems and the atmosphere. However, to provide meaningful outputs or products, these models need to meet two requirements: a) the important processes should be described with a balanced accuracy and complexity, and b) the impact of surface heterogeneity should be taken into account. Unfortunately these two requirements are not always respected in many existing models. It is common to find a model where, for example, the turbulent processes are represented in a sophisticated manner but the photosynthesis and plant growth processes are described in a very crude manner; or the radiative transfer is described in a sophisticated manner in the visible and near infrared, but crudely in thermal infrared bands.

In most ecosystems, soil and vegetation characteristics exhibit a large spatial and temporal variability, which greatly influences the partitioning of available energy into sensible and latent heat flux, and the partitioning of precipitation into runoff and infiltration. In such heterogeneous landscapes, model application has often been hampered by the inability to provide the complete set of required model parameters or initial conditions. In this regard, a promising way to overcome these difficulties is to use satellite data to derive fields of spatially-unknown surface characteristics and/or calibration parameters by minimizing the difference between the space-time radiometric behavior measured by the satellite-based sensor and simulated by the ecosystem model, combined with adequate radiative transfer models (RTMs). Using time series of TM and ETM+ images, this approach has been successfully used to refine a daily time-step short-grass ecosystem model to work on a spatially distributed basis over a semi-arid grassland watershed in Arizona, the Walnut Gulch Experimental Watershed (WGEW), to produce multi-year simulations of plant growth, water and carbon budget [1]. Here, these previous results are extended using a refined version of this model, designed to simulate both the diurnal and the multi-annual pattern of relevant hydro- and eco-physiological grassland processes. This Spatially Explicit Hydro-Ecological Model (SEHEM) describes radiative transfer processes in both the visible and thermal domain and was applied and calibrated over the WGEW using a 6-year time series of TM images. The first validation results obtained for one site within the WGEW are presented.

THE SEHEM MODEL

The SEHEM model is derived from both the daily time-step plant growth/water budget model described in [2], and the hourly time step hydrological model described in [3]. The model also includes visible and thermal RTMs (described in [4] and [5] respectively). The model is driven by hourly meteorological data and simulates latent and sensible heat

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fluxes, soil water content, biomass dynamics of green shoots, dead shoots and living root biomass, component temperatures and multi-spectral reflectance. The different sub-models interact with each other through information exchanges. For example, the hydrological sub-model (HM) parameterizes stomatal and aerodynamic resistances from the plant area index (PAI) computed in the plant growth sub-model (PGM). PAI is used by the RTMs to compute radiometric temperature and reflectance, shortwave, longwave and total net radiation for the soil and the canopy (Rns and Rnc), and the fraction of the photosynthetically active radiation absorbed by the canopy (fAPAR). In the HM, Rns and Rnc are used to compute plant transpiration and soil evaporation, leaf and soil temperatures. In turn, leaf temperature, stomatal conductance and fAPAR are used in the PGM to estimate gross photosynthesis and aboveground plant respiration.

Hydrological sub-model

In the HM [3], soil and vegetation are treated as two separate sources of latent and sensible heat, following the one-dimensional, two-layer Shuttleworth and Wallace approach. An energy budget is computed separately for both components. The soil water content and temperature are determined using the force-restore method. Compared to the previous version of HM [3], the main improvements were a more realistic description of soil and vegetation contribution to net radiation through RTMs in the visible and TIR domains; and the parameterization of stomatal conductance from solar incoming radiation, and leaf water potential. This latter is estimated iteratively assuming that hourly root water uptake equals hourly transpiration.

Plant growth sub-model

The main processes simulated in the PGM [2] are photosynthesis, photosynthate partitioning between aerial and below-ground compartments, translocation of carbohydrates from roots to shoots during the regrowth period, respiration and senescense. Gross photosynthesis is expressed as a function of (1) fAPAR, (2) a maximum energy conversion efficiency (ε_{bmax}) and (3) the depressive effects of sub-optimal leaf temperature, water stress and leaf aging. Water stress is a function of canopy stomatal resistance and mesophyll resistance to CO2 diffusion.

Radiative transfer models

Canopy structure impacts radiative transfers in both visible and thermal domains. In the two RTMs, the canopy structure was described using the same set of equations and parameters. This common set of parameters (obtained from [6]) includes those used in the leaf and stem angle distribution function (LSAD), and those used to describe the angular course of a leaf dispersion parameter (Markov parameter) which accounts for canopy clumping. The thermal RTM [5] is a probability (turbid-medium model) that computes the directional canopy radiance as a function of sensor view angle and leaf and soil temperatures. In the visible RTM [4], leaf optical properties are computed from the PROSPECT model [7]. In our study, pixel surface reflectance in the red and NIR bands were simulated for each Landsat TM overpass, using the same geometric configurations (sun/view zenith angles) as the TM sensor at the time of the measurements.

STUDY AREA AND DATA DESCRIPTION

The model was applied over the WGEW (150 km^2) within the San Pedro Basin, Southeast Arizona. A digital vegetation map was used to select the grassland areas. These grasslands are dominated by perennial C4 grasses whose dominant species are grama species (*Bouteloua spp.*).

Since June 1990, the Kendall site, central to the grassland area, has been instrumented by ARS to provide continuous hourly measurements of local meteorological conditions, sensible, latent and soil heat fluxes, and net radiation. Additionally, bi-monthly measurements of aboveground biomass were obtained from 1990 through 1992. Over the period covered by simulations (June 1990 through December 1995), two to three clear images were acquired for each summer growing season (approximately three months), and atmospherically corrected.

MODEL APPLICATION AND CALIBRATION

Lists of model parameters are provided in [2] and [3]. Several parameters of the HM are derived from soil texture properties, that were provided from a 30 m resolution digital soil maps. PROSPECT's model parameters were estimated from model inversion against published data of leaf reflectance and transmittance. In the PGM, one parameter (ε_{bmax}), and one initial condition, the initial root biomass (BR_{ini}) need to be calibrated. From June 1990 through December 1995, continuous simulations were performed using Kendall site meteorological data. Maps of calibrated ε_{bmax}, and BRini were obtained using the procedure described in [1], which is based on an iterative procedure which minimizes the difference between NDVI derived from TM images and simulated NDVI.

RESULTS

Model predictions of seasonal and inter-annual above-ground biomass compared well with measurements over the Kendall site, where data were available (Fig. 1). This result could have been expected since the calibrated parameters control directly the plant growth model. Model estimates of net radiation, sensible and latent heat fluxes were compared to data collected over the same site during Monsoon'90 Experiment (Fig. 2). The predicted values compared very well to the observation. The Root Mean Square Errors (RMSE) between measured and simulated fluxes were within the range of experimental errors (40 W/m^2). Similarly, model estimates of component surface temperature (e.g. soil and vegetation) were compared to the observations (Fig. 3). The model seemed to accurately reproduce the observed temperatures. The fact that the model performed well in estimating both the surface fluxes and the component temperature, suggests that the model partitioning of energy fluxes between the soil and the vegetation was correctly done.

DISCUSSION

In this study, a spatially explicit hydro-ecological model (SEHEM) has been presented. This model has been applied to a grassland sub-watershed in Arizona. LANDSAT images collected during a 6-year period has been used to spatially calibrate the model. The results indicated the model correctly described the observed spatio-temporal variations of biomass production. Additionally, model estimates of surface fluxes and temperatures compared equally well with the observations over the Kendall site during Monson'90 experiment. This is of interest since the satellite based TIR data could also be used as additional information for model's calibration and refinement. Ongoing work is directed toward the use of TM-based TIR data to calibrate and validate model estimates of spatial and temporal variability of radiative surface temperature, which is a good indication of the variability of surface energy balance. We are now in the process of correcting TIR data from atmospheric effects and gathering a spatially distributed field of meteorological forcing parameters using a dense raingage network and meso-scale model's outputs (RAMS).

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REFERENCES

[1] Nouvellon, Y., Moran, M.S., Lo Seen, D., Bryant, R.B., Rambal, S., Ni, W., Bégué, A., Chehbouni, A.G., Emmerich, W. B., Heilman, P., and Qi, J., 2000. Combining a grassland ecosystem model with Landsat TM imagery for a ten-year simulation of carbon and water budget. Remote Sens. Environ., (unpublished).

[2] Nouvellon, Y., Rambal, S., Lo Seen, D., Moran, M. S., Lhomme, J.P., Bégué, A., Chehbouni, A.G. and Kerr, Y., 2000. Modelling of daily fluxes of water and carbon from shortgrass steppes, *Agricultural and Forest Meteorology*, 100: 137-153.

[3] Lo Seen, D., Chehbouni, A., Njoku, E., Saatchi, S., Mougin, E. and Monteny, B., 1997. An approach to couple vegetation functioning and soil-vegetation-atmosphere-transfer models for semiarid grasslands during the HAPEX-Sahel experiment. Agricultural and Forest Meteorology, 83: 49-74.

[4] Kuusk, 1995. A Markov chain model of canopy reflectance. Agric. For. Meteorol., 76: 221-236.

[5] Prévot, L., 1985. Modélisation des échanges radiatifs au sein des couverts végétaux, application à la télédétection. Validation sur un couvert de mais. PhD thesis, Université Paris VI, 178pp.

[6] Nouvellon, Y., Bégué, A., Moran, M.S., Lo Seen, D., Rambal, S., Luquet, D., Chehbouni, A.G. and Inoue, Y., 1999. PAR extinction in shortgrass-ecosystems: Effects of clumping, sky conditions and soil albedo. *Agricultural and Forest Meteorology* (in press).

[7] Jacquemoud, S. and Baret, F., 1990. PROSPECT : A model of leaf optical properties spectra. Remote Sens. Environ., 34 :75-91.

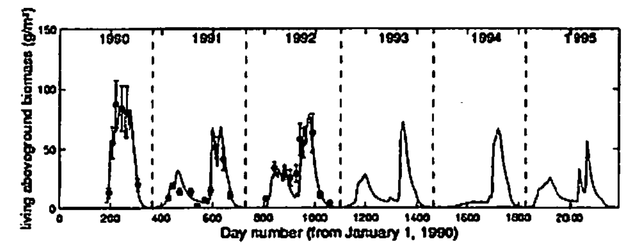

Figure 1: Comparison of simulated (circle) and measured (continuous lines) aboveground biomass at the Kendall site.

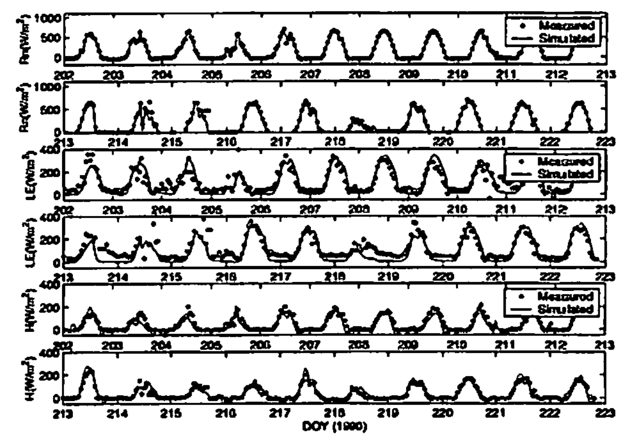

Figure 2: Comparison of simulated and measured net radiation (a and b), latent heat fluxes (c and d), and sensible heat fluxes (e and f) at the Kendall site from DOY 202 through 223, 1990.

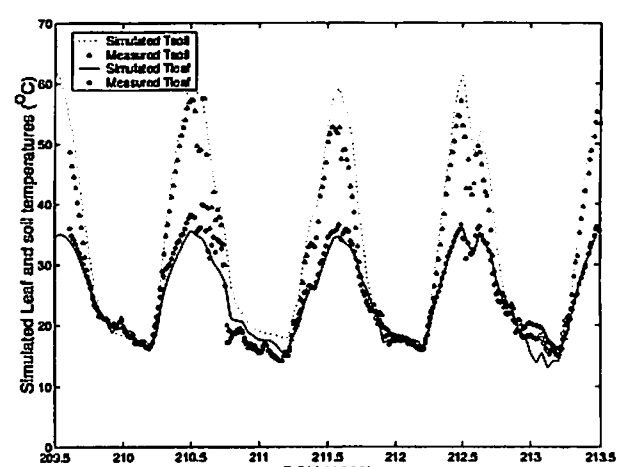

Figure 3: Comparison between measured and simulated components temperatures (leaf and soil), at the Kendall site from DOY 209 through 213, 1990.