The Impact of Land Cover Change on Surface Energy and Water Balance in Mato Grosso, Brazil

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ABSTRACT: The sensitivity of surface energy and water fluxes to recent land cover changes is simulated for a small region in northern Mato Grosso, Brazil. The Simple Biosphere Model (SiB2) is used, driven by biophysical parameters derived from the Moderate Resolution Imaging Spectroradiometer (MODIS) at 250-m resolution, to compare the effects of different land conversion types. The mechanisms through which changes in vegetation alter surface fluxes of energy, momentum, water, and carbon are analyzed for both wet and dry seasons. It is found that morphological changes contribute to warming and drying of the atmosphere while physiological changes, particularly those associated with a plant's photosynthetic pathway, counterbalance or exacerbate the warming depending on the type of conversion and the season. Furthermore, this study's results indicate that initial clearing of evergreen and transition forest to bare ground increases canopy temperature by up to 1.7°C. For subsequent land use such as pasture or cropland, the largest effect is seen for the conversion of evergreen forest to C3 cropland during the wet season, with a 21% decrease of the latent heat flux and 0.4°C increase in canopy temperature. The secondary conversion of pasture to cropland resulted in slight warming and drying during the wet season driven mostly by the change in carbon pathway from C4 to C3. For all conversions types, the daily temperature range is amplified, suggesting that plants replacing forest clearing require more temperature tolerance than the trees they replace. The results illustrate that the effect of deforestation on climate depends not only on the overall extent of clearing but also on the subsequent land use type.

KEYWORDS: Land cover change; Surface climate; Amazon; Deforestation

1. Introduction

Most of the deforestation in the Amazon has occurred in the transitional areas between moist tropical forest and drier, more seasonal cerrado (Alves 2002). The cerrado, a type of savanna–woodland (Klink et al. 1995; Miranda et al. 1997), is Brazil's second largest biome covering an area of approximately 2 million km^2. Cattle ranching has been the traditional form of land use following deforestation. More than 50% of the cerrado's primary vegetation has been transformed within recent decades (Klink and Machado 2005). In the last few years, commercial cropland has extended into the transition forest zone between cerrado and moist tropical forest (Morton et al. 2005a; Morton et al. 2005b). These new types of land cover transformations potentially affect climate through altered exchanges of water, energy, and momentum compared with traditional conversion to pasture (Klink et al. 1993).

Vegetation affects climate through distinct mechanisms. Its morphological structure alters the turbulent transfer of energy through roughness elements. Its optical properties alter the net solar radiation absorbed by the canopy and its physiological activity controls the partitioning of the incoming energy into turbulent fluxes. The impact of land cover change on climate has been explored in previous studies (e.g., Dickinson and Kennedy 1992; Zhang et al. 1996; Collatz et al. 2000; Costa and Foley 2000; Bounoua et al. 2002; Zhao and Pitman 2002; Nobre et al. 2004). While these studies focused on large-scale tropical deforestation, few have explicitly assessed the mechanisms through which changes in vegetation affect energy and water balance for specific land cover changes occurring in the transition zone where deforestation is most rapid.

In this paper, we analyze the mechanisms through which vegetation affects local energy and water balance by examining the interactions of morphological and physiological aspects of vegetation and comparing their effects on energy and water balance for different conversion types. We pay particular attention to land cover change occurring in the transitional areas between cerrado and tropical rain forest, including the conversion of tropical moist forest and seasonal transition forest to cattle pasture or cropland as well as the secondary transition of pasture to cropland.

2. Model and data

2.1. Study area

The study area is a region of approximately 45 000 km^2 in the north-central state of Mato Grosso (10.0°–13.0°S, 56.0°–54.5°W) undergoing rapid transformation from forest and cerrado vegetation types to cattle pasture and cropland. The region is located at the current agricultural frontier, a zone known as the "arc of deforestation." During the study period (2000–2003), Mato Grosso had the highest annual deforestation rate of any state in the Brazilian Amazon (www.obt.inpe.br/prodes). Historically, land has been cleared for cattle ranching. More recently, cash crops such as soybeans, corn, cotton, and sugarcane have been planted on lands previously cleared for pasture or in areas deforested specifically for cropland expansion. Substantial portions of the remaining forest and cerrado in the study area have high potential for future transformation (Jasinski et al. 2005).

The study region covers the transition zone from Amazon rainforest to cerrado, a complex mosaic of woody savanna, woodlands, and tropical forest. Roughly 50% of the study area was classified as transitional tropical forest in 2000 (Morton et al. 2005a; Figure 1). Transition forests are composed of both cerrado and Amazon tree species. Their leaf area index (LAI) values range between 4 and 5 depending on the season (Vourlitis et al. 2001; Priante-Filho et al. 2004). Canopy heights for transition forest in the study area are highly variable, ranging from 12–15 m on poor soils or steep slopes to 30 m in sites with higher soil moisture availability (Vourlitis et al. 2001).

Figure 1 shows changes in land cover that occurred during the three years documented in this study. According to Morton et al. (Morton et al. 2005a), about

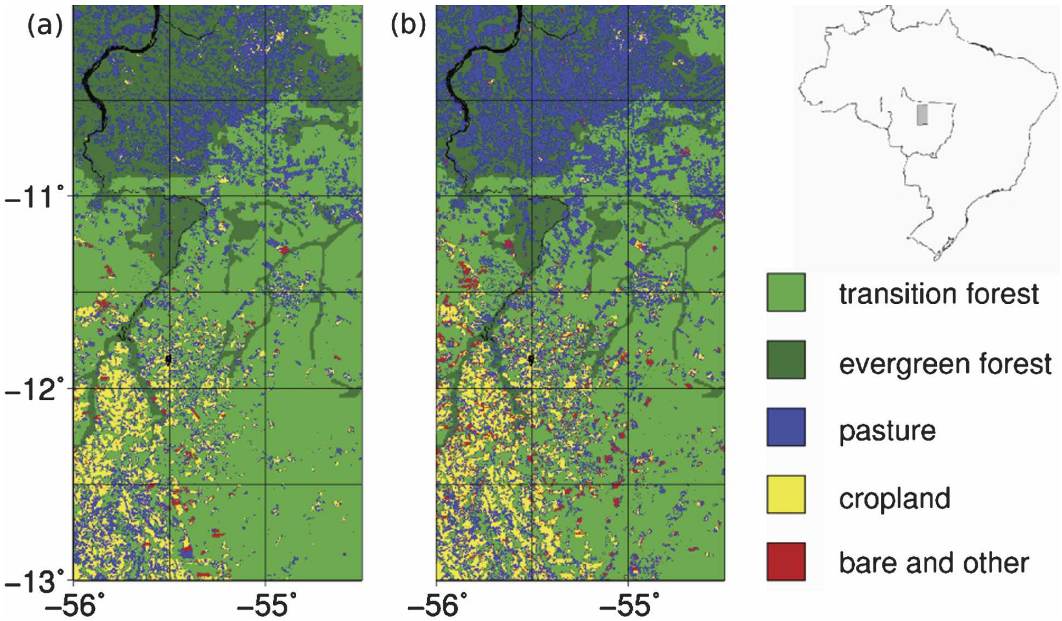

Figure 1. Land cover change over the study area for (a) 2000/01 and (b) 2002/03.

30% of the area of evergreen forest and 10% of transition forest were converted to pasture. Subsequently, areas of pasture were converted to cropland. Cropland occupied about 8% of the study area in 2000/01 and 9% in 2002/03. About one-third of the cropland expansion occurred through conversion of evergreen or transition forests to cropland with the remainder through secondary transition from pasture. The primary crop during the wet season is soybean, evident in satellite data by its distinct reflective spectrum and high seasonality. A secondary planting practice often bridges the wet and dry seasons. Crop selection is variable and includes millet, sorghum, rice, and corn.

2.2. Model

We use the Simple Biosphere Model (SiB2) of Sellers et al. (Sellers et al. 1996a; Sellers et al. 1996b) to assess the effect of changes in vegetation on local energy and water balance. SiB2 is a biophysically based land surface model that computes the exchanges of energy, water, momentum, and carbon between the biosphere and atmosphere accounting explicitly for 12 vegetation types. Time-varying parameters describing the vegetation phenology are derived from satellite data. SiB2 also accounts for hydraulic and thermal properties of different soil types to describe base flow and interlayer water exchange in the hydrological submodel. The prognostic variables in the model are canopy, surface, and deep soil temperatures; canopy and ground interception stores; soil moisture content in three soil layers; and canopy resistance to water vapor.

SiB2 includes a coupled photosynthesis–conductance submodel to simulate the simultaneous exchange of carbon and water vapor in and out of the leaf. Carbon assimilation is calculated from the fraction of photosynthetically active radiation (FPAR) constrained by light limitation, local environmental conditions, or maximum photosynthetic capacity ($V_{\max}$). Here $V_{\max}$ is a leaf-scale vegetation-dependent parameter (Table 1) that is modulated by water and temperature stress and enters the calculation of assimilation in different ways for C3 and C4 photosynthesis (Sellers et al. 1996a). The C4 leaf structure and physiology result in elevated CO_2 concentration at the sites of photosynthetic carboxylation compared to C3 plants. For given environmental conditions, C4 plants are capable of a higher photosynthetic rate even with lower values of $V_{\max}$ (Collatz et al. 1992). The canopy-integrated net carbon assimilation rate (A_c) is coupled to canopy stomatal conductance (g_c) as

$$g_c = m \frac{A_c}{c_S} h_S p + b L_T, \tag{1}$$

where p is the atmospheric pressure and L_T is the total leaf area index; m and b, the stomatal slope factor and minimum stomatal conductance, are vegetation-type dependent parameters that differentiate between C3 and C4 vegetation; c_S is the CO_2 partial pressure; and h_S is the relative humidity. While the control of atmospheric humidity on stomatal conductance is explicit through h_S, the effects of temperature and soil moisture stresses are implicit in A_c (Bounoua et al. 2004).

The model uses a two-stream approximation to compute surface albedo from soil and canopy reflectance. Fluxes of heat and water are calculated from the potential differences of temperature and vapor pressure and from aerodynamic resistances that depend on the roughness length. Therefore, a change in vegetation virtually affects all components of energy and water balance.

SiB2 can either be run coupled to a general circulation model (GCM) where the atmospheric data are made available by the GCM or it can be used in a stand-alone mode where climate drivers are fed to the land surface model from observations.

Table 1. Changes in aerodynamic conditions (roughness length for maximum LAI z_0, in m), physiology (carbon pathway, and maximum photosynthetic capacity $V_{\max}$, in μmol m^{-2} s^{-1}), and phenology for land cover conversion types. Also given are the number of points used for the area average of each conversion type. Types of land cover are denoted as follows: ft = transition forest, fe = evergreen forest, pa = pasture, cr = cropland, and bg = bare ground.

		Aerodynamic conditions	Physiology		Phenology
Conversion	No.	z_0	Carbon pathway	$V_{\max}$	NDVI, FPAR, LAI
ft → pa	47 416	0.90 → 0.13	C3 → C4	100 → 30	Constantly high → seasonal variation
fe → pa	57 698	2.56 → 0.13	C3 → C4	100 → 30	Constantly high → seasonal variation
ft → cr	9041	0.90 → 0.13	C3 → C3/C4	100 → 100/30	Constantly high → strong seasonal variation
fe → cr	299	2.56 → 0.13	C3 → C3/C4	100 → 100/30	Constantly high → strong seasonal variation
pa → cr	16 654	0.13 → 0.13	C4 → C3/C4	30 → 100/30	Seasonal variation → strong seasonal variation
ft → bg	11 772	0.90 → 0.07	C3 → C3	100 → 60	Constantly high → constantly low
fe → bg	1064	2.56 → 0.07	C3 → C3	100 → 60	Constantly high → constantly low

In this study, the offline mode is chosen with the same atmospheric forcing for all simulations. Thus, differences in model results are solely due to differences in vegetation properties.

SiB2 has been used in previous studies in stand-alone mode at 1-km resolution (e.g., Bounoua et al. 2004) and coupled with a GCM (e.g., Randall et al. 1996; Bounoua et al. 1999; Bounoua et al. 2000; Bounoua et al. 2002; DeFries et al. 2002).

2.3. Data

2.3.1. Land cover classifications

The land cover maps used in this study are derived from the Moderate Resolution Imaging Spectroradiometer (MODIS) 250-m horizontal resolution and 16-day composite normalized difference vegetation index (NDVI) for 2000/01 and 2002/03 (Huete et al. 2002). The classification is based on a decision tree after correcting for cloudy or other low-quality data (Morton et al. 2005a). Field data points from 2003 are used as training sites for the classification. With this method, areas of cropland, pasture, forest, and clearing are separated based on their phenological profiles. The forest class is further broken down to distinguish between tropical evergreen and transition forest types using a land cover classification of Mato Grosso (IBGE and IBAMA 1993). Evergreen forest, pasture, and cropland have distinct classes in SiB2 whereas the seasonal transition forest is associated with the broadleaf deciduous forest class as trees dominate over the grassland formations in the study area. Cleared area that is not yet planted is represented by shrubs with bare ground. Forest regrowth in cropland or pasture land due to agriculture abandonment is not captured in these short simulations.

2.3.2. Biophysical fields

The NDVIs of 2000/01 and 2002/03 are used to derive time-varying (16 day) biophysical parameters such as the FPAR, the LAI, the canopy greenness fraction, and the roughness length (Sellers et al. 1996b).

To separate the effects of changes in land cover from changes in the vegetation density due to interannual variation, we develop a control case in which the 2002/03 land cover change is assigned an NDVI from 2000/01. Specifically, for each pixel undergoing land cover change in the 2002/03 map, the annual cycle of the 2000/01 NDVI of the closest pixel with the same cover type is assigned. Spatial limits not to exceed 5 km × 5 km around the grid cell are imposed to constrain climate and soil stratification.

2.3.3. Soil and atmospheric data

To assess the sensitivity of surface energy and water balance to land cover changes, all drivers other than land cover and vegetation dynamics are identical between simulations.

The soil data required by the model are given by one of seven soil texture types each assigned a set of physical parameters (Sellers et al. 1996b). The soil texture map is derived from the Food and Agriculture Organization (FAO) at 4 km × 4 km resolution and interpolated to match the vegetation data at 250 m. The FAO data indicate some degree of homogeneity in soil texture over this relatively small domain. Although field observations show higher spatial heterogeneity, the impact on our study is minimal since the soil is kept identical in all simulations.

The atmospheric drivers for SiB2 include air temperature, surface pressure, relative humidity, convective and large-scale precipitation, wind speed, and longwave and shortwave diffuse and direct radiation. We use the International Satellite Land Surface Climatology Project (ISLSCP I; Meeson et al. 1995) dataset at $1° \times 1°$ and interpolate them to 250 m over our study region using a bilinear interpolation scheme (Bounoua et al. 2004). Similar to the soil data, the climate drivers are kept identical for all simulations; and even if they are likely to introduce a bias in the output, this bias is excluded by the analysis of the differences between simulations. The climate over the study area clearly features a wet (October–April) and a dry (May–September) season.

3. Experimental design

3.1. Experiments

Three experiments were conducted. The first two use NDVI and land cover from 2000/01 and 2002/03, respectively. The third is the control run and uses the land cover from 2002/03 and the NDVI obtained from 2000/01. For each of the three scenarios a 5-yr run was performed. Initial conditions were interpolated from previous runs of SiB2 at $1° \times 1°$ resolution (Bounoua et al. 2004). Since most variables are rather fast responding, equilibrium conditions for almost all land cover types were reached at the end of the second year. Soil moisture of the third layer for tropical evergreen forest points reached equilibrium by the end of the third year. To avoid the transitional phase of model adjustment, the analysis presented in this paper includes data from the last two years of each simulation, discarding the first three years to account for model spinup.

3.2. Modeling strategy

To account for local characteristics of the region, some modifications are applied to vegetation physiological properties. 1) Field studies and census data (Instituto Brasileiro de Geografia e Estatística, 2000–2003) show that over the study region, soy is planted during the wet season only while water efficient plants such as corn, sorghum, and millet are grown during the dry season. To better characterize the physiological behavior of the dry season plants, we assign a carbon pathway consistent with the stomatal response of heat tolerant, water-efficient C4 tropical plants. 2) Where forest is cleared within one year but not yet used for cropland or pasture, it is replaced by shrubs with bare ground during the dry season.

4. Results and discussion

Changes in land cover directly affect the energy and water balance in three major ways. First, changes in albedo affect the amount of shortwave radiation absorbed by the canopy. Second, vegetation alters the surface roughness and consequently the turbulent energy transfer of heat and momentum. Third, vegetation also controls the transfer of water from the soil to the atmosphere through photosynthetic transpiration. All these changes vary throughout the year and from year to year with varying phenology. Key changes associated with different conversion types over the study area are summarized in Table 1.

4.1. Daily response

Hourly values of output variables are recorded for selected points and are used to characterize the diurnal response. The locations of the points are identical in all simulations and are chosen to represent different land cover type conversions. Composite diurnal cycles are then formed for December, representing a typical wet season month prior to the peak of the phenological cycle.

We present results for three major conversion types: 1) conversion of transition forest to cropland, 2) conversion of pasture to cropland, and 3) conversion of transition forest to pasture.

4.1.1. Conversion of transition forest to cropland

Figure 2 shows composite diurnal cycles of canopy assimilation, conductance, transpiration, and temperature for a point in the transition forest that was converted to cropland. This type of land cover change resulted in a maximum decrease in net assimilation of 3 μmol m^{-2} s^{-1}. This decrease appears to be mostly driven by differences in phenology as both vegetation types have the same maximum photosynthetic capacity ($V_{\max}$) and both are C3 plants, thus having the same carbon

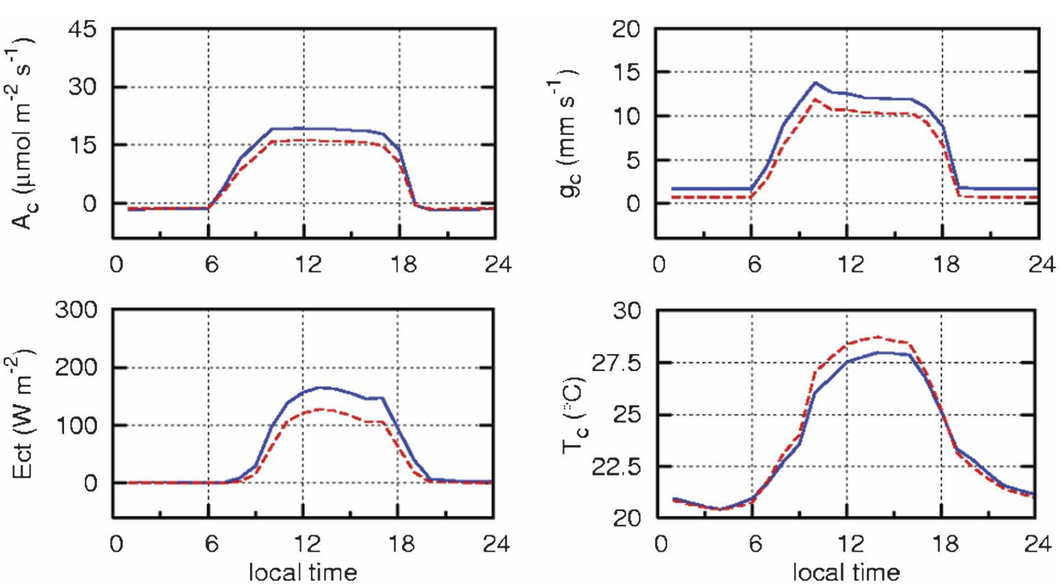

Figure 2. Composite diurnal cycles of net carbon assimilation A_c, canopy conductance g_c, canopy transpiration Ect, and canopy temperature T_c for the conversion of transition forest (blue solid line) to cropland (red dashed line) for the month of December.

pathway. The reduction in carbon assimilation leads to a decrease in canopy conductance of 2 mm s^{-1}. The decrease in conductance directly translates into reduced transpiration. This effect is further amplified by the reduction in roughness length, which for this type of conversion decreased from 0.9 to 0.13 (Table 1). The overall effect is an increase in canopy temperature of up to 0.7°C at midday. During nighttime, model-simulated canopy temperatures are similar between the two experiments. This is because canopy conductance is at its minimum and canopy transpiration is determined by a complex interplay of the water vapor deficit and a bulk canopy boundary layer resistance (Bounoua et al. 2004).

4.1.2. Conversion of pasture to cropland

The conversion of pasture to cropland is interesting because its impact on water and energy balance is entirely driven by physiological differences due to different carbon pathways. Canopy assimilation shows a dramatic reduction during the day of up to 23 μmol m^{-2} s^{-1} (Figure 3) driven partially by a 12% decrease in FPAR. The main forcing of the decrease in assimilation, however, is the conversion of C4 to C3 vegetation. The C4 species are highly water-use efficient, and with the same amount of water they are capable of a carbon assimilation rate almost twice as high as their C3 counterparts (Ludlow and Wilson 1971). As precipitation did not change between the two simulations, cropland has to down-regulate its biophysical activity in order to conserve its water resources. The decrease in assimilation is about 60%, while conductance decreased only 38% as the reduction in assimilation is partially compensated by a higher stomatal slope factor for C3 vegetation [Equation (1)]. The transpiration rate is closely coupled to canopy conductance during the day and leads to a drying and warming of the atmosphere. As a result,

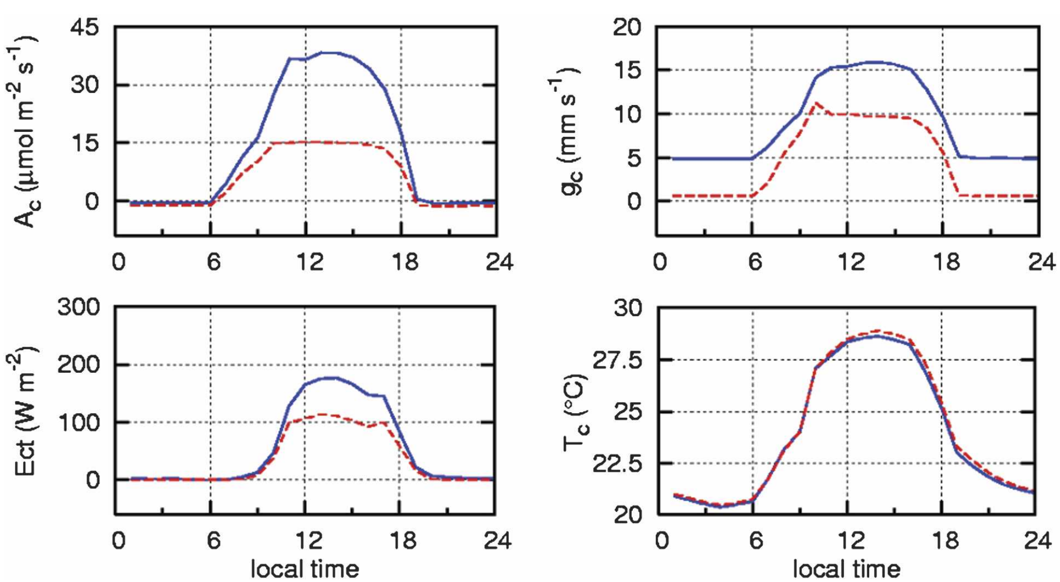

Figure 3. Same as in Figure 2, but for the conversion of pasture (blue solid line) to cropland (red dashed line).

maximum canopy temperature increases by 0.3°C. Since the morphological and optical properties assigned to pasture and cropland are identical, changes in the components of water and energy balance simulated for the wet season are exclusively a result of differences in the phenological cycle and carbon pathway.

4.1.3. Conversion of transition forest to pasture

The conversion of transition forest to pasture combines the effects of a change in morphological structure and physiological activity. The difference in physiological activity is associated with a replacement of a C3 with C4 vegetation, while the morphological difference is associated with conversion of tall tree to short vegetation. The morphological and physiological effects tend to compensate for each other in their overall impact on surface energy and water balance components. Midday assimilation is more than doubled (Figure 4), with nearly unchanged FPAR. This leads to a 30% increase in canopy conductance despite a 44% reduction of the stomatal slope factor (Equation 1) associated with the C3 to C4 transition. Canopy transpiration is reduced during most of the day. The increase in aerodynamic resistance associated with the reduction in roughness length more than compensates for the effects of physiological activity. Despite a higher assimilation rate, the water vapor transfer from the vegetation to the atmosphere declines, leading to a 0.5°C increase in the maximum temperature. For this conversion, the cooling effect associated with a higher physiological activity is compensated for by a warming due to reduced roughness length and increased aerodynamic resistance.

4.2. Seasonal response

Monthly mean values for several surface variables were saved for the entire study area. From monthly means, spatial averages are calculated using all pixels

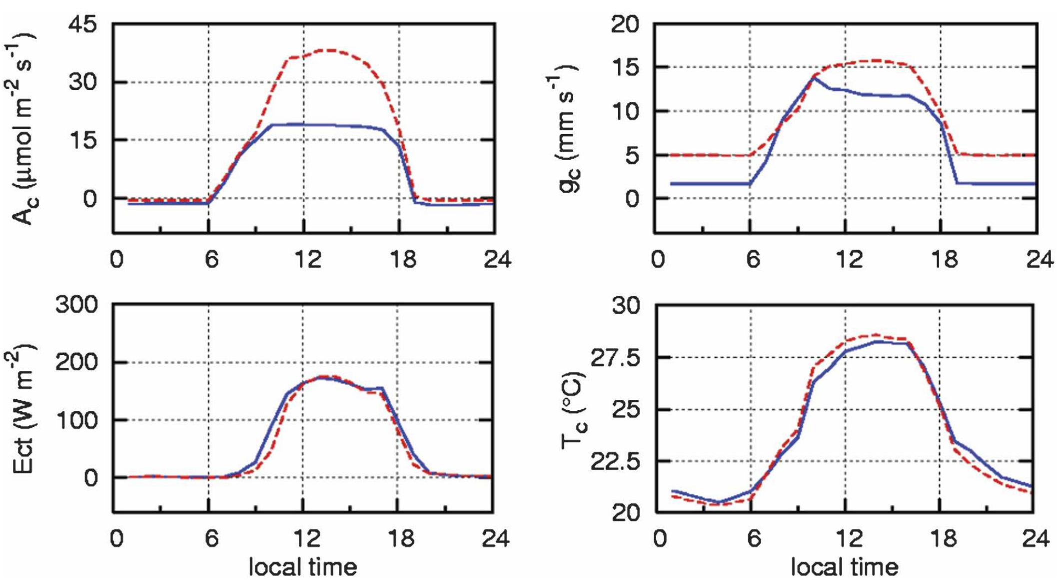

Figure 4. Same as in Figure 2, but for the conversion of transition forest (blue solid line) to pasture (red dashed line).

that underwent the same conversion type for the wet and dry seasons. For each season data are time averaged over three months: November, December, and March for the wet season and June, July, and August for the dry season. The wet and dry seasons are characterized by an average precipitation rate of 146 and 12 mm month^{-1}, respectively. As the clearing of forest usually takes place near the end of the wet season, prognostic variables for cleared but not yet planted pixels are only given for the dry season. Unlike other conversion types, the model response for this particular type of transformation does not describe a final state of land cover change but rather a transitional phase.

4.2.1. Phenology

Different land cover types in the study area have distinct phenology, and all conversion types are associated with a decrease in FPAR for both seasons. However, differences vary considerably among conversion types and seasons, as shown in Figure 5. The largest reduction, up to 36% for the conversion of transition forest to cropland, appears in the dry season when the physiology is less active and has therefore a smaller impact on assimilation than would be expected from similar differences during the wet season. For all conversion types the reduction in FPAR decreases canopy assimilation and conductance, which in turn affects the surface energy fluxes.

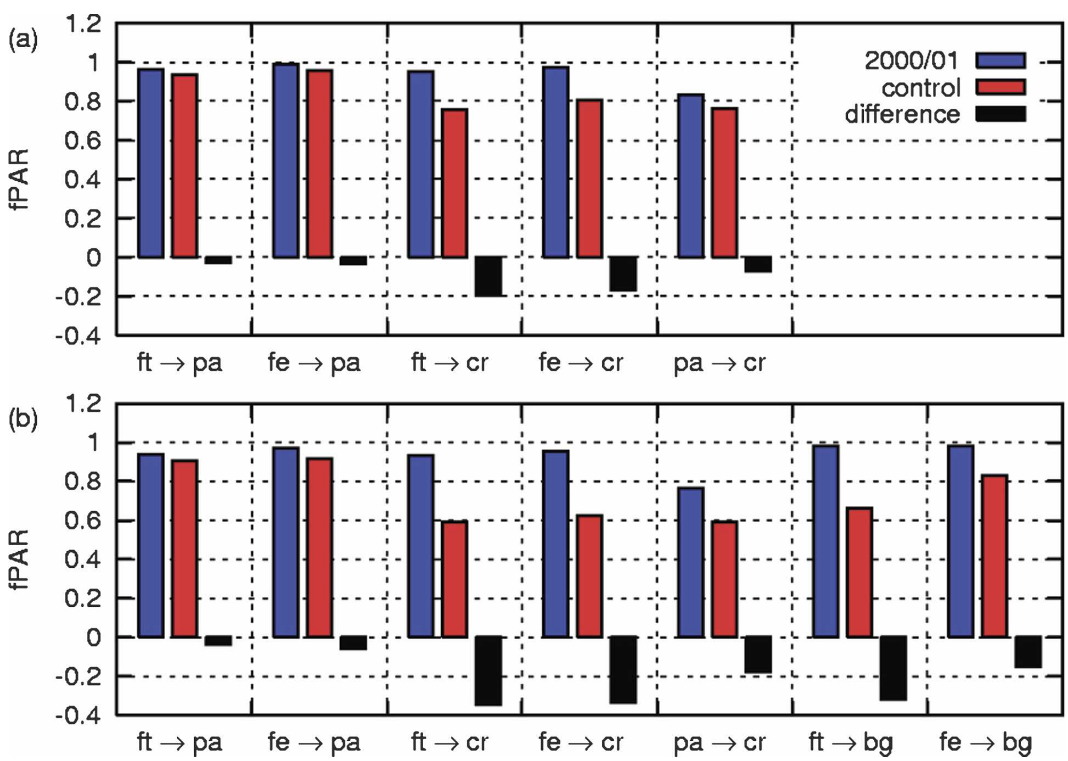

Figure 5. Seasonal differences in FPAR for major conversion types for the (a) wet and (b) dry season. Abbreviations as listed in Table 1.

4.2.2. Surface energy fluxes

Conversion of forest to short vegetation in the Tropics is generally associated with significant increase in albedo and a consequent reduction in the net energy absorbed by the canopy (Culf et al. 1995). A decrease in the net absorbed energy affects the magnitude of all fluxes but does not influence the partitioning of energy into different surface fluxes. During the wet season both latent and sensible heat fluxes decreased for all conversion types except for the conversion of pasture to cropland where a slight increase in sensible heating is simulated (Figure 6a). In most cases, however, the reduction in the latent heat flux is larger than the decrease in sensible heat. This is not the case for the conversion of transition forest to pasture, which resulted in the smallest decrease in the latent heat flux due to the water-use efficiency of pasture and its smaller leaf area index compared to the tall forest. The simulated trade-off between latent and sensible heat is entirely due to land cover change. In the case of conversion of forests to pasture, the morphological forcing tends to warm canopy, but this effect is partially offset by a physiological cooling due to a more heat-tolerant photosynthetic apparatus of C4 pasture.

During the dry season when water is limiting, most conversions lead to an increase in latent heat at the expense of sensible heat flux, except the conversion of forests to pasture, which shows insignificant changes in the latent heat flux (Figure 6b). The increase in latent heat flux for conversion of forests to cropland

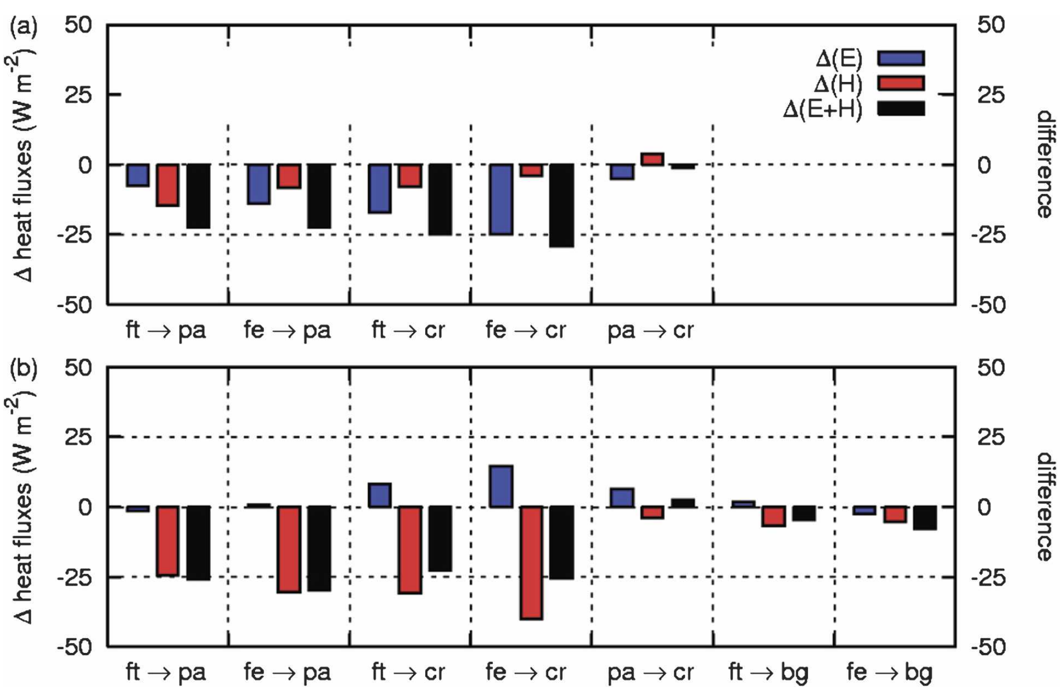

Figure 6. Seasonal differences in latent heat flux (*E*), sensible heat flux (*H*), and total (latent plus sensible heat fluxes) for major conversion types for the (a) wet and (b) dry season. Abbreviations as listed in Table 1.

is partly due to less water demand exerted by cropland due to a decreased FPAR and to a small water stress limitation simulated by the model for the forests during the dry season. Because of their developed root system, tropical forests access deep soil water during the dry season, greatly reducing water stress (e.g., Chavez 1991; Nepstad et al. 1994; Saleska et al. 2003). In SiB2 this effect is parameterized by allowing water to diffuse up from the deep soil layer to the root zone.

4.2.3. Canopy temperature

The complex interplay of morphological and physiological effects that altered surface energy fluxes is the primary determinant of surface and canopy temperature, which represents an integrated signature of the impact of land cover conversion on local climate. The conversion of transition forest to cropland is the most complex. During the wet season, which receives 146 mm month^{-1} of rain, both plants operate at full physiological capacity and therefore transpire nearly at potential rates. The large increase in aerodynamic resistance associated with the conversion of tall forests to short vegetation favors the energy flow toward sensible heating and increases canopy temperature. During the water-limited dry season, the conversion from a tall thick canopy to cropland relieves the water stress and enhances the transpiration rate for an overall cooling. When transition forests are converted to C4 pasture, the change in the physiological activity dominates the morphological effect and results in cooling the canopy during both wet and dry seasons (Figure 7). The conversion of evergreen forest to pasture or cropland is associated with warming in both seasons. However, the simulated warming is more intense for the conversion to cropland during the wet season (0.4°C) and for the conversion to pasture during the dry season (0.2°C). Conversion of pasture to cropland is characterized by a warming controlled by change in plants' physiology during the wet season when both plants are not water stressed. The largest difference in temperature is observed when forests are cleared and remain bare. The clearing of a transition forest results in a seasonal warming of 1.2°C, while the warming associated with the clearing of an evergreen forest is 1.7°C.

Canopy temperature is used to assess changes in the seasonal daily temperature range (DTR). Unlike the mean temperature, the DTR represents the amplitude of the daily temperature variation and is therefore indicative of the operating range of different vegetation types. Results for both seasons and all conversion types are summarized in Table 2. In general, all conversion types result in an increase of DTR for both seasons, and the increase is mainly due to an increase in the maximum daily temperature. Reduction in the minimum temperature also contributes to increase in DTR, especially during the dry season. The DTR increase is more evident during the dry season and is largest for conversion of forests to bare ground, reaching more than 7°C when evergreen forest is cleared. For the conversion of transition forest to either pasture or cropland the increase in DTR is about 3 times larger during the dry than the wet season. Similarly, the conversion of evergreen forest to pasture during the dry season resulted in a DTR increase that is almost double that of the wet season, while conversion of the same forest type to cropland led to about the same DTR increase for both seasons. The conversion of pasture to cropland has the smallest effect on the DTR and that holds true for

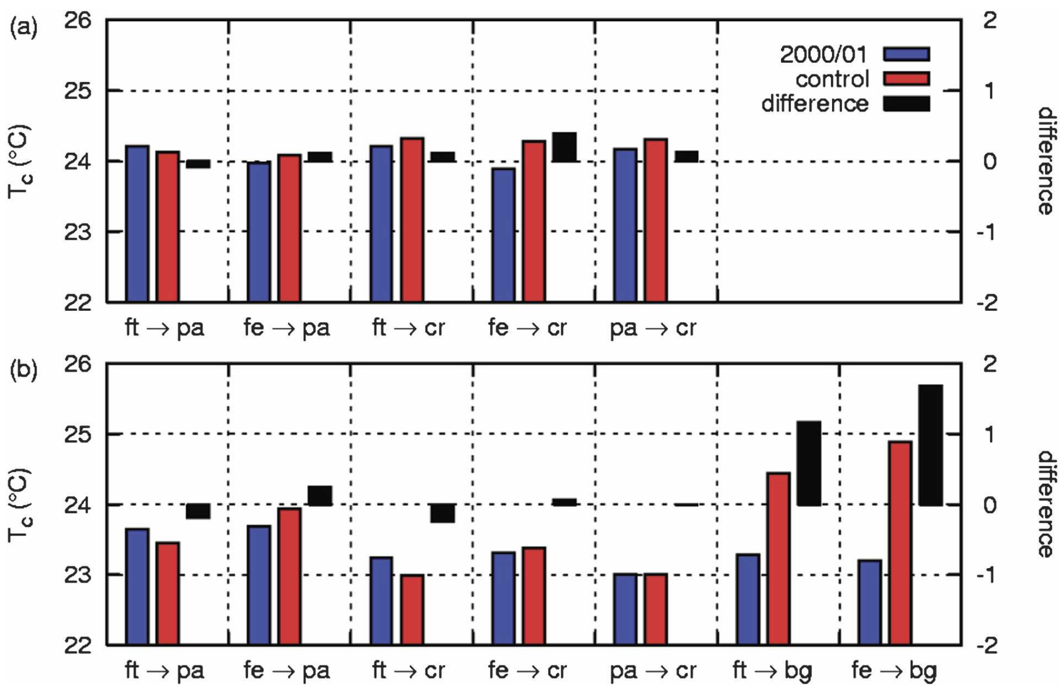

Figure 7. Seasonal differences in canopy temperature for major conversion types for the (a) wet and (b) dry season. Abbreviations as listed in Table 1.

wet and dry seasons. This is an important result, suggesting that plants replacing forest in the study area must be more temperature tolerant than the original forest.

A paired *t* test is performed using monthly and seasonal mean canopy temperatures to determine whether the differences in model response were statistically significant. Paired values were calculated twice for each conversion type to compare the 2000/01 to the 2002/03 experiment and to the control case. A statistical significance greater than 95% was reached for all months and seasons.

Table 2. Differences (control minus 2000/01, in °C) of daily minimum (Δmin) and maximum canopy temperature (Δmax) and of daily temperature range (ΔDTR) averaged over the wet season (November, December, and March) and the dry season (June, July, and August). Abbreviations as listed in Table 1.

	Wet season			Dry season		
Conversion	Δmin	Δmax	ΔDTR	Δmin	Δmax	ΔDTR
ft → pa	−0.07	0.27	0.34	−0.46	0.81	1.27
fe → pa	−0.19	1.35	1.54	−0.64	2.14	2.78
ft → cr	−0.04	0.58	0.62	−0.49	1.03	1.51
fe → cr	−0.07	1.63	1.70	−0.60	1.19	1.78
pa → cr	0.06	0.53	0.46	−0.05	0.00	0.05
ft → bg	—	—	—	−0.63	4.42	5.04
fe → bg	—	—	—	−0.82	6.85	7.67

5. Concluding remarks

The conversion of the primary vegetation of Brazilian Amazonia to pasture and cropland is projected to progress at an accelerating pace (Margulis 2004). By analyzing the mechanisms through which vegetation affects local energy and water balance, this study suggests that the impact of land cover change on local climate depends strongly on the type of conversion. Morphological changes tend to warm and dry the atmosphere but are counterbalanced or exacerbated by physiological activity depending on the land use type. This study shows that the photosynthetic pathway is a key parameter in biosphere–atmosphere interactions. The effect of land cover change on local climate therefore depends not only on the overall extent of clearing but on the subsequent land use type as well.

A warming and drying effect as suggested in this study for the conversion of evergreen forest and an increase in daily temperature range is in line with observations (Culf et al. 1996; Hoffmann and Jackson 2000). This study also suggests a decrease in evapotranspiration driven by changes in morphological structure for the conversion of transition forest. Canopy temperature increases when transition forest is converted to C3 soybean, but a cooling effect is simulated for the conversion to water-use-efficient C4 pasture grasses. The importance of biophysical activity for energy and water balance is also highlighted for the secondary transition of pasture to cropland. Here, the study suggests a warming and drying during the wet season due to the superior photosynthetic capacity of tropical C4 over C3 plants as described by Ludlow and Wilson (Ludlow and Wilson 1971). Several studies suggest that a drying of the atmosphere following the conversion of forest affects climate by reducing precipitation and moisture convergence (Shukla et al. 1990; Nobre et al. 1991; Henderson-Sellers et al. 1993; Bounoua et al. 2002). More detailed regional studies and comparisons to observations are necessary to assess climatic effects of the differential impact of land cover change occurring in the Brazilian Amazon.

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