Agricultural expansion dominates climate changes in southeastern Amazonia: The overlooked non-GHG forcing

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References
S1. Study area - Our study area is the upper Xingu basin in Mato Grosso, Brazil, a 176,892 km² area in southeast Amazonia that is dominated by transitional forests. The region encompasses the Xingu Indigenous Park and several adjacent indigenous reserves, which form a large (34,503 km²) mosaic of protected areas, hereafter referred to as the XIP. The area outside the parks is composed of private properties, many of which have been deforested and converted to croplands or pastures (Schwartzman et al 2013). In 2001 61% of the study area was forest, 24.5% was pasture and 1.2% was croplands, mostly soybeans. The remaining 13.3% of the area was occupied by cerrado, a native savanna (non-forest vegetation). By 2010, the forested area had decreased to 49% and the extent of pasture and cropland had increased to 31% and 6% of the total area, respectively. Almost all of the forest loss during this period occurred on private lands outside the XIP (Macedo et al 2012). At the same time, 4,962 km² of pasturelands were converted to croplands (2.8% of the upper Xingu basin).

S2. Net radiation estimation

Net radiation ($R_{\text{net}}$) at the land surface can be expressed as

$$R_{\text{net}} = R_S^\downarrow (1 - \text{albedo}) + R_I^\uparrow - R_I^\downarrow$$  \hspace{1cm} (Eq. 1)

where $R_S^\downarrow$ is downward shortwave radiation; $\text{albedo}$ is the reflection coefficient of shortwave radiation; and $R_I^\uparrow$ and $R_I^\downarrow$ are downward and upward longwave fluxes, respectively. We estimated daily average $R_{\text{net}}$ under all sky conditions using MODIS and weather station data, according to previously published methods for calculating $R_{\text{net}}$ based on remote sensing products (Bisht and Bras 2010, Bisht et al 2005, Ryu et al 2008). We followed five steps (a-e) to calculate $R_{\text{net}}$ (Fig. S1).

Fig. S1. Diagram of steps to calculate net radiation based on MODIS and weather station data.
a) **Albedo** – We calculated actual albedo using the broadband black-sky and white-sky (0.25 – 4.0µm) albedo layers from the 500 m MODIS albedo product (MOD43A3, collection 005), as in Eq. 2 (Schaaf et al 2002):

\[
abledo = [1 - S(\theta, t)]\alpha_{bs} + S(\theta, t)\alpha_{ws} \quad (Eq. 2)
\]

where \( t \) is the atmospheric optical depth (AOD), \( S(\theta, t) \) is the fraction of diffuse light, \( \alpha_{bs} \) is the black-sky albedo, \( \alpha_{ws} \) is the white-sky albedo. We retrieved \( S(\theta, t) \) from the look-up table available in the MOD43 software (Schaaf et al 2002). We calculated the actual albedo at local noon and we retrieved AOD from MOD08 (Hubanks et al 2014) (we assumed that AOD was homogeneous in our study area).

b) **Downward shortwave radiation** \((R^1_s)\) - We estimated daily \( R^1_s \) for clear sky days as described in Bird and Hulstrom (1981) and implemented by the *insolation* function in the *insol* R package (Corripio 2014). Based on solar position algorithms, the model computes direct and diffuse solar irradiance perpendicular to the beam, for a given zenith angle (one-hour intervals from sunrise to sunset), Julian Day (every 8 days), altitude, and atmospheric condition (Corripio 2003, Reda and Andreas 2004, Bird and Hulstrom 1981).

The input data to calculate \( R^1_s \) was altitude (derived from a 1 km DEM; http://www.worldclim.org), air temperature, relative humidity (RH), albedo of the surrounding terrain, ozone thickness (OZ) and atmospheric optical depth (AOD). The air temperature and RH were estimated by kriging data from 12 weather stations belonging to the Brazilian National Meteorological Institute (INMET) (INMET 2012) (Table S1). Albedo was calculated based on MOD43A2 as explained in step (a). We used OZ (at 550 nm) and AOD from the 8-day MODIS atmospheric product (MOD08E3) (Hubanks et al 2014). We assumed that OZ and AOD were homogeneous in a 1º grid. AOD was used to calculate horizontal visibility in km (as in Eq. 64 of Român et al (2010)).

Table S1. List of INMET weather stations used for air temperature and relative humidity.

| Municipality            | Lat     | Lon     | Altitude (m) |
|-------------------------|---------|---------|--------------|
| Caceres                 | -16.05  | -57.68  | 118          |
| Canarana                | -13.47  | -52.27  | 430          |
| Cuiaba                  | -15.61  | -56.1   | 145          |
| Diamantino              | -14.4   | -56.45  | 268          |
| Gleba Celeste           | -12.28  | -55.29  | 415          |
| Matupa                  | -10.25  | -54.91  | 285          |
| Nova Xavantina          | -14.7   | -52.35  | 316          |
| Padre Ricardo Remetter  | -15.78  | -56.06  | 140          |
| Poxoore                 | -15.83  | -54.38  | 450          |
| Rondonopolis            | -16.45  | -54.56  | 284          |
| São José do Rio Claro   | -13.43  | -56.71  | 350          |
| Aragarças               | -15.9   | -52.23  | 345          |
uncertainty – Our estimated shortwave radiation for clear sky days showed good agreement to observed data from a nearby INMET (INMET 2012) weather station (INMETA916, located at -12.62°S, -52.22°W, in Querência Mato Grosso) (Fig. S2).

We calculated the effect of clouds on \( R_\text{S}^{\text{cloudy}} \) using Eq. 3 (Bisht and Bras 2010):

\[
R_\text{S}^{\text{cloudy}} = R_\text{S}^1 (1 - f_c) + f_c e^{-t_c/cos(\theta)}
\]

(Eq. 3)

where \( R_\text{S}^1 \) is estimated shortwave radiation for clear sky days, \( f_c \) is cloud fraction (retrieved from MOD08E3 (Hubanks et al 2014)), \( t_c \) is cloud optical thickness (MOD08E3), and \( \theta \) is the solar zenith angle (MOD08E3).

c) Downward longwave radiation (\( R_\text{L}^4 \)) – We calculated \( R_\text{L}^4 \) for all sky condition by using Eq. 4 (Bisht and Bras 2010).

\[
R_\text{L}^4 = \sigma \varepsilon_a T_a^4 + \sigma (1 - \varepsilon_a) \varepsilon_c T_c^4
\]

(Eq. 4)

Where \( \sigma \) is the Stefan-Boltzmann constant (5.67 X 10^{-8} W m^{-2} K^{-4}), \( \varepsilon_a \) is atmosphere emissivity, \( T_a \) is air temperature (from INMET weather stations), \( \varepsilon_c \) is cloud emissivity (MOD08E3), and \( T_c \) is cloud temperature (MOD08E3). To estimate \( \varepsilon_a \) we first estimated the dew point temperature based on relative humidity (as in Eq. 64 of Lawrence (2005)), then calculated near surface pressure (Rogers and Yau 1989), and finally calculated \( \varepsilon_a \) using the scheme proposed by Prata (1996).

To estimate \( \varepsilon_a \) we first computed the near-surface vapor pressure \( (e_0) \) as in Eq. 5 (Rogers and Yau 1989), where \( L_V \) is the latent heat of vaporization (2.5x10^6 [J kg^{-1}]), \( R_V \) is the gas constant for water vapor (461 [J kg^{-1}]) and \( T_d \) is the dewpoint temperature, computed based on relative humidity (Lawrence 2005). Then we
computed $\epsilon_a$ using the scheme proposed in Prata (1996), as Eq. 6, where $\xi = (46.5/T_a)\epsilon_0$.

$$e_0 = 6.11 \exp\left[\frac{L_v}{R_v}\left(\frac{1}{273.15} - \frac{1}{T_d}\right)\right] \quad \text{(Eq. 5)}$$

$$\epsilon_a = 1 - (1 + \xi) \exp\left(-\sqrt{(1.2 + 3\xi)}\right) \quad \text{(Eq. 6)}$$

d) **Upward longwave radiation** ($R_L^1$) – we calculated $R_L^1$ as in Eq. 7, using land surface temperature and surface emissivity (Ryu et al 2008):

$$R_L^1 = \sigma \epsilon_s T_s^4 + (1 - \epsilon_s) R_L^1 \quad \text{(Eq. 7)}$$

where $\sigma$ is the Stefan-Boltzmann constant ($5.67 \times 10^8$ W m$^{-2}$ K$^{-4}$), $\epsilon_s$ is surface emissivity, $T_s$ is surface temperature in Kelvin (MOD11A2), and $R_L^1$ is downward longwave radiation (Bisht and Bras 2010).

The surface emissivity was calculated as:

$$\epsilon_s = 0.273 + 1.778 \epsilon_{s1} - 1.807 \epsilon_{s31} \epsilon_{s32} - 1.037 \epsilon_{s32} + 1774 \epsilon_{s32}^2 \quad \text{(Eq. 8)}$$

where $\epsilon_{s1}$ and $\epsilon_{s2}$ are the emissivity in bands 31 and 32 of MOD11A2 product, respectively (Ryu et al 2008). These bands are in the thermal infrared regions, covering the spectrum of maximum longwave radiation values of natural objects (17).

e) **Net radiation** ($R_{net}$) - Finally we estimated daily average $R_{net}$ under all sky conditions as in Eq. 1.

S3. Analyses

Our analyses consisted of three main components: a) **Land cover effects on the energy balance**: assessed how specific land use transitions (LUTs) contribute to observed changes in the energy balance and each of its components (per unit area); b) **Cumulative LUT effects**: estimated the net contribution (forcing) of historic LUTs (2001-2010) to observed changes in the regional evapotranspiration (ET) and temperature; c) **Protected areas**: investigated to what extent the XIP mitigates historic changes to the regional ET and surface temperature.

a) **Land cover effects on the energy balance** – We analyzed how the energy variables of interest, net radiaton ($R_{net}$), evapotranspiration (ET), sensible heat (H), and temperature (LST) varied with the fractional canopy cover for each LUT. To do this, we first computed the proportion of forest, pasture, or cropland (mapped at 250-m resolution) occupying each 1-km grid cell (i.e. fractional cover) for the entire 10-year time series. Using this fractional cover map, we estimated the effects of three specific land-use transitions (forest-to-crop, forest-to-pasture, and pasture-to-crop) by comparing their fractional cover to each of the response variables ($R_{net}$, ET, H and...
LST). To do so, we: 1) Fit a regression model treating fractional cover as the independent variable and $R_{\text{net}}$, ET, H and LST as dependent variables; 2) Calculated confidence intervals by fitting linear regression slopes for each year and retaining the minimum and maximum observed slope. All variables were summarized by growing year (defined as August in the year of planting through July in the year of harvest) to match the data used to generate the land-use maps (Macedo et al 2012). The intercept and slope for each variable in different years are presented in Table S2.

b) Cumulative LUT effects - To evaluate the regionally integrated effect of historic LUTs on ET and temperature, we compared observations in areas that had experienced LUTs with those in nearby unconverted areas. We split this analysis into two parts: one to evaluate the effect of land use transitions occurring in the 2000s (2000s effect), and a second to evaluate the total effect, including areas deforested before 2001 (pre-2001 effect).

2000s effect. To estimate the amount of water associated with reductions in ET due to LUTs in the 2000s, we used yearly maps of ET in the unconverted portion of the upper Xingu to estimate losses in the converted portion. In the case of forest-to-pasture or forest-to-cropland transitions, we used yearly maps of ET in the forested portion of the study area to estimate losses in the deforested portion (converted to pasture or cropland). In the case of pasture-to-cropland transitions, we used maps of ET in the pasture portion of the area to estimate losses in the portion converted to cropland. First, we used the focal function in the raster R raster package (Hijmans et al 2014) to estimate what the ET in converted pixels would have been if they had remained forest. We did this by taking the mean ET of all neighboring forested pixels within a 20x20 window. The resulting forest ET value was applied to the central cell in the 20x20 window and stepping forward one cell. We then calculated the difference between the observed and estimated ET in pixels that had experienced a transition. Finally, we used the difference (reduction) in ET to calculate the total volume of water not recycled to the atmosphere as a result of a given LUT. We performed this analysis for all years, allowing us to calculate the total effect of deforestation on ET in the 2000s for each LUT. To quantify the variability of data, we followed the same steps to calculate the first and third quartiles (results on Fig. 3 of paper). We also retrieved the number of unconverted neighboring pixels used to estimate values of each converted pixel. The choice of window size was based on experimentation to ensure that: (1) the window was large enough to guarantee at least 5 pixels for our calculation and (2) the window was small enough to allow for the variability of ET in space (e.g., ET tends to decrease with decreasing latitude). Ninety-nine percent of our estimates were based on more than 5 neighboring pixels.

We used the same methodology described above to assess changes in LST resulting from land use transitions in the 2000s. In this case, we first calculated the yearly mean of real observed temperature. Second, we estimated values for the portion that had experienced a LUT in previous years based on neighboring unconverted pixels and calculated the mean LST for the entire region. Finally, we calculated the difference between observed and estimated mean temperatures for each year and each LUT (see Fig. 4A on the paper).
Table S2. Slope and intercept (int) of regressions between fractional cover of specific land use transitions and response variables (R\textsubscript{net}, ET, H, and LST) from 2001 to 2010.

| Year | Forest-pasture | Forest-cropland | Pasture-cropland |
|------|----------------|-----------------|------------------|
|      | int  | slope SE | int  | slope SE | int  | slope SE |
| R\textsubscript{net}  |
| 2001 | 12.99 | -1.60 0.002 | 12.98 | -2.74 0.012 | 11.40 | -1.12 0.012 |
| 2002 | 12.10 | -1.62 0.002 | 12.10 | -2.36 0.014 | 10.49 | -0.63 0.015 |
| 2003 | 12.62 | -1.62 0.002 | 12.61 | -2.53 0.006 | 10.97 | -0.85 0.011 |
| 2004 | 12.68 | -1.49 0.002 | 12.67 | -2.38 0.007 | 11.17 | -0.83 0.009 |
| 2005 | 12.54 | -1.69 0.002 | 12.53 | -2.53 0.004 | 10.83 | -0.81 0.006 |
| 2006 | 12.67 | -1.71 0.002 | 12.66 | -2.34 0.003 | 10.95 | -0.60 0.005 |
| 2007 | 12.93 | -1.61 0.002 | 12.93 | -2.44 0.003 | 11.31 | -0.77 0.006 |
| 2008 | 12.70 | -1.52 0.002 | 12.68 | -2.28 0.004 | 11.14 | -0.69 0.006 |
| 2009 | 12.81 | -1.60 0.002 | 12.79 | -2.41 0.004 | 11.20 | -0.78 0.005 |
| 2010 | 13.29 | -1.51 0.002 | 13.28 | -2.40 0.004 | 11.77 | -0.84 0.005 |
| ET   |
| 2001 | 7.85  | -2.39 0.006 | 7.82 | -2.95 0.037 | 5.17 | -0.25 0.057 |
| 2002 | 8.14  | -2.69 0.006 | 8.12 | -3.29 0.031 | 5.17 | -0.21 0.049 |
| 2003 | 7.36  | -1.80 0.005 | 7.36 | -2.23 0.026 | 5.42 | -0.26 0.040 |
| 2004 | 6.93  | -1.97 0.005 | 6.92 | -2.70 0.022 | 4.78 | -0.66 0.027 |
| 2005 | 8.52  | -1.95 0.006 | 8.50 | -3.22 0.012 | 6.33 | -1.04 0.031 |
| 2006 | 7.16  | -1.46 0.005 | 7.16 | -1.70 0.010 | 5.57 | -0.04 0.024 |
| 2007 | 8.28  | -1.74 0.005 | 8.26 | -2.82 0.008 | 6.32 | -0.78 0.025 |
| 2008 | 7.69  | -1.61 0.005 | 7.68 | -2.45 0.008 | 5.91 | -0.67 0.022 |
| 2009 | 7.66  | -1.31 0.005 | 7.64 | -2.01 0.008 | 6.14 | -0.57 0.021 |
| 2010 | 9.08  | -2.62 0.006 | 9.04 | -3.71 0.008 | 6.05 | -0.77 0.023 |
| H    |
| 2001 | 5.12  | 0.89 0.010 | 5.15 | 0.36 0.047 | 6.26 | -0.80 0.088 |
| 2002 | 3.94  | 1.16 0.010 | 3.97 | 1.05 0.044 | 5.34 | -0.31 0.075 |
| 2003 | 5.24  | 0.26 0.008 | 5.24 | -0.20 0.031 | 5.58 | -0.53 0.059 |
| 2004 | 5.73  | 0.57 0.009 | 5.74 | 0.40 0.028 | 6.40 | -0.08 0.040 |
| 2005 | 3.99  | 0.35 0.009 | 4.01 | 0.76 0.013 | 4.51 | 0.27 0.046 |
| 2006 | 5.49  | -0.15 0.007 | 5.49 | -0.56 0.010 | 5.39 | -0.51 0.036 |
| 2007 | 4.62  | 0.21 0.008 | 4.66 | 0.48 0.008 | 5.01 | 0.05 0.037 |
| 2008 | 4.99  | 0.16 0.008 | 4.99 | 0.23 0.010 | 5.25 | -0.01 0.032 |
| 2009 | 5.12  | -0.20 0.008 | 5.15 | -0.31 0.010 | 5.09 | -0.15 0.032 |
| 2010 | 4.18  | 1.19 0.009 | 4.23 | 1.41 0.010 | 5.74 | -0.05 0.033 |
| LST  |
| 2001 | 27.15 | 4.07 0.010 | 27.10 | 6.25 0.058 | 31.62 | 1.82 0.099 |
| 2002 | 27.32 | 4.28 0.010 | 27.27 | 6.60 0.052 | 31.99 | 1.73 0.088 |
| 2003 | 27.32 | 4.42 0.011 | 27.24 | 6.53 0.051 | 32.04 | 1.97 0.075 |
| 2004 | 26.90 | 4.30 0.011 | 26.82 | 7.04 0.038 | 31.54 | 2.34 0.058 |
| 2005 | 27.06 | 4.40 0.012 | 26.98 | 7.06 0.028 | 31.80 | 2.28 0.046 |
| 2006 | 26.94 | 4.47 0.011 | 26.86 | 6.59 0.026 | 31.71 | 1.72 0.042 |
| 2007 | 27.31 | 4.30 0.011 | 27.25 | 6.36 0.022 | 31.92 | 1.65 0.040 |
| 2008 | 27.53 | 4.11 0.011 | 27.46 | 5.84 0.022 | 31.97 | 1.34 0.035 |
| 2009 | 27.35 | 4.15 0.011 | 27.30 | 6.05 0.021 | 31.92 | 1.53 0.037 |
| 2010 | 27.25 | 3.98 0.011 | 27.21 | 6.35 0.019 | 31.70 | 1.93 0.035 |

ns= not statistically significant (p>0.05); SE= standard error
Pre-2001 effect. We used the same method described in the first part of this analysis to evaluate changes in ET and LST associated with deforestation before 2001 (Fig. S3). The only difference was that in this case we used a bigger moving window (30x30 pixels). Only 1% of pixel estimates relied on fewer than 5 neighboring pixels.

c) Protected areas - We evaluated the mitigating effect of protected areas by comparing LST and ET changes inside and outside of the XIP in the 2000s. First, we compared the yearly mean temperature inside the XIP to the yearly mean temperature in the entire upper Xingu basin (see Fig. 4B on the paper). Finally, we evaluated the mitigating effect of the XIP on ET by calculating the contribution of ET inside the XIP to the total ET of the Xingu basin.

Fig. S3. Effect of land use transitions (including areas deforested before 2001) on temperature (from MOD11A2) and ET (from MOD16A2) in the entire upper Xingu basin. The shaded areas denote the inter-quartile range.
S4. Data uncertainty

*Land use maps* - We used a time series of land use maps (from 2001 through 2010) produced by Macedo *et al* (2012). These maps depict the main land uses in the region, classified based on their characteristic phenology as reflected by temporal vegetation index profiles (MOD13Q1). The final land-use classification was validated using 302 data points collected in 2010 across Mato Grosso and distinguishes the three main land uses (forest, pasture, cropland) with an accuracy of 92% (Macedo *et al* 2012).

*Net radiation* ($R_{\text{net}}$) - To validate our $R_{\text{net}}$ estimates, we used measurements from a net radiometer installed on a tower in Sinop, Mato Grosso (-13.06°S, -52.38°W; Beija-flor Project: www.lba.cptec.inpe.br/beija-flor). The daily mean of these in situ $R_{\text{net}}$ measurements was 11.45 (SD±2.06) MJ m² day⁻¹ between 2000 and 2002, compared to 11.37 (SD±1.77) MJ m² day⁻¹ in the MODIS-based estimates for the same location and period. We also averaged the in situ measurements every 8 days to match the temporal resolution of the MODIS data. A comparison of the two datasets indicates that the MODIS-based estimates adequately capture the actual $R_{\text{net}}$ in terms of magnitude (root mean square errors = 1.15 MJ m² day⁻¹; 10%; Fig. S5) and seasonality (Fig. S4).

![Fig. S4. Comparison of MODIS-based estimates of $R_{\text{net}}$ (every 8 days) and daily measurement from a net radiometer on an eddy flux tower located in Sinop, Mato Grosso.](image)

![Fig. S5. Comparison of $R_{\text{net}}$ measured with a net radiometer on an eddy flux tower in Sinop and MODIS-based $R_{\text{net}}$ estimates. All data are shown as 8-day means. RMSE = Root Mean Square Error.](image)
\textbf{Evapotranspiration} (ET) - ET data were obtained from the MOD16 product (Mu et al 2011), available at 8-day intervals and 1km spatial resolution. The MOD16 ET algorithm was validated in a previous study, using data from 10 eddy covariance flux towers that represent different land covers and uses. The estimated error was less than 4\% in savannas, 5\% in tropical forests, and 13\% in pasture/agriculture (Loarie et al 2011, Ruhoff et al 2013). The MODIS ET product contains several temporally static inputs, including the MODIS land cover from 2001 (MOD12Q1). The land cover classification is used in the MODIS ET calculation mainly to parameterize stomatal and leaf conductance per unit of leaf area, and to set the range of climatic conditions when stomata are active (Mu et al 2011). Since the ET model does not update these parameters when forest is converted to other uses, ET is likely underestimated in those areas (White et al 2000), and our estimates of change due to LUTs are likely conservative. To test whether this influenced our results, we repeated the regression analyses comparing energy and water fluxes to fractional land cover, using only pixels classified as ‘Evergreen Broadleaf forest’ in the MOD12Q1 product (Fig. S6). The results were similar unchanged (Table S3).

\textbf{Land surface temperature} (LST) - Previous studies indicate that the MODIS land surface temperature product has an error less than 1 degree Celsius (Wan et al 2004) in tropical forest areas.

Table S3. Regressions parameters to evaluate the effect of deforestation on energy balance variables. We compared results using only areas classified as Evergreen Broadleaf forest in the MODIS Land Cover product (MOD12Q1, labeled “Forest”) to those using all areas of the Xingu basin that were forest originally (labeled “All LC”).

| Var  | Transitions     | LC     | Intercept | slope  | SE     | P  |
|------|-----------------|--------|-----------|--------|--------|----|
| R_{net}  | Forest -> Pasture | All LC | 12.72     | -1.57  | 0.001  | <0.01 |
|        | Forest -> Pasture | Forest | 12.72     | -1.34  | 0.002  | <0.01 |
|        | Forest -> Cropland | All LC | 12.71     | -2.26  | 0.003  | <0.01 |
|        | Forest -> Cropland | Forest | 12.71     | -2.20  | 0.006  | <0.01 |
| ET     | Forest -> Pasture | All LC | 7.85      | -1.91  | 0.002  | <0.01 |
|        | Forest -> Pasture | Forest | 7.86      | -1.40  | 0.004  | <0.01 |
|        | Forest -> Cropland | All LC | 7.84      | -2.50  | 0.006  | <0.01 |
|        | Forest -> Cropland | Forest | 7.86      | -3.16  | 0.013  | <0.01 |
| H     | Forest -> Pasture | All LC | 4.85      | 0.42   | 0.002  | <0.01 |
|        | Forest -> Pasture | Forest | 4.84      | 0.16   | 0.004  | <0.01 |
|        | Forest -> Cropland | All LC | 4.86      | 0.32   | 0.006  | <0.01 |
|        | Forest -> Cropland | Forest | 4.85      | 1.05   | 0.013  | <0.01 |
| Temp   | Forest -> Pasture | All LC | 27.21     | 4.26   | 0.003  | <0.01 |
|        | Forest -> Pasture | Forest | 26.98     | 2.94   | 0.005  | <0.01 |
|        | Forest -> Cropland | All LC | 27.14     | 6.40   | 0.008  | <0.01 |
|        | Forest -> Cropland | Forest | 26.95     | 5.90   | 0.013  | <0.01 |
Fig. S6. Map of the upper Xingu basin derived from MOD12Q1. Areas colored in green were classified as forest in 2001 and served as an input to the MODIS ET algorithm.

Table S4. Daily mean of albedo, net longwave, net shortwave and net radiation for the three land cover types analyzed in the upper Xingu basin (standard deviation in parenthesis).

| Land cover   | Albedo (reflectivity) | Net longwave (MJ m$^{-2}$ day$^{-1}$) | Net shortwave (MJ m$^{-2}$ day$^{-1}$) | Net radiation (MJ m$^{-2}$ day$^{-1}$) |
|--------------|-----------------------|----------------------------------------|----------------------------------------|----------------------------------------|
| Forest       | 0.130 (0.002)         | -2.65 (0.196)                          | 15.29 (0.24)                           | 12.64 (0.31)                           |
| Pasture      | 0.143 (0.003)         | -3.93 (0.196)                          | 15.15 (0.24)                           | 11.22 (0.34)                           |
| Cropland     | 0.164 (0.003)         | -4.25 (0.200)                          | 14.68 (0.26)                           | 10.43 (0.32)                           |
**Fig. S7.** Temporal pattern of evapotranspiration (ET, MJ m$^{-2}$ day$^{-1}$), net radiation ($R_{\text{net}}$, MJ m$^{-2}$ day$^{-1}$), and land surface temperature (°C) for three polygons experiencing a forest-to-pasture transitions in 2005 in the upper Xingu basin. Horizontal lines represent the average over the period when the area was covered by forest (solid line) or pasture (dashed line).
Fig. S8. Yearly mean of ET in 2010 from MOD16A3 (right panel) and protected areas and indigenous land in the Brazilian Amazon Biome (left panel).

Fig. S9. Net shortwave radiation (incoming shortwave solar radiation minus the fraction reflected by the land surface), net longwave radiation (the difference between incoming and outgoing longwave radiative fluxes) and net radiation (net longwave plus net shortwave radiation) in 2010 for the upper Xingu basin in MJ m\(^{-2}\) day\(^{-1}\).
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