Short technical report

Understanding the maps of risk assessment of deforestation and carbon dioxide emissions using scenarios for 2020

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Introduction

This technical report aims to describe the methodology followed to calculate the map of risk assessment of deforestation and carbon emission using a scenario for 2020 to the Brazilian Amazon. In the following sections it is provided detailed information regarding the database adopted as source to the risk assessment maps as well as the premises considered for scenario projections.

It is important to mention that these products are the results of joint effort of National Institute for Space Research in Brazil together with Planetary Skin Institute, and they intend to give the final user a broad view of the deforestation risks and CO_2 emissions associated in the forthcoming years. The database adopted was assembled using different data sources from several governmental Brazilian institutions, being the methods and land use/cover /CO_2 emissions models are developed at the National Institute for Space Research. In addition to this report, further information regarding the methods, database and models can be found in specialized literature cited in the final references of this report.

Risk assessment map of deforestation

The risk assessment of deforestation is based initially on historical remote sensing data that compose land use maps gathered in a yearly basis from 1988 to 2009. These data are freely available at INPE's website (INPE, 2009). Added to historical land use maps, the database used to calculate risk maps also adopted the following variables (see detailed description in Table 1):

- Accessibility measures to main infrastructure (roads, urban areas, ports)
- Accessibility to main national markets (São Paulo, Rio de Janeiro, Northeastern region)
- Accessibility to areas of economic attractiveness (wood extraction poles and mining areas)
- Environmental aspects
    - Soil fertility
    - Climatic variables: precipitation, humidity, temperature, soil wetness
    - Slope
- Public policies (forest reserves and indigenous land)
- Agrarian structure (agrarian projects with slash and burn or sustainable land use practices)

The database containing all these variables was used as input to a land cover change model that runs inside the framework developed by INPE named LuccME. The differential of LuccME consists on its integrative computational tool where different LUCC models can be implemented together in a unique environment, taking into account different spatial and temporal scales. In this study a specific model named LuccME/BRAmazonia was implemented at the Brazilian Amazon scale. It uses potential and allocation sub-models based on the CLUE model (Veldkamp and Fresco, 1996; Verburg et al., 2002), and is adapted to the Brazilian Amazon case by Aguiar (2006). The LuccME/BRAmazonia model uses a spatial database based on the variables mentioned above, organized in a regular grid of 25x25 km^2. Therefore, the calculation of the risk assessment map of deforestation considers the same spatial scale and spatial resolution of LuccMe/BRAmazonia.

An empirical model of deforestation based on linear regression was implemented using LuccME, where 2006 is considered the baseline year, i.e. the regression models are run for 2006 and the amount of forest varies every year according to the demand of change in the adopted scenario. LuccME performs several iterations for each year of the simulation in order to allocate the informed demand values of forest losses. Once the demand is allocated a projected land use map is recorded and then used to start the next time step of the simulation. The allocation procedure is based on the results of the regression model, which procedure is described next.

First the variables built from the spatial database were used in an exploratory analysis in order to exclude independent variables highly correlated to each other. coefficients higher that 0.6 can not be used together in the same regression model. The initial regression model was tested using the variables presenting the highest correlation to deforested areas and considering previous results of studies performed at INPE. Several alternative models were tested by including or excluding some variables depending on their individual significance in model estimates. The final model was the one that maximized the R square at a minimum of 0.7 and at the same time presented high significance for the model as whole as for the individual variables (5 % significance level). Stepwise variables selection method was also used to improve the models together with graphical analysis of normal p-plots and residual analysis.

Beyond allocation of changes and demand scenarios, the deforestation model requires expert knowledge also to set specific model parameters concerning spatial variability and reversibility of changes. At last, the simulation of land cover changes adopted 2006 also as the baseline year and 2020 as the end year to allocate the plausible deforestation according to a scenario of carbon emission reduction target proposed by the Brazilian government. The final results of the simulations provide the percentage of deforested area in each cell of the database (25 by 25 km as mentioned before).

Finally, to obtain the map representing the risk assessment of deforestation we calculate the difference of deforested areas between 2020 and 2006. This difference results in a transitional potential between 0 and 1 for each cell in the database to be deforested within this period. Therefore the map of risk assessment of deforestation can be interpreted as the risk of deforestation in the forthcoming years based on the scenario of carbon emission reduction target. The codification of classes in the final map of risk assessment of deforestation follows 5 classes of percentage deforested inside each cell of the database according to:

Transitional potential equal 0	= No risk of deforestation
Transitional potential > 0 and < 0.04	= Low risk of deforestation
Transitional potential > 0.04 and < 0.4	= Moderate risk of deforestation
Transitional potential > 0.4 and < 0.5	= High risk of deforestation
Transitional potential > 0.5	= Very high risk of deforestation

Scenario of carbon emission reduction target

A scenario of deforestation that follows the Brazilian government targets for deforestation in the next ten years. In 2008 the Brazilian Government made a formal announcement within the United Nations climate treaty framework of reducing Amazon deforestation by 80% compared to the historical rate from 1996-2005 of 19,500 km^2 yr^{-1} by 2020 (Government of Brazil 2008). According to the target, deforestation rate would drop to 3900 km^2 in 2020. This target is in full-association with the voluntary commitment assumed later on (Dec.2009) by Brazil in the United Nations Climate Change Conference in Copenhagen to reduce its greenhouse gas emissions from 36.1% to 38.9% by 2020.

The scenario adopted takes into account Brazilian governmental policies to mitigate greenhouse gases emissions until 2020. To run the scenarios, we used the PRODES increments from 2006 to 2009, and from 2010 to 2020, we assume deforestations rates has an exponential decrease rate until 3900km^2.

Table 1 - Potential determinants of land use change represented by spatial variables obtained from different data sources and using distinct numerical methods to fill in the cell space of 25 x 25 km

Variable name	Description	Numerical Function used to fill cellular space	Type	Source	Scale/level	Statistical variables
Deforestation	% cummulative deforested area	Percentage of deforested area interpreted using remote sensing images (Landsat/TM) produced by PRODES until 2006	interval [0,1]	PRODES, 2006 (www.inpe.br/prodes)	1:500000	dependent
Forest	% remaining area of forest inside cells	Percentage of deforested area interpreted using remote sensing images (Landsat/TM) produced by PRODES until 2006				
Acessibility						
ED_highway	Distance to paved and unpaved highways	Euclidian distance to reference points	real (>=0)	IBGE, 2006	at least 1:1000000	independent
Conn_SP_RJ	Connection to market in São Paulo and Rio de Janeiro	Connectivity of each cell to national markets (São Paulo, Rio de Janeiro, Northeast, state capitals), to regional markets (urban areas inside the Brazilian Amazon) and to ports. Connectivity measures are inversely proportional to the minimum path distance from each cell using the roads network. Paved and non-paved roads are distingued by considering duplicated distances in the latter.	real (>=0)	IBGE, 2006 Aguiar et al., 2003	1:1000000	
Conn_SP_NE	Connection to market in São Paulo and the Brazilian Northeast					
Conn_ports	Connection to ports					
Conn_capitals	Connection to state capitals in Brazil					
Economic attractiveness						
ED_mineral	Distance to mineral reserves (under exploitation and/or economic relevant)	Euclidian distance to reference points	real (>=0)	CPRM, 2006	1:1000000	
ED_woodpole	Distance to wood extraction poles (sawmills, wood forest management areas)			MMA, 2006		

Colonization history (Agrarian structure)					
Sust_COL	*Official agrarian projects under land concession regimes allowing only sustainable exploration*		nominal		1:250000
NSust_COL	*Official agrarian projects under land concession regimes allowing slash and burn practices*				
Environmental					
	Slope				
slope_steep	Steep (>20%)	Percentage of elements (pixels) of every slope category inside each cell	nominal	SRTM (NASA, 2000) refined to 30 m by TOPODATA project (VALERIANO, 2007)	1:250000
slope_mod	Moderate (between 11 and 20%)				
slope_smooth	Smooth (between 5 and 10%)				
slope_flat	Flat (up to 5%)				
	Soil fertility				
fert_high	High	Percentage of area of polygons for the attribute of reference inside each cell	nominal	IBGE 1996/EMBRAPA 2000	1:1000000
fert_low	Low				
fert_velow	Very low				
	Climatic factors				
precip_dry3	Average precipitation given by the minimum value per pixel within 3 consecutive months	Average of minimum values occurring within three consecutive months independently to each pixel of the data set according to the climatic variable considered.	real (>=0)	INPE/CPTEC	at least 1:5000000
hum_dry3	Average humidity given by the minimum value per pixel within 3 consecutive months		interval [0, 100]		
temp_dry3	Average temperature given by the minimum value per pixel within 3 consecutive months		real		
	PVM-CPTEC climatic-vegetation model				
PVM_tmin	the mean temperature of the coldest month	Derived from PVM-CPTEC model calculated in a land use model perpectve according to the Master Dissertation of ThomasFriedman (2010)	real (>=0)	Derived from the water balance model of CPTEC-PVM described in Oyama & Nobre, 2004	
PVM_gdd0	the number of growing degree days using a 0°C threshold				
PVM_weti	wetness index indicating the potential of the areas of higher humidity		integer		
Public Policies					
TI_2006	Indigenous land existing in 2006	Percentage of area of polygons for the attribute of reference inside each cell	nominal	MMA, 2006	at least 1:1000000
UC_2006	Protected areas under different levels of law enforcement existing in 2006				

Risk assessment map of CO_2 emissions until 2020

The risk assessment map of CO_2 emissions was obtained by crossing the simulation results of LuccME from 2006 to 2020 to a map of aboveground biomass contained in the remaining forest (Saatchi et al. 2007). The map represents the risk of CO_2 emissions at 25x25 km until 2020 under the scenario of carbon emission reduction target, as described before.

Once areas are at a high risk of deforestation and contain the highest levels of vegetation carbon are the ones depicted as having a very high risk of carbon emission in the assessed map. Conversely, areas under a low risk of deforestation have also a low risk of CO_2 emission. Therefore, the CO_2 emissions resulting from deforestation in the Amazon are not solely dependent on the extent of forest that is cleared, but also on the amount of carbon stored in the forest.

The employed map of Saatchi et al. (2007) uses a combination of inventory data (obtained *in loco*) and satellite imagery to estimate the biomass of live trunks, stems, leaves and shoots over the entire Amazon. In order to convert live biomass into CO_2 we assume that each unity of biomass contains 47% of carbon.

Units used in the map are Tg CO_2 [Teragram (=10^{12} gram) of carbon dioxide]. It is suggested that the map be presented using the following division of classes of data:

Class "Low risk of CO_2 emission" = from 0.0 to 0.2
Class "Medium risk of CO_2 emission" = from 0.2 to 3.0
Class "High risk of CO_2 emission" = from 3.0 to 6.0
Class "Very high risk of CO_2 emission" = from 6.0 to 13.0

Estimated CO_2 emissions from deforestation in 2002-2020

The data contained in the attached excel sheet are the outputs of INPE's greenhouse-gas (GHG) emission model. The model is driven by annual maps of deforestation, either real or projected, and computes the associated CO_2 emissions of primary forest and also the emission or absorption of CO_2 resulting from secondary forest clearing / re-growth.

CO_2 emission of primary forest is estimated via two different methods: process-based and non-process-based. In the first there is the consideration of some realistic processes that underlie the dynamics of the Amazon forest carbon cycle and the influence of humans on it (via land-use practices), such as the speed and frequency that trees are cut and burned; the percentage of timber extracted; equations of organic matter decay in soils; root decomposition; fire intensity, and type of organic matter. For example, in this more realistic emission pathway method a large portion of the vegetation CO_2 is readily emitted to the atmosphere due to biomass burning, but another part of the CO_2 stays for a longer time in the soil and is decomposed via biological processes at different rates depending on the type of biomass (roots, disposal of logging activities, etc). In the latter method all the CO_2 contained in the cleared forest is readily emitted to the atmosphere within one year following deforestation. In this method there is no consideration of processes that can hold carbon for a longer time in the environment, such as land-use practices or microbial decomposition rates. Although less realistic, this emission estimate method is useful to depict the amount of CO_2 directly committed with each deforestation burden.

Most of the knowledge underlying INPE's emission model derives from previous works by Hougthon et al. (2000; 2003, 2005) e Loaire et al. (2009), where more information about the modeling methods can be found. Currently only the emission of CO_2 is estimated by the model, but model development is underway to consider other important GHG such as methane (CH4) and nitrous oxide (N_2O).

The secondary vegetation re-growth and its dynamic are also considered. The parameters of secondary forest growth and deforestation are based in the study by Almeida (2009) and is driven namely by the agrarian structure and the intensity of land use, which varies from region to region. For example, secondary forest re-growth is more intense in recent deforestation frontiers than in older ones in the Amazon, especially in areas colonization by small farmers due to land tenure issues.

The data comprised in the attached excel sheet shows the estimated CO_2 emissions from the period spanning the years 2002 to 2020, divided into two sets:

- Observed: 2002-2009; using observed (PRODES) deforestation maps
- Modeled: 2007-2020; using deforestation maps generated by the LuccME/BRAmazonia model under the a scenario that follows the governmental targets for deforestation until 2020 (see above).

Explanation to the variables shown in each column is given below (units are Tg CO_2 [Teragram (=10^{12} gram) of CO_2], except deforestation that is in km^2):

1. *Year*: 2002-2009 (for CO_2 estimates using observed deforestation maps); 2007-2020 (for CO_2 estimates using projected deforestation maps).
2. *Deforestation*: observed (real) Brazilian Amazon deforestation data from PRODES satellite survey database; and modeled deforestation data from the LuccMe model
3. *Emission from primary vegetation (no process, 100% in the 1st year)*: the CO_2 contained in the vegetation that has been cleared (deforested) is all emitted to the atmosphere in the first year following deforestation.
4. *Emission from primary vegetation (via process, gradual)*: the CO_2 contained in the vegetation that has been cleared (deforested) is gradually emitted to the atmosphere according to different natural and human-driven processes of carbon decomposition.
5. *Assimilation from secondary vegetation growth*: represents the assimilation or absorption (opposite of emission) of CO_2 by forest regrowth (secondary vegetation). Values are negative due to convention.
6. *Emission from secondary vegetation*: CO_2 that is emitted due to the clearing (deforestation) of secondary vegetation. It uses the 'process' (gradual) emission pathway method, just like for the variable "*Emission from primary vegetation (via process, gradual)*" explained above.

7. *Balance*: = variable 4 + variable 5 + variable 6. It shows the balance between emissions and assimilation of CO_2. Positive values represent a net emission of CO_2 from land vegetation to the atmosphere. Negative values represent a net absorption of atmospheric CO_2 to the land vegetation.

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