Analysis of vegetation growth in regeneration in the Brazilian Amazon based in a model of land cover trajectories

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ABSTRACT

The regrowth of vegetation in previously deforested areas in the Brazilian Amazon plays an important role in the global carbon cycle, functioning as a dynamic carbon sink. Here, we used multi-temporal post-deforestation land cover trajectories and RADAR-derived above ground biomass (AGB) maps to quantify the patterns of biomass accumulation at different stages of vegetation regeneration in the Brazilian Amazon for the years 2008 and 2010. Our results showed that the combination of trajectories based on TerraClass product with AGB maps was consistent for tracking AGB changes across the Brazilian Amazon, showing the potential biomass increase across the regeneration process. Although the dynamics of the regeneration process can be interpreted in relation to Shrubby pasture, Regeneration with pasture and Secondary vegetation classes, the amount of accumulated biomass by them will depend on the previous class and the regeneration time.

Key words* — *Trajectory, TerraClass, Palsar-Alos, biomass, Amazon.

1. INTRODUCTION

The removal of the forest biomass carbon through tropical deforestation has a large impact on carbon emissions, contributing to 6 to 17% of the global anthropogenic CO_2 emissions [1]. On the other hand, the regrowth of forests on land previously deforested has the potential to offset emissions from deforestation and forest degradation [2] [3].

In the Brazilian Amazon, the patterns of land use allow regeneration of secondary vegetation in around 20% of the areas deforested [4]. However, changes prior to the formation of secondary vegetation may play an important role in the regeneration process, from vegetation structure changes and biomass accumulation over time, which result in different successional stages.

We proposed a trajectory conceptual model to simulate net carbon fluxes associated with tropical deforestation, based on dynamics of land cover in Amazon. The estimate the above-ground biomass (AGB) associated with the cover classes in different stages may provide information on the regeneration process, specifically informing about changes in biomass over time and what the capacity to accumulate biomass of each class. For this, we used multi-temporal post-deforestation land cover and RADAR-derived above ground biomass (AGB) maps to quantify the patterns of biomass accumulation at different history of land cover in the Brazilian Amazon between 2004 and 2010.

Specifically, the trajectory map built with Shrubby pasture, Regeneration with pasture and Secondary vegetation classes, from TerraClass data of 2004, 2008 and 2010, was used as mask over AGB maps of 2008 and 2010 to estimate the mean AGB of each trajectory and each class. The results were used to identify: 1) the overall growth pattern through trajectories; 2) the overall growth pattern over cover class; 3) Influence of cover land history in biomass accumulation.

2. MATERIAL AND METHODS

The study area encompasses the Brazilian Amazon biome, in areas previously deforested, abandoned and derived from pasture use. We used three cover classes of TerraClass project [4] to build 7 cover trajectories that simulate the regeneration process in Amazon: Shrubby pasture, Regeneration with pasture and Secondary vegetation. Difference among them are in the proportion between herbaceous and tree vegetation. Each trajectory represent a temporal sequence of classes in the years of 2004, 2008 and 2010, from the class of lower biomass potential for higher class. Therefore, the class Shrubby pasture was consider previous class of Regeneration with pasture which in turn is earlier of Secondary vegetation, representing regeneration process in relation to biomass and structural changes. Two additional trajectories were built to check the consistency of the 7 regeneration trajectories and help to represent the thresholds of biomass that occur in the

Brazilian Amazon. The first (Control 1), based in Herbaceous pasture class (pasture managed without any level of regeneration), characterizes the minimum AGB, the second (Control 2), based in Forest class, characterizes the climax stage of succession, showing the maximum AGB over all. The trajectories are presented in Table 1. This conceptual model was used to build a map, in cells of 100 x 100 meters, showing where the classes are coincident in space, according to the temporal sequence of them in each trajectory.

Table 1. Temporal sequence of cover class in each trajectory.

Trajectory	Cover class 2004	Cover class 2008	Cover class 2010
Control 1 (Cr1)	Hp	Hp	Hp
Trajectory 1 (Tr1)	Sp	Sp	Sp
Trajectory 2 (Tr2)	Sp	Sp	Rp
Trajectory 3 (Tr3)	Sp	Rp	Rp
Trajectory 4 (Tr4)	Rp	Rp	Rp
Trajectory 5 (Tr5)	Rp	Rp	Sv
Trajectory 6 (Tr6)	Rp	Sv	Sv
Trajectory 7 (Tr7)	Sv	Sv	Sv
Control 2 (Cr2)	Fo	Fo	Fo

Fo: Forest; Sv: Secondary vegetation; Rp: Regeneration with pasture; Sp: Shrubby pasture; Hp: Herbaceous pasture.

Above-ground biomass (AGB) maps were produced from radar backscatter data from Phased Array type L-band Synthetic Aperture Radar (PALSAR) onboard the Advanced Land Observing Satellite (ALOS), by the Japan Aerospace Exploration Agency (JAXA), for the years 2008 and 2010. Before AGB calculation, four pre-processing steps were done, in this sequence: 1) Aggregating L-band RADAR at HV polarization at 25 m spatial resolution to a 100 m spatial resolution by averaging pixel with the original resolution using a 4 by 4 pixels moving window. This procedure is required to reduce speckle noise commonly found in radar measurements at spatial resolution higher than 1.0 ha [5]. 2) Analyzing the frequency distribution of the RADAR-derived AGB pixels and filtering out all pixels falling outside the range between -1 and +1 standard deviations to eliminate pixels with inconsistent values. We do not consider RADAR data saturation in this study, because the intention was verify the growth pattern of the regeneration in the Amazon in relation to the TerraClass classes. The limitation of the data (e.g. 150 $Mg.ha^{-1}$) could misrepresent this pattern, since would reach only most advanced classes in the succession (Secondary vegetation and Forest). 3) Converting the backscatter digital numbers (DN) from the PALSAR product to backscatter coefficient (sigma-0) in units of decibel (dB). 4) Converting data from units of decibel (dB) to linear power (Pw).

Above-ground biomass values were calculated based on the Pw values. Flooded forests should be treated separately those where no occurs inundation [6]. Therefore, we applied 2 equations to calculate the AGB in the Brazilian Amazon: (1) for *Terra Firme* areas; (2) for *Varzea* areas. We used a remote sensing derived Wetlands map [7] to delimit the flooded areas. After the AGB calculation for the two areas, both were merged into a single AGB map of Brazilian Amazon for 2008 and 2010.

$$AGB = 0.40478 * \exp(88.43 * Hv\ Pw) \quad (1)$$

$$AGB = 0.57843 * \exp(75.051 * Hv\ Pw) \quad (2)$$

3. RESULTS

3.1. Growth pattern over trajectories

The result was coherent with the conceptual model of land cover trajectories, confirming the expectation that trajectories represent different regeneration stages in relation to AGB accumulated (Figure 1). The mean values, in $Mg.ha^{-1}$, of trajectory 1 to 7 were: 7.52; 9.37; 17.03; 27.79; 42.84; 59.44 and 95.28. Control 1 and 2 presented mean AGB of 0.9 $Mg.ha^{-1}$ and 179.28 $Mg.ha^{-1}$, respectively, showing the thresholds in AGB that occurs in Amazonian landscape. The increment needed to move from one trajectory to another was: 1.85 $Mg.ha^{-1}$ (Tr1/Tr2); 7.66 $Mg.ha^{-1}$ (Tr2/Tr3); 10.76 $Mg.ha^{-1}$ (Tr3/Tr4); 15.05 $Mg.ha^{-1}$ (Tr4/Tr5); 16.6 $Mg.ha^{-1}$ (Tr5/Tr6); 35.84 $Mg.ha^{-1}$ (Tr6/Tr7).

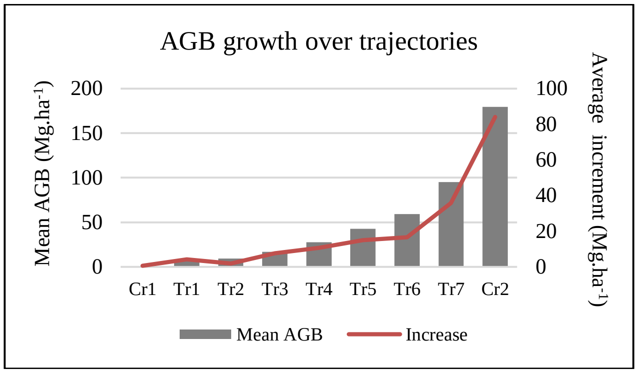

Figure 1. Results of association between AGB maps (2008 and 2010) and trajectory map. AGB values represent a mean of 2008 and 2010 for each trajectory. X-axis represents the trajectories from 1 to 7, with Control-trajectories at the extremes.

3.2. Growth pattern over cover class

Figure 2 shows results of mean AGB for cover classes. The mean values, in $Mg.ha^{-1}$, for each cover class were 0.94 (Hp), 3.02 (Sp), 12.78 (Rp), 64.12 (Sv) and 180.34 (Fo). Average increase necessaries for Herbaceous pasture reaches biomass levels of Shrubby pasture was 0.51 $Mg.ha^{-1}$; from shrubby pasture to Regeneration with pasture was 11.33 $Mg.ha^{-1}$; Regeneration with pasture to Secondary vegetation, 51.34 $Mg.ha^{-1}$; and from Secondary vegetation to Forest was 116.22 $Mg.ha^{-1}$. As consequence of the presence of multiple regeneration stages and land-cover history within each class, the potential increments were greater than among the trajectories.

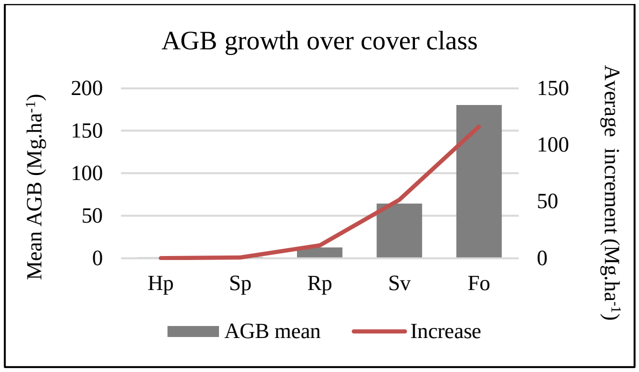

Figure 2. Results of association between AGB maps (2008 and 2010) and trajectory map. AGB values represent a mean of 2008 and 2010 for each cover class. Fo: Forest; Sv: Secondary vegetation; Rp: Regeneration with pasture; Sp: Shrubby pasture; Hp: Herbaceous pasture.

3.3. Influence of land cover history in biomass accumulation

We use the respective AGB and cover class data of 2008 and 2010 to summarize the results in function of the regeneration time and the previous class, in order to test influence of history of land cover. The cover class in 2004 worked as a reference point in time. 'Regeneration time' is understood as period between the years: 2 years (2008-2010), 4 years (2004-2008), or 6 years (2004-2010); while 'previous class' represent the changes of cover classes, according each trajectory, that can be (*1*) transitions from a class to other, or (*2*) growth of the same class. Results are in Tables 2 and 3.

Table 2. Mean AGB estimated for transitions between cover classes, in 2 and 4 years of regeneration.

Trajectory	Regeneration Time	Transition	Mean AGB (Mg.ha^{-1})
2	2-yr	Sp / Rp	9.05
3	4-yr	Sp / Rp	15.75
5	2-yr	Rp / Sv	40.05
6	4-yr	Rp / Sv	66.42

Sv: Secondary vegetation; Rp: Regeneration with pasture; Sp: Shrubby pasture

Table 3. Mean AGB estimated for growth of same class, in 2, 4 and 6 years of regeneration.

Trajectory	Regeneration Time	Cover class	Mean AGB (Mg.ha^{-1})
1	4-yr	Sp / Sp	6.31
1	6-yr	Sp / Sp	7.25
3	2-yr	Rp / Rp	15.99
4	4-yr	Rp / Rp	23.61
4	6-yr	Rp / Rp	26.60
6	2-yr	Sv / Sv	53.60
7	4-yr	Sv / Sv	106.12
7	6-yr	Sv / Sv	88.75

Sv: Secondary vegetation; Rp: Regeneration with pasture; Sp: Shrubby pasture

Comparing transitions of 2 and 4 years (Table 2), the influence of the regeneration time on the AGB accumulation was confirmed, since after 4 years the value were greater than in 2 years. Growth within of same class (Table 3) presented a similar behavior in the classes of Shrubby pasture and Regeneration with pasture. However, there was a discrepancy in the Secondary vegetation class, because the AGB reached in 6 years (88.75 Mg.ha^{-1}) was lower than in 4 years (106.12 Mg.ha^{-1}).

The influence of the previous class on the amount of accumulated biomass also was consistent with conceptual model of trajectories, since changes involved transitions between classes resulted in lower AGB values than in the growth of same class, for the same regeneration time. For example, in 2 years of growth of Regeneration with pasture reached 15.99 Mg.ha^{-1} of AGB (Table 3), but in transition from earlier class in the regeneration process (Shrubby pasture), the AGB reached was 9.05 Mg. ha^{-1} (Table 2). In 4 years, the Regeneration with pasture class reached 23.61 Mg. ha^{-1} (Table 3), but in the transition from Shrubby pasture the AGB value was of 15.75 Mg.ha^{-1} (Table 2). The same behavior occurred with Secondary vegetation, presenting lower AGB values in the transitions from Regeneration with pasture than in continuous growth.

In summary, the amount of biomass reached in the transitions of cover classes represent the lower level of AGB of each one them. From transition, they continue their growth, until the structural changes are sufficient for them to move to the next class in the process of regeneration.

4. DISCUSSION

The AGB values found were consistent with the design of the trajectories, allowing the determination the growth evolution in relation to cover class, in terms of AGB, as well as mean values of BAS for the cover class, according to the previous class and the regeneration time. This result prints a leap in TerraClass data utilization potential, as it integrates structural features with biomass.

Only the secondary vegetation class showed inconsistency with the conceptual model, because with 6 years of regeneration (Tr.7 in 2010) it presented biomass lower than with 4 years (Tr.7 in 2008). One hypothesis for this is that more advanced vegetations suffered some negative effect on their biomass as a response of severe drought of 2010 [8], in function of water deficit, which promotes leaf shedding [9] and increase in tree mortality rates [10]. However, the general AGB patterns allow the quantification of wall-to-wall carbon fluxes from secondary forests, which is critical for calculation of the net biome productivity of Amazonian forest.

The methodological strategy of combining the trajectories with multi-temporal data of above-ground biomass derived from PALSAR-ALOS images was efficient. Although RADAR data have limitations because of their high sensitivity to environmental variations and data saturation in high biomass forests [5] [5] [11], the results showed the capacity of the backscatter to detect structural variations of vegetation, and can be extremely useful when associated with land use and land cover maps.

These analyzes reflect the carbon fluxes in the vegetation after deforestation when derived from the Terraclass classes. Evidently, these transitions make up a simplification, since the growth pattern is not linear, neither in time nor in space. However, the analysis presented helps to understand the potential of carbon accumulation in biomass regrowth.

5. CONCLUSIONS

Shrubby pasture, Regeneration with pasture and Secondary vegetation are classes which can be used to interpret the AGB levels in regeneration process.

Shrubby pastures presets general mean AGB of 3.02 $Mg.ha^{-1}$, but they can reach 7.25 $Mg.ha^{-1}$ in 6-yr of regeneration time.

Regeneration with pasture presets general mean AGB of 12.78 $Mg.ha^{-1}$, but they can vary from 7.25 $Mg.ha^{-1}$ (2-yr of transition) to 26.6 $Mg.ha^{-1}$ (6-yr growth continuous).

Secondary vegetation presets general mean AGB of 64.12 $Mg.ha^{-1}$, but they can vary from 40.05 $Mg.ha^{-1}$ (2-yr of transition) to 106.12 $Mg.ha^{-1}$ (4-yr growth continuous).

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