MAPAS DE CARBONO DA AMAZÔNIA DOS DADOS GLOBAIS IPCC TIER 1 PARA UMA ABORDAGEM REGIONAL TIER 2 DA COMUNICAÇÃO NACIONAL DO BRASIL À CONVENÇÃO-QUADRO DAS NAÇÕES UNIDAS SOBRE MUDANÇA DO CLIMA

AMAZON FOREST CARBON MAPS, FROM GLOBAL IPCC TIER 1 TO A REGIONAL NATIONAL COMMUNICATION OF BRAZIL TO THE UNFCCC TIER 2 APPROACH

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ABSTRACT

Brazil has the major area of tropical forest and carbon stocks of the Amazon. There are plenty biomass distribution analysis with great difference between them, that make impossible to determine which is closer to the reality. IPCC (2006) recommends a biomass stratification at different levels of complexities (“tiers”), tier 1 requires IPCC default assumptions, methods and data; tier 2 requires detailed country specific strata, methods, assumptions and data. Thus, the aim of the study was to compare the carbon map of the Brazilian Amazon at IPCC tier 1 with the tier 2 carbon map used in Brazil`s Second National Communication to the UNFCCC and suggest the improvements that can be made. We started analyzing the forest biomass stratification and the emission factors (carbon estimates) to get tier 1 and tier 2 maps. As the biomass distribution of tier 2 MCT (2010) results in quadrants because of the RADAM Volumes extrapolation, an alternative tier 2 carbon map was elaborated using the mean biomass of the RADAM plots of each forest stratum. Tier 1 map simplified a more complex reality comparing to MCT (2010) tier 2 map with more detail and number of stratums. The alternative tier 2 carbon map had better carbon stocks distribution, even though future studies and an uncertainty analyses are needed to compare, validate and improve the MCT (2010) tier 2 approach and thus get a consistent carbon map for the Brazilian Amazon.

Keywords: Carbon maps, Amazon forest, IPCC tiers, Biomass.

INTRODUCTION

Amazon forest, one of the largest forests in the world, has a potential to constitute an important carbon sink with relevance at regional and global scales, while providing habitat to one-third of Earth’s species (TOLLEFSON, 2008). Brazil is the country with the major area of tropical forest of the Amazon basin and the country with the largest forest carbon stocks of the world (BACCINI *et al*., 2012). The relevance of determining the biomass distribution not only lies in the conservation of tropical rain forest, also in the carbon emissions estimations and mitigation mechanisms as REDD (reducing emissions from deforestation).

Biomass estimates in the Amazon has been having a lot of uncertainty in it estimates, not only in quantity but also in the spatial distribution (OMETTO *et al.* 2014). In the carbon emissions estimations biomass is the largest source of uncertainty (AGUIAR *et al*. 2012, BACINNI *et al*., 2012; HARRIS *et al*., 2012). Brazilian Amazon is plenty of biomass distribution analysis from field forest permanent plots (e.g. RADAM project) and biomass distribution maps combining both, remote sensing and field data (e.g. NOGUEIRA *et al*., 2008; SAATCHI *et al*., 2007 and 2011; MCT, 2010; BACCINI *et al*., 2012). However, when it comes to compare the biomass maps, the distribution and carbon stocks differ so much that it is almost impossible to determine which one is closer to the reality (OMETTO *et al.* 2014). The high uncertainty could be due to field biomass extrapolations, allometric equations, remote sensing methods and forest biomass stratification (HOUGHTON *et al*., 2010; AGUIAR *et al*., 2012).

A biomass stratification is fundamental to extrapolate field and remote sensing derived biomass data. To estimate carbon stocks related to agriculture and forestry it is necessary to stratify land-use and land cover in order to create homogeneous spatial units that can be linked to corresponding emissions factors (IPCC, 2006; SEIFERT, 2011). IPCC (2006), recommends stratifying climate, ecological zones, soil, and vegetation types, at different levels of complexities ("tiers"): tier 1 requires IPCC default, assumptions, methods and data, tier 2 requires more detailed country specific strata and emission factors using country specific data for key categories, and tier 3 requires country specific assumptions, methods and data.

Brazil is preparing the third National communication on Green House Gases (GHG) for the United Nations Framework Convention on Climate Change (UNFCCC) with IPCC (2006) and (2003) methods. The biomass maps used in the first and second communications have shown great differences with other regional and global carbon maps (OMETTO *et al.* 2014). Thus, the aim of the study is to compare the carbon map of the Brazilian Amazon at IPCC tier 1 (global products and default emissions factors) with the tier 2 MCT (2010) carbon map used in Brazil`s Second National Communication to the UNFCCC and to suggest the improvements that can be made.

METHODS

The study area is the Brazilian tropical rain forest in 2011 using the PRODES forest mask (INPE, 2013) to remove all the previous deforested areas. To understand all the tier 1 and tier 2 process, we acquired all the published data for stratification (inputs maps for each tier) and overlapped them to get the forest biomass stratification at tier1 and tier 2. For tier, 1 the emission factors (biomass in ton per hectare) were from the IPCC (2006). For tier 2 the emission factors (carbon estimates for the different carbon pools) were from the Brazilian communications to the UNFCCC (MCT, 2004 and MCT, 2010).

Stratification data

Referring tier 1, IPCC GHG 2006 recommends stratifying climate, ecological zones, soil, and vegetation types using different global data sets and provides default values (emission factors) for the carbon pools described in Table 1. Regarding tier 2, IPCC (2006) also recommends stratifying climate, ecological zones, soil, and vegetation types, including more detailed country specific strata and using country specific data for key categories (in this case forest land). The tier 2 stratification inputs and carbon estimates used by the MCT (2010) is compared with tier 1 analysis in Table 1.

Methods

We start with the forest biomass stratification for each tier, which consist in overlapping all the input maps to get spatial units that will represent the biomass carbon stocks. Next, the emission factors for each biomass strata was assigned to get the IPCC (2006) tier 1 and MCT (2010) tier 2 carbon maps. Finally, an alternative tier 2 carbon map was elaborated using the mean biomass from the measured plots in each vegetation class without extrapolating the RADAM volume as it was done by the MCT (2010) in the tier 2 carbon map. The flowchart representing each step of the analysis is in Figure 1.

Table 1. Products and emission factors used under tier 1 and tier 2 carbon estimates.

Carbon pools	**Tier 1 IPCC (2006)**		**Tier 2 MCT (2010)**		
	Global products	**Default Emission Factors of IPCC (2006)**	**Regional products**		**Emission Factors**
Above-ground biomass (AGB)	Global ecological zones (FAO, 2001)	Above-ground biomass in forest (table 4.7 vol.4) Carbon fraction of aboveground forest biomass (table 4.3 vol.4)	Vegetation Map of Brazil (IBGE, 2004)	Vegetation map used by MCT (2004) and (2010)	RADAM biomass field data using HIGUCHI et al., 1998 biomass equations (for Aa, Ab, As, Da, Db, Dm, Ds, La, Ld)[1]
			RADAM vegetation map		Bibliography biomass data (for Fa, Fb, Fm, Fs, Lb, Lg, Pa, Pf, Pm, Rm, Rs, Sa, Sd, Sg, Sp, Ta, Td, Tg, Tp)[2]

<table>
<tr><td rowspan="2">Soil organic carbon (SOC)</td><td>Climate regions</td><td>Global ecological zones (FAO, 2001)</td><td>Climate domains, climate regions and ecological zones (table 4.1 vol. 4)</td><td>Soil-vegetation association map (SVA)</td><td rowspan="2">Soil organic carbon map (BERNOUX et al., 2002)</td><td rowspan="2">Soil organic carbon stock data (BERNOUX et al., 2002)</td></tr>
<tr><td colspan="2">IPCC mineral soils map (WRB, 2009)</td><td>Default reference soil carbon stock (SOC_{ref}) for mineral soils (table 2.3 vol.4)</td><td>Soil profile data bases</td></tr>
<tr><td rowspan="2">Below-ground biomass (BGB)</td><td colspan="2" rowspan="2">Global ecological zones (FAO, 2001)</td><td rowspan="2">Above-ground biomass in forest (table 4.7 vol.4) Ratio of below-ground biomass to above-ground biomass (R) (table 4.4 vol.4)</td><td>Vegetation Map of Brazil (IBGE, 2004)</td><td rowspan="2">Vegetation map used by MCT (2004) and (2010)</td><td>RADAM biomass field data using SILVA (2007) biomass equations (for Aa, Ab, As, Da, Db, Dm, Ds, La, Ld)[1]</td></tr>
<tr><td>RADAM vegetation map</td><td>Bibliography biomass data (for Fa, Fb, Fm, Fs, Lb, Lg, Pa, Pf, Pm, Rm, Rs, Sa, Sd, Sg, Sp, Ta, Td, Tg, Tp)[2]</td></tr>
<tr><td>Litter</td><td colspan="3" rowspan="2">Under tier 1 are supposed to be 0 according to IPCC GHG 2006</td><td colspan="3" rowspan="2">Considering that litter and dead wood is 3% of total biomass (AGB + BLG biomass) SILVA (2007)</td></tr>
<tr><td>Dead wood</td></tr>
</table>

Note: For our study purposes, Harvest Wood Products carbon pool is not taking into account.

1. Aa:Floresta Ombrófila Aberta Aluvial; Ab:Floresta Ombrófila Aberta Terras Baixas; As:Savana Arborizada; Da:Floresta Ombrófila Densa Aluvial; Db:Floresta Ombrófila Densa de Terras Baixas; Dm:Floresta Ombrófila Densa Montana; Ds: Floresta Ombrófila Densa Submontana; La:Campinarana Arborizada; Ld:Campinarana Florestada.
2. Fa:Floresta Estacional Semidecidual alluvial; Fb:Floresta Estacional Semidecidual de terras baixas; Fm:Floresta Estacional Semidecidual Montana; Fs:Floresta Estacional Semidecidual Submontana; Pa:Vegetação com influência fluvial e/ou lacustre; Pf:Pioneiras com influência fluviomarinha (mangue); Pm:Pioneiras com influência Marinha (restinga); Sa:Refúgio Submontano; Sd:Savana Florestada; Ta:Savana Estépica Arborizada; Td: Savana Estépica Florestada.

For tier 1, we used the global ecological zones map FAO (2001) for above-ground biomass (AGB) and below-ground biomass (BGB), also as a climate map that together with IPCC mineral soils map (WRB, 2009) were necessary for the emission factors of soils carbon stocks (Table 1 and Figure 1). Overlapping these maps, we got the tier 1 forest biomass stratification with a the corresponding emission factors of IPCC (2006) shown in Table 1. In the case "Spodic soils" class, was used the data of BERNOUX et al. (2002) due to the value was missing in IPCC (2006). Litter and dead wood carbon pools are supposed to be zero under tier 1 (IPCC, 2006).

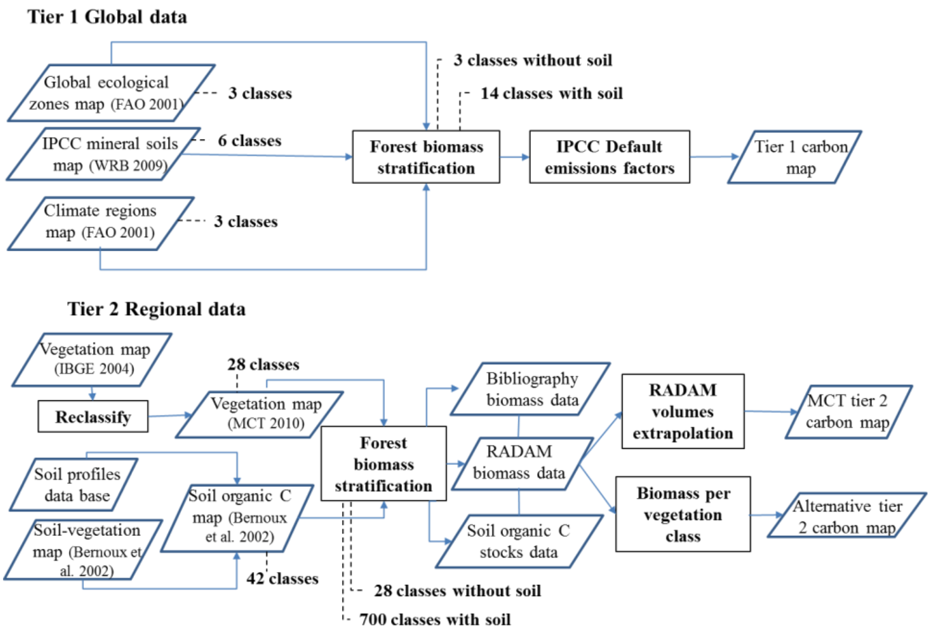

Figure 1. Flowchart of the tiers analyses.

The stratification of tier 2 according to MCT (2010), used the vegetation map of IBGE (2004) without transition vegetation classes resulting in a reclassify vegetation map (Figure 1) for AGB and BGB. The Soil Organic Carbon Stocks map (BERNOUX et al., 2002) that derived from a carbon-vegetation association map and many soil profiles database was used for soil carbon classes.

The emission factors (i.e. carbon stocks) of tier 2 were assigned according to the MCT (2004) and (2010) national communications for each carbon pool (Table 2). Above-ground biomass estimates, were based on 1710 plots (sampling units) inventoried by the RADAM project (1971-1986), where all the trees greater than or equal to 31.83 cm of diameter at breast height (DBH) or more were measured. Trees with less than 31.83 cm of DBH, lianas, and palm trees were not measured and regional assumptions (correction factors) were assumed to estimate the carbon stocks (MCT, 2010). Below-ground biomass was also calculated from AGB but only in the second national communication. The main difference between the first (MCT, 2004) and second (MCT, 2010) national communications is that BGB biomass was not included in the first, also palm trees and lianas used other correction factors in the second (see Table 2). Litter and dead wood carbon pools were not measured and for them regional assumptions were used too (Table 2). RADAM project did not covered all the forest vegetation physiognomies, for these instead of RADAM biomass data it was used literature references detailed in MCT (2010) also in Table 2. All the equations, literature references and regional assumptions used for tier 2 are described in Table 2.

After estimating the plots average carbon density for every forest vegetation physiognomy, the MCT (2010) extrapolate the biomass values per vegetation class in each of the RADAM Volumes according three rules: 1) If there were plots measured in the vegetation class of the Volume, then the average carbon stock of this plots were used. 2) If there were not plots measured in the vegetation class of the volume, then the average carbon stock of the plots in the same vegetation class of the neighbor volumes were used. 3) If there were not plots measured in the same vegetation class of the neighbor volumes, it was used the average carbon stock of the vegetation class of all Volumes.

The RADAM volumes extrapolation lead to a carbon stocks distribution in quadrants. In an attempt to improve the carbon stocks distribution of MCT (2010) tier 2 carbon map, an alternative tier 2 map was elaborated, using only the mean biomass value of the RADAM plots measured in each vegetation physiognomies ignoring the RADAMBRASIL Volumes. For the vegetation physiognomies not included in the RADAM plots as for the soil carbon stocks, the same procedure as MCT (2010) was applied.

Table 2. Carbon estimates of the first and second National Communications of Brazil to the UNFCCC (MCT, 2004 and 2010).

<table>
<tr><th>Carbon pools</th><th colspan="4">Description</th><th colspan="2">Equations</th></tr>
<tr><td rowspan="7">Above-ground biomass (AGB)</td><td rowspan="7">Woody</td><td rowspan="6">For (Aa, Ab, As, Da, Db, Dm, Ds, La, Ld)[1] vegetation strata it was used measured RADAM plots of 1ha (20m x 500m) for florestas ombrofilas and ½ ha for (20m x 250 m) for florestas estacionais</td><td colspan="2">Measure CDH of all tress with >= 100 cm (30.83 cm DBH)</td><td colspan="2">. ln P = -0.151+2.170 ln D (D>=20)
. C = 0.2859 * P (biomass to C content
P: AGB of tree (kg); D: DBH of tree (cm) (HIGUCHI et al. 1998)</td></tr>
<tr><td colspan="2">Trees <= 100 cm (30.83 cm DBH) (not measured)</td><td colspan="2">Using an extrapolation factor of 1.316 (Meira Filho, 2000): $C_{(total)}$=1.315698 C (CBH >100 cm)</td></tr>
<tr><td rowspan="2">1st Commu nication</td><td>Palm trees (not measured)</td><td>2% mean values</td><td rowspan="2">$C_{(total)}$=1.35 (CBH>100 cm)</td></tr>
<tr><td>Lianas (not measured)</td><td>1% mean values</td></tr>
<tr><td rowspan="2">2nd Commu nication</td><td>Palm trees (not measured)</td><td>2.31 % (Silva 2007)</td><td rowspan="2">$C_{acima\ do\ solo} = 1{,}3717 \times C_{(CAP > 100\ cm)}$. Correction value according to Silva (2007)</td></tr>
<tr><td>Lianas (not measured)</td><td>1.77% (Silva 2007)</td></tr>
<tr><td colspan="3">For (Fa, Fb, Fm, Fs, Lb, Lg, Pa, Pf, Pm, Rm, Rs Sa, Sd, Sg, Sp, Ta, Td, Tg, Tp)[2] (not measured) vegetation strata</td><td colspan="2">Bibliography data for each vegetation stratum</td></tr>
<tr><td>Below-ground biomass (BGB)</td><td colspan="4">Was not include in the 1st communication only in the 2nd. In the 2nd, it was not measured. It was assumed that 27.1% of total alive biomass (woody) are roots (or 37,2% of the carbon) according to SILVA (2007)</td><td colspan="2">BGB = $C_{acima\ do\ solo}$ * 0.372 (from carbon of total alive biomass) (SILVA, 2007)</td></tr>
<tr><td>Soil organic matter</td><td colspan="6">It was not measured, it was used the Soil organic carbon map carbon values of BERNOUX et al. (2002)</td></tr>
<tr><td>Dead Wood</td><td colspan="6" rowspan="2">It was not measured. It was assumed that 3% of total alive biomass (woody) is litter and dead wood according to SILVA (2007)</td></tr>
<tr><td>Litter</td></tr>
</table>

1. Aa:Floresta Omrófila Aberta Aluvial; Ab:Floresta Ombrófila Aberta Terras Baixas; As:Savana Arborizada; Da:Floresta Ombrófila Densa Aluvial; Db:Floresta Ombrófila Densa de Terras Baixas; Dm:Floresta Ombrófila Densa Montana; Ds: Floresta Ombrófila Densa Submontana; La:Campinarana Arborizada; Ld:Campinarana Florestada.
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RESULTS AND DISSCUSION

Understand the whole process of getting the publish data to get a tier 1 and tier 2 carbon map, helps to realize that the scale and details information of the global data versus regional data are relevant to interpret the biomass carbon stocks distribution.

Comparing tier 1 and tier 2 (MCT, 2010) carbon maps was possible to see that tier 1 simplifies a more complex reality since it uses global data, default methods and assumptions. Considering the number of stratums at tier 1, the biomass map had 3, climate map had 3 and the soil map had 6 resulting in a total carbon map of 14 stratums (3 without soil). Tier 2 map had more detail considering that it came from regional inputs (maps), regional methods, assumptions and local biomass data (Figure 2 and Table 1). The number of stratums at tier 2 are 28 for biomass and 42 for soils, resulting in a total carbon map of almost 700 stratums (28 without soil) (Figure 1 and 2). In the tier 1 analysis, only 3 of the 5 carbon pools are considered. Under tier 2, the 5 carbon pools are taking into account.

In the tier 2 MCT (2010) carbon map, the biomass carbon distributions resulted in quadrants due to the RADAM volume sheets extrapolation. That is why, an alternative tier 2 carbon map was made with the mean biomass value of each forest vegetation physiognomies (ignoring the RADAMBRASIL Volumes) (Figure 2). According to IPCC GHG (2006) and VCS (2011), the mean biomass of plots measured in each stratum is the correct form to represent the forest biomass content after an statistical analyses to calculated the number of plots needed to represent each forest vegetation stratum. Taking into account the soil carbon pool, increases a lot the number of stratums in the final biomass carbon maps it could be seen in Figure 2.

The number of plots calculation has to be made before the biomass measurements starts. In the RADAM case, plots measurements were made using another approach according Volume sheets. That is why the alternative tier 2 map was a first approximation to a series of analyzes that have to be made to improve the biomass distribution of tier 2 MCT (2010). Between them, a) Use the RADAM data of each forest vegetation strata to see if the number of plots are enough to represent the biomass content in the stratum or if it is needed more local biomass data (ignoring the Volumes). b) Use another available biomass databases as the RAINFOR database (http://www.forestplots.net/) to complete, validate and improve the RADAM data in the forest vegetation stratums were the RADAM plots are not enough. c) Make an uncertainty analysis of all the inputs, methods and assumptions to have a clear idea of where the MCT (2010) approach can be improved (for tier 1 an uncertainty analysis has to be made too). d) A comparison of the tier 1 and tier 2 MCT (2010) maps with other regional and global carbon maps as the analysis made in Ometto et al. (2010) but including an uncertainty analysis can lead us to a consistent and trustful carbon map for the Brazilian Amazon.

CONCLUSIONS

In this study, we understood the whole process of the Brazilian Amazon at IPCC tier 1 carbon map (global products and default emissions factors) as the tier 2 carbon map used in Brazil`s Second National Communication to the UNFCCC (MCT, 2010), also we made some suggestions to improve the MCT (2010) approach.

Tier 1 carbon map, simplifies a more complex reality due to global data, default methods and assumptions. On the other hand, MCT (2010) tier 2 map has much more detail due to regional inputs (maps), methods, assumptions, measured biomass data and carbon pools. However. the biomass distribution of tier 2 MCT (2010) results in quadrants because of the RADAM Volumes extrapolation, in an intent of improve these distribution, an alternative tier 2 carbon map was elaborated using the mean biomass of the RADAM plots measured in each forest vegetation stratum. This alternative map has a better carbon stocks distribution, even though future studies have to be made to compare, validate and improve the RADAM data used in the MCT (2010) tier 2 approach, most of all an uncertainty analysis that will give the key points to get a consistent carbon map for the Brazilian Amazon.

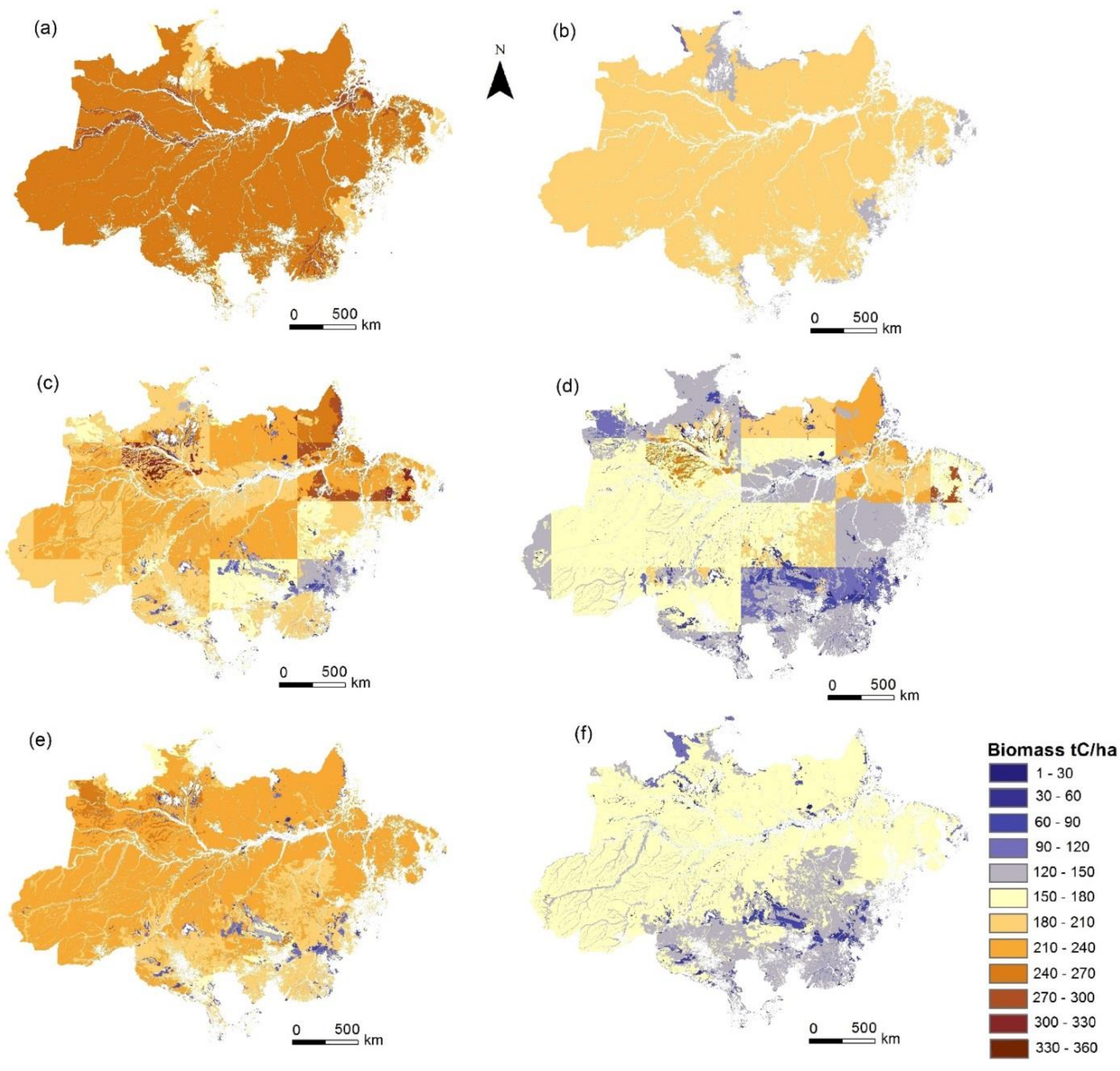

Figure 2. (a) Tier 1 carbon map including soil. (b) Tier 1 carbon map without soil. (c) MCT (2010) Tier 2 carbon map including soil. (d) MCT (2010) Tier 2 carbon map without soil. (f) Alternative tier 2 map using MCT (2010) data including soil. (g) Alternative tier 2 map using MCT (2010) data without soil.

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