Effect of CO_2 increase on ecological parameters of plant ecosystems of Central and South America countries

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Abstract. The carbon sink capacity of the forest makes forest conservation a mitigation mechanism against climate change. Therefore, carbon sequestration studies allow to assess forest productivity and control carbon budgets. Thus, the changes in environmental parameters (carbon amount in humus and phytomass) as effect of the increase of CO_2 emissions, deforestation and erosion were calculated for countries of the Central and South between 2000 and 2060 through the Spatial Mathematical Model of the Global Carbon Dioxide Cycle in the biosphere. The majority of countries show a decrease in total carbo of humus and phytomass between 2000 and 2010, which is attributed to the extreme deforestation that they suffered. Subsequently, there is a moderate increase in countries that has better polices in favour of environmental protection. Finally, in all countries an exponential increase until 2060 is observed, which is expected thanks to forest conservation, reforestation policies and the compensatory effect between the atmosphere and forests. The highest values of total carbon belong to one country in the Caribbean (Belize with 21,5%). This analysis is useful for planning environmental practices in order to increase carbon storage.

1 Introduction

Global climate change is threatening the world as result of the imbalance between population increase and the natural resources ability to sustain the growing demand. Latin American and the Caribbean region (LAC) has made a small contribution to the climate change across the time. However, it has suffered the impact of physical and biophysical climate change under different levels of global warming and it is predicted that the future impact of climate change will be severely, even under lower levels of warming. The LAC region is highly vulnerable to climate change due to its geography, climate, socioeconomic conditions and demographic factors [1–3].

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The main cause of climate change are the greenhouse gas emissions. Carbon dioxide is one of them and has increased its levels due to anthropogenic impacts such as deforestation, land degradation and atmosphere pollution. LAC region had the highest emissions of CO_2 as a result of land use change, mainly deforestation, from the 1980s to 2000s [4]. The forest area of South and Central America has decreased between 1990 and 2015. Although the deforestation rate in the period 2010–2015 (0.23% per year) is almost the half in comparison to the period 2000–2010 (0.44% per year), it still remains high. The Caribbean deforestation is considerably less than in Latin America, owing to smaller country size, but when relative deforestation rates are considered, Honduras and Nicaragua show the highest values for LAC region. Agricultural expansion and more recently the land use for biofuel are the principal cause of deforestation [2, 5].

LAC region has a very large amount of organic carbon stored in the forests, the carbon amount accumulated in these forests biomass was 104 Gt by 2012. From 2000 to 2005, the gross carbon emission due to deforestation of tropical forests averaged 0.81 billion tons per year [6, 7].

Biomass estimation allows to assess the forest productivity, control carbon budgets and have a better understanding of carbon cycle [8]. Therefore, the objective of this research is to analyse the effect of CO_2 increase on ecological parameters of forest communities in Central and South America countries by estimating and forecasting the carbon amount in phytomass and humus through the spatial model of the global carbon cycle of the Computing Center of the Russian Academy of Sciences (CC RAS) to evaluate and compare the compensatory functions of forest communities under anthropogenic impacts in the LAC region.

The model of global carbon cycle used in this research is a better methodology to forecast the carbon dynamics and know the role of terrestrial ecosystems in anthropogenic compensation because it is not invasive, time and labour consuming and the only method that forecast future variations [9–11].

2 Materials and methods

To study the regional effects of global warming and land use in countries of South and Central America, we calculated changes in phytomass, humus and total carbon due to industrial CO_2 emissions, deforestation and humus erosion associated with poor land management under the Spatial Model of the Global Carbon Cycle [9] between 1860 and 2060. It is a universal model where the land surface is divided into cells of 0.5 x 0.5 degrees in the geographic grid (50 x 50 km).

The model describes the processes of vegetation growth, decay, accumulation and humus decomposition in terms of carbon exchange between the atmosphere, plants and soil in every cell. It takes into account that industrial CO_2 emissions are mixed about two weeks in the latitudinal direction and for 2–3 months in the meridional direction, for one year. Therefore, each country or region simultaneously experiences an effect of climate change, depending on the total emissions of all countries of the world during the year. To calculate climate changes occurring during global warming in one region or country, the global spatial model of the Carbon cycle was applied, which takes into account that the total CO_2 emissions started in the industrial period (1860).

The model variables are the carbon amount in the phytomass of land vegetation and in the humus of soil in each cell, as well as the amount of CO_2. The classification of J. Olson's ecosystem types was adopted that includes agricultural ecosystems [12]. For the carbon balance of the country, the CO_2 absorption capacity should be assessed as an integral part of the global balance, taking into account the contribution of not only forest but also other biomes (meadows, farmland, swamps, tundra) [13].

The climate in each cell is characterized by the average annual air temperature near the earth surface and the precipitation amount per year, it also considers the greenhouse effect of CO_2 emissions. The values of temperature and precipitation for each land cell are calculated using the climate model of the general circulation of the atmosphere and the ocean [14]. The model is supplemented by a carbon cycle model in the atmosphere-ocean system [9].

In order to model the dynamics of the biosphere from 1860 to 2060, the following baseline scenario was adopted. The anthropogenic release of CO_2 into the atmosphere begins in the industrial age (1860), these values of industrial CO_2 emissions between 1751 and 2013 were taken from literature [15]. After 1950, the deforestation and subsequent destruction of tropical forests is underway. During this period, the mass of tropical forests decreases by 0.6% each year [9] and the corresponding amount of CO_2 from decomposed organic matter of wood went into the atmosphere. In addition, the unsustainable exploitation of land generated soil erosion and the corresponding amount of CO2 from the released humus enters the atmosphere. The rates of erosion started in 1860 and were 0.15% per year [9]. A different change in deforestation and erosion in time is taken into account in different scenarios over time. The deforestation and erosion area is given by the type of ecosystem.

To study the regional effects of global warming and the effects of improper land use in the countries of the Central and South American region, we plot the changes in phytomass, humus and total carbon due to industrial CO_2 emissions, deforestation and soil erosion for the period 1860–2060. Plots of humus, phytomass and total carbon variation are given for relative values of variables; number 1 on them means the year 2000. This method of presenting results is convenient for the comparison of the growth of variables for one plot and for different variables in different countries.

All countries in Central and South America were grouping according to similar bioclimatic, land productivity potential and the effect on temperature, and humidity. Within this classification, 4 groups of countries were identified:
Andean America: Venezuela, Colombia, Peru, Ecuador, Bolivia
Central America and the Caribbean: Belize, Trinidad and Tobago, Costa Rica, Jamaica, Dominican Republic, Panama, Nicaragua, Cuba, Haiti
Tropical South America: French Guiana, Paraguay, Suriname, Brazil, Guyana
Southern South America: Argentina, Uruguay, Chile

3 Results and discussion

In Andean America countries, a decrease in carbon content of phytomass and humus between 2000 and 2020 is observed. Subsequently, it increases until 2060 (Fig. 1). The humus decrease until 2020 is coordinated with numerous studies of deforestation in these countries [3–5, 16–19]. The following soil humus increase during 2020-2060 is opposed to soil erosion, it is a compensatory effect associated with an increase in productivity and phytomass. Also, the increase is influenced by regional climate change resulting from global warming. The greatest humus increase occurs in Venezuela and Colombia (Table 1). The increase in 2060 compared with 2000 is 5 and 4.7%, respectively and the smallest in Bolivia (1.7%), which is associated with biogeochemical soil characteristics and the different responses of vegetation to an increased concentration of carbon dioxide in the atmosphere.

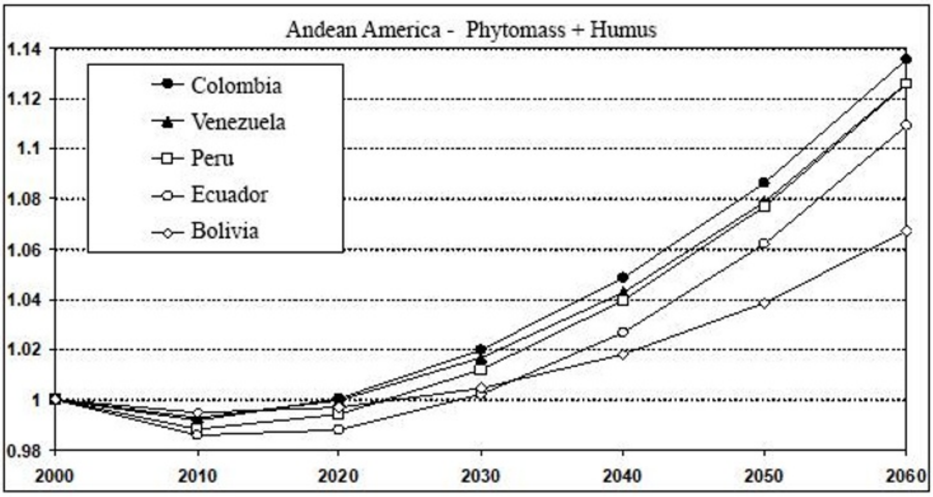

Fig. 1. Total carbon change (humus + phytomass) in Andean America between 2000 and 2060.

Bolivia plays an important role in deforestation owing to the laws promotion about alienation of forest land. In the period 1994–2004 as a result of the agriculture expansion, the deforestation area was 10,110 km^2 [20]. In addition, gold mining is another deforestation cause in Colombia, Venezuela, Ecuador, Peru and Bolivia, resulting in a forest loss of approximately 1,680 km^2 [17, 21]. In Peru, the average annual deforestation associated with gold mining increased tree times between 1999–2007 and 2008–2012 (from 21.66 km^2/year to 61.56 km^2/year, respectively). Forest biomes are also subject to anthropogenic degradation as a result of the heavy metals emissions (Cu, Zn, Hg) of the gold mining industry [22].

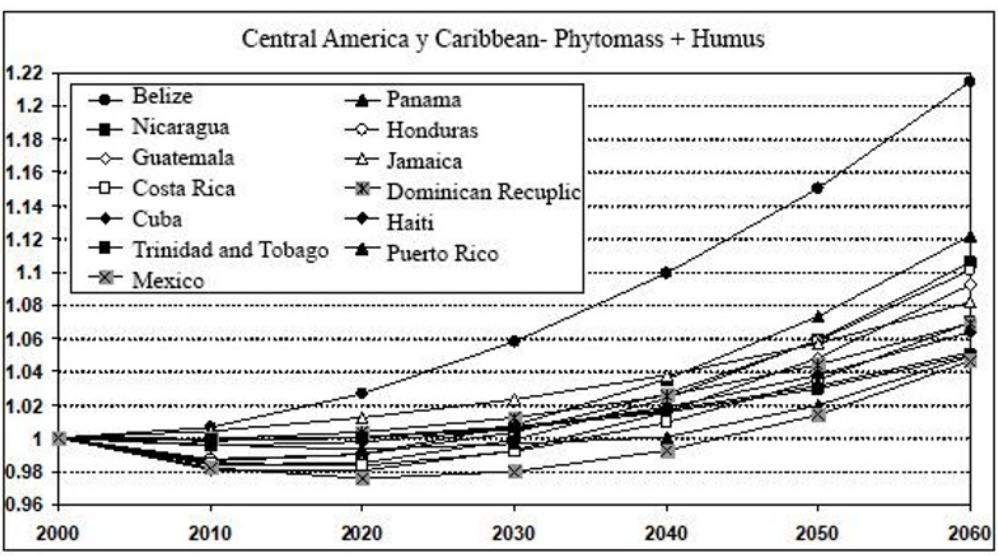

Fig. 2. Relative change in total carbon in Central America and the Caribbean during 2000–2060.

For the countries of Central America and the Caribbean a similar trend is observed. The results show a decrease in carbon content of phytomass and humus until 2020, except for

Belize (Fig. 2). Belize has the highest growth (21.5% compared between 2000 and 2060, Table 1). It is because more than 40% of the territory belongs to reserves and national parks. Furthermore, a significant part of relict forests (65%) remains intact, and forests occupy almost half of the country's territory. Also, organizations such as the World Wide Fund for Nature and the Smithson Institute support Belize in the field of environmental protection. Thus, the country has become a recognized leader in this field. Belize has an environmentally friendly tourism policy and today there are more protected areas in the country than in any other region of Latin America. In contrast, Costa Rica, Guatemala, Nicaragua, Panama and Honduras show a decrease after 2000 that it is associated with deforestation of tropical vegetation. After 2010 countries increase the total carbon amount. Trinidad and Tobago and Mexico have the lowest growth. For Trinidad and Tobago, the problem of illegal quarrying is acute today, which is accompanied by significant deforestation in the north of the country [23].

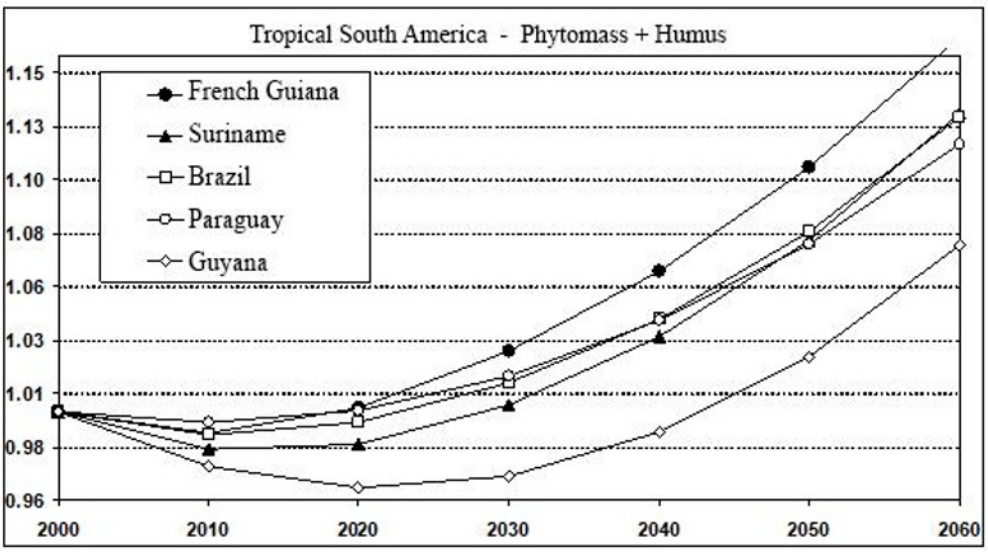

Fig. 3. Total carbon changes in Tropical South America counties during 2000–2060.

Analysis data for Tropical South America countries showed (Fig. 3) that the greatest increase in phytomass carbon and humus until 2060 is for French Guiana (15.7%, Table 1). It is reported that since 2009, the Government of French Guiana has supported the project of Low Carbon Development Strategy (LCDS). This project seeks a low-deforestation, low carbon, and climate-resilient economy. Also, it supports the payments to rainforest countries like Guyana for its storage of forest carbon under the REDD + mechanism (Reduce Emissions from Deforestation and Degradation). As a conceptual basis of the applied methods in the framework of REDD, it can be designate the theory of "forest transition", which implies a transition from reducing forests to increasing forest cover, which means an increase in the area of natural absorbers of greenhouse gases, and thus the prevention of emissions [24]. For Suriname, Brazil and Guyana there is a decrease in humus between 2000 and 2020. Then an increase in the amount of carbon for all countries is observed. The smallest increase is attributed to Guyana (5.8%).

In the estimation of humus in Southern South America countries (Fig. 4), a decrease is observed in Chile and Uruguay between 2000 and 2020. Then, the humus decrease stops and is replaced by growth. In the case of Argentina there is a humus and phytomass increase across the time and has the highest values (9.8%, and 25%, respectively, Table 1).

The lowest value is observed in Uruguay with -5.7% of carbon in humus. In Southern South America countries, forest plantations for industrial use partially compensate the loss of natural forests. For instance, Chile increased the area of commercial plantations in the period 2005-2010 with commercial species like *Pino rabiata*, *Pino insigne*, *Eucaliptos globulus* and *Eucaliptos nitens*, which disrupt water regime, increase soil aridity and reduce carbon sequestration potential. However, the increase in forest area for industrial use decreases the area of primary forests, releases the carbon stored and when planting "carbon" forests is in wetlands, carbon release from soil may exceed its accumulation in wood [25].

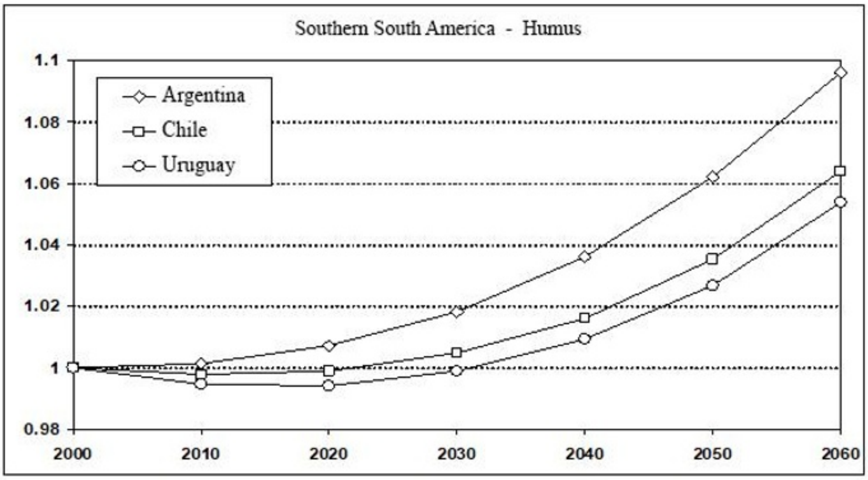

Fig. 4. Carbon change in humus of the countries of Southern South America during 2000–2060.

Table 1. Maximum carbon changes (%) in humus, phytomass and total change in Central and South America plant formations under the influence of anthropogenic factors.

Region	Country (Highest value)	Humus	Phytomass	Humus + Phytomass
Andean America	Venezuela (V) Colombia (C)	5 (V)	11.8 (V)	13.8 (C)
Tropical South America	French Guiana (FG) Brazil (B)	8.1 (FG)	12 (B)	15.7 (FG)
Central America and Caribbean	Belize	10	13,8	21.5
Southern South America	Argentina	9.8	25	25.8

4 Conclusions

In general, a low amount of carbon in humus and phytomass in the carbon dynamic of LAC countries forests from 2000 to 2010 is consistent with the rate of deforestation and erosion. In the following 10 years a slight increase in biomass is observed as a result of two possible reasons 1) Implementation of conservation and reforestation projects, such as REDD+ and 2) Compensatory effect between the atmosphere and forest ecosystems. Finally, the trend for 2060 is an exponential increase in biomass. This increase is also attributed to the same two reasons. The highest values of total carbon belong to one country in the Caribbean (Belize with 21,5%) thanks to a stronger emphasis on the recognition of environmental services of forest ecosystems. In Southern South America a theory of forestry transformation is identified as the reason of the carbon amount increase. Nevertheless, this establishment of agroforestry systems also has a negative effect (primary forests loss and decrease of carbon sinks), so the main short-term mitigation potential is reducing deforestation.

The calculations for different climatic zones of South and Central America can be used to determine the criterion of biospheric resistance of countries to anthropogenic impact in conditions of increasing carbon dioxide concentration and in studying the dynamics of forest degradation from anthropogenic and climatic influences. The resulting forecast can be carry out conservation strategies such as mapping of the potential damage to forests, calculation of the biological damage to forest biogeocenosis, and implementation of the concept of “deforestation prevention” for all countries of Central and South America.

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