LAND USE AND LAND COVER MAP OF A SEMIARID REGION OF BRAZIL FOR METEOROLOGICAL AND CLIMATIC MODELS

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ABSTRACT

An updated vegetation cover and land use map over a semiarid region of Brazil has been produced at a 1 km spatial resolution, using satellite data and remote sensing techniques, for application in climate modeling. The map presents the location and distribution of major vegetation types and non-vegetated land surface formations for the Northeast Brazil Region, which includes the semiarid region. In this study, Radambrasil and IBGE vegetation maps, a digital mosaic of ETM[+] Landsat 7, and TM Landsat 5 images from the period 1999-2000 were used. To update the map, the techniques of segmentation and unsupervised classification (ISOSEG) were applied. A total of 7 land cover and land use categories were mapped according to the "Simplified Simple Biosphere"(SSiB) model legend. This map shows that there has been a considerable increase in agricultural activities and pasture area. The vegetation in this region is an intricate combination of different life forms (e.g., trees and shrubs forming a closed cover) in this region. The semiarid region of Brazil is susceptible to desertification due to climatic and environmental conditions. This updated map should provide important input for regional stratification in climate studies.

Keywords: Land use change, Biogeophysical Model, Remote Sensing, Semiarid.

RESUMO: MAPA DE USO E COBERTURA DA TERRA DO SEMIÁRIDO DO BRASIL PARA MODELOS CLIMÁTICOS E METEOROLÓGICOS

Através da utilização de imagens digitais e técnicas de sensoriamento remoto, foi produzido um mapa de uso e cobertura da terra da região do semiárido do Brasil para aplicação em modelagem climática. O mapa apresenta a localização e distribuição dos principais tipos de vegetação e de formações não vegetacionais da superfície da terra para a região Nordeste do Brasil. Neste estudo foram utilizadas mapas de vegetação do Radambrasil e IBGE, mosaico digital de imagens Landsat 7 ETM[+] e Landsat 5 TM do período de 1999-2000. Para atualizar o mapa foram aplicadas técnicas de segmentação e classificação não supervisionada (ISOSEG). Foram mapeadas um total de sete classes de uso e cobertura da terra, que foram compatibilizadas com a legenda do modelo de superfície "Simplified Simple Biosphere – SSiB" para o uso em modelos climáticos e meteorológicos. A vegetação nesta região é caracterizada por diversos padrões morfológicos, que dependem da localização geográfica e das condições climáticas. Os resultados obtidos pelo mapeamento indicam um aumento considerável nas atividades agrícolas e nas pastagens, e consequentemente, a redução da vegetação natural. Considerando que a região é suscetível a desertificação, devido as suas condições climáticas e ambientais, o mapa atualizado é de extrema importância para estudos que envolvam os impactos das mudanças dos usos e cobertura da terra no clima.

Palavras-chave: Mudança de uso da terra, Modelos biofísicos, Sensoriamento Remoto, Semiárido.

1. INTRODUCTION

During the last few decades, the scientific community has dedicated efforts to evaluate the climatic impacts resulting from anthropogenic and natural land cover changes (Gao et al., 2003; Souza, 2006; Findell et al., 2007). Numerous studies using General Circulation Models and Regional Climate Models (GCMs and RCMs, respectively) have shown that climate is sensitive to the physical characteristics of vegetation and soil because these characteristics control the exchange of energy, water and *momentum* between the atmosphere and land surface (Xue and Shukla, 1993; Clark et al., 2001; Taylor et al., 2002; Oyama, 2002; Xue et al., 2004; Souza, 2006; Oliveira, 2008, Souza and Oyama, 2011). Moreover, the misrepresentation of land cover in atmospheric models may have negative impacts on the accuracy of weather forecasts and seasonal climate predictions (Wilson et al., 1985; Hall et al., 1995; Sud et al., 1996; DeFries et al., 1999; Champeaux et al., 2000; Kang et al., 2007, and others). Fenessy and Xue (1997) studied the impacts of the representation of vegetation on GCM simulations during summer. For the United States, their results showed that the use of a new vegetation map based on 1990 satellite and surface observations produced significant differences in both monthly and seasonal simulations of evaporation, surface air temperature, and precipitation. Champeaux et al. (2000) created a satellite-derived land cover map for Western Europe for use in the operational French ARPEGE model. The new map contributed to improvements in weather forecasting. Errors, especially in the description of the diurnal cycle of temperature and relative humidity, were reduced. Therefore, to obtain more accurate simulations, it is necessary to provide realistic and up-to-date land cover spatial distribution data to the land surface schemes within atmospheric models.

Among the different land surface schemes developed to be coupled with atmospheric models, the Simplified Simple Biosphere Model (SSiB) (Xue et al., 1991) is used within the operational atmospheric models (GCM and RCM) of the Center for Weather Forecasts and Climate Studies (CPTEC). SSiB is a simplified version of the Simple Biosphere Model (SiB) (Sellers et al., 1986) and simulates the land-atmosphere interactions including radiative and turbulent processes, and biophysical control of transpiration. In SSiB, a vegetation class is prescribed in each grid cell. Therefore, it is important to have accurate and updated vegetation maps. The main sources for the distribution of world vegetation types were the physiognomic classification of Kuchler (1983) and the land use database of Matthews (1984), which were used to form the original SSiB vegetation map (Fenesssy and Xue, 1997). SSiB uses the vegetation classification proposed by Dorman and Sellers (1989), which considers 11 natural biomes and 1 crop class (winter wheat) (Table 1). It is emphasized that the CPTEC operational system uses the global base of the vegetation information in the SSiB scheme coupled with GCM and RCM. This global base was produced at the University of Maryland (UMD) based on data from Pathfinder AVHRR Land (PAL) at a horizontal resolution of 1 km. This map was prepared using 13 years of remote sensing data (1981-1994, De Fries et al. 1999; Hansen et al., 2000).

Cândido (2002) found that the vegetation map classification from UMD for the SSiB scheme classes produced inconsistencies in some regions of the Brazilian territory. For example, a large area of "caatinga" (Broadleaf Shrubs with Groundcover in SSiB legend) was found in parts of the Central Region and in Southern Brazil, and it led to excessively high temperature values in simulations performed by the RCM Eta coupled with SSiB. Cândido used the natural vegetation map of Brazil (IBGE, 1993) to determine the extent of biomes that

Table 1- Classes compatibility of ProVeg, IBGE and SSiB

ProVeg-NEB	IBGE	SSiB
Broadleaf Evergreen Trees	Pioneer Formations and *Ombrofila* Forest	Tropical Rain forest
Deciduous Forest	Seasonal Deciduous and Semi-deciduous Forest	Broadleaf Deciduous Trees
Savanna (*cerrado*)	Savanna	Broadleaf Trees with Groundcover (Savanna)
Caatinga	Steppe and Steppic Savanna	Broadleaf Shrubs with Groundcover
Farming	Agricultural activities	Crops
Bare soil	Not mapped	Desert
Water bodies	Not mapped	Ice and water bodies

were incorrectly classified and created a new version of the vegetation map including only the natural biomes.

Lapola et al. (2008) developed a new world natural vegetation map at a horizontal resolution of 1 degree for use in global climate models. They used the Dorman and Sellers (1989) vegetation classification with the inclusion of a new biome, Tropical Seasonal Forest, which refers to both deciduous and semi-deciduous tropical forests. The natural vegetation maps of Ramankutty and Foley (1999) and of Matthews (1983), both at a horizontal resolution of 1 degree, were used to create a unified map. Other digital maps, such as that of the natural vegetation of Brazil (IBGE, 2004) and that of Alaska (Küchler, 1996), were also used. This new map was designed to accurately reproduce the large-scale distribution of the main vegetation types and regional details. Similar to the map of Cândido (2002), the map produced by Lapola et al. (2008) did not consider land use changes.

Even though there are other vegetation cover maps (Eva et al., 2004; Hodges, 2002 and others) available to use in meteorological and climate models, this work is part of an attempt to map the land cover and land use of the Brazilian territory with greater resolution (30 meters) than the existing global maps (1 km). This greater resolution allows the creation of maps with a more detailed scale (1:250 000).

The first part of the research involved developing a vegetation map of Legal Amazon (named Proveg-AMZ) with a spatial resolution of 1 km for the year 2000. The inputs for this map were obtained from a variety of sources: 1) the digital vegetation data of the RADAM-IBGE project; 2) the thematic data of deforestation generated by the Amazon Program (deforestation assessment in the Brazilian Legal Amazon - PRODES); and 3) Landsat TM image mapping (Sestini et al., 2002). The second part of this research effort, Proveg-NEB, was created to improve the representation of land cover and land use spatial variability of Northeast Brazil (NEB). The semiarid region of NEB presents environmental problems of degradation (for example, desertification processes), and the affected areas may significantly expand as a result of human activities.

Thus, the goal of this paper is to present an updated vegetation map of NEB, including its semiarid region. The map also includes land cover changes, i.e., is not restricted to natural biomes, and is suitable to be coupled with the numerical models used at CPTEC and in other meteorological centers.

2. SEMIARID REGION OF BRAZIL

The study area (Figure 1) is located in the equatorial zone (1-21ºS, 32-49ºW), covering an area of 1,797,123 km^2 and representing approximately 20% of Brazilian territory. The limits of the study area were defined by the "Superintendência de Desenvolvimento do Nordeste (SUDENE)". The study area is covered by 86 Landsat images and is monitored in real time by CPTEC within the scope of the Climate Monitoring Program of the Northeast Region (PROCLIMA) (Souza at al., 2001).

The rainy season extends from February to May, when the Intertropical Convergence Zone (ITCZ) reaches its southernmost position (Kousky, 1979; Oyama and Nobre, 2004). Annual precipitation is less than 800 mm on average and is subject to large interannual variability. Part of this variability is explained by El Nino –Southern Oscillation (ENSO) related large-scale climate teleconnections (Hastenrath and Heller, 1977; Kousky et al., 1984, Kayano and Andreoli, 2006). Other factors, in addition to ENSO, that take relevant part in the interannual climate variability over NEB are associated with the tropical Atlantic SST variability. A SST variability mode in the tropical Atlantic, referred to as a SST dipole mode and
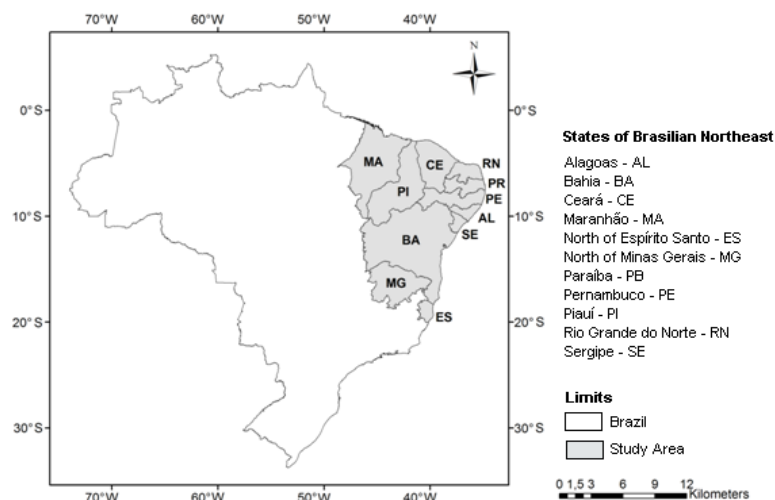

Figure 1 - Study Area.

displaying an asymmetric SST anomaly pattern about the equator, has long been related to interannual climate variations over NEB (Hastenrath and Heller, 1977; Hastenrath, 1978; Moura and Shukla, 1981; Hastenrath, 1990; Hastenrath and Greischar, 1993; Souza et al., 2000, Kayano and Andreoli, 2006).

The soils present a large variation in type and association. Soils in the coastal zone are deep, low fertility Latosols; in the semiarid zone, the soils are shallow, high fertility Luvisols; and in the western portion, the soils are similar to those in the coastal zone.

There are different types of vegetation covering the region. Along the coastal areas, there are mangroves and dune vegetation, whereas places with tropical climate, such as the middle of the western region, are covered with savanna. In the western extreme of Northeast Brazil, where the climate is equatorial, the Amazonian Forest is found next to an area known as "Mata de Cocais" due to the abundance of babaçu (Orbignya oleifera Burret) and carnauba (Copernicia prunifera) palm-trees. A xeromorphic vegetation classified as Savanna Estepica (Broadleaf Shrubs with Perennial Groundcover), regionally known as caatinga (Veloso et al., 1991), covers an area of 558,526 km^2 in the semiarid area. The semiarid climate dominates the regional landscape. During the dry season, the vegetation is dry and without foliage, the trees are sparse, and the soil is mostly uncovered, showing isolated shrubs and exposed roots.

In the semiarid areas of the NEB, rural areas in the interior are generally used for subsistence agriculture, primarily with crops of beans, manioc, potatoes and others (Cavalcanti, 1999).

3. METHODS

The methodology included two distinct steps: 1) the correspondence between the classes of the RADAMBRASIL (1:1000000) and IBGE (1:5000000) vegetation maps and those included in the SSiB model (Table 1) and 2) the mapping of the classes of land use and land cover. Because the number of classes in the SSiB model is limited, adaptations were made for some classes and different types were grouped into a single category. The farming class corresponding to type 12 of the SSiB model includes crops in different stages of growth, as well as pasture. The bare soil class, corresponding to the type 11, includes areas with rock formations, sand dunes, bare soil, roads and urban areas.

It is important to note that the RADAMBRASIL and IBGE vegetation maps were used as auxiliary data, serving as a basis for compatibility of the legend and assisting the image interpretation process.

3.1 Image classification techniques

The methodology used in this study was developed by Sestini et al. (2002) and originally was used for mapping the area of Legal Amazon. The authors integrated data from PRODES and used automatic classification and visual interpretation of Landsat TM images. Enhancement techniques were also used to minimize possible errors concerning the interpretation of vegetation classes, mainly between short and open vegetation and anthropogenic areas. The image processing was also adopted to resolve conflict areas of vegetation. Thus, a number of different remote-sensing data sets were used to create the map presented in this work. Mosaics for each of the states of the region were composed of high resolution (30 and 60 m) Landsat Thematic Mapper TM data from the years of 1999, 2000 and 2001 (Table 2). A total of 162 satellite images were used in the preparation of the vegetation cover map.

The RADAMBRASIL and the IBGE vegetation map (1:1000000 and 1:5000000, respectively) were adjusted over the satellite images and used as auxiliary data. The images were classified by means of unsupervised classification, using the Isoseg algorithm. Unsupervised classification is a method that examines a large number of unknown pixels and divides them into a number of classes based on natural groupings present in the image values. The classification process can be described briefly as follows: first, the user provides a percentage acceptance threshold. This threshold defines the maximum Mahalanobis distance (Richards, 1995) from which regions can be from the center of one class and still be considered as belonging to that class. It also determines the number of class "clusters" detected by the algorithm. Iteratively, the classifier removes from the list all regions with a Mahalanobis distance smaller than the acceptance threshold. The user controls the level of detail through the acceptance threshold: more classes for higher significance levels (<80%) or fewer classes for lower significance levels (> 95%). After testing several thresholds, the threshold of 90% was accepted, which appropriately separated classes without creating redundancy.

The images for each state of the RADAMBRASIL and IBGE maps and the corresponding SSiB classes were re-sampled to 1 km resolution. The zonal majority operator was used, where by the value in all geographical locations within a region is equal to the most frequently found value in that region (Barbosa et al., 1998).

4. RESULTS

Figure 2 illustrates the correspondence between the vegetation classes of the IBGE map (IBGE, 1993) and the classes of the SSiB model. The areas of ecological tension or

Table 2 - Summary of the data sets used for the image mosaics

State	Dates	Cloud Cover (%)	Number of images	Resolution (m)
MA	2000	2	22	60
PI	1999-2000	5	21	30
CE	1999-2000	5	11	30
RN	2002	6	07	15
PB	1999-2000	6	06	30
PE	1999-2000	5	09	30
AL	1999-2000	5	05	30
SE	1999-2000	3	03	30
BA	1999-2001	2	36	30
MG	2001	0	36	30
ES	2001	0	06	30
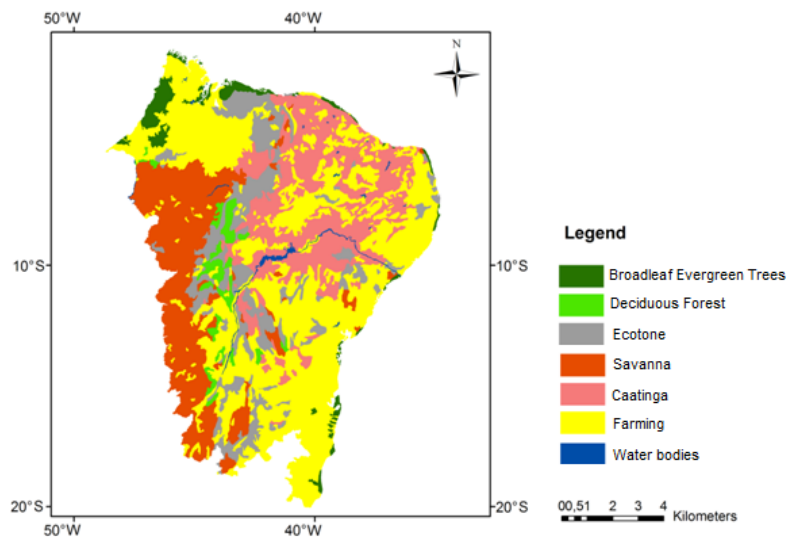
Figure 2 - IBGE map with SSiB classes.

contact are defined as those that combine two or more types of vegetation cover with physiognomic structures that are similar or dissimilar. The contacts map depends on the type and scale (Veloso et al., 1991).

When data or maps at finer spatial resolutions are used, the contacts can be resolved. It is very important to resolve the contact areas because they may contain significant areas of human activities (or anthropized areas). Mapping these areas, for example, enables investigation about the possible effects and feedbacks induced by anthropogenic land use change on the climate.

The contact areas in the IBGE vegetation map were classified and resolved by image segmentation, visual interpretation and information from experts in semiarid environments (Figure 3). The ecological tension areas in the IBGE map are extensive, corresponding to 20% of the total area of natural vegetation (Table 3). The land use and land cover map of NEB, including the semiarid region, is shown in Figure 4.

In Table 3, Column 2 shows the amount of area covered by natural vegetation without anthropogenic land use in the IBGE map (1993), while Column 3 shows the area estimates for each vegetation type with anthropogenic land use in the

Table 3 - The distribution of land cover classes across Northeast**.**

| Land Cover and Land Use	IBGE classes (1993)		Natural vegetation and anthropogenic land use (IBGE, 1993)		ProVeg-NEB classes (2000)	
	(km²)	(%)	(km²)	(%)	(km²)	(%)
Broadleaf Evergreen Trees	255.25	14.34	53.02	2.96	102.034	5.68
Deciduous Forest	284.26	15.96	45.60	2.54	114.79	6.39
Savanna	344.56	19.34	310.54	17.32	241.40	13.43
Caatinga	558.53	31.36	352.36	19.65	273.59	15.22
Ecotone	338.87	19.00	221.57	12.36	solved	-
Bare soil	-	-	-	-	23.19	1.29
Farming	-	-	798.38	44.50	1,024.62	57.01
Water bodies	-	-	11.92	0.66	17.50	0.97
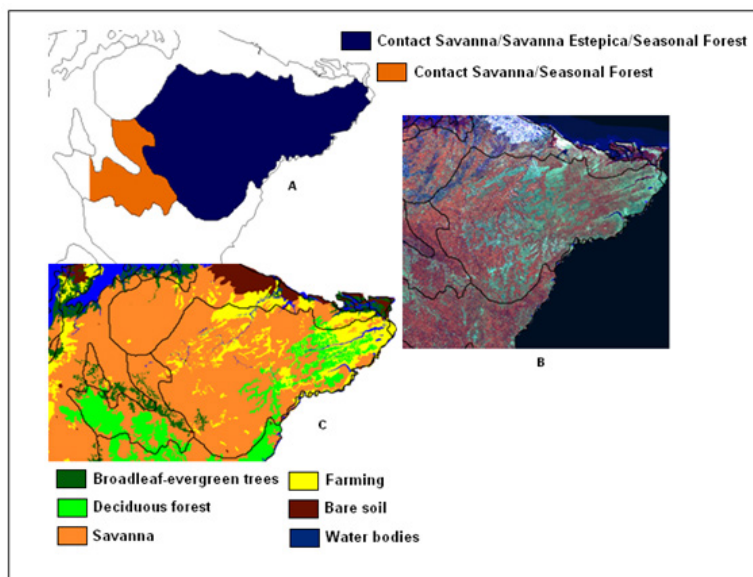
Figure 3 - Contact areas in the IBGE vegetation map

IBGE map (1993). The different types of land cover mapped by the Proveg-NEB project are shown in Column 4. The results obtained from the Proveg-NEB map show that many classes of natural vegetation considered in the IBGE map were degraded with a consequent reduction in area.

Comparing the new vegetation map (2000) with the map of IBGE (1993), it can be noticed that a large savanna area was devastated, meaning that approximately 22% of the natural vegetation has been degraded. In addition, in 1993, the *caatinga* occupied 352,364 km², while by 2000 it had been reduced to

273,590 km², meaning that there was a loss of approximately 22% within a 7 year period. Combined, these two ecosystems, which accounted for 37% in 1993, have been reduced to 29%. However, the areas of Broadleaf Evergreen Trees (53,023 km²) and Deciduous Forest (45,596 km²) increased to 102,034 km² and 114,790 km², respectively. These increases were due to the physiognomic-structural interpretation of the conflict areas (221,573 km²).

An analysis of Figure 4 and Table 3 reveals that there is a notable increase in the extent of the Farming class in the
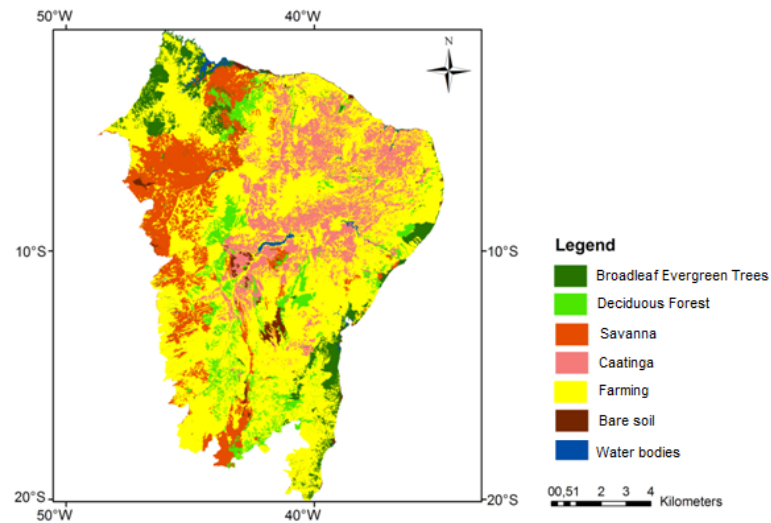
Figure 4 - Land use and land cover map of the Brazilian Northeast (ProVeg-NEB map).

updated map (1,024,621 km²) compared to the IBGE map (798,376 km²). These results correspond with those found in the 2006 agricultural census of the IBGE, which stated that the crop area has increased 20% since the 1996 census. This increase may have occurred due to the progressive integration of grain production and intensive livestock production within the world market (IBGE, 2010). Thus, the increase of crop area can aggravate the problem of local desertification, although other factors must be incorporated into the analyses to validate this hypothesis.

The areas of bare soil, which were not identified in the RADAMBRASIL and IBGE maps, occupy an area of 23,190 km², corresponding to more than 1% of the total area. The areas of highland and rupestrian fields were converted to bare soil, based on the physiognomic characteristics and spectral responses. Bare soil regions have a characteristic spectral signature in Landsat satellite images and a higher albedo than vegetated areas, as evaluated by Cunha et al. (2009). The increase in surface albedo reduces the radiation balance in the top of the atmosphere, inducing subsidence anomalies to maintain thermal equilibrium and, consequently, reducing moisture convergence in low levels, as highlighted by Oyama and Nobre (2004). Thus, it is important to include bare soil areas in maps for surface models because the processes of biosphere-atmosphere interaction for bare soil areas are distinct from those for land covered by vegetation.

The percentages of vegetation cover and land use in the study area are shown in Figure 5. The results indicate that the State of Bahia incorporates the largest number of classes, both in terms of vegetation cover and in terms of use and occupation; this result is expected because it is the largest state in the Northeast region. The state covers 566,049 km², corresponding

to 38% of the total study area and 6.9% of the country. Additionally, the area covered by water in the study area (50%) is concentrated in the State of Bahia. The distribution of land cover types varies in proportion to the area of each state in the region.

In general, the land use and land cover map presented here shows, on a regional scale, the conversion of natural vegetation of *caatinga* and Savanna areas into farming regions (including crop and pasture lands) in the NEB region.

This map is also compared with the default map (not shown) previously used in surface models coupled with the numerical models at CPTEC/INPE. It was observed that in NEB, some classes of natural vegetation were over-estimated. The area of caatinga, for example, was more than 78% of the updated map. Thus, the inconsistencies were detected and resolved, which was possible due to the spatial accuracy of the Landsat data (30 m).

5. DISCUSSION AND CONCLUSIONS

The land use and land cover map of the semiarid region of Brazil for meteorological and climatic models presented here shows that 57% of NEB territory represents anthropic areas, which were previously occupied primarily by caatinga. In addition to anthropic areas and natural vegetation, the map also includes areas covered by bare soil and bodies of water.

It was not possible to compare the area values of land cover change with others publications in the northeast of Brazil, because there is not any other map that covers the whole northeast region and also includes the same classes. However, analyzing regional and Biomes maps (MMA/PROBIO, 2007; IBAMA, 2010) it was noted an accelerated degradation of the natural vegetation corroborating the results presented in this study.
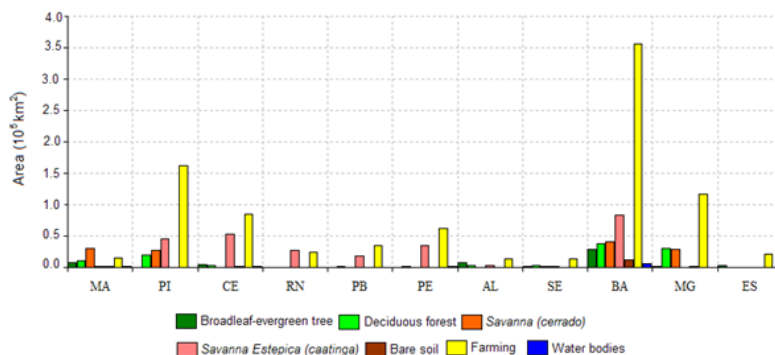
Figure 5 - Area of vegetation cover and land use.

In the context of meteorological modeling, Souza (2006) evaluated the impact of the use of an updated vegetation map for the semiarid region of Brazil on the seasonal climate using the regional model ETA coupled with the SSiB scheme (ETA/SSiB). The experiment considered a previous version of the map presented here. The principal difference between the map used in the simulations and the one used previously in the model was the replacement of caatinga and Savanna by farming (crop/pasture), considered by Souza as corresponding to biome type 12 of Dorman and Sellers (1989). These changes in vegetation cover impacted the simulations of the seasonal climate, mainly in precipitation over the regions (and adjacent areas) of modified vegetation. The results showed that the degradation of small scale areas can also impact climate on both local and seasonal scales (summer and autumn).

The map presented here was originally developed to provide a more detailed representation of the surface in the CPTEC GCM for weather and climate forecasting. However, because the initial spatial resolution is 30 m, the map can be easily adaptable to other surface schemes coupled with atmospheric models.

An assessment concerning this new map is being carried out to investigate the potential climatic impacts resulting from changes in vegetation cover due to human activities or natural processes in the semiarid region of Brazil. The evaluation of land use and land cover dynamics and its climatic implications are essential for decision makers, for public policies and for an integrated management plan of an important region of Brazil.

The four desertification areas of the region are currently being mapped, which is an effort that includes a multitemporal evaluation. It is emphasized that the land use and land cover map of the semiarid region presented here is in the process of being updated to include the most recent data and a finer resolution for crop lands. This initiative must be maintained to support the high demand for a more detailed representation of the Earth's surface, which is essential for the new surface models in development in Brazil.

Compared to IBGE and RADAM maps, the present map used finer spatial resolution data and it allowed more realistic mapping of the land cover/land use spatial distribution as well as the elucidation of the areas of ecological tension.

Although this map was based on 1999-2001 satellite images, there are no maps with recent satellite data for the same studied region. There are Biomes maps developed with different methodologies and also the legend is not compatible for surface models, such as the ones used by CPTEC. Besides that the map presented in this study is being updated with more recent satellite images.

In the future, it will be necessary to identify the types of crops in the study area. In addition, it would be interesting to consider studies with multitemporal images to better delimit vegetation types and cultures that vary seasonally. Finally, field work is extremely important to validate the present map.

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