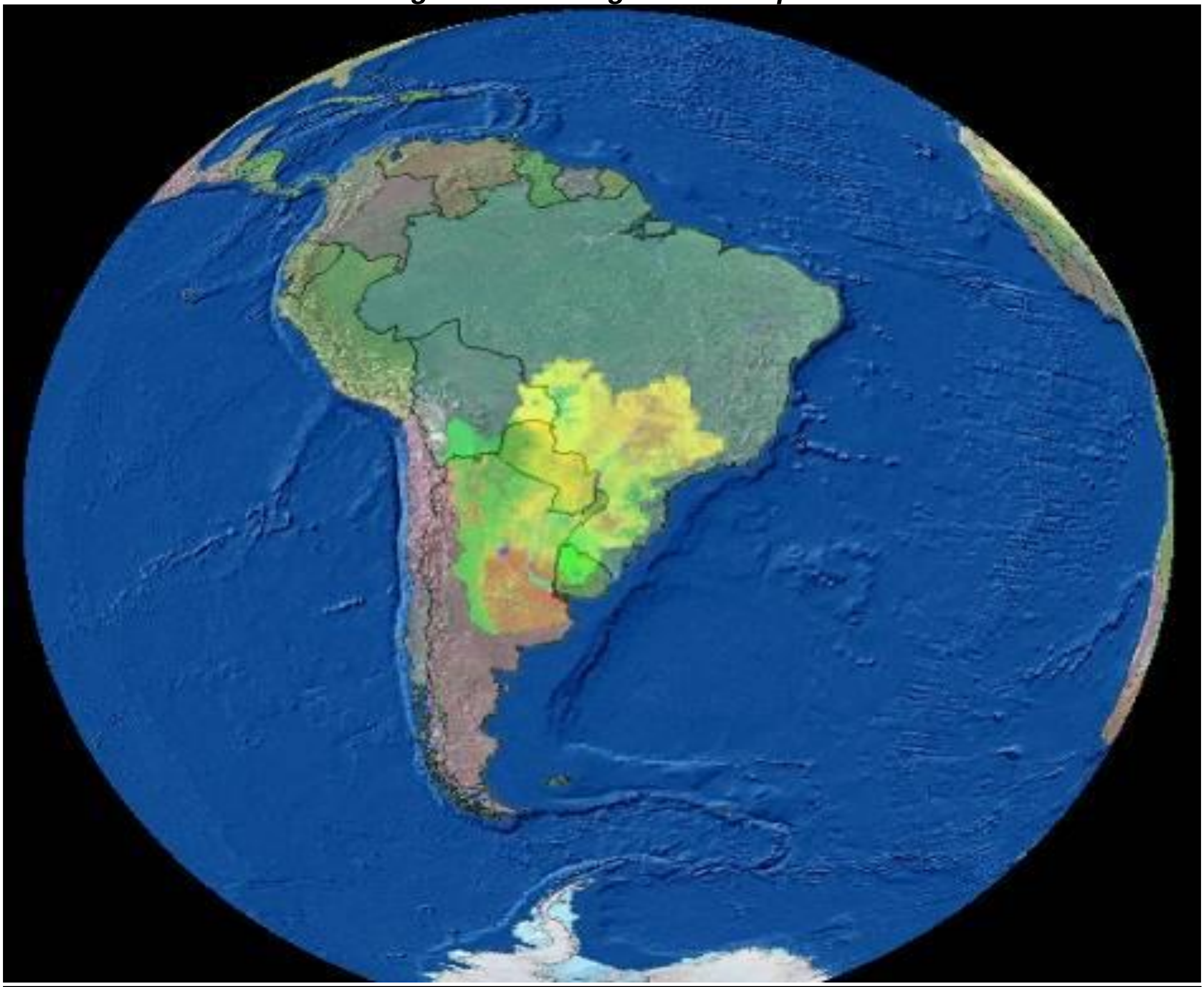
SYNTHESIS REPORT

Land Use Change Monitoring and Dynamics in the La Plata River Basin Using Remote Sensing – Methodological Developments



A synthesis of activities developed under the **IAI/CRN II** and **IAI/IDRC** funded projects *"Land Use Change in the Rio de La Plata Basin: Linking Biophysical and Human Factors to Understand Trends, Assess Impacts, and Support Viable Strategies for the Future"* and *"Landuse Change, Biofuels and Rural Development in the La Plata Basin"*, respectively.

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Plata: a socially, economically and environmentally attractive Basin

The La Plata basin is a region of global importance for the production of agricultural commodities. At the same time, presents fragile biomes for flora and fauna, and a sensitive hydrological system. The Upper Paraná River Basin, for example, supports over 300 species of fish, with a high degree of endemism individual tributaries. The three major ecosystems which are of international importance for conservation of Paraná Plata Basin are the Pantanal, Chaco and Alto Parana Atlantic Forest.

Only 7.4% of the Atlantic Forest cover in Brazil, Paraguay and Argentina exists nowadays. This semi-deciduous subtropical forest is estimated to contain about 7% of the world's species (Bitetti et al., 2003), with many of them endemic.

The Gran Chaco Americano is the largest dry forest in South America and the continent's most extensive forested region after the Amazonia. It occupies territories in Argentina, Paraguay, Bolivia, and Brazil. Extending from tropical latitudes (18°S) to subtropical zones (31°S), the Chaco shows strong climatic gradients, generating (together with geological and topographic characteristics) a range of environments: wide plains, swamps, and dry or seasonally flooded savannas, marshes, salt flats and a variety of forests and scrublands (TNC et al., 2005).

The Pantanal, part of the Upper Paraguay River Basin is one of the largest complexes of wetlands in the world. The ecologically extremely rich Pantanal wetlands cover an area of over 250.000 km^2 shared by Brazil, Bolivia and Paraguay. The diverse Pantanal landscape comprises large rivers, floodplains, alluvial fans, (seasonal) lakes, fossil dunes and saltpans (Jongman, 2005). The three countries protect discontinuous areas of the Pantanal, as national parks and biosphere reserves. This ecologically important region is being threatened. Land that was opening up in an upstream part of the watershed for the cultivation of soybean was left idle when it appeared to be insufficiently fertile for economically viable cultivation. Soil erosion caused silting up of major rivers currently cause serious social and economic problems in the Pantanal, which are mainly used extensive cattle breeding, fishing and tourism (Jongman, 2005). This undesirable situation resulted from improper planning of land use and insufficient biodiversity conservation and water management.

Expected developments and problems in Plata Basin

The pressure on the Plata basin to further boost agricultural activities is vast. The basin assumes, through its growing export of agricultural products, a key role in the international food security (Imhoff et al., 2004). An area of 22 million hectares of natural land has been converted for the cultivation of soybean over the past decade in Brazil and Argentina to meet the growing demands for feed and food exportation. The demand for bio-energy will put further pressure on the natural ecosystems for growing crops (soybean, sugarcane, etc) and for raising cattle. Estimated amounts of soybean production for the year 2020, made ten years ago by the International Food Policy Research Institute, have already been reached today. Millions of liters of bio-diesel and ethanol are required due to government policies and the desire by the largest energy consuming nations to diminish the dependence on petrol. The Plata basin will provide a substantial part of this demand, as demonstrated by the Brazilian Agro-ecological Zoning (Manzatto et al, 2009).

A major external influence on these developments is climate change. This might enhance the pressure on the agro-ecological and economic system of the Plata basin as a whole. The natural environment as present nowadays will have to adapt to the changing climate, agricultural activities have to adapt as well to the already changing conditions to be sustainable in the future.

The Pantanal is expected to play a special role in the climate change scenarios for the basin, being an evaporation window (a source of air humidity) surrounded by an area of dry Chaco and Cerrado.

The implications climatic changes in the Plata basin are not precisely known. Analyses for the Pantanal basin show that several species of plants and animals could become extinct and that open areas could be rapidly colonized by xerophyte species leading to the savanisation under the more dry weather scenarios (Marengo, 2006). Certain phenomena related to climatic variability occurring today appear to be poorly understood, such as the 10% higher discharge of the Upper Paraguay in the 1990s compared to the time before the dry period of the 1980s. The increasing temperatures might reduce crop yields due to a longer dry season (Mata and Campos, 2001)

Apart from the effects of climate change on the basin, the effects of agricultural activities and land use changes in the basin on climate change need to be considered. The large-scale cattle raising in the basin is a major source of methane, a greenhouse gas that has a much higher Global Warming Potential than CO_2. Finally, it also have to be considered, that clearing and burning of natural lands for conversion into rangelands or (subsequent) crop cultivation emit great amounts of CO_2 and CH_4..

<u>The Plata Basin Challenge</u>

Beyond any doubt, the pressure on the resources of the Plata Basin will dramatically increase over the coming decades. The climate changing will have an overall impact on any possible spatial development and ecosystem. The challenge for the Plata Basin is to come up with an increase production of food, (bio)fuel and feed in a changing environment (climatologically as well as socio-economically), with the least impact on remaining natural ecosystems, and incorporating strategies to adapt to and to mitigate climatologically trends in the region. To minimize that challenge, the Land Use Monitoring is necessary, with high temporal satellite data and automatic algorithm land use dynamic detection.

<u>Remote Sensing as Tool to Monitoring and Analyse Land Use Dynamic in “real time”</u>

Contribution of Remote Sensing techniques for crop mapping

Before analyzing agricultural intensification forms and its effects in Plata Basin, it is necessary to map agricultural practices and crops efficiently. In many emergent countries such as Brazil, agricultural statistics are collected through surveys with local subjects leading to a high level of uncertainty and subjectivity. Then, Remote Sensing techniques represent an efficient tool to improve the quality of agricultural statistics. High spatial resolution data such as Landsat images have been historically used to map crops due to their good spatial accuracy. Main projects were developped in USA and the late USSR through the Large Area Crop Inventory Experiment (LACIE) project (Erickson, 1984), and in the European Union through the Monitoring Agriculture through Remote Sensing Techniques (MARS) project (Gallego, 1999). Recent studies have proven the usefulness of moderate resolution data in providing accurate land cover/use classifications. For example, the Medium Resolution Imaging Spectrometer (MERIS) data (with a 300 m spatial resolution) have been used to map land cover at global scale (GlobCover project, http://ionia1.esrin.esa.int/). In countries such as the United States and Brazil, where agricultural areas are characterized by large open fields, the Moderate Resolution Imaging Spectroradiometer (MODIS) data have also been successfully processed to map agricultural areas (Doraiswamy *et al.* 2007, Wardlow *et al.* 2007, Meirelles et al, 2007, Arvor et al 2009a,b, Arvor et al, 2008a,b,c).

Indeed, the MODIS data are commonly used for vegetation mapping. Its spectral (36 bands), spatial (250 m to 1000 m) and temporal (1 to 2 days) resolutions allow for the constructing of time series of Vegetation Indices (VI) used for monitoring vegetation's spatio-temporal variability. Normalized Difference Vegetation Indice (NDVI) time series have been used to identify both vegetation covers and land use changes (Ferreira and Huete 2004, **Meirelles et al, 2007, Jonathan et al, 2007, Arvor et al, 2009a,b**).

Methodology for automatic crop mapping based on Modis time series

A new method to detect crops through a two-step classification was proposed (Meirelles et al, 2007, Jonathan et al, 2005, Arvor et al, 2009, 2011, Meirelles et al, 2011) and developed in the framework of *Enviair Project (Advanced Image Processing Technologies for the Automatic Montoring of Defoestation, Soil Degradation and Expansion of No-Tillage System, http://enviair.cnps.embrapa.br), Cnpq/INRIA* (MEIRELLES, 2010), improved in IDRC/IAI Plata Basin Project. The first step consists in separating agriculture areas from native vegetation and pasture based on Modis multitemporal profiles. Once the agricultural area is classified, the second Modis Based automatic classification step separates the crop classes generating a crop mapping. This two-step methodology is necessary because vegetation types and crop classes are not separable by the same characteristics of EVI time series. Main vegetation types may be discriminated by metrics computed on their EVI temporal profiles while crop classes are more easily differentiated by including information from their agricultural calendars on those metrics (Meirelles at al, 2007, Jonathan et al, 2008).
Figure 1 presents the methodology.

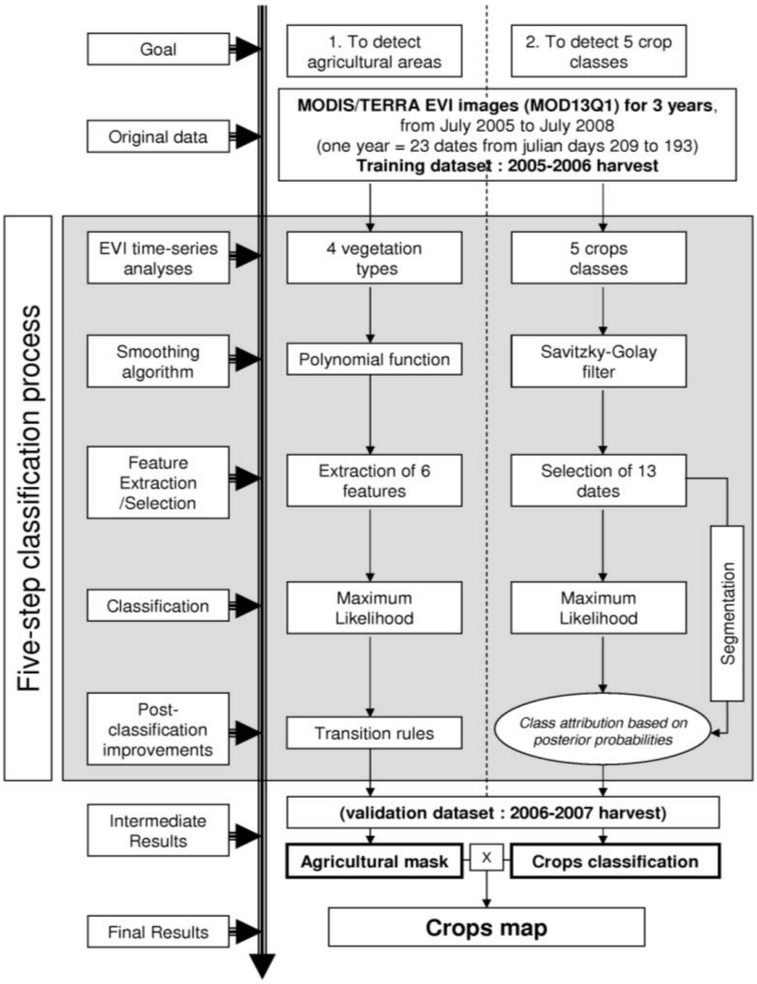


Figure 1 - Classification methodology based on a five-step process applied on MODIS-TERRA/EVI data.(MEIRELLES,2010, ARVOR, 2009)

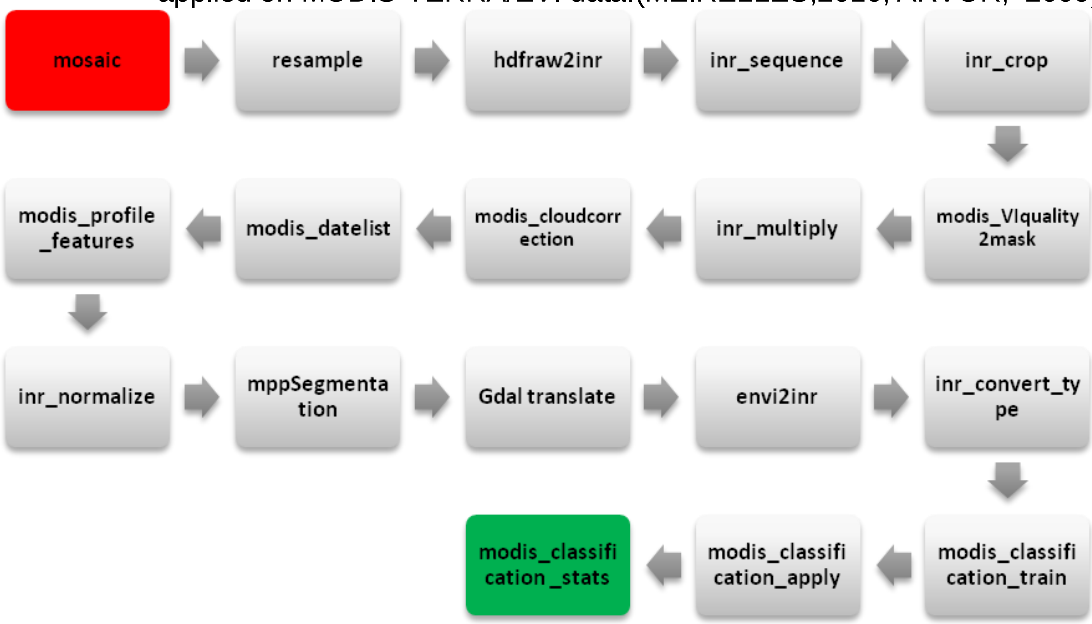


Figure 2. Land Use Changes monitoring - algorithm chain (JONATHAN & MEIRELLES, 2007).

The intention of applying the automatic classification based on the developed algorithm was to have the possibility to make a LUC classification updated, as the only official classification we have in Brazil for all the biomes (Probio, MMA) were done in 2002. With the Modis and the developed algorithms we can make a sequence of classification, for a region, making it possible to have a monitoring LUC process automatically and with low cost (images are free of charge).

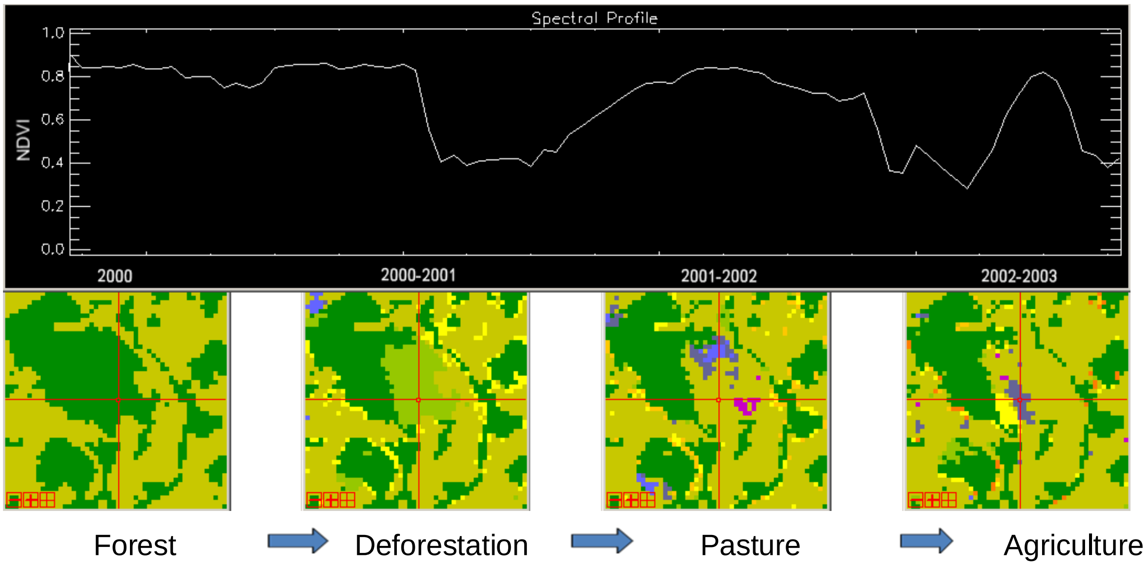


Figure 3. Land use changes with MODIS temporal profiles (JONATHAN & MEIRELLES, 2007)

The methodology was successfully tested at Taquari River Basin, in MatoGrosso do Sul, as well as Rio Verde, in Goias, after that, we tried the challenge of use the method for the whole Plata Basin watershed (5 Biomes).

Mapping the agricultural frontier based on Remote Sensing data

Actually, the territorial evolution studied in Mato Grosso illustrates the progress of an active pioneer frontier, which can be defined as a rural area in contact with virgin areas, implying some transformations of the natural space (Droulers et Le Tourneau, 2000). The agricultural activity usually represents the driving force of the pioneer frontier, so that it sometimes corresponds to an agricultural frontier. This agricultural frontier progresses through five stages (pre-settlement, occupation, consolidation, intensification and intensive stages) transforming a territory from a wild land to an agriculturally intensive territory (DeFries et al., 2004). These stages, presented in Figure 4, are characterized by different land-use types and the land-use transitions from one type to another corresponding to three successive frontiers (Arvor, 2009):

- The **deforestation frontier** marks the land-use transition from a *pre-settlement* to an *occupation* stage. It is linked to the arrival of migrants who need to clear some areas in order to begin an agricultural activity. In that case, the amount of deforestation is correlated to the number of new migrants.

- The **economic frontier** marks the land-use transition from an *occupation* stage to a *consolidation* stage. It is linked to the transition from subsistence to a capitalist agriculture. Thus, its evolution depends on the profitability of the agricultural commodities produced, i.e. on the price of commodities as defined by the international rate exchanges in the context of soybean crops.

- The **intensification frontier** marks the land-use transition from a *consolidation* to an *intensification* stage, leading to the ultimate *intensive* stage. It appears when new areas to expand crops become rare and expensive. The only way to improve the production then consists in adopting new agricultural practices. In Mato Grosso, this intensification process is done through the application of double cropping systems, the soybean harvest being quickly followed by a corn or cotton harvest.

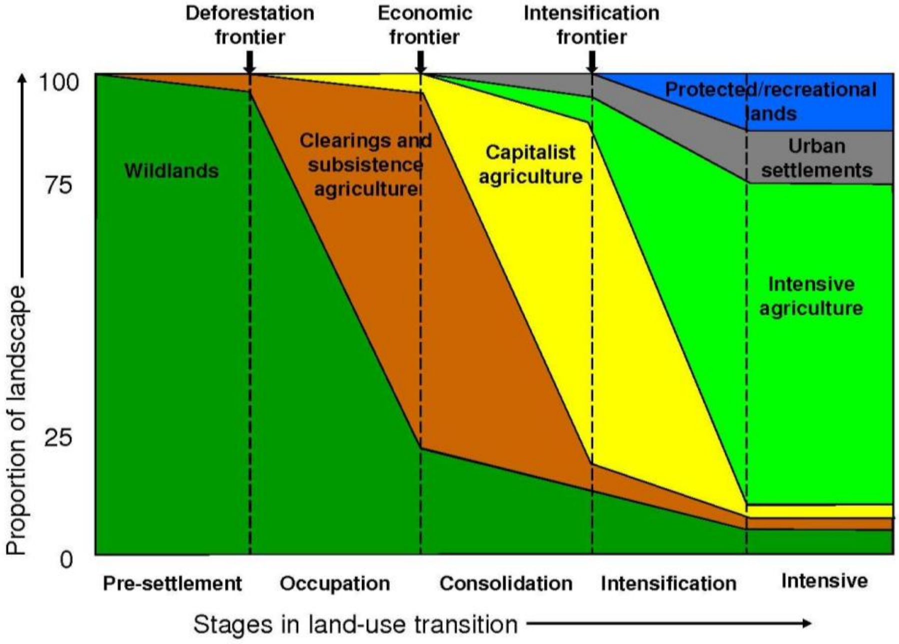


Figure 4. Stages of the evolution of the agricultural frontier and the corresponding land-use types (adapted from DeFries et al., 2004).

As the evolution of the agricultural frontier can be characterized by a succession of land-use transitions (DeFries et al., 2004), relevant remote sensing techniques can be used to map frontiers. Indeed, remote sensing data have proven to be efficient for mapping deforestation, crops and agricultural practices. For instance, the PRODES and DETER projects lead by INPE (National Institute for Space Research) are two successful initiatives implemented to map deforestation in Brazilian Amazonia. Relevant examples of crop mappping based on MODIS data include soybean and corn mapping in the US Great Plains (Wardlow and Egbert, 2008) or even in Mato Grosso (Morton et al., 2006). Finally, agricultural practices such as double cropping systems were accurately detected by MODIS imagery in Mato Grosso by Galford et al. (2008). Most classifications techniques based on MODIS data are based on time series of vegetation indices (either NDVI or EVI) that allow analyzing the phenological cycles of the vegetation cover.

Based on the concepts of the agricultural frontier stated above and the potentialities of Remote Sensing techniques at moderate spatial resolution (MODIS sensor), and the algorithm of Land Use monitoring developed and described, a satellite-based method was developed to: 1) monitor the evolution of the deforestation, economic and intensification frontiers and 2) map the evolution stages of the agricultural frontier in Mato Grosso (Arvor et al, 2011).

<u>Case Study: Land Use Change Cartography of Plata Basin at Mato Grosso State</u>

Due to the pressure of agriculture areas in Mato Grosso, encompassing not only the Amazon forest but also, specifically within the Plata basin portion, the *cerrado* area, this site was selected as a case study. The main objective was to study the land use change and its dynamic on the the Plata Basin in Mato Grosso state, which is one of the greatest crop producer in Brazil. Figure 5 presents the location of this case study region.

Figure 5. Location of the case study region - Plata Basin in Mato Grosso state

Deriving Deforestation Map Through MODIS DATA

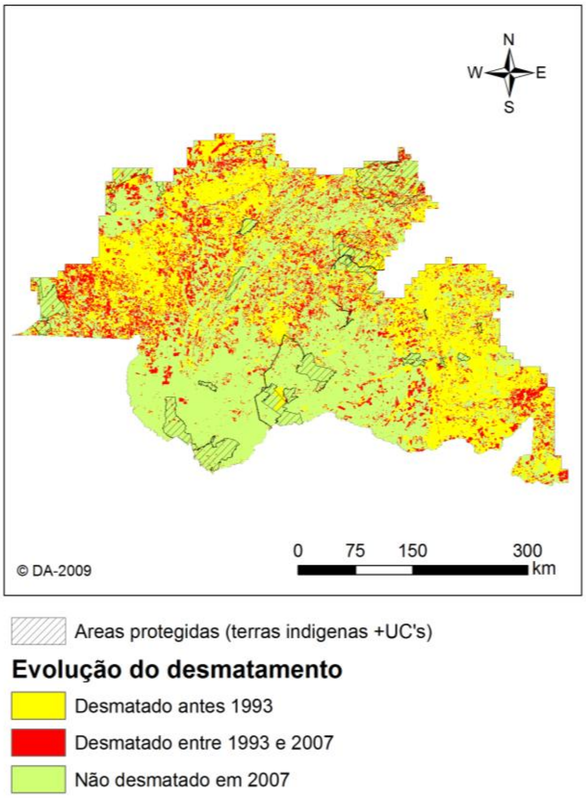


Figure 6. Deforestation evolution in the case study region - Plata Basin in Mato Grosso state

The map of deforestation was carried out based on data derived from several sources: SEMA-MT, Prodes, IMAZON (Table 1). There were different sources, spreaded, covering different areas that needed to be combined in one unique database, those are the sources:

- PRODES (Deforestation Program for Amazon Region), produced by INPE – the deforestation data does not provide information for the cerrado, only for Amazon forest;
- SEMA (State Environmental Secretary) provides data for all MT, but missing a few years;
- IMAZON only provides data from 2006 on. The combination of data was performed as:
  - When a deforested area was detected as deforested by two sources (SEMA and PRODES for example), it has been considered as deforested in the first year of the two sources that found the deforestation.
  - When a deforested area was detected as deforested by only one source (eg SEMA found a clearing and PRODES does not), the area was considered as detected (as deforestation).

Table 1. Deforestation data and source used.

	SEMA	PRODES	IMAZON
1992	X		
1993	X		
1994	X		
1995	X		
1996			
1997	X		
1998			
1999	X		
2000		X	
2001	X	X	
2002	X	X	
2003	X	X	
2004	X	X	
2005	X	X	
2006		X	X
2007			X

Deriving Agriculture Maps through MODIS DATA

Agricultural areas and crops have been mapped from classifications of time series MODIS / EVI (MOD13Q1 product) with a temporal resolution of 16 days and a spatial resolution of 250 m. The study period extends from the crop season of 2000-2001 until 2006-2007. The classification methodology is summarized in Figure 33.

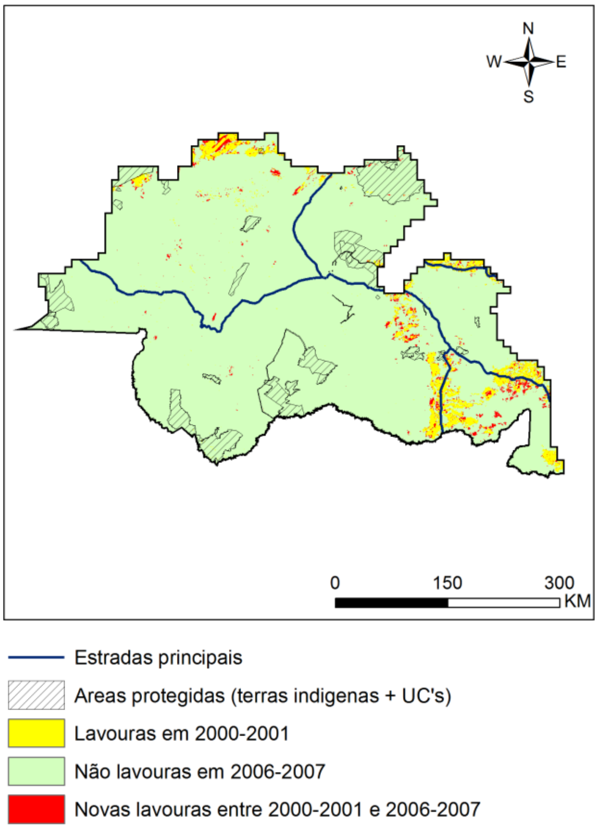


Figure 7. Agricultural Areas of Plata Basin (Mato Grosso)

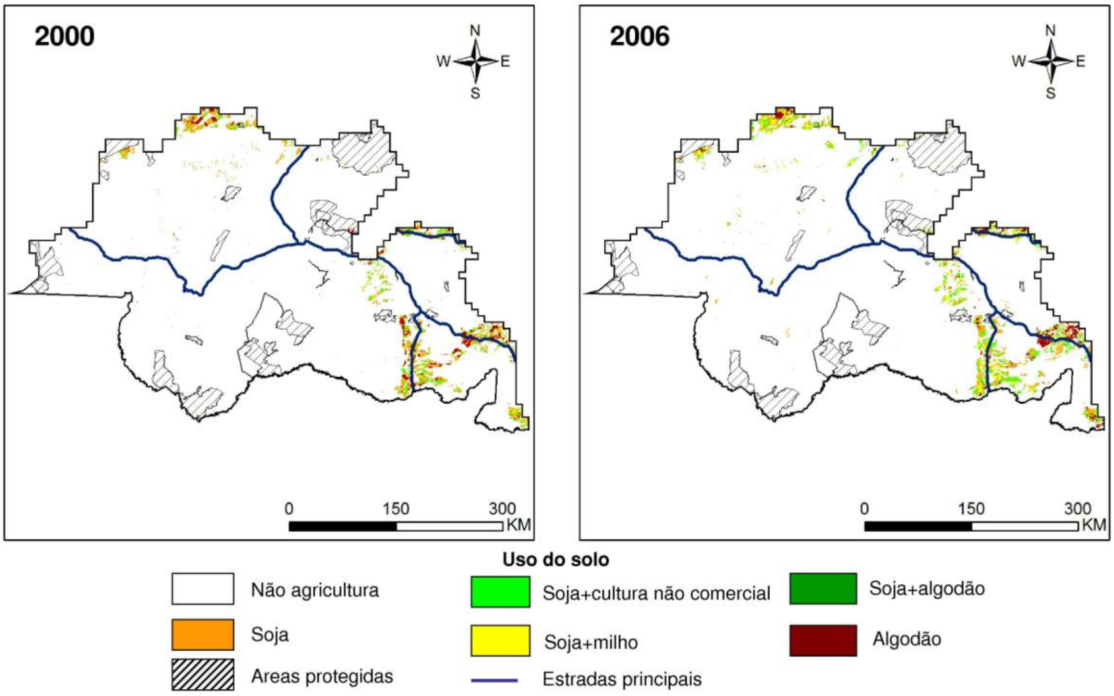


Figure 8. Crop Maps in Plata Basin (Mato Grosso) crop calendar 2000-2001 e 2006-2007.

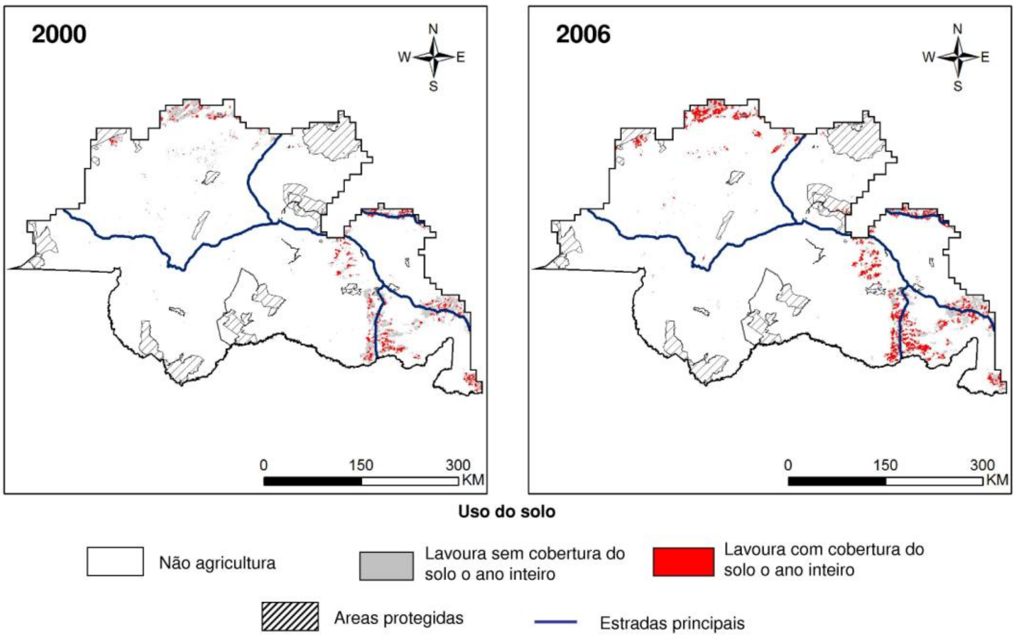


Figure 9. Map of agricultural land in the La Plata being cultivated with a soil covering the entire year.

From the crops maps of the production systems were produced:

- maps of agricultural land being cultivated with a soil cover throughout the year: the areas planted with a ground cover year-round correspond to "non-commercial soy + soybean", "soybean + corn" and "soy + cotton ". These production systems are a sign of the advancement of no-tillage in the region and an effort to combat soil erosion.

- The maps of agricultural areas being cultivated with two crops per year: the areas cultivated with two crops per year are the classes "Soybean + corn" and "soy + cotton" in Figure 10. These systems of production are a sign of diversification and agricultural intensification in the region.

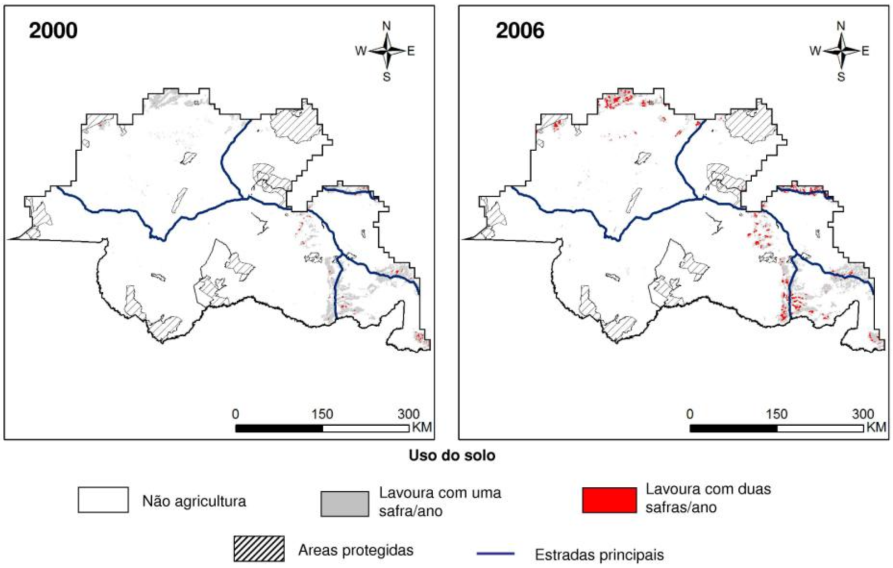


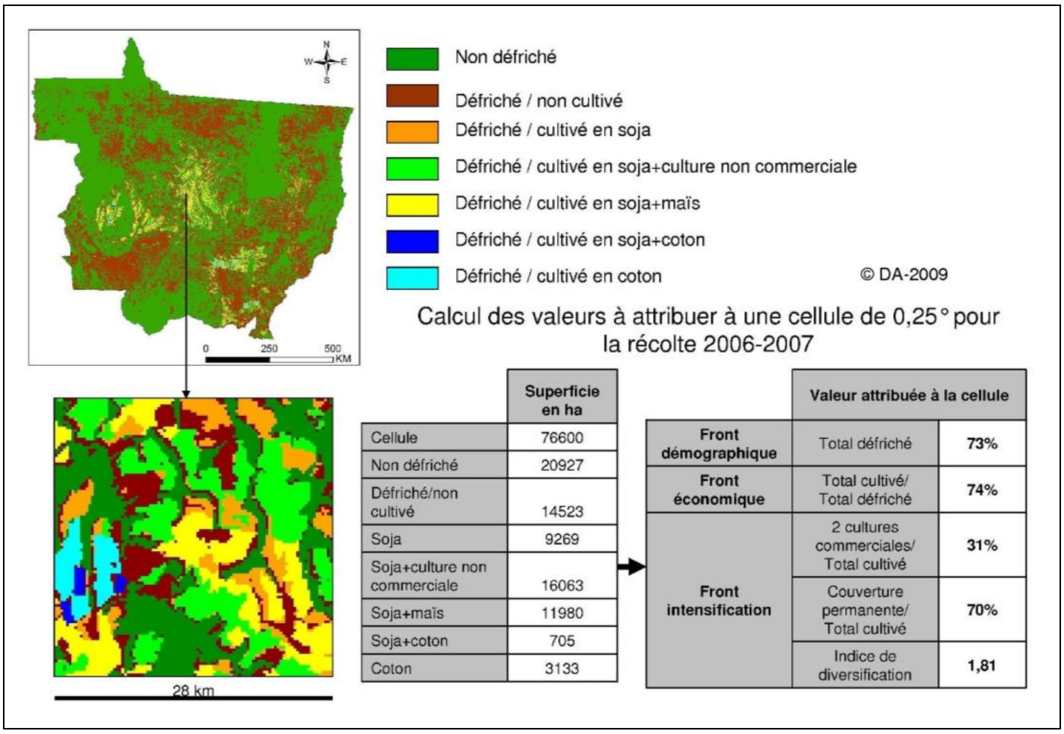
Figure 10. Map of agricultural land in the La Plata being cultivated with two crops per year

The Modis scale used in some cases does not always to properly observe the evolution of land use changes. Therefore, the maps were resampled on the scale of the agrarian localities. According to SEMA, there are 1175 agrarian localities in Mato Grosso. Thus, each locality covers an average area of 771 km ², or 0.25 ° (side). Therefore, the maps were cut out in cells with 0,25 ° for each side and the percentage of land use in each cell was calculated (Figure 11).
After having calculated the percentage of each land use in the cells, the maps were resampled using a Spline algorithm in order to improve the look of the land use change evolution (Arvor, 2009).
This methodology was used to map:

- The progress of deforestation : deforested area / cell area
- The advancement of the crops : Agricultural area per cell / area deforested
- the advancement of agricultural intensification: agricultural area being cultivated with two commercial crops / total agricultural area per cell.
- The advancement of agricultural intensification: agricultural area is planted with ground cover the entire year / total agricultural area per cell.
- The advancement of agricultural diversification: calculation of an index of diversification Herfindhal per cell. The index is defined using the following formula:

$$ID = \frac{1}{\sum_{i=1}^{n} P_i^2}$$

Where P_i is the part of the ith crop in the total of the crop area. The calculation was performed from the three main crops: soybean, maize and cotton. If ID = 1, is a monoculture situation. If ID = 3, is a situation of equilibrium among the three crops.



	Superficie en ha
Cellule	76600
Non défriché	20927
Défriché/non cultivé	14523
Soja	9269
Soja+culture non commerciale	16063
Soja+maïs	11980
Soja+coton	705
Coton	3133

	Valeur attribuée à la cellule	
Front démographique	Total défriché	**73%**
Front économique	Total cultivé/ Total défriché	**74%**
Front intensification	2 cultures commerciales/ Total cultivé	**31%**
	Couverture permanente/ Total cultivé	**70%**
	Indice de diversification	**1,81**

Figure 11. Presentation of the methodology applied to a cell of 0.25 ° for the 2006-2007 season (Arvor, 2009)

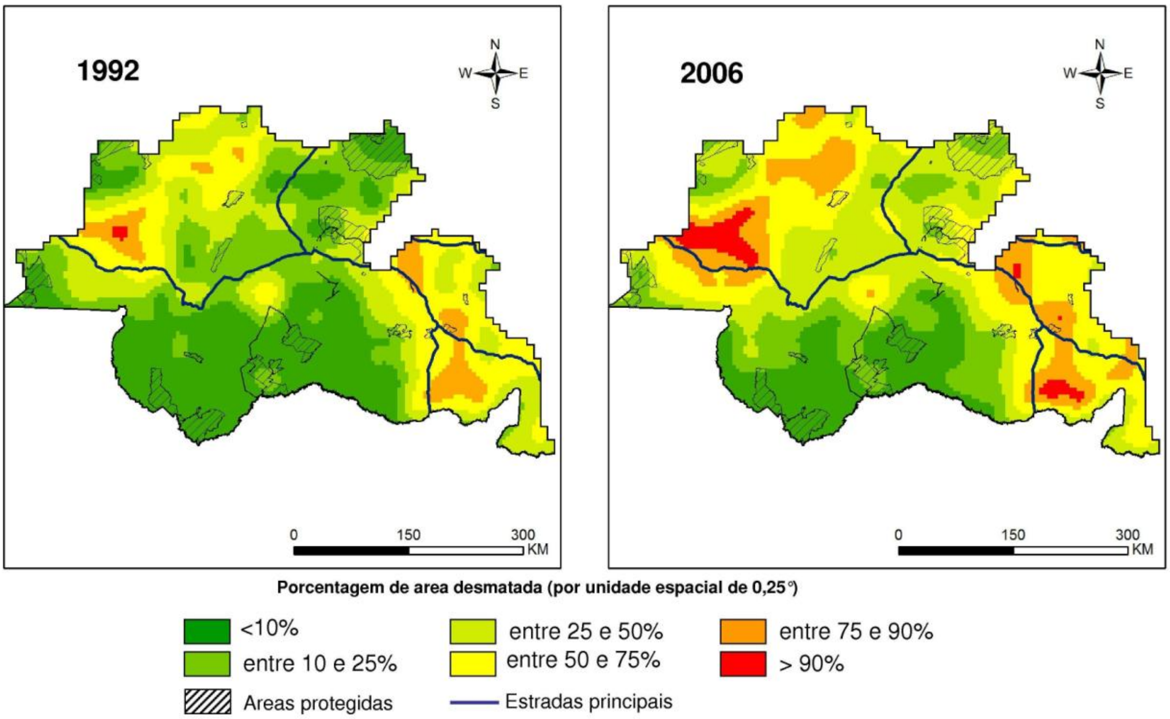


Figure 12. Advancement of deforestation from 1992 to 2006

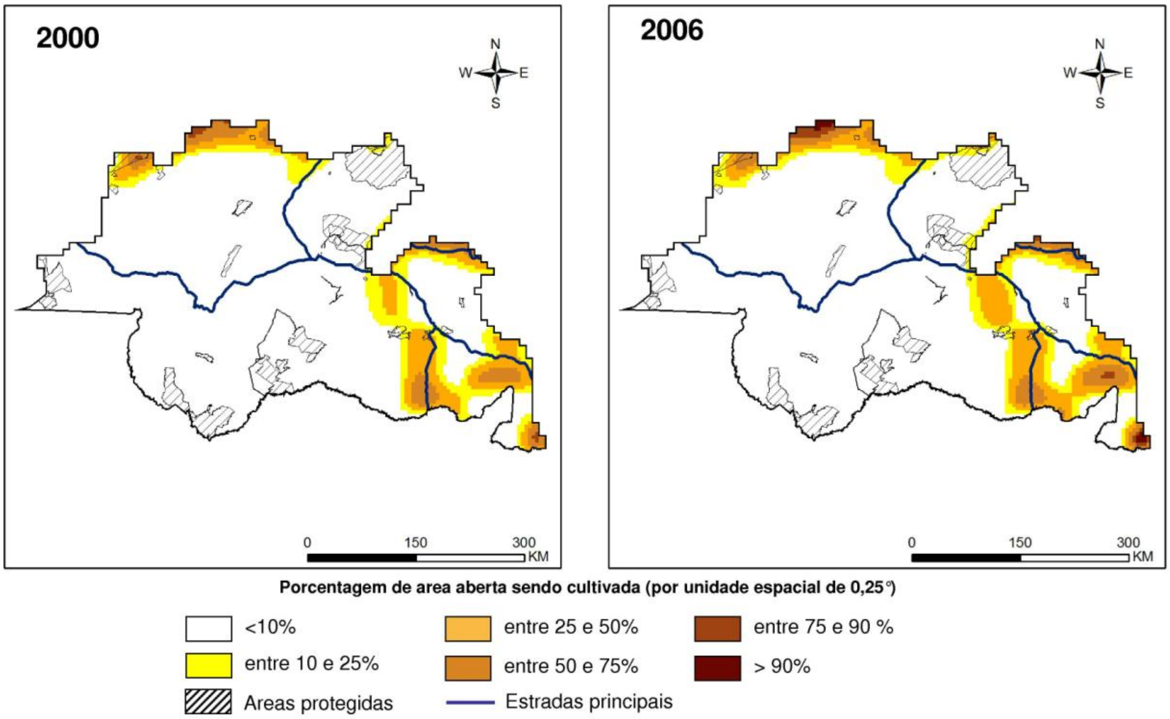


Figure 13. Advancement of agricultural areas from 2000 to 2006

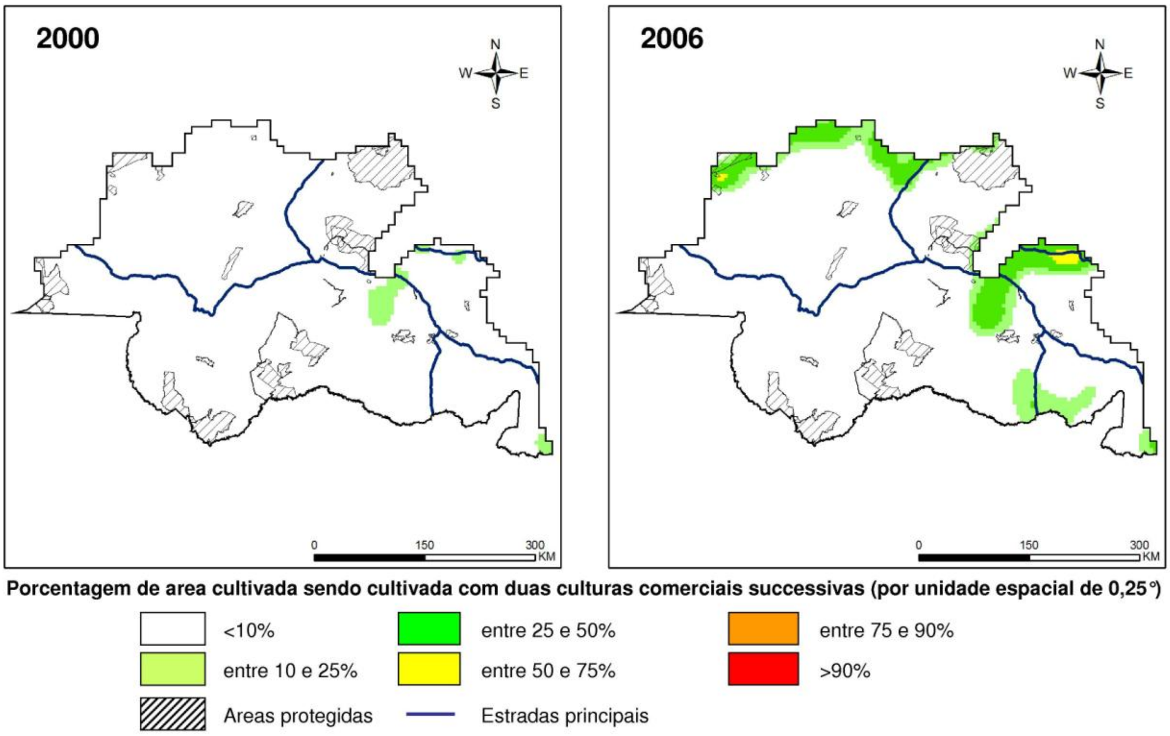


Figure 14. Advancement of agricultural intensification (with two commercial harvests per year)

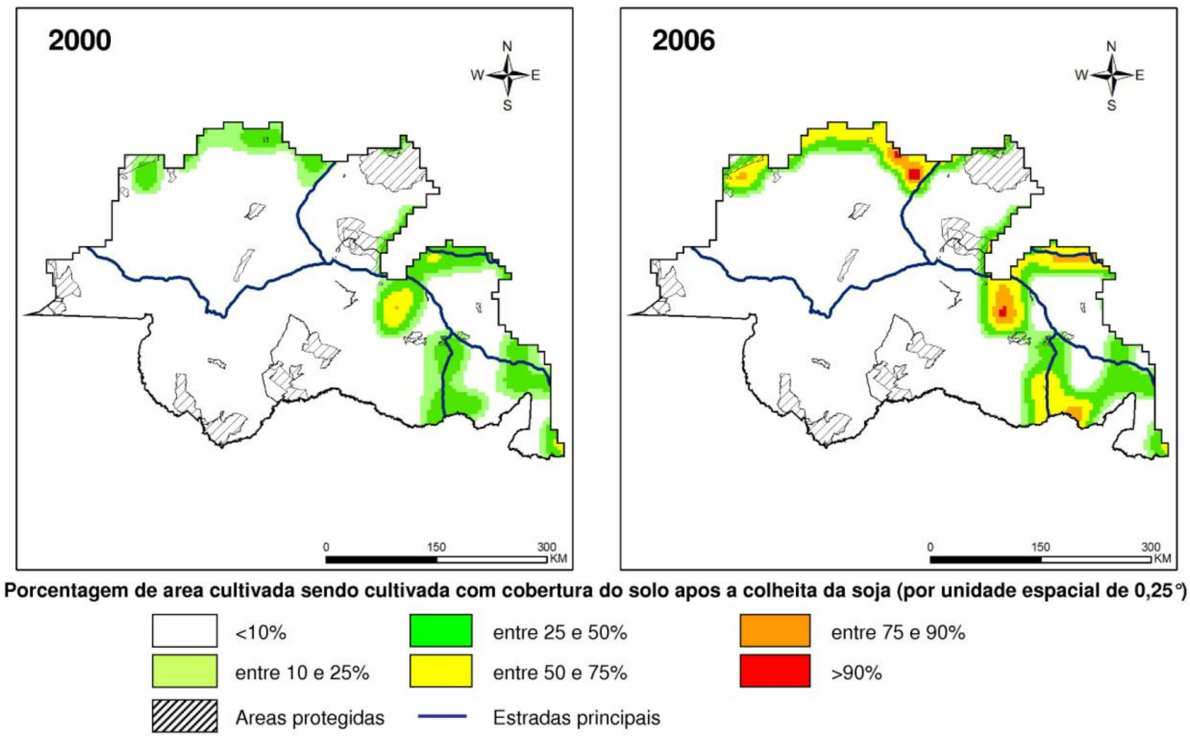


Figure 15. Advancement of agricultural intensification (soil cover year-round)

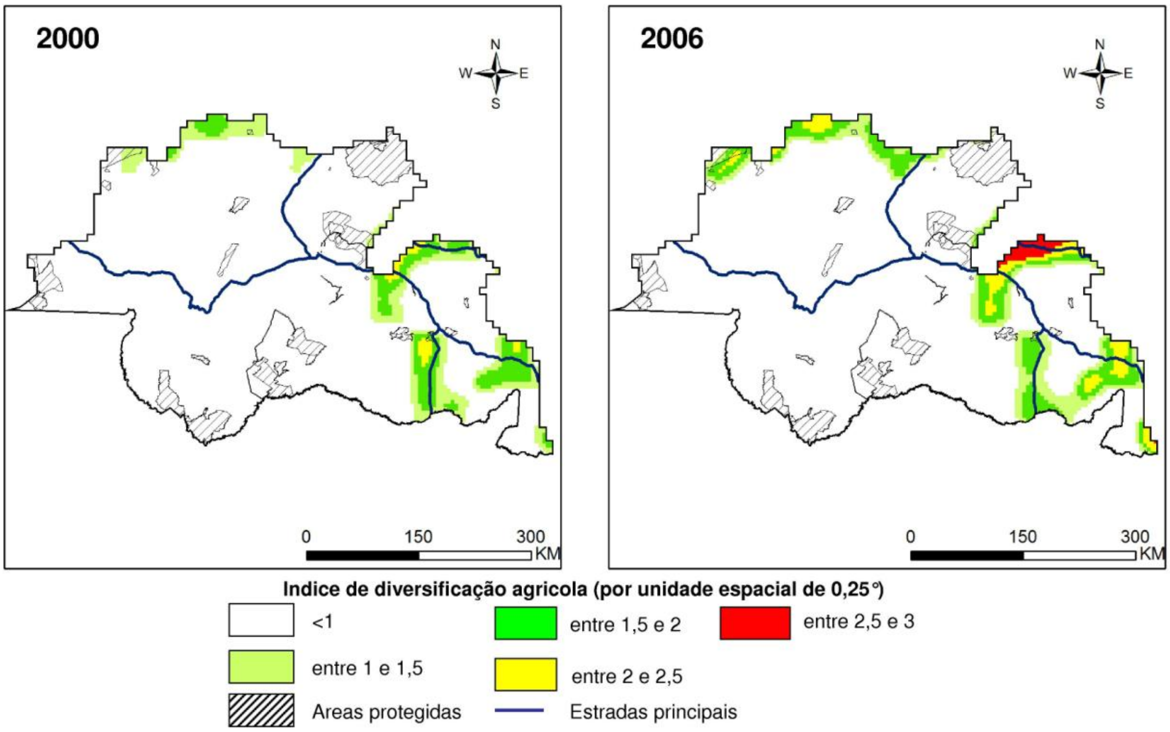
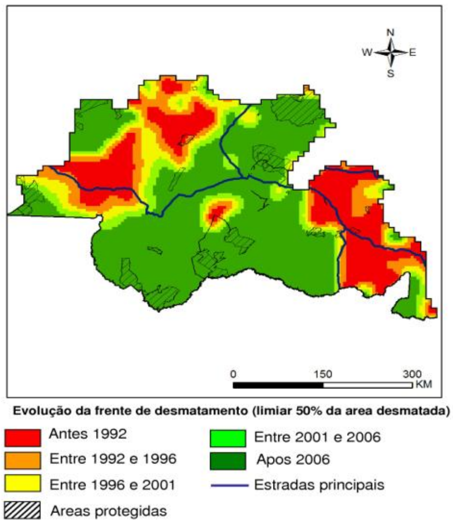


Figure 16. Advancement of agricultural diversification

Mapping the Deforestation Frontier

The deforestation front and agricultural front were mapped as presented Figures below. For the *deforestation front*, it was estimated for which year the threshold of 50% of the cell area of 0.25 ° was exceeded. The year found was signed the value of the cell and a spatial interpolation (Spline) was performed.

For the agriculture front, it was estimated for which year the threshold of 50% of the total deforestation in a cell of 0.25 ° was exceeded. The year found was signed the value of the cell and a spatial interpolation (Spline) was performed (Arvor,2009).



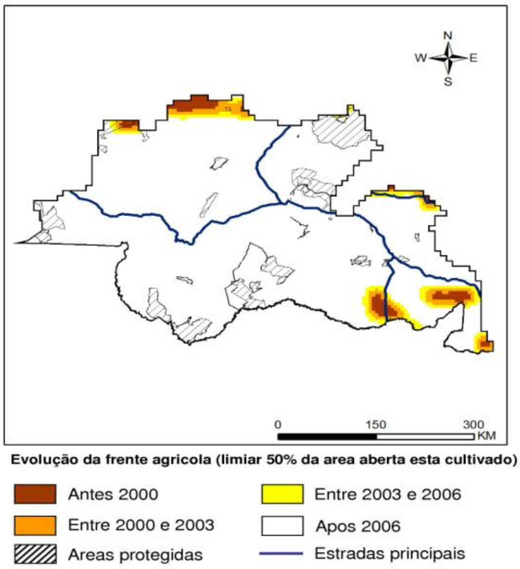


Figure 17. (a) Deforestation Front (b) Map of Agricultural Front evolution in Plata Basin at Mato Grosso from 2000-2006

Methodology to automatically detect agricultural transition (dynamic) through Remote Sensing Data, Modis Data

Based on Remote Sensing Maps, LUCC mapping through the use of Modis data, presented above, it is possible to analyse the **agricultural transition** by defining a list of indexes providing information on the three stages of the agricultural dynamics: agricultural expansion, agricultural intensification and ecological intensification. In this way, four terms were defined in: Net Cropped area (NC), Double Cropped area (DC), Permanently Covered area (PC) and Total Cropped area (TC). Net Cropped area refers to the agricultural area, independently from the cropping system applied on this area. The Double Cropped area is defined as the agricultural area that is cultivated with double cropping systems involving two commercial crops (e.g. soybean, corn and cotton). The Permanently Covered area considers the agricultural area cultivated with double cropping systems involving commercial and non-commercial crops (e.g.millet or soghum). Such a practice allows the producers to limit soil erosion by covering soils during the entire rainy season, which represents a sign of ecological intensification. Finally, the Total Cropped area is calculated by adding NC and DC. This term is important to compute because it is linearly linked to the agricultural production, while it is not true for Net Cropped area. (Arvor et al., 2011)

3.2.1. Agricultural expansion indexes in Mato Grosso – Soybean Crop

Agricultural expansion consists in land-use conversions into crops and it is here characterized by three indexes. The first index (NC, for Net Cropped) consists in quantifying the evolution of the Net Cropped for each biome (forest and cerrado) based on the agricultural maps extracted from MODIS Terra/EVI time series. Two types of agricultural expansion are distinguished: direct and indirect agricultural expansion. The first term corresponds to extensification as defined by Redo and Millington (2010), i.e. "*the process of expanding new production onto areas of natural vegetation that were previously unused*". Complementary, the second term can be defined as the process of expanding new production onto areas that were already used but for other purposes than planting crops. Then, direct conversions are considered when crop areas are detected within the two years after being deforested.

3.2.2. Agricultural intensification index

Agricultural intensification is defined by "*higher levels of inputs and increased outputs (in quantity or value) of cultivated or reared products per unit area and time"* (Lambin *et al.*, 2001). Thus, we assumed that adopting double cropping systems involving commercial crops (soybean, corn and cotton) is a type of agricultural intensification because it implies increasing inputs and outputs in a same area. The three indexes can be calculated based on the agricultural maps issued from MODIS EVI time series in order to identify the importance of the agricultural intensification process.

- The first index (DC, for Double Cropping) consists in quantifying the evolution of the *Double cropping area* for each biome (forest and cerrado).
- The second index (DC/NC, for Double Cropping area divided by Net Cropped area) is computed to estimate the proportion of the net cropped area sown with double cropping systems involving two commercial crops. It then allows evaluating the intensification level on the arable lands.
- Finally, the third index (DC/TC, for Double Cropping area divided by Total Cropped area) is calculated to estimate the proportion of the total cropped area which is due to areas cultivated with double cropping systems involving two commercial crops. This last index is

an indicator of the part of the agricultural production which results from agricultural intensification.

3.2.3. Ecological intensification indexes

The principles of ecological intensification are based on the adoption of new agricultural management practices to (i) improve fertilizers efficiency, (ii) improve water use efficiency, (iii) maintain and retrieve soil fertility, and (iv) improve crop diseases monitoring (Tilman *et al.*, 2002).
We calculated the proportion of the net cropped area which is permanently covered by vegetation during the entire rainy season for all cropping years between 2000-2001 and 2006-2007 (PC, for Permanent Cover). This index is considered as a sign of ecological intensification as it allows limiting soil erosion and water pollution by protecting soils from intense rain events occurring at the end of the rainy season, after the harvest of the first crop. Thus, computing this index implied to take into account areas cultivated in double cropping systems involving both commercial (corn, soybean, cotton) and non-commercial crops (millet and sorghum).

<u>Mechanized agriculture as a driver of deforestation</u>

The impact of soybean expansion on deforestation must not be minimized in Plata Basin Brazilian Cerrado. Moreover, an important issue to be considered regards the indirect impact of soybean expansion on deforestation. Indeed, when formerly deforested areas, as pastures, are converted into soybean areas, it is important to understand where the previous cattle farmers are moving to. If they decide to migrate up north into the Amazonian forest in order to clear new areas and establish a larger cattle farm, soybean expansion may be considered as an important indirect driver of deforestation. However, the impact of such an indirect agricultural expansion on deforestation may remain important because it may support the pasture expansion on natural vegetation areas, such as forests and Cerrado.
Moreover, as deforestation in tropical areas is an important issue for global environment, agricultural intensification has long been expected to be a solution to reduce the role of agriculture as a driver of deforestation. This hypothesis was especially defended by Norman Borlaug (Borlaug, 2000a) since the 1960's who argued that the Green Revolution was the best way to limit deforestation. In the case of Mato Grosso, the project checked this hypothesis at state level. Indeed, it was estimated that without agricultural intensification (double cropping systems with two commercial crops), it would be necessary to cultivate an additional 1.68 million of hectares to achieve an equivalent production in 2006-2007.

<u>Land Use Change (LUC) as one of the drivers of water impacts</u>

There are several forms of anthropogenic transformation of landscapes, and among these, stand out as a strong feature of human action, the remarkable changes of land use and land cover associated with the intensification and expansion of agriculture. In fact, agriculture is renowned for its ability to promote rapid changes in landscape spatial patterns of large geographical extent and temporal cycles of long duration. Indeed, dramatic environmental degradation has been observed as a direct consequence of agricultural exploitation intensification. Evidence in this way, the massive deforestation, fragmentation of ecosystems, the dizzying loss of biodiversity, the severe erosion, changes in watershed dynamics, scarcity of water resources and extensive land degradation, as some of the processes widely reported (Vitousek et al., 1997, Meyer and Turner, 1994;. PARUELO and ROOM & 1997).

Within the scientific community there is a growing recognition that LUC are the main determinant of changes in the global environment, and therefore the assessment of impacts related to these, is a field of scientific research of outstanding importance that can contribute significantly to the understanding of the biogeochemical cycles of disturbed environments (Meyer and Turner 1994).

The impact of land use change in the environment has generated observable consequences from local scales to global proportions, among which stand out, for their potential to have serious implications for the sustainability of the agricultural sector, changes in hydrological regimes, the change in cycle carbon and climate change (MATSON et al. 1997). One of the features of agricultural systems is the fact that the impacts generated by its inherent transformative capacity are not an externality to the production process, but affect the natural resource base that sustains it. Consequently, disruption of ecosystem services induced by land use changes in rural areas, represents one of the main obstacles to the sustainability of Plata Basin agriculture.

Whereas the land use changes can modify the partition of water from the rainfall intercepted by river basin, the water balance at various scales of observation, may also suffer significant changes. As a land use change effect in hydrological cycle, the impairment of the ecosystem service considered most critical is the provision and regulation of the water cycle.

The hydrologic cycle regulation and maintenance of seasonal climatic change are essential environmental services to the sustainability of agricultural production activities, since they regulate the availability of water which constitutes a vital resource and essential input for the maintenance of biological systems and viability of agricultural production.

The evapotranspiration is remarkable, within the hydrological cycle and climate, because it represents a key variable connection between climate and hydrology. The seasonal dynamics of evapotranspiration is one of the major functional processes of terrestrial ecosystems, since, being a mediator of energy balance between the soil surface and atmosphere, evapotranspiration is directly related with the climatic water balance.

Considered one of the main regulators of water availability, surface and groundwater, evapotranspiration has obvious influence on the functions of aquifer recharge and groundwater flow regime in the river watershed (VICTORIA, 2004, Santos et al, 2007). Moreover, the evapotranspiration is closely related to the type of use and coverage found in the earth's surface. These effects are related to the adaptive differences of the various vegetation types, with regard to absorption capacity of water, dependent on the structure and depth of root systems and the phenological stage related to the potential transpiration (leaf area, etc.) (CALDER , 1998).

Playing a key role in water balance and climatic regime, a major research effort was dismissed by researchers worldwide in an attempt to improve the estimation of radiative fluxes and energy flows aiming at the indirect estimation of the components of the hydrological cycle, especially, evapotranspiration. This effort has been directed towards improving both the traditional methods of direct measurement, as well as finding alternative methods to allow for parameterization and modeling of flow-radiative energy (NICACIO, 2008).

However, measurements of surface flow require highly sophisticated and expensive instrumental, limiting the data acquisition, as well as, the spatial density of those measurements. On the other hand, the direct measurements of evapotranspiration in the field level are hampered by the uncertainty concerning the methods used, and also by the fact of being limited to specific studies, not distributed in space and time.

Thus, the continuous spatial monitoring of flows on the surface at different scales, which are relevant to the modeling of the hydrological regime as well as to forecast the weather and climate, cannot be based on those methodologies. The difficulties are, primarily due to the complexity of the physical system involved, and also due to the operational cost of the conventional methods, not to mention that it would be necessary an extensive system of meteorological measurements.

Estimation of evapotranspiration, by indirect means, from the measurement of the energy flux, sensible and latent heat, can be conducted in the field by different techniques. The various methods of direct measurement of real evapotranspiration as lysimeters, mass or drainage, soil moisture balance, or evaporimeters are also sufficiently cumbersome to derail the systematic acquisition of data distributed in space and time. Thus, considering the absence of such measures, an alternative approach is the use of physical and mathematical models, based on climatic variables from meteorological stations.

The different approaches, whether based on direct measurement or on various models with meteorological data, or even on the estimated evapotranspiration of energy flows on the surface, all require data that are not necessarily collected systematically and are not appropriately spatially.

One alternative to the evapotranspiration and energy fluxes from the surface estimation, is to use Remote Sensing, that allows a systematic and regular acquisition of spatial data as a complement to meteorological information in applications in which it is imperative a spatial vision.

The MOD16 global evapotranspiration (ET), latent heat flux (LE), potential ET (PET), potential LE (PLE) datasets, a regular 1-km2 land surface ET, with the ET algorithm based on the Penman-Monteith equation (Monteith, 1965), was applied in the project for the Brazilian Plata Basin.

Maps of evapotranspiration, based on Modis 16 data (MU at al., 2007) were then, produced from 07/2000 to 07/2001 (Figure 1a) and from 07/2005 to 07/2006 (fig. 1b). Those maps confirm the potential of MODIS data to detect the seasonal cycles of Real evapotranspiration.

The assessment of spatial and seasonal evapotranspiration variability estimated for the agricultural year 07/2000 to 07/2001, shown in figure 18a, can be considered as a promising application of the algorithm that is being improved for the estimation of real evapotranspiration in environmental studies at regional scale.

It is observed that for the crop year 2000/2001 the monthly evapotranspiration estimated is related with the climatic seasonality, reflecting the dry, wet and intermediate seasons. Another important record is the observed relative difference in magnitude of the estimated values of ET in each sub-basin of the Brazilian Plata Basin. So the estimates made by this methodology allowed to distinguish the magnitude among the Cerrado, Atlantic Forest, Pantanal and steppes biomes inserted in different regions of the country.

Considering the seasonal variation observed, values are consistent with the normal climate variability (drought and rainfall regime) of the different biomes as the rate of water loss through evapotranspiration typically varies linearly with the water storage in soil, being maximum when the soil moisture corresponds to the field capacity, which occurs when the water balance indicates excess of water during periods of heavy precipitation. Moreover, the evapotranspiration tends to void when the soil moisture is in the permanent wilting point.

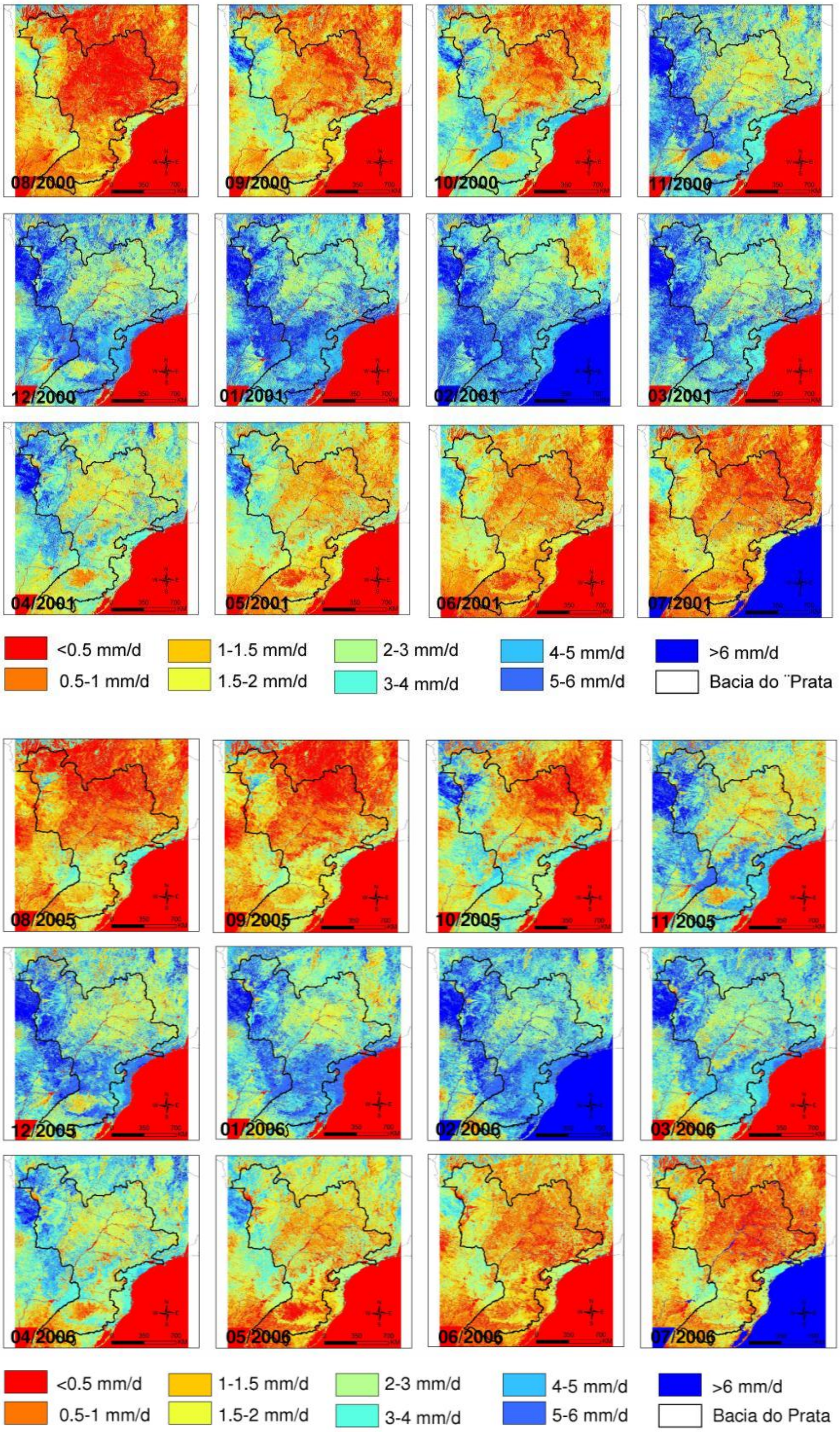


Figure 18. Monthly actual evapotranspiration, expressed on an average day (mm / d) for the Plata Basin (Brazilian Portion) for the crop year 2005/2006

In relation to variations due to seasonal climate for the crop year 2000/2001 should be noted, due to the dry season, very low values in August varing in the range of 0.5 to 1 mm / d on average for the region southern and western states of Mato Grosso and Mato Grosso do Sul, just at the depressed region of the Paraguay River and pantanal areas. In the Southeast and especially the portion of the watershed that occupies the center-west region the values of actual ET are located for the duration of the interval in the range below 0.5 mm / d.

Gradually through the months of September and October with the gradual increase in precipitation estimates actual ET also rise for the whole basin of the River Plate. Noteworthy in the month of October where the values reported generally fall in the range of 4-5 mm / d for greater part of the south region of the country, serving to highlight the occasional occurrence of major and minor.

In November 2000 to March 2001 it is recorded a gradual increase in the rates of actual evapotranspiration, especially in the south region, southeast and far western states of Mato Grosso and Mato Grosso do Sul, reaching values of approximately 4 to 6 mm / d as the areas observed. In the catchment area of the Plata Basin which is the Midwest region of the country values record the climatic constraints typical of the Cerrado biome showing maximum values of 3 mm / d for most of the area considering the same period.

The subsequent months from April to July 2001 occurs with the approach of the dry season a remarkable decrease in the values of actual ET estimates for the entire basin of the Plata Basin in the barzilian portion, reaching a record in June of that year the lowest values, below 2 mm / d on average, for most of the region studied.

Another important point is that when considering, for example, the month of February 2001, where in the South Central region of Brazil the summer crops are in full development phase, we observe a value of 4-6 mm day-1 which corroborates the data obtained by Martorano (2007) with the actual evapotranspiration of soybean, in Eldorado do Sul, Rio Grande do Sul, based in field experiments. The low values in August and September indicate that the soil with straw coverage in areas planted with no tillage, stressing that the estimated values are very close to the possible responses of soil cover.

Methods of Land Use Change Modeling

The study was based on a conceptual framework that describes three focuses of land use change analysis, in which different approaches are possible, as follows:

a) land use dynamics models: **intelligent multi-agent models**, sustainability scenarios simulation and LUC simulation model.

b) land use cover change model: transition probability model, e.g. **Markov Chain** method, spatial statistical model and dynamic process model.

c) regional and global model (spatially explicit model, integrated **dynamic multi-scale model**)

The land use change modelling concept for the Plata Basin aims to understand agents' behaviour in the sensitive areas, to comprehend drivers' linkages in different scales and to identify issues related to vulnerability and sustainability of regions, in order to evaluate the sensitivity of models to land use change.

The case studies in the La Plata River basin were conducted using different approaches in each area. Two different modelling approaches were applied in the Mato Grosso do Sul state, where the Sugar Cane case study were evaluated by two post graduate students: the CLUE-S model (Conversion of Land Use and its Effects at Small Regional Extent), was used to allocate land use claims for sugar cane in the next years till target year 2015, and TerraME was tested to the same purpose, and results were obtained for the simulations of climate change scenarios until the next 100 years (scenarios after 10, 20, 30, 40 and 100 years).

Different model approaches take advantage of the GIS analytical tools to model land use and land cover patterns by detecting spatial autocorrelation in landscape features groups (clusters). Such groups of features determine patterns in a specific land use and between variations of land use types. Spatial interactions can act upon large distances. Modelling spatial patterns and simulating spatial-temporal processes can be carried out by using spatial interactions through cellular automata (AC) calculation techniques (Figure 19). A cellular automata (CA) calculates the pixel initial state based on neighbourhood conditions and on transition rules series. CA structure can be presented as cells, grids, states, neighbourhood and transition rules (MEIRELLES, 2007).

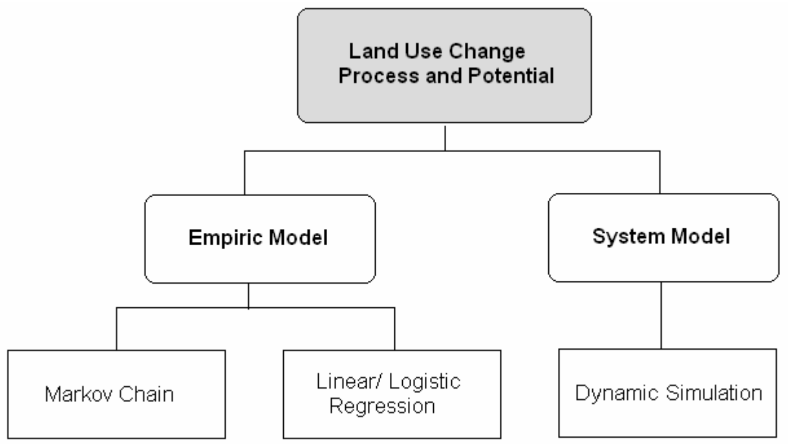


Figure 19. Multiplicity of land use modeling techniques used in the case studies.

Policy options and scenarios of Sugar Cane Expansion in Dyna-CLUE Model

The representation of policy options settings within the land use allocation model Dyna-CLUE consisted on the spatial restrictions and the transition settings. The spatial restrictions were represented by different information plans (IP), while the transitions settings are done by a transition matrix. The IPs and the transition matrix used in the Dyna-CLUE to the Sugar Cane policy case are described, it was developed initially on the framework FP6 Sensor Project.

The possible policy settings are the combinations derived from the set of policy options by the end users. The four groups of policy options available may be divided in two kinds of restriction policies (spatial component and transition rules) and one demand incentive policy (non-spatial component):

- ✓ Spatial restrictions to sugarcane cultivation
  1. No restriction
  2. Agroecological Zoning restriction
  3. Inclusion or Exclusion of Ethanol Plants in Upper Paraguay River Basin (currently this area is not allowed to ethanol plants installation)
  4. Inhibit pre-harvest burning, limiting sugar cane cropping to areas with slopes lower than 12% (where mechanized harvest is feasible) or not (when manual harvest is used in higher slopes with pre-harvest burning).
- ✓ Restrictions of land use class previous to sugarcane
  1. Any previous use;
  2. Only pastures;
  3. Pastures and crops allowed.

✓ Demand Incentive by Different Financial Support level

1. No support (business as usual)
2. High Level of Support
3. Intermediate Level of Support
4. Low Level of Support

The **spatial restrictions** are represented in the Dyna-CLUE model by Layers, which contains spatial restriction areas data in raster format as ASCII files. In the first attempt of Dyna-CLUE execution, the plan of information used was the “Agroecological Zoning restriction”.

The Dyna-CLUE model the preferential allocation of a given set of land use claims based in a range of variables candidates to driving-forces. These variables are of two types:

Continuum variables (distances):

- Minimum distance to river (meters)
- Minimum distance to ethanol plant (meters)
- Distance to municipality core (meters)
- Minimum distance to road (meters)

1. Indicator variables related to the Suitability zoning:

- Low suitability zone;
- Intermediate suitability zone;
- High suitability zone.

The land use change driving forces related to a continuum variables, such as the minimum distance to an ethanol plant, were transformed into categories of distance (“greater than” or “lower than”).

- Minimum distance to river < 10 km
- Minimum distance to ethanol plant < 50 km
- Distance to municipality core < 50 km

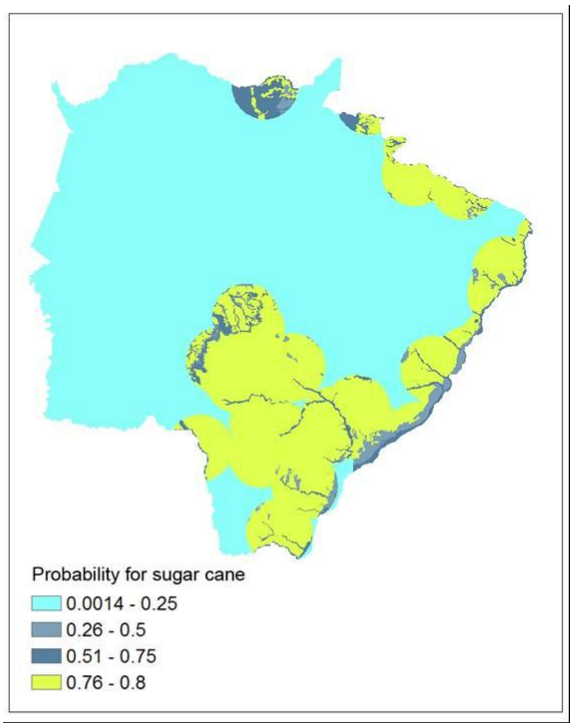


Figure 20 – Probability map for Sugar cane.

Future Activity

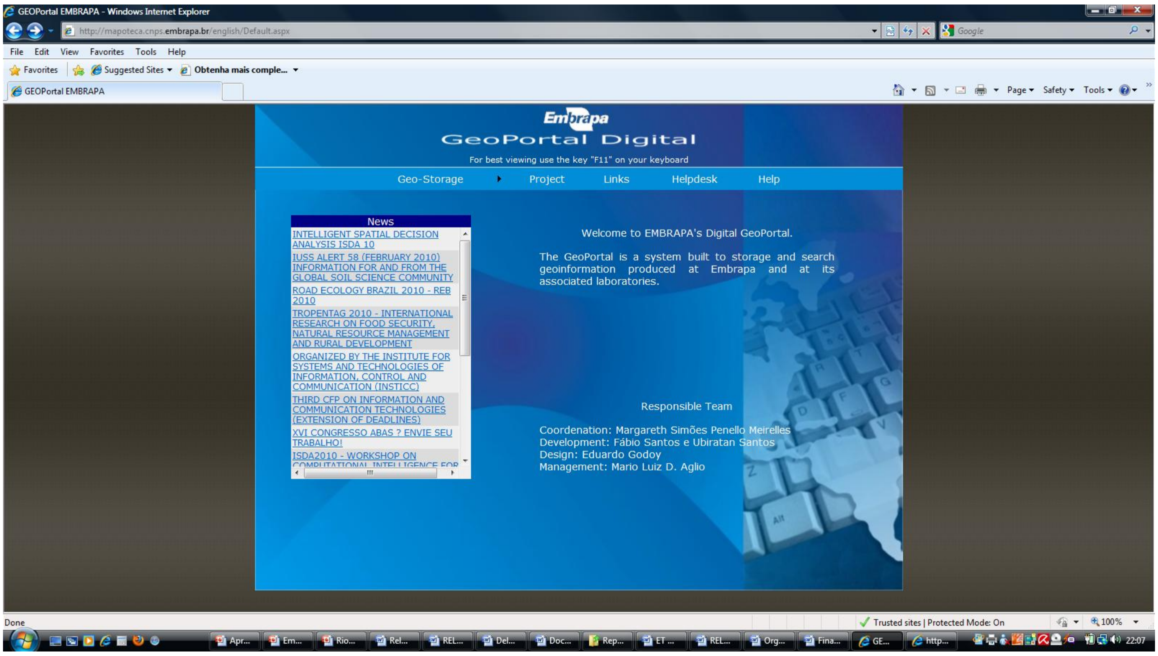
The scientific problem defined for the proposals of future work relates to understanding the environmental issues associated with the spatio-temporal changes in land cover as a function of the dynamics of land use in agricultural areas. Currently the most important case in Brazil is the great changes in land use due to the expansion of the sugarcane cultivation on the savanna's areas in central-southern of Brazil. More specifically and with a regional perspective, the objective of future work is to study the water availability impact of the expansion of sugarcane in the Brazilian Cerrado, in order to establish water supply scenarios and thresholds of sustainability to support proposals for policies for the sustainable development to Brazilian sugar and ethanol production sector.

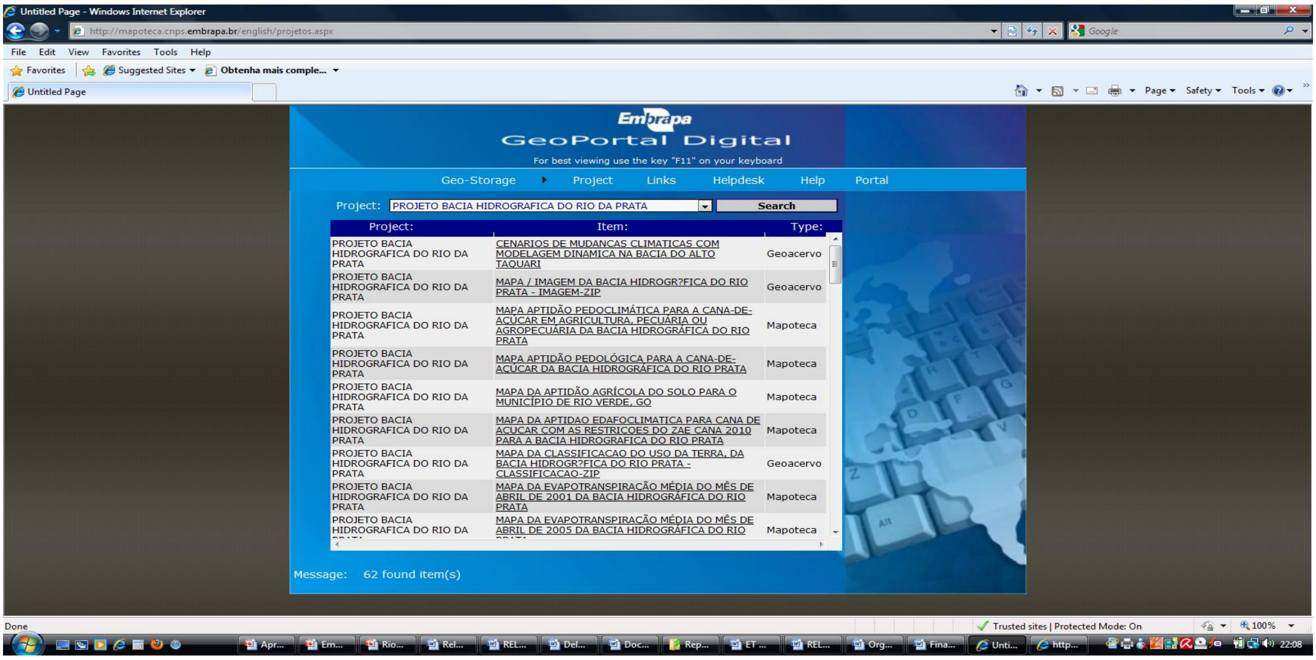
In general, the methodological approach to be developed by Embrapa proposed by LabEx Europe Program includes the integration of the methodology for automatic detection of land use change with the methods for assessing the water demand of different land cover and also the climatic and surface water availability. Thus, there are two main goals. First, studying the effects of different types of land use on water balance variables the following steps will be implemented: (i) Mapping the land use and cover in the watershed of interest with special attention to characterize adequately the covers like Cerrado, sugarcane, pasture and crops; (ii) calculate the climatic water balance (Thornthwaite & Mather 1955) from the input of data: ETr MODIS16 and PPT GOES; and map the water availability (water deficits and surpluses); (iii) Analyze statistically the differences of the water balance variables due to soil types and types of land use, like a spatial and seasonal rates of real evapotranspiration, water deficits and surpluses. Second, with the aim of studying the impacts on water availability, the following steps will be implemented: (i) Quantify the water supply (water balance by Thornthwaite & Mather, 1955) and map the spatial and temporal variation of water availability from hydro-meteorological variables; (ii) Calculate the water requirements of different types of land cover (iii) Estimating the surface water availability through the regionalization of flow indices (iv) establishment of sustainability thresholds and indicators.

Technology and decision makers.

Characterize and monitor LUC and *predict future Land Use patterns*, is an even more real necessity. That means, a **constant evaluation of land use dynamic** using satellite tools, taking advantage of Remote Sensing products and techniques able to monitor real evapotranspiration, emissivity, surface temperature, biomass, and using those products in a regional, synoptic and with a huge temporal repeatability, being able to monitor, not only land use change, but also *land use impacts*, specially on water and climate issues. Moreover, evaluating the influence of land use change, especially the cultivation of sugar cane on the Cerrado, grassland or annual crops such as soybeans and rotation, the water dynamics of the Cerrado, through the analysis of spatial and seasonal rates of evapotranspiration and soil moisture. An efficient way to do that is using even more state of art Remote Sensing techniques and system developments based on Digital Image Processing, as input to methods and procedures to generate land use changes scenarios not only *business as usual*, but also *favorable* and *pessimist or restrictive*, and with those scenarios, make simulations of land use impacts. Consequently, study and improve adaptation and mitigation of negative impacts, providing decision makers with strategic land management information in a feedback cycle, generating *hotspots* analyses, going from planning to monitoring land use and its dynamic. Another important issue is to make information available, disseminating maps and images to the society and decision makers. Those were the contribution of this research work to the IDRC Project.

The project results are available at IAI/DIS metadata, as well as the maps and metadata at Embrapa Geoportal (http://mapoteca.cnps.embrapa.br):





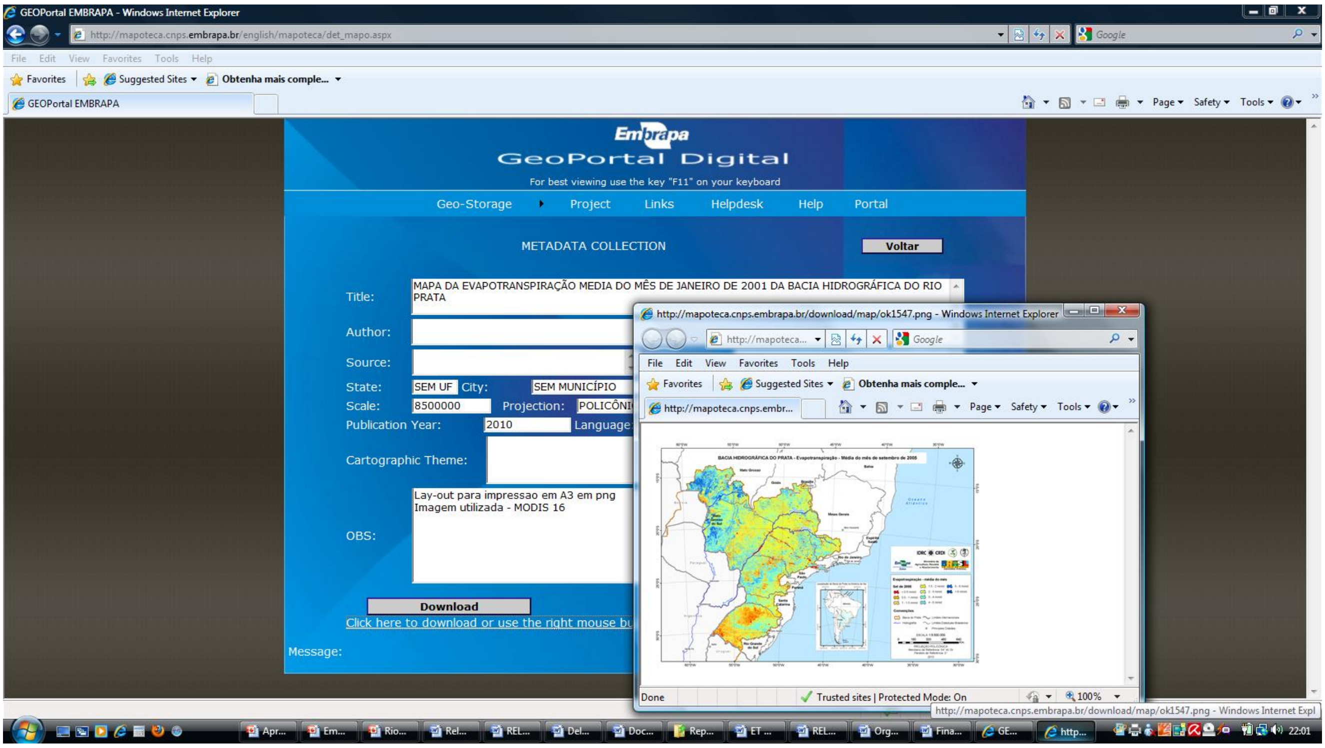
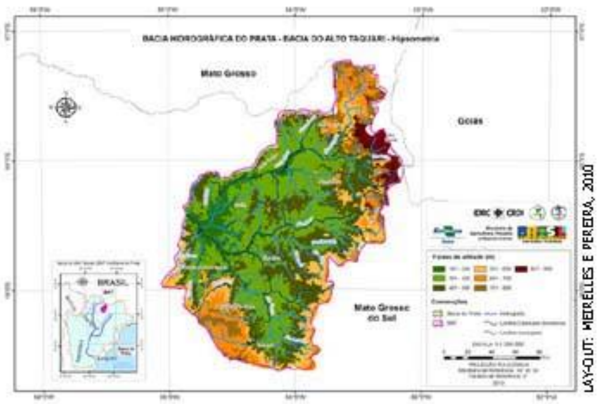
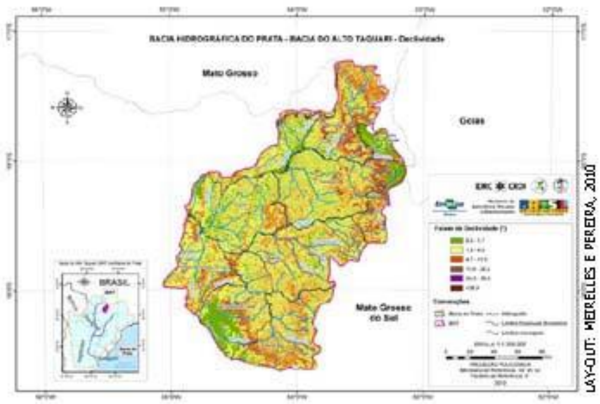


Figure 2. Geoportal (http://mapoteca.cnps.embrapa.br) : Metadata , Query For Map, web Download.

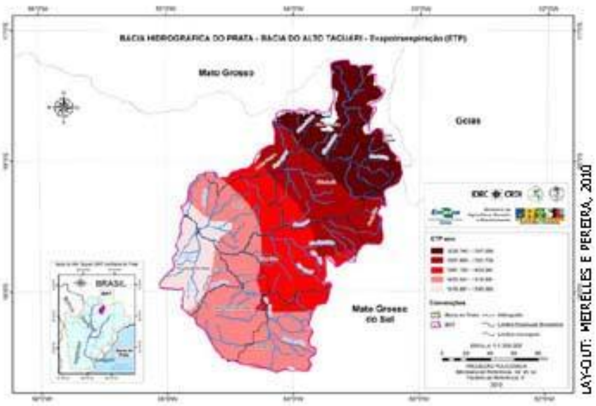
The vector, raster, grid files as well as the Plata Basin files, were organized in a GIS, 262 layers in shape file (ArcGis format) were used to produce the final Plata Basin Maps, the Figures below, present layout of the A3 maps produced for the Plata Basin (brazilian portion), Rio Verde and Taquari area (study case).





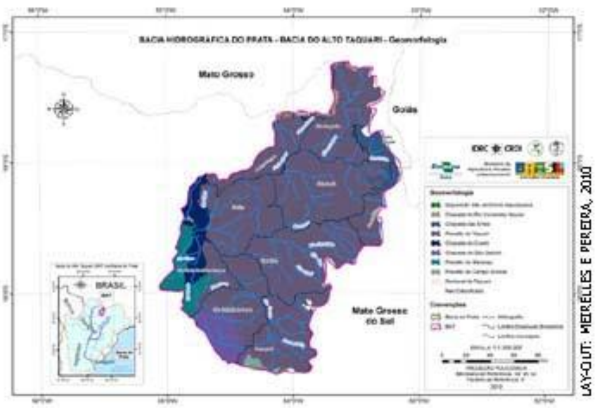
Mapa 1. BAT - SIGPrata A3 - Altitude.png

Mapa 2. BAT - SIGPrata A3 - Declividade.png

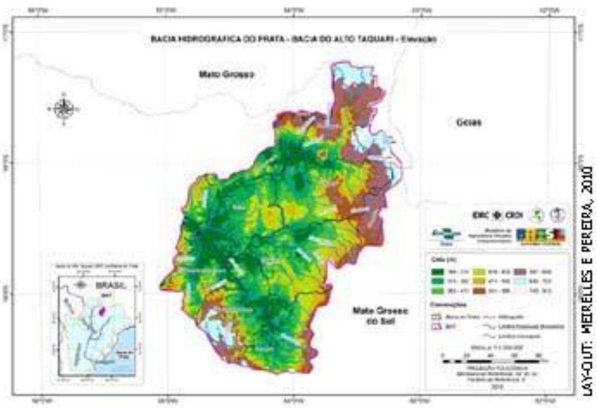


Mapa 3. BAT - SIGPrata A3 – Evapotranspiration

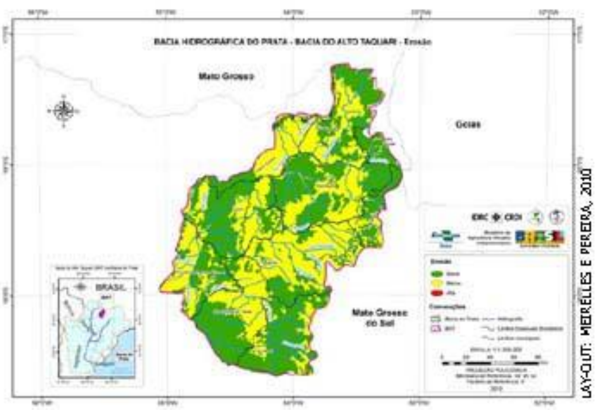
Mapa 4. BAT - SIGPrata A3 - Geology



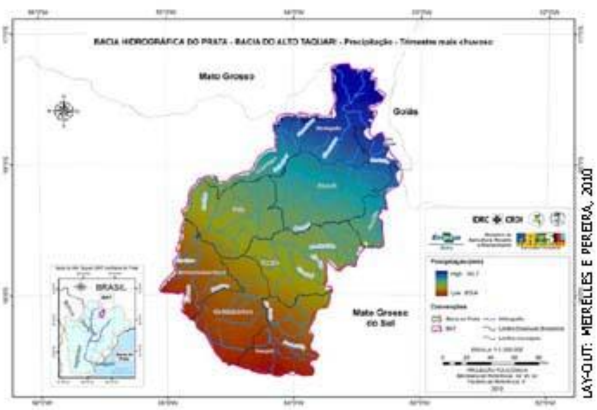
Mapa 5. BAT - SIGPrata A3 - Geomorfology.png



Mapa 6. BAT - SIGPrata A3 - MDE-Elevation.png

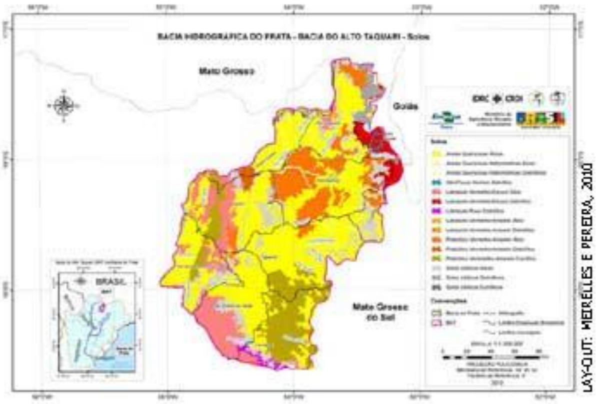


Mapa 7. BAT - SIGPrata A3 - MDE-Erosao



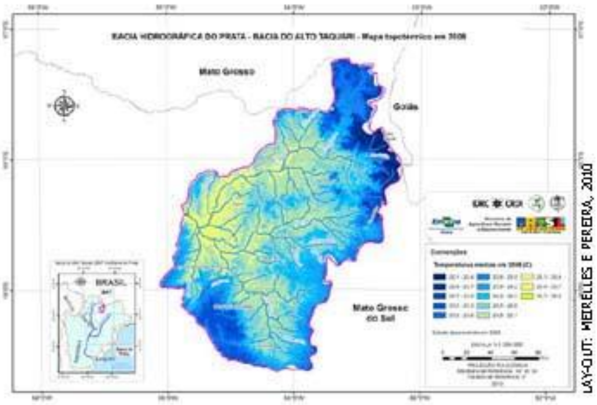
Mapa 8. BAT- Precipitação Trimestre Mais Chuvoso

Mapa 9. BAT-Precipitação Trimestre Menos Chuvoso

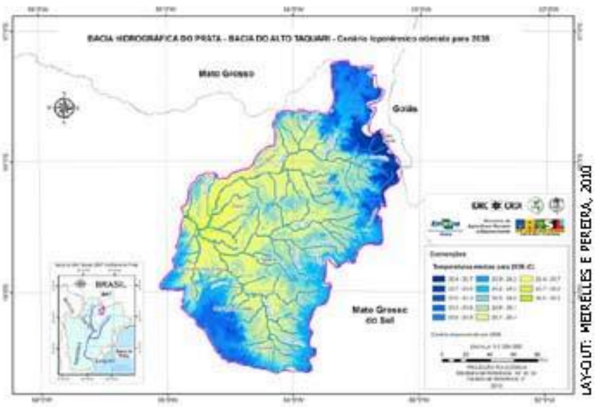


Mapa 10. BAT - SIGPrata A3 - Solos

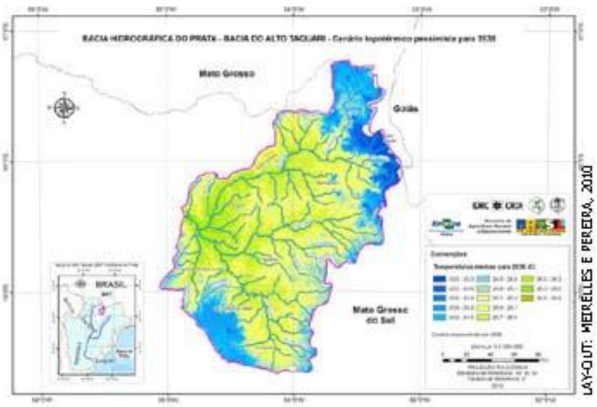
Mapa 11. BAT - SIGPrata A3 - Subacias.png



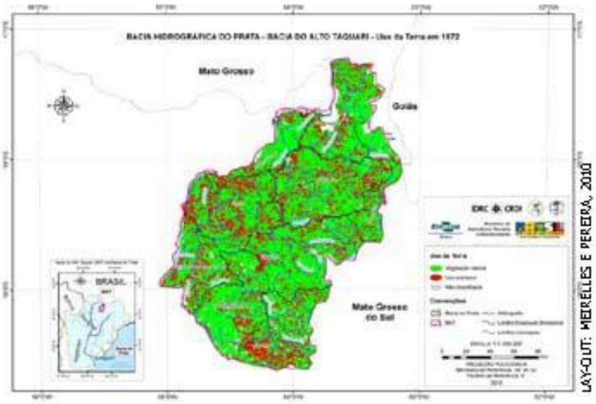
Mapa 12. BAT-SIGPrata A3-Topotermico Atual em 2008



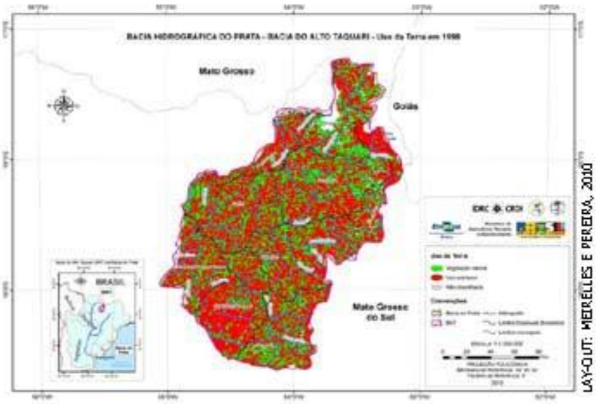
Mapa 13. BAT- Topotermico Cenário Otimista em 30 anos



Mapa 14. BAT- Topotermico Cenário Pessimista em 30 anos



Mapa 15. BAT - SIGPrata A3 – Uso da Terra 1972

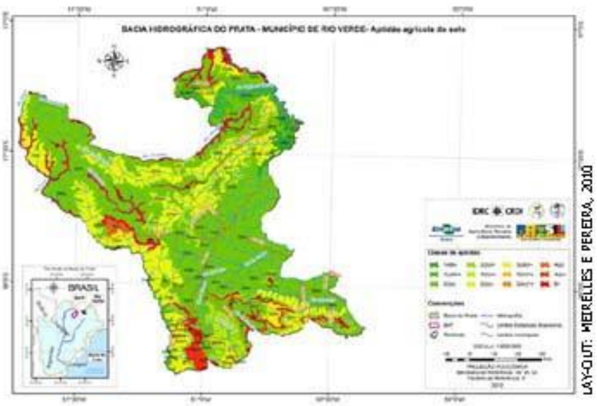


Mapa 16. BAT - SIGPrata A3 – Uso da Terra 1998

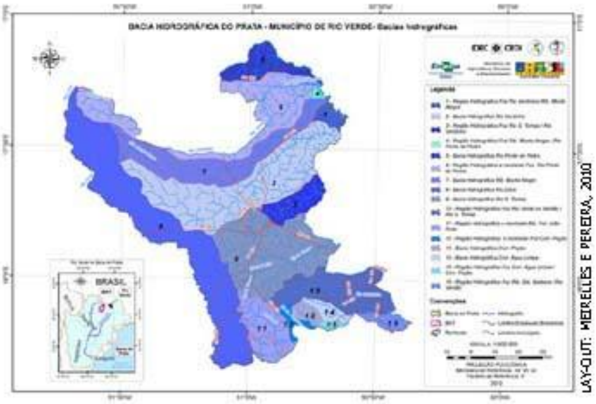
Mapa 17. BAT - SIGPrata A3 – Uso Terra da 2001

Mapa 18. BAT - SIGPrata A3 - Vegetacao

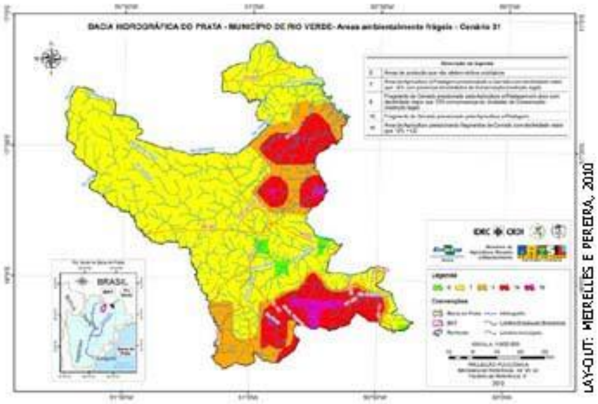
Mapa 19. BAT - SIGPrata A3 Municipios.png



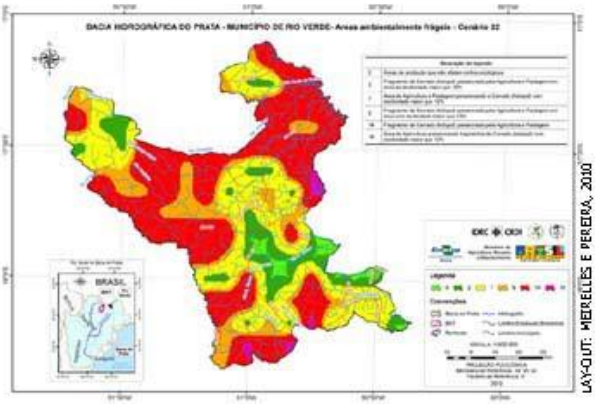
Mapa 20. RioVerde - SIGPrata A3 – Aptdão Agricola.png



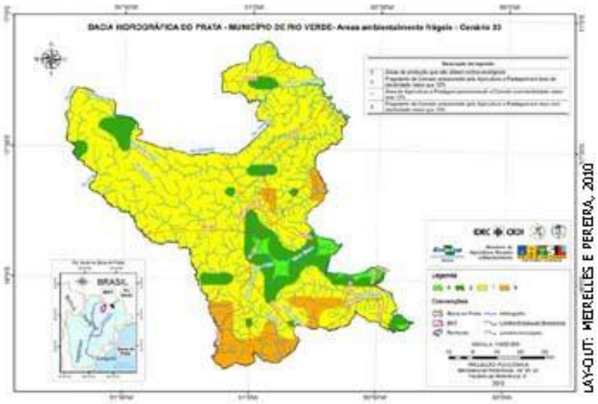
Mapa 21. RioVerde - SIGPrata A3-BaciasHidrograficas.png



Mapa 22. RioVerde - SIGPrata A3 - Cenario1.png



Mapa 23. RioVerde - SIGPrata A3 - Cenario2.png

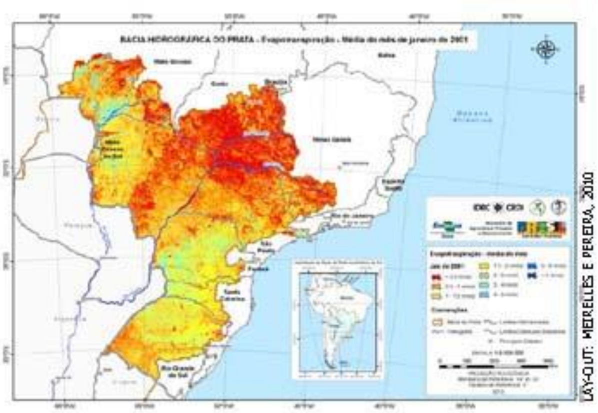


Mapa 24. RioVerde - SIGPrata A3 - Cenario3.png

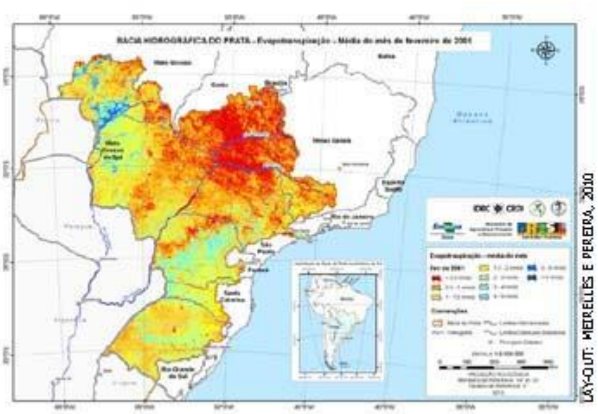
Mapa 25. RioVerde - SIGPrata A3 - Solos.png

Mapa 26. SIGPrata A3 - CanaSat2007.png

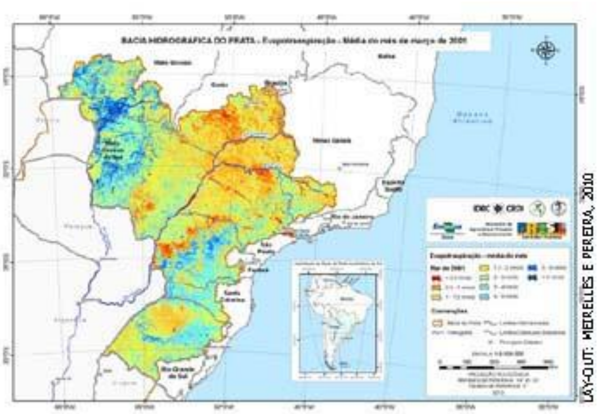
Mapa 27. SIGPrata A3 - Clima.png



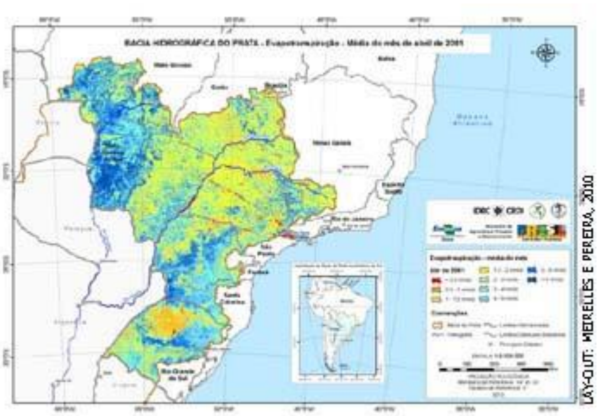
Mapa 28. SIGPrata A3 - EvapoTranspiracao 200101.png



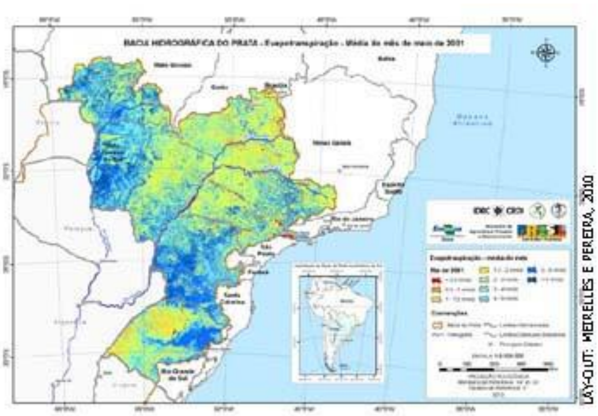
Mapa 29. SIGPrata A3 - EvapoTranspiracao 200102.png



Mapa 30. SIGPrata A3 - EvapoTranspiracao 200103.png

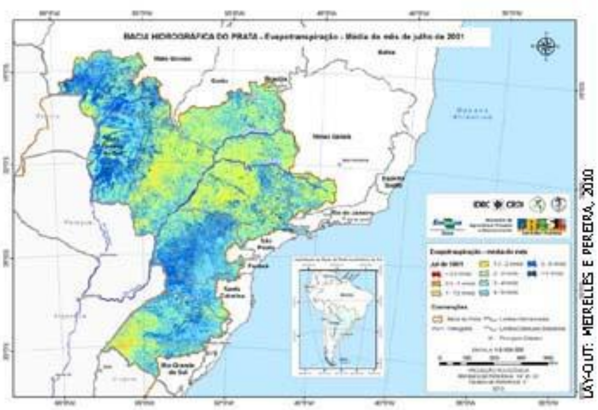


Mapa 31. SIGPrata A3 - EvapoTranspiracao 200104.png

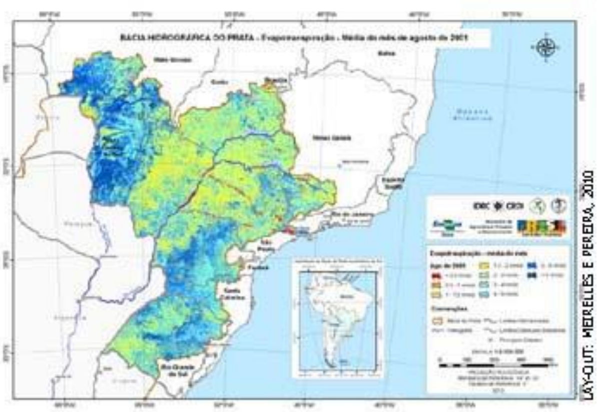


Mapa 32. SIGPrata A3 - EvapoTranspiracao 200105.png

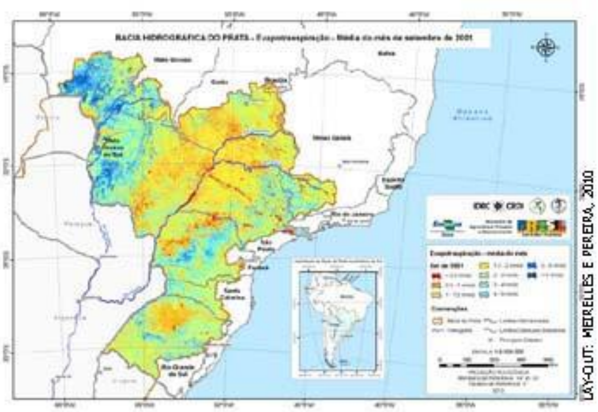
Mapa 33. SIGPrata A3 - EvapoTranspiracao 200106.png



Mapa 34. SIGPrata A3 - EvapoTranspiracao 200107.png

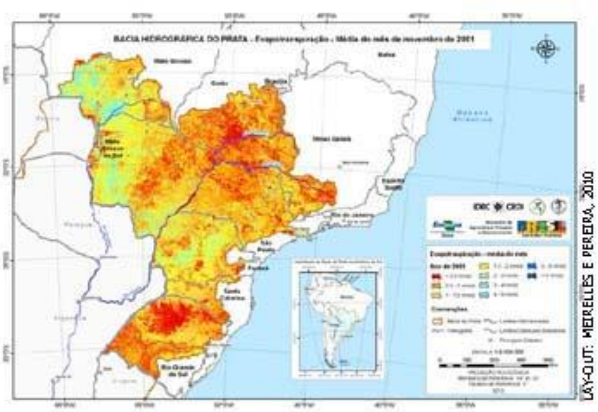


Mapa 35. SIGPrata A3 - EvapoTranspiracao 200108.png



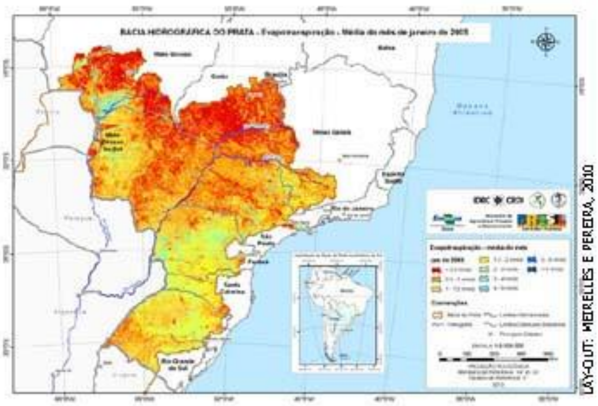
Mapa 36. SIGPrata A3 - EvapoTranspiracao 200109.png

Mapa 37. SIGPrata A3 - EvapoTranspiracao 200110.png



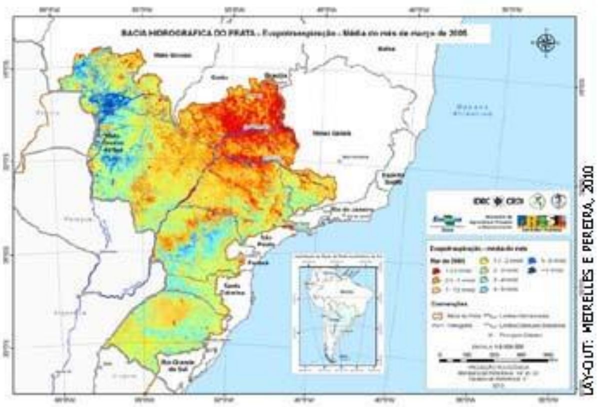
Mapa 38. SIGPrata A3 - EvapoTranspiracao 200111.png

Mapa 39. SIGPrata A3 - EvapoTranspiracao 200112.png

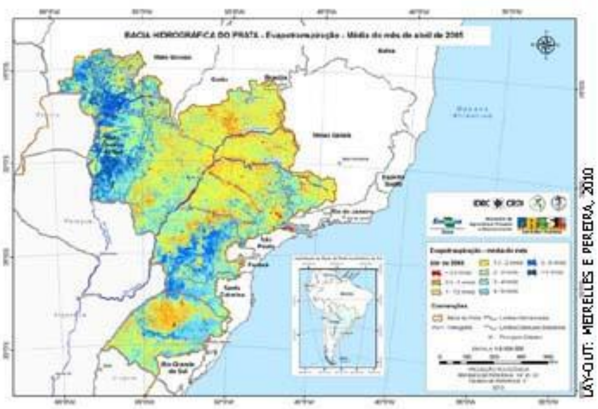


Mapa 40. SIGPrata A3 - EvapoTranspiracao 200501.png

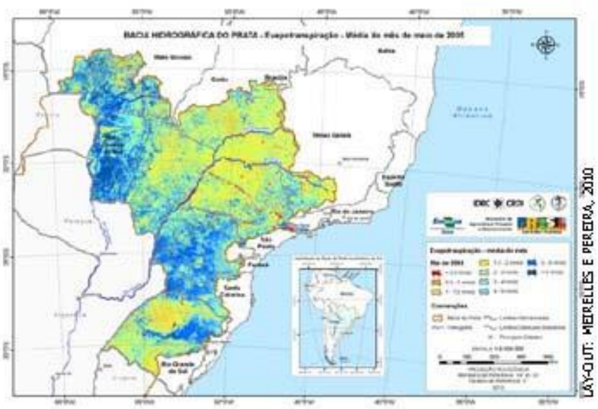
Mapa 41. SIGPrata A3 - EvapoTranspiracao 200502.png



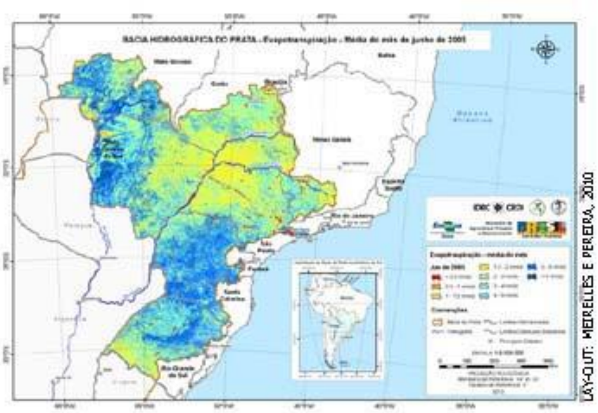
Mapa 42. SIGPrata A3 - EvapoTranspiracao 200503.png



Mapa 43. SIGPrata A3 - EvapoTranspiracao 200504.png

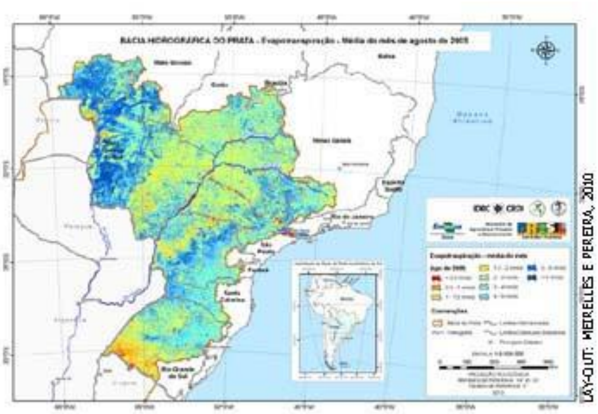


Mapa 44. SIGPrata A3 - EvapoTranspiracao 200505.png

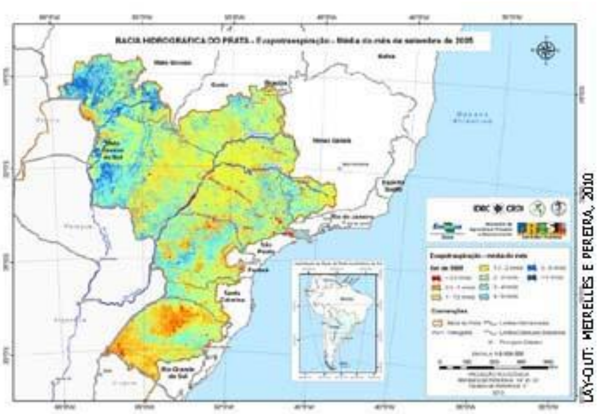


Mapa 45. SIGPrata A3 - EvapoTranspiracao 200506.png

Mapa 46. SIGPrata A3 - EvapoTranspiracao 200507.png

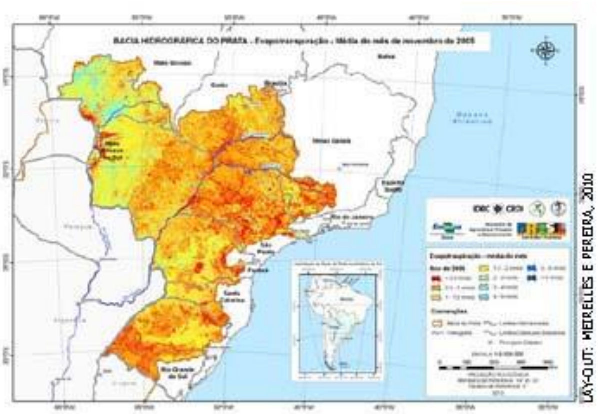


Mapa 47. SIGPrata A3 - EvapoTranspiracao 200508.png

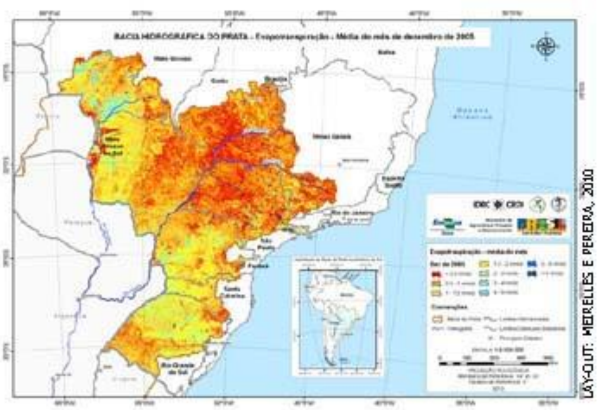


Mapa 48. SIGPrata A3 - EvapoTranspiracao 200509.png

Mapa 49. SIGPrata A3 - EvapoTranspiracao 200510.pn

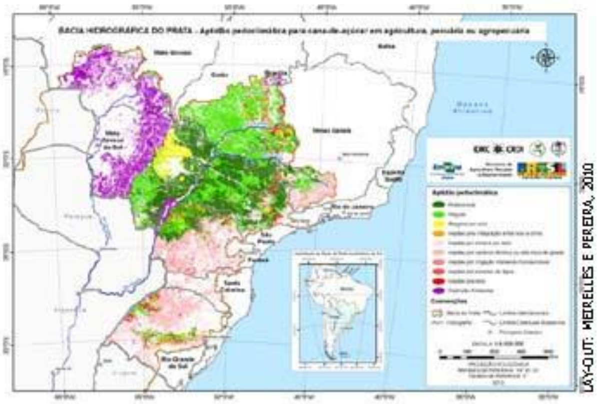


Mapa 50. SIGPrata A3 - EvapoTranspiracao 200511.png



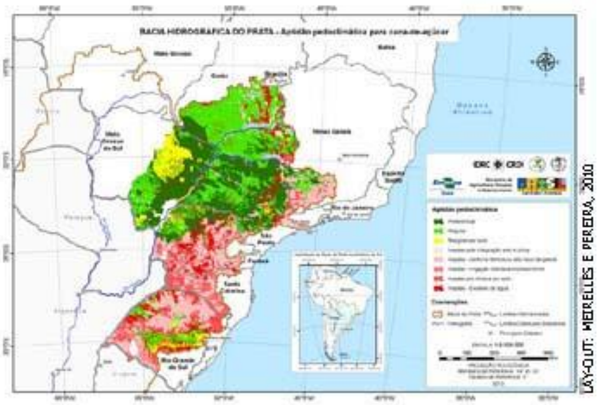
Mapa 51. SIGPrata A3 - EvapoTranspiracao 200512.png

Mapa 52. SIGPrata A3 - ISNA.png

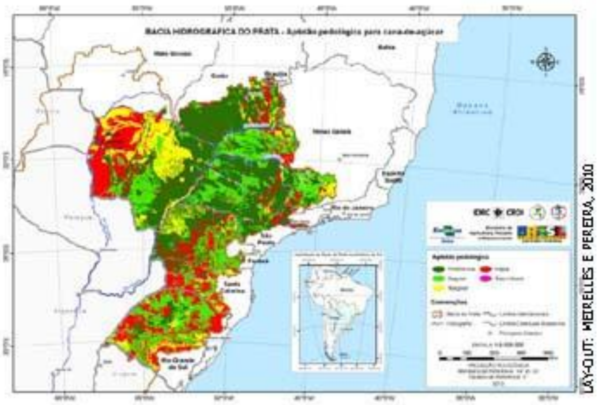


Mapa 53. SIGPrata A3 - PedoClim_ApAcAg.png

Mapa 54. SIGPrata A3 - PedoClim_P&ReCanasat.png



Mapa 55. SIGPrata A3 - PedoClim_Tudo.png



Mapa 56. SIGPrata A3 - Pedologica_Tudo.png

Mapa 57. SIGPrata A3 - RiscoClimaCana_2009.png

Mapa 58. SIGPrata A3 - UsoTerra_2002.png

Mapa 59. SIGPrata A3 - UsoTerra_2008-2009.png

Mapa 60. SIGPrata A3 Solos.png

Figure 69. The layout of the maps produced (A3 format)

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