Mapping changes in forest cover using multi-scale MODIS imagery

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Abstract – A simple change detection methodology based on Vegetation Indices (VI) is applied to MODIS images with different spatial resolutions (250, 500 and 1000 m), in view of detecting changes in forest cover caused by forest fires, clear cuts and new plantations. The study also includes an analysis of the effect of the minimum mapping unit and of the different spatial resolutions on the technical characteristics of the final maps of forest-cover changes. The study is carried out with data from the central region of Portugal.

Keywords: Forest, change detection, burned area, forest plantation, clear cut, MODIS, multi-scale, Kyoto Protocol

1. INTRODUCTION

With the awareness that climate changes are affecting us with more intensity than ever, several nations signed in 1997 the Kyoto protocol, in an attempt to control the processes which induce those changes. One of the main processes that leads to temperature increase and therefore to climate change is the carbon dioxide release. Forests are the main carbon dioxide retainers in the biosphere. Since they are continuously changing, their monitoring is crucial for climate change control. It is therefore important to develop objective, expeditious and reliable methodologies to quantify changes in forest cover, i.e. forest fires, clear cuts and new plantations.

Forest biomass has a direct relation with the carbon quantity it stores. Remote sensing techniques can be used to quantify existing biomass, as well as its changes. Thus, these techniques are potential tools to identify and quantify carbon change, allowing us to accomplish Kyoto protocol article 3.4, which determines that changes in carbon stocks should be identified (United Nations, 1997).

Several scientific studies and operational programs based on satellite imagery have been carried out to produce cartography and statistics of forest changes (e.g., Barbosa et al.; 2001; Salmon et al., 2003; Armas and Caetano, 2004). Within these projects, several types of methodologies have been applied to satellite imagery with different spatial resolutions, often generating different assessments of the same changes in forest cover. Even though it is recognized that these different results and the technical cartographic specifications (e.g. minimum change area identified) are a consequence of the spatial resolution (i.e., pixel size) of the input images, there hasn't been, to the best of our knowledge, any study on the relationship among these variables.

Various countries (e.g., United States of America) and international space agencies (e.g., European Space Agency) have been launching satellites with sensors for regional or global scale environmental monitoring. Moderate Resolution Imaging Spectroradiometer (MODIS) hyperspectral sensors, installed in TERRA (1999) and AQUA (2002) satellites from National Aeronautics and Space Administration (NASA), stand out amongst these sensors. There are already many studies showing the potential and ability of MODIS images to detect and map forest cover changes (e.g., Barbosa et al., 2001; Salmon et al., 2003; Armas e Caetano, 2005). The potential of MODIS images for detecting changes in forest cover has already been confirmed. Nevertheless, there is still little scientific work aiming at determining the smallest change area, i.e., the minimum mapping unit (MMU) that can be identified by each type of MODIS imagery. Furthermore, most of the studies dealing with forest changes are focused on burned areas and very few address clear cuts and new forest plantations.

In this study, we used a very simple methodology to identify changes in forest cover caused by forest fires, clear cuts and new plantations. This methodology is based on differences of vegetation indexes (VI) derived from MODIS images with different spatial resolutions (250, 500 and 1000 m) and acquired in different dates. We also analysed the effect of spatial resolution and MMU on the technical characteristics of the final output maps of forest cover change.

2. STUDY AREA AND DATA USED

The study area is located in the central region of Portugal's mainland and has about 1 430 000 ha. This region of Portugal is ideal for our study because of its heterogeneous land cover, large abundance of forests, diversity of forest types, and heterogeneous terrain (smoother and mountainous areas).

In this study we address forest cover changes occurred between September 2002 and September 2003. This period was chosen as a result of imagery availability [in this case, a national cover of SPOT High Resolution Geometric (HRG) satellite images taken in September 2003 and owned by the Portuguese Geographic Institute (IGP)]. These images have a spatial resolution of 10 meters and, together with other ancillary data, were used to generate, through visual interpretation, the

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reference map (i.e., "ground truth") for the accuracy assessment procedure. This reference map has 3 land cover classes: burned areas, clear cuts and new forest plantations.

The main data used in this study are: (1) MODIS images with 250, 500 and 1000 m spatial resolutions; (2) CORINE Land Cover 2000 map (CLC2000); and (3) SPOT High Resolution Geometric (HRG) satellite images.

The MODIS satellite images used in this study are described below:

- MODIS MOD 43 B4 (MODIS 1000), which are 16 days' composites, from TERRA and AQUA satellites, with a spatial resolution of 1000 m. These images are corrected for atmospheric elements such as water vapour, aerosols, cirrus and clouds. Additionally, they also have a correction made with the bidirectional reflectance surface distribution function (BRDF), through which the spectral reflectance is adjusted to the mean zenithal angle, allowing for the correction of different illumination angles (Strahler and Muller, 1999). The composites used in this study were made with images acquired between 14 and 29 September 2002 and 2003.
- MODIS MOD 09 A1 (MODIS 500), which are 7 days' composites, from AQUA satellites, with a spatial resolution of 500 m. These images are corrected for atmospheric elements such as water vapour, aerosols, cirrus and clouds (Vermote e Vermeulen, 1999). The composites used in this study are made with images acquired between 6 and 13 September 2002 and 2003.
- MODIS MOD 09 A1 (MODIS 500), which are similar to MODIS 500 (Vermote e Vermeulen, 1999), except in the fact that they have a spatial resolution of 250 meters.

The CLC 2000 (Instituto do Ambiente, 2005) is a land cover map with 44 classes, produced at the scale of 1:100000 and has a MMU of 25 ha. CLC 2000 was used to produce different types of spatial masks to isolate specific land cover types.

3. METHODOLOGY

The methodology applied in this study consists of two main steps:

1. Change detection – identification of changes in forest cover through a multi-temporal approach based on differences detected in vegetation index (VI).
2. Identification of change type – separation of the forest changes identified in the first step, by type (i.e., burned areas, forest clear cuts and new plantations); this is done through simple spectral analysis.

The VI difference methodology was chosen because it has already been applied for the same purposes, achieving good results (e.g., Salvador *et al.*, 2000; Sunar and Özkan, 2001; Armas and Caetano, 2004; Armas e Caetano, 2005). The VI applied was the Normalized Difference Vegetation Index (NDVI), which is the most commonly used in vegetation studies, including change detection.

In the VI difference methodology, NDVI from two different dates are subtracted, resulting in a new image with null values for places where no changes have occurred and positive or negative values for areas with change (corresponding to an increase or decrease in vegetation biomass, respectively). To discriminate the less significant differences in NDVI from the relevant ones (which correspond to real changes), a threshold is applied to the NDVI difference image (Jensen, 1996).

In a first step, NDVI was calculated for all images (MODIS 250, MODIS 500 and MODIS 1000) of the two consecutive years (2002 and 2003). Afterwards, each difference image was generated by subtracting the 2002 NDVI image from the correspondent 2003 one. Then, a threshold was applied, based on the mean and standard deviation of the VI difference image. Pixels with a value above a certain number of standard deviations to the mean value of the NDVI difference were considered to be changes. To identify the best threshold, we tested three different values of standard deviation (0.75, 1 and 1.25). These values were selected taken into account previous studies (Armas and Caetano, 2004; Armas and Caetano, 2005). Since the objective was to detect NDVI decrease, the different values of standard deviation were subtracted from the correspondent mean value of the VI difference image. For each forest change, all possible combinations among the MODIS images, the change detection thresholds, the minimum mapping units and the masks used for analysis, were considered.

The MMU can be defined as the minimum area that is represented within a map. In the change maps produced in this study, the MMU concept is applied to both change and no change areas. All areas smaller than the MMU are generalised (i.e., eliminated) before the derivation of the final product. In Table 1 the area of the MMU considered in this study is presented, for the various spatial resolutions of the MODIS images.

Table 1. Area (ha) of the MMU (in pixels) considered in this study for the 250, 500, and 1000 m MODIS imagery

	MMU (pixels)					
	1	**2**	**4**	**6**	**8**	**10**
MODIS 250	5.4	10.7	21.5	32.2	42.9	53.7
MODIS 500	21.5	42.9	85.9	128.8	171.7	214.7
MODIS 1000	85.9	171.7	343.5	515.2	686.9	858.6

The following masks produced with the CLC2000 cartography were tested:

- No mask - all the CLC 2000 classes;
- Urban and water - all land covers, except artificial areas, humid areas and water bodies;
- Forests - broad-leaved, coniferous and mixed forest;
- Grasslands and shrubs - natural grassland, shrublands and transitional woodland/shrub;
- Integrated - forests, grasslands and shrubs (including transitional woodland/shrub).

After applying, for each image, all possible combinations of the parameters above mentioned (change detection threshold, MMU and masks), the results were compared to the reference map (i.e., "ground truth"). An error matrix was created for each map, and standard accuracy assessment indices (i.e., commission and omission errors) were calculated. The omission error of the "change areas", which is complementary to the producer's accuracy, indicates the percentage of changes that were not identified. The commission error of the "change areas", which is complementary to the user's accuracy, indicates the percentage of areas that were misclassified as "change areas".

4. RESULTS AND DISCUSSION

The analysis of the effect of the change threshold, MMU and land cover mask on the technical cartographic characteristics was carried out on maps where the type of forest cover change (i.e., burned areas, clear cuts and new forest plantations) is not discriminated. The most relevant results of this analysis are:

- An increase of the change threshold leads to an increase of the omission errors and to a decrease of the commission errors. Therefore, the lowest omission error was reached with a threshold of 0,75, while the lowest commission error was reached with a threshold of 1,25;
- As the MMU increases, the commission errors decrease and the omission errors increase. When increasing the MMU, the number of "change areas" smaller than that parameter that are eliminated also increase, causing a raise in the omission errors. On the other hand, as MMU increases, the false alarms (i.e. areas detected as changes but that are not real changes) are reduced, and the commission errors decrease. The decrease of the commission errors caused by the increase of the MMU is more notorious in the MODIS images with larger spatial resolution. Conversely, the increase of the omission errors caused by the increase of MMU is more explicit in images with smaller spatial resolution;
- The best results were obtained with the application of the integrated mask, since this mask reduces the commission errors associated with NDVI changes in land cover classes other than shrublands and forests. However, the use of this mask does not allow the detection of new forest plantations in agricultural areas.

Table 2 presents the best results obtained for each type of MODIS image. The best combination of parameters (the change threshold, MMU and land cover mask) was selected through minimisation of the sum of omission and commission errors.

For all types of images, the best results were obtained with a change threshold value of 1.25 and using the integrated land cover mask. For MODIS 250 and 500, the best results were obtained using a MMU of 10 pixels, which has an area of 53.7 and 214.7 ha, respectively. However, using MODIS 1000 imagery, the best results were obtained with a MMU of 2 pixels, which has an area of 171.7 ha.

Prior to the second step of the methodology, we carried out an analysis of the area (i.e., extension) of each type of forest cover change in the study site (Table 3). In this analysis we used the forest cover changes presented in the reference map produced by visual interpretation of the SPOT HRG imagery and ancillary data.

Table 2. Best accuracy assessment indices for the forest cover change maps derived from MODIS 250, 500 and 1000

MODIS 250	Standard deviation	1.25
	MMU (ha)	53.66
	Commission error (%)	42.18
	Omission error (%)	52.37
MODIS 500	Standard deviation	1.25
	MMU (ha)	214.66
	Commission error (%)	39.38
	Omission error (%)	60.65
MODIS 1000	Standard deviation	1.25
	MMU (ha)	171.73
	Commission error (%)	44.98
	Omission error (%)	48.49

Table 3. Characterisation (number of areas and extension) of the three types of forest cover changes (i.e., burned areas, clear cuts and new plantations)

Classes of area (ha)	**Burned Areas**		**Clear Cuts**		**New Plantations**	
	Num	**Area (ha)**	**Num**	**Area (ha)**	**Num**	**Area (ha)**
< 5	126	259	1089	2054	496	949
5.4-10.8	29	237	132	975	67	508
10.7-21.5	31	477	63	935	35	544
21.5-32.2	16	437	9	229	10	285
32.2-42.9	4	149	8	301	8	286
42.9-53.7	4	200	4	187	1	43
53.7-85.9	11	764	4	245	4	251
85.9-128.8	7	712	3	299	3	334
128.8-171.7	9	1390	0	0	0	0
171.7-214.7	6	1181	0	0	1	180
214.7-343.5	7	1870	1	264	1	216
343.5-515.2	8	3560	1	345	1	399
515.2-686.9	7	3990	0	0	0	0
686.9-858.6	2	1440	0	0	0	0
>= 858.6	15	37662	0	0	0	0
Total	282	54328	1314	5835	627	3995

In the study site, the total burned area is very large but clear cuts and new forest plantations occupy a rather small area. In fact, most of the burned land is concentrated in very few but very large burned areas. On the other hand, the total area of clear cuts and new plantations is spread by a very high number of very small areas. It is worthwhile noticing that there are only 9 areas of clear cuts and 10 areas of forest plantations larger than 10 pixels of MODIS 250 (53.7 ha).

The results presented in Table 3 indicate that MODIS images do not have enough spatial detail to identify most of the clear cuts and forest plantations in the study area. This is due to the fact that even the small MMUs of maps derived from the MODIS images with the best spatial resolution (Table 2) are too large when compared to the small extension of these forest cover changes. On the contrary, these results suggest that MODIS imagery can be used to identify burned land since most of this type of change in the study site is concentrated in very large areas.

Having into account the considerations above presented, the second step of the methodology focused only on the identification of burned areas. It was found that when the first step based on VI difference images is calibrated exclusively to burned areas, and not to forest cover changes in general, the results are slightly better. These results were then refined by applying thresholds to the red (5%) and NIR (20%) reflectance of the areas identified as burned in the first step (Fig. 1).

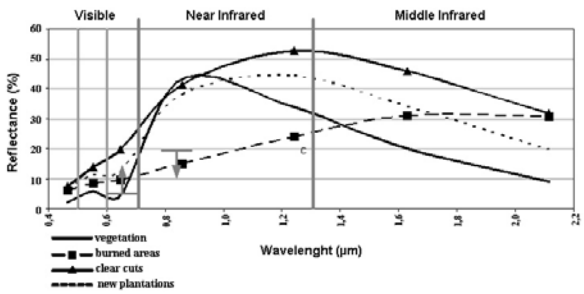

Figure 1. Spectral characterisation of healthy forest, burned areas, clear cuts, and new forest plantations, using MODIS 500 imagery. The thresholds applied to the red and near infrared reflectance to discriminate the burned areas are also plotted.

The map of burned areas with lowest omission (32,53 %) and commission errors (39,93 %) was obtained using the MODIS 1000 imagery, a change threshold of 0.75, a MMU of 1 pixel, and spectral thresholds of 5% and 20% for the red and NIR reflectance, respectively.

The application of the same methodology and exactly the same parameters to the detection of burned areas in a larger region (3 350 000 ha), also located in central Portugal, generated a map with omission and commission errors of 18 % and 17%, respectively. The larger errors in the smaller study area are a result of the larger proportion of natural grasslands/shrublands that exhibit (because of phenology) significant changes in biomass from one year to the other. These changes are easily confounded with burned areas. Furthermore, the smaller study area has a lower abundance of large forest fires when compared to the larger study site.

5. CONCLUSIONS

The most important results obtained from this study can be formulated as follows:

- A simple methodology based on VI image differencing was efficient in detecting changes in forest cover in the central region of Portugal using MODIS 250, 500 and 1000 m;
- The MMU and the standard deviation used to establish the change threshold, strongly affect the technical characteristics of the maps of forest cover changes;
- An analysis of the size and number of clear cuts, new plantations and burned areas in the central region of Portugal revealed that only forest fires are large enough to be adequately mapped by MODIS imagery;
- The application of spectral thresholds to the red and NIR reflectance, in view of refining the identification of burned areas using the VI image difference methodology, improved the accuracy of the burned areas maps.

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