Intercomparison between forest cover mapping for two areas in Santa Catarina (Brazil)

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Abstract.
Land cover mapping, especially with regards to forest cover, resulting from different methodologies will likely disagree in forest cover proportions. This study evaluates and compares consolidated thematic maps, in vector and raster formats, derived from national and international research efforts at larger regional or global extents. The municipalities of Blumenau (BL), Rio do Oeste and Presidente Getúlio (RO/PG), in the state of Santa Catarina (Brazil), were selected as representative of both a high percent and a low percent forest cover within the subtropical evergreen rainforest. In this characterization of the forest cover response at local scales when using generalized products, the raster products provided the highest scores: e.g., 97% in BL and 83% in RO/PG for rasters versus 70% and 46% for vectors respectively. The minimum scores attained were respectively 65% and 34% (rasters) versus 52% and 18% (vectors). All in all, on the basis of fotointerpretation and field work estimates of >50% of forest surface in BL and <30% of forest in RO/PG, too divergent over/under-rated scores are found. As expected, overlap of maps resulted in reduced coincident forest surface: agreement of less than 50% (e.g., 35% for BL), decreased considerably to a 5% in RO/PG. Nonetheless, vector-vector and raster-raster comparisons work better (e.g., agreement in RO/PG vector 10.4% and 13.5% raster). Although the diversity of methods and forest definitions lie beneath the discrepancies found, the need of homogeneous accurate workflows and products in forest cover estimation and monitoring at regional and local scale is proved.

Key words: land cover monitoring, remote sensing, Blumenau, Rio do Oeste, Presidente Getúlio.

1. Introduction

Changes in land use have enabled humans to appropriate an increasing share of the planet's resources, but they also potentially undermine the capacity of ecosystems to sustain food production, maintain freshwater and forest resources, regulate climate and air quality, and ameliorate infectious diseases (Foley et al., 2005). Therefore, the biodiversity-productivity relationship is foundational to our understanding of the natural ecosystem functioning (Liang et al., 2016). The ongoing species loss in forest ecosystems worldwide could substantially reduce forest productivity and thereby forest carbon absorption rate (Liang et al., 2016).

In the state of Santa Catarina, Vibrans et al. (2013), evaluated and cross-validated with field sample units in the forest (i.e. forest plots) four thematic maps. As abovementioned, intercomparison of map products for the same region is prone to disagreement. In that case, the contrast showed varying forest cover percentages, from 22 to 41%, whereas the

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estimations derived from field observations provided 27.7% percentage of forest cover (Vibrans et al., 2013).

The present study, considers in particular the identification of forest/non forest areas within the Atlantic Forest domain, in turn subdivided into diverse vegetation physiognomies, from which the evergreen rainforest constitutes the forest cover in the municipalities of Blumenau (BL), Rio do Oeste and Presidente Getúlio (RO/PG), selected for the analysis. Although a binary legend is chosen for the analysis, it should be kept in mind that the specific features of each forest type have an effect on the adequacy of the materials and methods in map products. The quantification of global land cover through mapping techniques is aimed at producing consistent features of global, regional and local relevance (Hansen et al., 2013). Land cover maps constitute one source of relevant source information for land use planning (Vibrans et al., 2013). Often, estimation of large area of forest cover, from remote sensing-based maps is challenging because of image processing, field validation logistical issues, and data acquisition constraints (Vibrans et al., 2013). All the map products analysed in this study are derived from remote sensing data. Even though the products result in more than acceptable accuracies at the global scales addressed in their construction, the analysis at local scales is useful for a further understanding on the behaviour at management unit from the decision making point of view. On the other hand, from the research perspective, it is an initial step in the achievement of relevant improvements of the already tested methods in the generation of more accurate products adapted to the local context.

This study is considered an initial assessment of forest/non-forest areas estimation and change detection within a larger project of remote sensing monitoring in liaison with the ongoing Forest and Floristic Inventory of Santa Catarina, in Brazil. Thus, a first step requires the comparison of estimates of forest area obtained from available forest/non-forest maps and an historical, baseline forest/non-forest maps of different spatial resolutions and data sources.

2. Methods

The area of study selected in the evaluation of forest cover comprise BL and RO/PG municipalities in the state of Santa Catarina, in Brazil, located between 26°36'50"S/49°00'50"W and 27°15'50"S/49°55'56"W. The surface of each municipality is 518.539, 294.148 and 247.686 km² respectively. These municipalities are located within the Rio Itajaí basin, in the phytoecological region of evergreen rainforest of the Atlantic Forest domain (Oliveira Filho, 2009). As a methodological resource, the municipalities of RO/PG were considered as a single unit of study, since together they represent a similar surface compared to BL (518.5 km^2 versus 541.8 km^2), while presenting diverse land use patterns.

In order to compare the forest cover behaviour in both areas aforementioned, maps available in vector format and raster format were used (Table 1). Vector maps analysed were: a) Ground location of the Forest Remnants cover in Santa Catarina –LCF/SAR (SAR, 2005); b) Ground location of the natural vegetation cover of native Atlantic Forest domain – PROBIO (Cruz & Vicens, 2007); c) Atlas of the Remnant Forest of Atlantic Forest –Atlas 2008, Atlas 2012 and Atlas 2014 (Fundação SOS Mata Atlântica, 2009, 2013, 2015) and d) General Thematic Map of the Santa Catarina State, Mata Atlântica Protection Project - PPMA (Geoambiente, 2008) ordered by the Fundação do Meio Ambiente de Santa Catarina (FATMA) – Santa Catarina Environmental Foundation. In turn, the raster product maps employed were: e) Global Forest Change generated by Hansen et al. (2013); f) Global Land Cover produced by the European Space Agency (ESA) and the Catholic University of Louvain in Belgium (UCL) – Globcover (ESA & UCL, 2011); g) Annual Land Cover and Land Use Mapping Project, executed for the Atlantic Forest domain by the "Fundação SOS Mata Atlântica" and ArcPlan, comprising 8 annual periods (2008-2015) – MapBiomas

(MAPBIOMAS, 2015, Rosa et al., 2016); h) Global forest/non forest map, developed by the Japan Aerospace Exploration Agency (JAXA), comprising 5 periods (2007-2010, 2015) – PALSAR-2/PALSAR (Shimada et al., 2014; JAXA, 2016). Description features are found in Table 1 for the products introduced in this study. In Vibrans et al., (2013), a similar characterization of a), b) c) (2008) and d) products is available.

Table 1. Land cover and land use map products features in Santa Catarina.

Map product	**ATLAS 2012**	**ATLAS 2014**	**Hansen 2010**	**GLOBCOVER 2009**	**MapBiomas 2008-2015**	**PALSAR-2 / PALSAR 2015**
Satellite / Sensor	Resourcesat -1 LISS III, Landsat-5 TM	Landsat-8 OLI	Landsat-7 ETM+	Envisat MERIS	Landsat-5 TM, Landsat-7 ETM+, Landsat-8	ALOS (PALSAR) / 1 and 2
Spatial resolution	30 m	30 m	30 m	300 m	30 m	25 m
Method	Visual	Visual	Decision tree algorithm/ Google Earth Engine	Pixel level classification, temporal characterization by clustering, cluster classification	Spectral mixing models (SMA), indices, Google Earth Engine	Multiresolution segmentation of each HH and HV PALSAR mosaic
Global accuracy	Unknown	Unknown	Unknown	58% - 70% (1.408 points)	Unknown	84%
Forest definition	Primary and secondary forests (*)	Primary and secondary forests (*)	Tree cover > 5m height	Vegetation > 5 m	Unknown	Area > 0.5 ha, > 10% cover

* excluding the mangroves and restinga classes

In all, 22 map products have been compared, 6 in vector format and 16 in raster format (i.e., derivations from 2 - Hansen - based corresponding to two percent bands >50% (tree cover) and >94%, 5 - PALSAR-2/PALSAR, 8 - MapBiomas, 1 - GlobCover), developed in different temporal periods, derived from diverse methodologies and remote sensing sources. These map products were subset to the two study area units (BL and RO/PG) and overlaid using the ArcMap/ArcGis 10.1 version software. In order to quantify the classes in the raster format map products, the raster to polygon data transforming tool was applied. All areas computation was related to the cartographic projection UTM 22S zone, datum WGS84.

For each municipality, the binary forest/non forest land use class from the map was determined after reclassification of the legend provided in each of the maps products. Although this stage constitutes a simplification in most of the products from the hierarchical and more detailed legends available, indeed suitable in different forest types spectral distinction and management targets, the homogenization of forest definitions is an unavoidable step undertaken for the sake of feasibility of the intercomparison purposes. Hence, for further analyses, land use classes were aggregated to forest and non-forest. Thus, a conservative estimate of forest cover is to be obtained by eliminating possible sources of overestimation. All analyses were based on the two classes, forest and non-forest.

3. Results and discussion

The percentage of forest cover for BL, municipality with a high forest cover, vary between 52.5% (Atlas SOS 2005/08) and 70.3% (PPMA) as shown in Figure 1 (vector maps forest cover). Analogously, 65.3% (Hansen >94%) and 97.0% (PALSAR-2 2015) as shown in Figure 2 (raster maps forest cover). Therefore, the range of forest cover for BL scored 17.8% between vector maps, among which four of them slightly differed circa 53% (Atlas SOS products, PROBIO) whereas two of them scored close to the 69% value (LCF/SAR & PPMA). Coherently, a similar variation ratio was detected in the forest covers scores for the municipalities of lower forest covers, RO/PG: close scores for the Atlas SOS products (circa 18-20%) and larger disagreement in the case of LCF/SAR (45.8%), PROBIO (25%) and PPMA (37.7%) (Figure 1). Scores variation were detected between different periods (i.e., year) for the same map product and among the different products (maps). The behavior of the forest cover in the two products derived from the Hansen map (“Hansen >50%” and “Hansen >94%”) was logical: higher tree cover percentages ranges provide the best agreements in forest cover. Regarding the forest cover in the PALSAR product periods (2007-2010) it was similar for BL, although varied in the same period for RO/PG (53.6%, 42.3%, 47.7% and 55.5%). Surprisingly. in the continuity Project of JAXA, PALSAR-2, the highest cover percent value for BL was obtained (97%), even surpassing the high values obtained from the GlobCover 2009 (ESA & UCL, 2011). This product, due to its spatial resolution of 300 m, was supposed to provide the highest values of forest surface in a municipality with high forest cover, like BL. In turn, the MapBiomas product (MAPBIOMAS, 2016) did not generate large discrepancies during the period analysed (2008 – 2015). Nonetheless, in the two areas evaluated, the percents obtained were higher than the scores provided by the Atlas SOS Mata Atlântica (3 years) and PROBIO. Only the PPMA (BL – 70.3%) and LCF/SAR (RO/PG - 45.8%) behaved similarly to the MapBiomas product.

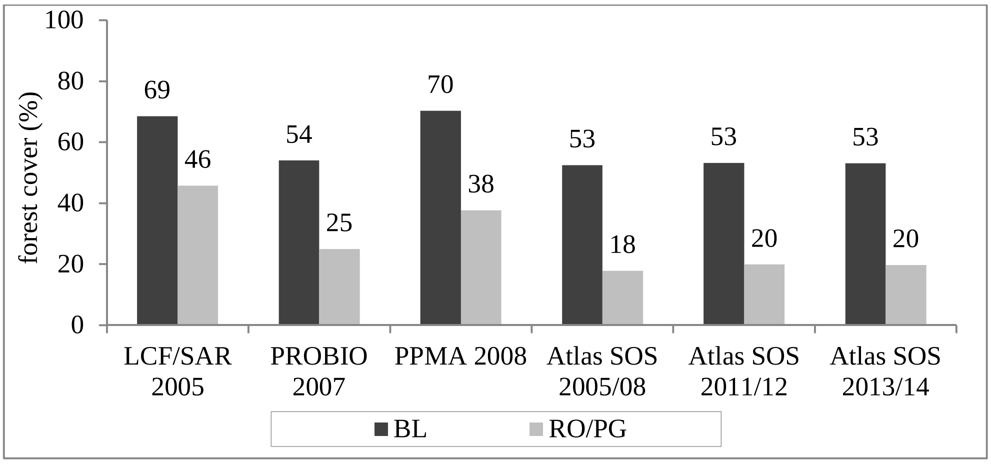

Figure 1. Forest cover percentage found in the vector maps tested for the area of study: municipalities of BL and RO/PG, in Santa Catarina, Brazil.

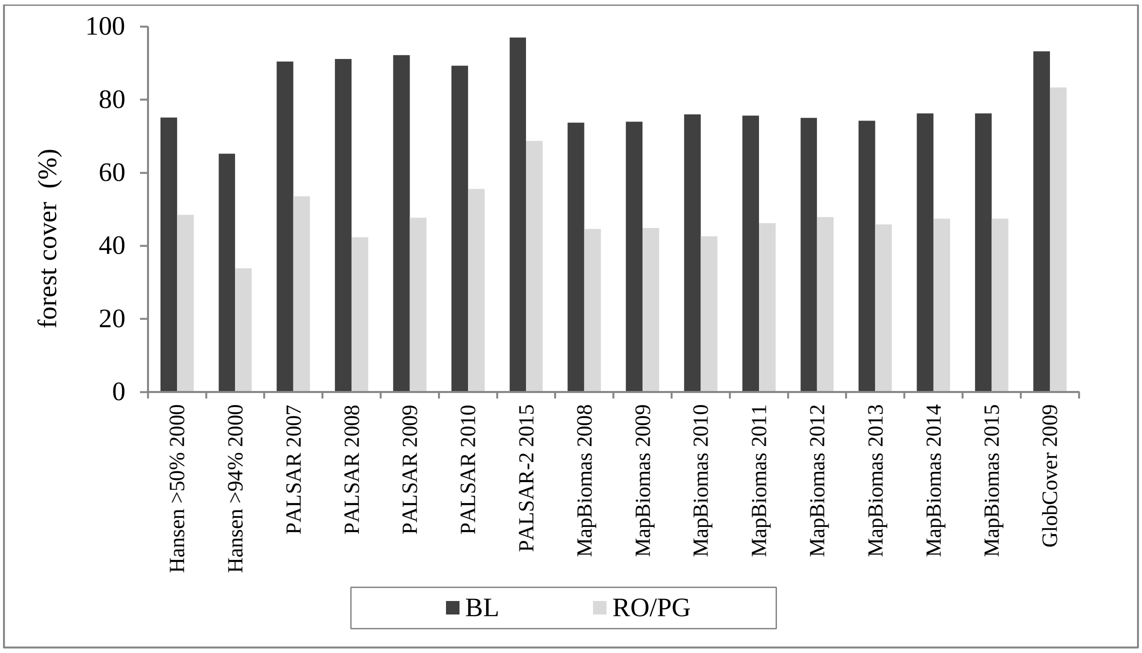

Figure 2. Forest cover percentage found in the raster maps tested for the area of study: municipalities of BL and RO/PG, in Santa Catarina, Brazil.

Remote sensing-based estimation of forest area and forest area change in tropical regions incurs both technical and scientific challenges. These include the diversity of definitions of "forest" and the large number of land use forms and anthropic vegetation types in the tropics (Steininger, 2000). Also, frequent issues are the shortage of adequate remote sensing data and rural cadastral information in many regions, as well as the lack of personnel qualified to process remote sensing data for large geographic regions. Among the products analysed, the legend most times is not too specific regarding the forest class. For instance, Atlas SOS (mata), LCF/SAR (forest), MapBiomas (forest) and PALSAR-2/PALSAR (forest/non forest) and PPMA (secondary early stage or intermediate stage forest, primary forest). In contrast, some products provide more specific legends: GlobCover provides 5 forest classes, or PROBIO, that provides 4 forest classes. Obviously, there is also a significant difference between the dates of the map products (e.g., Global Forest Change -Hansen et al., 2013- relates to year 2000).

Table 2 shows the results of the overlaying of all the map products, from which the estimation of the forest cover agreement is obtained. In the overlapping procedure of the six vector maps, 20745.3 ha were classified as forest in BL and 5621.8 ha in RO/PG, corresponding to a 40% and 10.4% of their total area respectively. Analogously, for the 16 raster maps, the coincident forest areas were 27076.2 ha in BL and 7334.9 ha in RO/PG, corresponding to the 52.2% and 13.5%. Last, considering all products, the agreement for the forest cover was of 17778.6 ha (34,3%) in BL and 2956.6 ha (5.5%) in RO/PG. The discrepancies in the percentages scores showed the different responses of the global products when applied to local scales such as the municipalities considered. For instance, maps with lower spatial resolution like GlobCover (300 m), tends to overrate some of the land cover/land use classes. Nonetheless, this fact was not expected to occur for the higher spatial resolutions like the 25m PALSAR-2 product. The fact that each product is based on different scenes and dates (ranging from 2000 to 2015) must however be taken into account in these considerations. In addition, the temporal dynamics regarding the annual loss ratio of the Atlantic Forest domain in Santa Catarina has changed during this period (Fundação SOS Mata Atlântica, 2015): i.e., surface decline until 2012, slowly incrementing since.

Tabela 2. Coincident forest cover between all the map products for BL and RO/PG.

			Forest cover agreement					
	Total area (ha)	Estimated forest cover %*	Vector maps (ha)	Vector maps (%)	Raster maps (ha)	Raster maps (%)	All products (ha)	All products (%)
BL	51,853.9	>50%	20,745.3	40.0	27,076.2	52.2	17,778.6	34.3
RO/PG	54,183.4	<30%	5,621.8	10.4	7,334.9	13.5	2,956.6	5.5

* basead on fotointerpretation and field work

Although automated digital image processing methods are generally preferable to other methods, they may be less efficient for very large tropical areas. This is due to complicating factors such as the sizes of the areas which are on the order of hundreds of thousands of square kilometers, the large numbers of image scenes that must be combined, the large number of forest formations in a variety of environmental conditions, and selection of areas for acquiring proper training data. Further, techniques that have been used vary considerably with respect to factors such as sources, resolutions, and transformations of remotely sensed data and parametric, non-parametric, and segment-based classification techniques (Carvalho & Scolforo, 2008; Oliveira et al., 2010). As expected, the complexity of the forests, the diversity of data sources, and variety of classification techniques inevitably lead to differences among maps of the same region. One issue is that as expected, thematic classes for the four maps were similar but not always directly comparable. The map products legend is most times not so specific considering the forest class. Some of the products analysed are based not only on different remote sensing sensors, but also on classification methods considering decision tree algorithms that differ in the suitability of the application at the local scale, as was proved in this study.

In the previous study comprising the state extent, the Santa Catarina Forest and Floristic Inventory (IFFSC) enabled statistically rigorous comparisons of remote sensing-based forest/non-forest maps. One important remark regarding to the limitations of the intercomparison results is that in this case a baseline ground truth data or derived map product that could constitute a reference support for quantification of statistically significant metrics of the analysis is not available at present. For use as an accuracy assessment dataset, the IFFSC data satisfy important criteria: independence from training data, adequate sampling intensity, and broad geographical coverage. Nonetheless, the sample size is not enough for the scales considered in the present analysis. Thus the discrepancies observed between the products analysed highlights the urgent necessity of a critical appraisal and a reliable ground truth data pool. Errors may be caused not only by classification errors, but also by land use changes such as deforestation that occur between the image acquisition and ground observation dates, errors in the rectification of the plot locations and map pixels, and discrepancies between the plot and pixel sizes. The latter two issues pertain to whether plots and pixels represent the same area on the ground.

4. Conclusions

Different mapping regimes and conceptions of area classes create challenges for the mapping process, including the consistency and comparability of the final product. A priori clarification of the definition of forest is crucial for study areas with biological diversity and anthropogenic history similar to that of the Atlantic forest. Failure to clarify the definition could lead to the conclusion that remote sensing techniques are faulty or inadequate when, in fact, observed deviations are the result of a priori assumptions or prejudices.

In fact, data sources are essential in the selection of adequate training samples both for classification methods and evaluation processes in the generation of map products for the region at the state and local scales under consideration. This point is relevant for the project of remote sensing monitoring complementing the ongoing IFFSC, in Brazil. This recently started project aims at the optimization and coordination of sources and methods in both remote sensing and field work techniques for an accurate quantification of forest resources, as well as for map products provision tailored to planning applications. In this sense the IFFSC also provides socioeconomic data for the whole state.

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