Perspectives on remote sensing monitoring applied to forest inventory and land cover mapping for management purposes in Santa Catarina (Brazil)

Eva Sevillano Marco [1]
Adilson Luiz Nicoletti [1]
Marcus Moresco Boeno [1]
Veraldo Liesenberg [2]
Julio Cesar Refosco [1]
Débora Vanessa Lingner [1]
Alexander Christian Vibrans [1]

[1] Universidade Regional de Blumenau – FURB. Programa de Pós Graduação em Engenharia Florestal – PPGEF. Rua São Paulo, 3250, 89.030-000, Blumenau – SC, Brasil
alnicoletti@al.furb.br; emarco@al.furb.br; marcusboeno@gmail.com; refosco@furb.br; dlingner@furb.br; acv@furb.br

[2] Universidade do Estado de Santa Catarina – UDESC. Centro de Ciências Agroveterinárias – CAV. Av. Luiz de Camões, 2090 - 88.520-000, Lages – SC, Brasil
veraldo.liesenberg@udesc.br

Abstract
Remote sensing (RS) is an adequate analysis tool when complemented by field work, providing new information for carbon accounting and the management of diverse species, covering a research topic which has a significant interest nowadays in the climatic change context. Dynamic models and forest inventory data improve the ability to estimate forest parameters and temporal changes, thus providing valuable information for the establishment of more adequate management practices. The analysis of RS images coupled to the Santa Catarina Forest and Floristic Inventory (IFFSC) sound products is intended to enable standardization of methods, assessment of accuracy, development and calibration of models, practical application and extrapolation to large areas, stand attributes mapping and estimation, considering diversity of scales, species and uses. The IFFSC confirmed a preoccupying biodiversity loss (e.g., scarcely 32% of the tree/shrub species identified from the pool recorded in prior inventories) and noticeable forest cover fragmentation compromising populations viability. The final target is to contribute to territorial management in the near future at a regional level, obtaining a detailed knowledge of forestry uses of RS techniques and improving experimental design in biogeography studies. This paper sketches the objectives and methodological design.

Keywords: Santa Catarina Forest and Floristic Inventory, forest cover, subtropical forest.

1. Introduction

The value of forests is becoming increasingly evident and is clearly highlighted by the numerous multilateral environmental agreements as well as by the multipurpose objectives sought in land management. Land uses and management practices, especially in complex regions, are key factors in monitoring studies.

Remotely sensing (RS) data have been used to map land cover, land use change, and forest structural variables such as forest density and tree height. Because of the potential capacity for systematic observations at various scales, remote sensing technology extends possible data archives from present time to over several decades back. For this advantage, enormous efforts have been made by researchers and application specialists to delineate vegetation cover from local scale to global scale by applying remote sensing imagery (Xie et al. 2008). The integration of the data and information collected from satellite images and field data is the base of modern forest biometry (Ghahramany et al. 2012). The relationship between spectral reflectance and relevant stand characteristics in different geographic settings must be quantified. Many studies have used satellite data to estimate forest quantitative parameters such as density, standing volume, or basal area (Ghahramany et al. 2012).

Therefore, RS scenes are not a substitute for field-based data collection. Field data are always required to calibrate and validate remote sensing analyses. Likewise, remote sensing can help to add value to field surveys. The synergies of both methods should lead to a more efficient system for data capturing to render abundant and reliable information (Suárez et al. 2005). Consequently, due to the great diversity of forests land uses and management, the utility of RS data and feasibility of methods needs to be evaluated in a range of environments and under different management strategies.

The calibration and validation of RS models have in common that they require the integration of remotely sensed and ground reference data. Feasibility of model applications and practical uses of the results must not be overlooked. Therefore, the establishment of this permanent monitoring project is aimed at developing the following objectives:

1) To dynamically define an appropriate categorical legend of land uses and land cover change detection tailored to the features and socioenvironmental context in the region of Santa Catarina (southern Brazil), containing diverse forest covers within the Atlantic Forest domain as well as agriculture and grassland land uses.

2) To analyse the significance of possible relationships between field-measured variables in the IFFSC and RS data in forest stands and land cover/land use monitoring.

3) Assessment of the standardization of methods, including coordination of field work procedures adapted to RS studies, redundancy of data sources, accuracy improvement and error sources detection, magnitude definition and minimization.

4) Evaluation of the potentiality of estimation of stand attributes and ecological parameters by fitting adequate model equations derived from the RS data, accordingly selected to outline the spatial distribution/quantitative mapping of stand variables and land cover parameters.

5) Finally, by the establishing of permanent update workflows, outlining practical territorial management application, considering socioeconomic aspects, of the RS and GIS implementation.

In this paper we will address the first legend definition, data sources selection and methods proposed for a successful project implementation.

2. Methodology

The approach will be a larger scale forestry study in diverse areas in Santa Catarina, employed to tune specific calibration requirements however targeted at methods homogenization and generalization of estimation and validation procedures, using and comparing the suitability and accuracy of available auxiliary data bases, in order to compare methods responses and for evaluation purposes, in the line of Vibrans et al. (2013). The territorial scale consideration and comparison utilizing different RS data sources aim at the improvement of methodology limitations by standardization of practices and defining research requirements (better match between field work procedures and RS studies), at the same time achieving practical environmental applications of models, estimation and mapping of variables in large areas.

2.1 Study area

The study area was defined as the southern Brazilian state of Santa Catarina, located between latitudes 26° and 29° S and between longitudes 48° and 53° W and with area of 95,737.895 km^2 (Figure 1).

2.2 Data sources

2.2.1 Field data

The field data will be mainly based on the IFFSC, Brazil, carried out by the Universidade Regional de Blumenau (FURB), Universidade Federal de Santa Catarina (UFSC) and Empresa de Pesquisa Agropecuária e Extensão Rural de Santa Catarina (EPAGRI), under the funding programme provided by the Fundaçao de Amparo à Pesquisa e Inovação de Santa Catarina (FAPESC) and Serviço Florestal Brasileiro (SFB) in the period between 2007-2011 on its first measurements, and is currently in the second measurement period (2014-ongoing). If available, other data sources provided by external institutions would be added. The sample plots follow a systematic distribution of points located at the intersections of a 10 x 10 km grid for the phytogeographic subdivisions: Atlantic evergreen rainforest and Araucaria forest. The sample plots of the remnants of the semi-deciduous forest was densified in a grid of 5 x 5 km, because this forest is extremely reduced and fragmented. Sample units were measured when the location fell within a forest land cover (i.e., secondary or primary forest) and currently total 597 sample units were established.

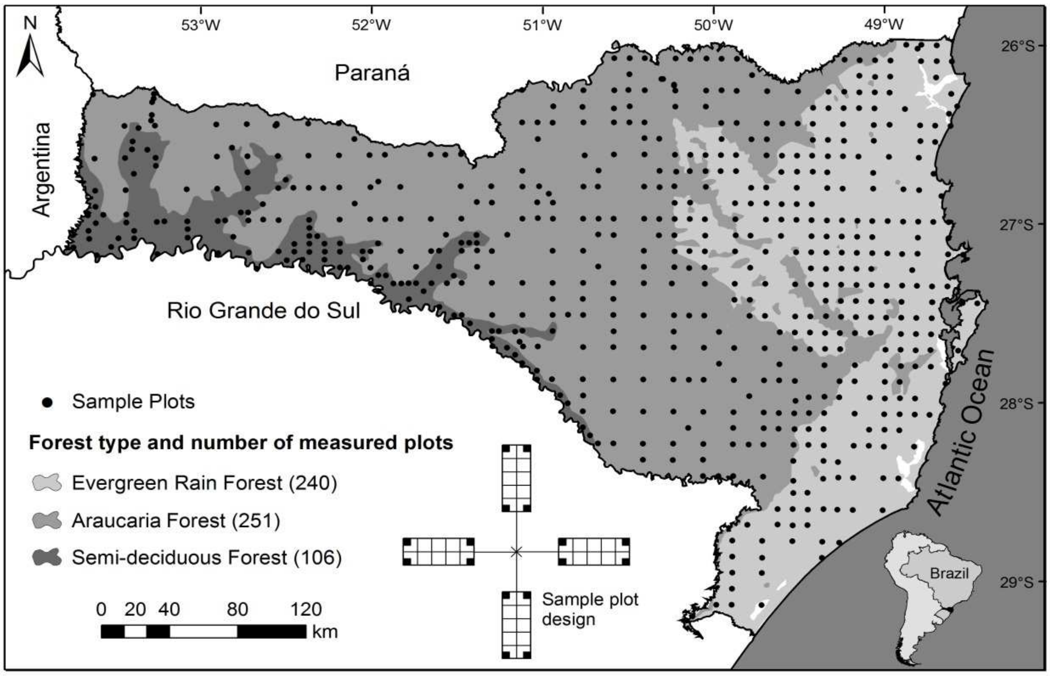

Figure 1. Distribution of systematic sampling plots of the IFFSC.

2.2.2 Remote sensing data

Giardin (2010) notes the relevance of remote sensing-based components for estimating activity data for forest area and forest area change. At present, 2789 scenes have been reviewed, and classified according to cloud cover ranges, from the catalogues of Instituto Nacional de Pesquisas Espaciais (INPE) and United States Geological Survey (USGS), from the 1990-2016 period. From this review, the limitation of optical imagery of the Landsat archive is evident as an 85.6% of the scenes were cloudy over the area of study. Therefore, other sensors like the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER), recently freely released the Chinese-Brazilian Earth Resources Satellite CBERS Charge-Coupled Device (CCD) CBERS, and the SENTINEL archive will be searched. Nonetheless, the inclusion of some radar sensor, less subject to be affected by cloud cover, will be seriously considered in the remote RS data pool compilation.

2.2.3 Ancillary data

To be used either in the training data sample delimitation, test data for evaluation purposes, support in field work calibration journeys, in the segmentation, classification, or other RS techniques, a digital elevation model (e.g., NASA's Shuttle Radar Topography Mission (SRTM), Secretaria de Estado do Desenvolvimento Econômico Sustentável 2011), and derived slope and aspect maps, will be likely used. Among the available sources, vector and raster remote sensing-based maps of forest areas from diverse authors have been previously researched and intercompared: e.g., Global Forest Change (Hansen et al., 2013), Globcover (ESA & UCL, 2011), Global forest/non forest map PALSAR-2/PALSAR (JAXA, 2016), MapBiomas (MAPBIOMAS, 2015), LCF/SAR (SAR, 2005), PROBIO (Cruz & Vicens, 2007), Atlas (Fundação SOS Mata Atlântica 2015), PPMA (Geoambiente, 2008).

2.3 Methods

Firstly, a provisional classification legend for the land cover/land use mapping has been chosen considering the features in the area of study: agriculture, meadows, water, urban areas and roads, permanent crops (e.g., banana, apple, vineyards, orange), rice crops, forest (not discerning between forest types although a further hierarchical division of this class is envisaged on the basis of the spectral responses), reforestation, mangroves, restinga (coastal and dunes shrub type vegetation), mining and extraction areas, bare soil and shadows/clouds (nodata assigned) masking. It must be remarked that the definition of the forest class is a key issue on any forest cover mapping (as was shown in many a study REF), and that the definition in the IFFSC of forest is vegetation with height ≥10 m and stand basal area of ≥10 m². This step is essential in the undertaking of thematic classification. In this sense, segmentation and classification techniques will be essayed (Garofalo et al., 2015).

RS measurements are typically made in several wavebands (multispectral data), which are described by their spectral sensitivity functions. Spectral vegetation indices (SVIs), defined as dimensionless mathematical transformations combining digital values of different bands, have been designed to isolate the contribution of other materials (background, atmosphere) to the reflectance (Asner et al. 2003). Examples of SVIs that can be tested are Global Environmental Monitoring Index (GEMI) (Pinty and Verstraete 1992), Soil-Adjusted Vegetation Index (SAVI) (Huete 1988), and Normalized Difference Vegetation Index (NDVI) (Rouse et al. 1973). Tasseled cap transformation (humidity component) could also be considered in methodology testing, following Moré and Pons (2008). An approach that has been proved useful when studying vegetation is to use a mixed pixel method or spectral mixture analysis (SMA). This method recognizes that a single pixel is typically made up of a number of varied spectral types, i.e. soil, water, vegetation (Quintano et al. 2012) and it is used to measure the percentage of spectra for each land-cover type in a single pixel.

Varied methods have been used for calibrating models between ground reference data and satellite data, for example, linear spectral unmixing, regression analysis, k-nearest-neighbours method (k-nn) and neural networks (Fernandes et al. 2004). Last, evaluation stages (e.g., confusion matrix, spatialized quality indicators, error maps, graphics) will determine the accuracy, the threshold of acceptable estimations, and most importantly further revision of the workflow in order to improve the processing steps and design tailored monitoring and update flows (e.g., predictability, map products updating, field work procedures design for cost-effective environmental surveillance).

3. Preliminary results and discussion

The present study, considers in particular the identification and monitoring of land cover/land uses categories. Three phytogeographic subdivisions established by Oliveira-Filho (2009) are described, within the Atlantic Forest domain: Atlantic evergreen rainforest, Araucaria forest and semi-deciduous forest. The latter is the one most vastly devastated and less largely represented (1251 km^2 - estimated forest cover), within a scarcely 7671 km^2 of suitability area in Santa Catarina. The Araucaria forests and Atlantic evergreen rainforest cover similar surfaces in the region (approximately 12500 km^2 estimates). However, the potential area for the Atlantic evergreen rainforest is much smaller (31281 km^2 versus 56395 km^2 potential area for Araucaria). Pioneer formations are represented by the restingas (dune vegetation), mangrove and hydromorphic herbaceous communities (riparian), closer to the sea and present in relevant river valleys. In addition, highland vegetation communities are also present in the mountainous range lands. This brief description allows for a first notion on the diversity and challenges that the estimation techniques face when considering a suitable definition of forest and a categorical legend division.

At the state scale, the IFFSC presents an unprecedented opportunity to conduct statistically rigorous comparisons of remote sensing-based forest maps. For use as an accuracy assessment dataset, the IFFSC data satisfy important criteria: independence from training data, adequate sampling intensity, and broad geographical coverage (Vibrans et al., 2013). The fusion techniques, enhanced spatial and spectral resolutions in the most recent dates provided by the new sensors launched, will enable the optimization in the usage of the information contained in the visible and near infrared, short wave infrared radiometer (SWIR), thermal infrared radiometer (TIR) channels and other wavelengths. Although not comparable in terms of spatial resolution, the advantages of the temporal resolution of sensors suchlike MODIS products, will be taken into account.

On the basis of the sample points measured in field-work campaigns, following a simple random sampling method, the forest cover in Santa Catarina was estimated in 27.8% (confidence interval from 25.1-30.5% estimates). Within the Atlantic Biogeographic Rainforest Domain, the phytoecological subdivisions in the estimated forest cover found were: Subtropical Atlantic evergreen rainforest 40.4% (confidence interval 35.2-45.4%), Araucaria forest 22% (confidence interval 18.7-25.3%) and semi-deciduous forests 16.3% (confidence interval 8.6-24%) (Vibrans et al. 2013). In the period 2007-2011, 860 tree and shrub species, 560 epiphytes, 270 vines, 315 pteridophytes and 707 plant species were recorded. However, the biodiversity loss in terms of tree species is disturbing when compared with the numbers identified in the previous inventories published in the Flora Ilustrada Catarinense (Reitz, 1965): scarcely 32% of the tree/shrub species were found, and this with less than 10 individuals each. The genetic samples of some of the species in Santa Catarina is a clear consequence of forest cover fragmentation and the population size decline sadly leads to pessimistic still worse biodiversity loss prospects for several species. The findings of the IFFSC in all its facets (floristic-forestry, genetic and socioenvironmental) showed an urgent need of public policies suited to the conservation of the forest cover in Santa Catarina and specifically imperative in the priority areas identified.

4. Conclusions

The statistical relationship of spectral features with the stand variables provided by the field data processing is to be quantified. Special attention is to be paid to common error sources (saturation, classification, age, silvicultural noise). The combination of SVIs and empirical modelling has been particularly common in the estimation of vegetation attributes. Quality of results in vegetation studies is enhanced by addition of the time component (temporal resolution) to the spectral classification. The categorical legend definition is to be adapted to available data sources and methods implementation. The target of the project is to design fully operational workflows leading to map products for management purposes, enabling the establishment of permanent monitoring milestones and continuous update.

Acknowledgements

The authors are grateful to the Fundação de Amparo à Pesquisa e Inovação de Santa Catarina (FAPESC; Santa Catarina State Research and Innovation Support Foundation) for the support to the Inventário Florístico Florestal de Santa Catarina (Santa Catarina Forest and Floristic Inventory (IFFSC), Brazil) and to the Fundo Especial de Proteção ao Meio Ambiente – FEPEMA (Environmental Special Protection Fund) for the financial backup of the subproject of Monitoramento da cobertura florestal do Estado de Santa Catarina (Monitoring the forest cover in the Santa Catarina State in Brazil).

References

Asner, G. P., Hicke, J. A., Lobell, D. B., **Per-pixel analysis of forest structure: vegetation indices, spectral mixture analysis and canopy reflectance modeling.** In Remote sensing of forest environments: concepts and case studies, Wulder M A and Franklin S E (Eds), pp 209–254, 2003.

Cruz, C. B. M., Vicens, R. S. **Levantamento da Cobertura Vegetal Nativa do Bioma Mata Atlântica**. Relatório Final. Rio de Janeiro: IESB/IGEO/UFRJ/UFF 84 p., 2007.

ESA. European Space Agency. UCL. Université catholique de Louvain. **GlobCover 2009.** Products description and validation report. Frascati, Itália: ESA Communication Department. 2011. 53 p.

Fernandes, R., Fraser, R., Latifovic, R., Cihlar, J., Beaubien, J., Du, Y. Approaches to fractional land cover and continuous field mapping: a comparative assessment over the BOREAS study region. **Remote Sensing of Environment** 89:234–251, 2009.

Fundação S.O.S Mata Atlântica. **Atlas dos remanescentes florestais da Mata Atlântica, período 2013–2014**. Relatório Técnico. São Paulo: Fundação S.O.S. Mata Atlântica / Instituto Nacional de Pesquisas Espaciais 60 p., 2015.

Garofalo, D. F. T., Messias, C. G., Liesenberg, V., Bolfe, E. L., Ferreira, M. C. Análise comparativa de classificadores digitais em imagens do Landsat 8 aplicados ao mapeamento temático. **Pesq agropec bras Brasília**, v50 n7 p. 593-604, 2015.

Geoambiente. **Mapeamento Temático Geral do Estado de Santa Catarina: Projeto de Proteção da Mata Atlântica em Santa Catarina (PPMA/SC)**. Relatório Técnico. Geoambiente Sensoriamento Remoto Ltda. São José dos Campos 90 p., 2008.

Ghahramany, L., Fatehi, P., Ghazanfari, H. Estimation of basal area in west oak forests of Iran using remote sensing imagery. **International Journal of Geosciences**, v. 3, p. 398-403, 2012.

Giardin, C. **UN-REDD/FAO to publish national forest MRV system recommendations** UN-REDD Programme Newsletter, Issue 8, May 2010, 2010.

Hansen, M. C., Potapov, P. V., Moore, R., Hancher, M., Turubanova, S. A., Tyukavina, A., Thau, D., Stehman, S. V., Goetz, S. J., Loveland, T. R., Kommareddy, A., Egorov, A., Chini, L., Justice, C. O., Townshend, J. R. G. High-resolution global maps of 21st-century forest cover change. **Science** v. 342, p. 850-853, 2010.

Huete, A. R. A soil-adjusted vegetation index (SAVI). **Remote Sensing of the Environment**, v. 25, p. 295-309, 1988.

JAXA, Japan Aerospace Exploration Agency. **Global 25 m resolution PALSAR-2/PALSAR mosaic and forest/non-forest map (FNF).** Dataset description. Tsukuba, Japão: Japan Aerospace Exploration Agency / Earth Observation Research Center 7 p., 2016.

Liang, S. **Quantitative remote sensing of land surfaces**. pp 534. Hoboken: John Wiley & Sons, 2004.

MapBiomas, **Projeto de Mapeamento Annual da Cobertura e Uso do Solo.** Nota metodológica v1 Brasil 12 p., 2015.

More, G., Pons, X. Influencia del número de imágenes en la calidad de la cartografía detallada de vegetación forestal. **Revista de Teledetección**, v. 28, p. 61-68, 2008.

Oliveira-Filho, A. T. Classificação das fitofisionomias da América do sul cisandina tropical e subtropical: proposta de um novo sistema – prático e flexível – ou uma injeção a mais de caos? **Rodriguésia**, v. 60, n. 2, p. 237-258, 2009.

Pinty, B., Verstraete, M. M., GEMI: a non-linear index to monitor global vegetation from satellites. **Vegetatio**, v. 101, p. 15-20, 1992.

Quintano, C., Fernández A., Shimabukuro, Y., Pereira, G. Spectral unmixing: a review. **International Journal of Remote Sensing**, v. 33, p. 5307-5340, 2012.

Reitz, R. **Flora Ilustrada Catarinense**. Plano de coleção. Itajaí. Herbário Barbosa Rodrigues, 1965.

Rouse, J. W. J., Haas, R. H., Schell, J. A., Deering, D. W. **Monitoring vegetation systems in the Great Plains with ERTS**. In Third Earth Resources Technology Satellite-1 Symposium, 10–14 December 1973, Washington DC (Washington DC NASA) p. 309–31, 1973.

SAR Secretaria de Agricultura e Abastecimento do Estado de Santa Catarina. **Inventário Florístico Florestal de Santa Catarina**. Relatório do Projeto Piloto. Florianópolis. Mimeo 170 p,. 2005.

Secretaria de Estado do Desenvolvimento Econômico Sustentável. Governo do Estado Santa Catarina. **Levantamento Aerofotogramétrico de Santa Catarina**. Relatório de Produçao final, 2011.

Suárez J.C., Smith S., Bull G., Malthus T.J., Donoghue D., Knox, D. The use of remote sensing techniques in operational forestry, **Quarterly Journal of Forestry**, v. 99, p. 31-42, 2005.

Vibrans, A. C., McRoberts, R. E., Moser, P., Nicoletti, A. L. Using satellite image-based maps and ground inventory data to estimate the area of the remaining Atlantic forest in the Brazilian state of Santa Catarina. **Remote Sensing of Environment,** v. 130, p. 87-95, 2013.

Xie, Y., Zongyao, S., Yu, M. Remote sensing imagery in vegetation mapping: a review. **Journal of Plant Ecology**, v. 1, n. 1, p. 9–23, 2008.