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Seasonal mixing in forest-cover maps for humid tropics and impact of fluctuations in spectral properties of low vegetation

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ABSTRACT

With advances in satellite data, computer storage capacities and processing technologies, it is increasingly feasible to map forest cover over large areas at high spatial resolutions that are relevant for most decision-makers. For outputs to be informative, however, they must be accurate. The finer spatial resolution of recent large-scale forest products comes at a cost of lower temporal resolution. With few input images available for a given year, appropriate image selection in the creation of forest cover and forest-cover change maps is critical. This work highlights the need for more careful consideration of seasonality in mapping forest cover in the tropics. While most studies of seasonality on forest mapping focus on deciduousness and potential errors of omission, this study highlights seasonal fluctuations in non-forested vegetation and likely errors of comission. Vegetation indices provided good separability between tropical forests and low vegetation including commercial crops, pasture and young fallow, in the dry season, but not in the wet season. Forest-cover maps and change analyses that combine wet- and dry-season images without accounting for seasonality risk overestimating initial forest cover and subsequent deforestation. Likewise, analyses that do not distinguish between truly aseasonal wet equatorial regions and seasonal regions of the tropics risk overestimating forest cover in the former.

1. Introduction

The capacity to quantify and monitor tropical forest cover is critical for balancing the global carbon budget, mitigating climate change, motivating sustainable resource management and conserving important and increasingly rare habitat. With advances in satellite data, computer storage capacities and processing technologies, it is increasingly feasible to map forest cover over large areas at small spatial and temporal resolutions that are relevant for most decision-makers (Ban, Gong, & Gini, 2015; Boyle et al., 2014; Nelson & Robertson, 2007). In the past few years, several global forest-cover products with 30 m pixel resolution have been made readily available to the public via the internet (e.g. Chen et al., 2015; Gong et al., 2013; Hansen, 2013; Kim et al., 2014; Sexton et al., 2013; Yu, Wang, & Gong, 2013). The combination of global contextualization, high spatial resolution and highly automated procedures allowing for continued monitoring offers great potential to expand the reach of remote sensing data and facilitate its impact on decision-making for resource management. However, wide disagreement between available products at local levels currently obscures their usefulness and motivates examination of the methodology used to produce global maps.

One area that warrants more attention in large-area, high-resolution tropical forest mapping is seasonality and selection of input images. Intra-annual fluctuation in spectral signatures of vegetation has long been recognized as an important factor in land-cover mapping and is directly incorporated into algorithms used to generate many land-cover products of coarser spatial resolution (e.g. Arino et al., 2008; DiMiceli et al., 2011; Friedl et al., 2010; Ganguly, Friedl, Tan, Zhang, & Verma, 2010; Hansen, DeFries, Townshend, & Sohlberg, 2000; Hansen et al., 2003; Tateishi et al., 2014). With recent Landsat-based products, however, the benefit of higher spatial resolution comes at a cost of decreased temporal resolution. While coarser AVHRR and MODIS images are available on a daily basis, Landsat images are only available for a given location every 16 days. This small data stack is further reduced by persistent cloud cover in much of the tropics (Ju & Roy, 2008), precluding the intrinsic modeling of seasonality that is common with AVHRR- and MODIS-based products.

When intra-annual variation cannot be directly incorporated into the model, appropriate selection of input imagery becomes critical. For forest mapping in temperate zones, it is common practice to target images from the growing season to avoid underestimation of forest cover due to deciduousness (Townshend et al., 2012; Tucker, Grant, & Dykstra, 2004). Targeting of greenest periods is also sometimes recommended for tropical-forest mapping to avoid underestimating seasonal forests during leaf-off periods (Tucker & Sellers, 1986) and help reduce

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noise from clouds (DeFries, Hansen, & Townshend, 1995). In many cases, seasonality is simply ignored for tropical regions of global forest-cover maps (Kim, Narasimhan, Sexton, Huang, & Townshend, 2011; Tucker et al., 2004). In commonly used global products, target acquisition dates for tropical regions generally correspond to those of adjacent temperate regions (e.g. Latifovic, Zhu, Cihlar, Giri, & Olthof, 2004), use all available images (e.g. Hansen, 2013; Mayaux, Achard, & Malingreau, 1998), or use the least cloudy image from any season (e.g. Gutman, Chengquan, Gyanesh, Praveen, & G., 2013). Given that over 70% of the tropics experience some degree of seasonality (Kottek, Grieser, Beck, Rudolf, & Rubel, 2006), ignoring seasonality in tropical regions seems unadvisable. Inclusion of seasonality in the tropics, however, merits different considerations than for temperate zones. While some deciduousness occurs in most tropical forests and seasonal variation has been noted even in tropical evergreen forests (Asner, Townsend, & Braswell, 2000; Moreau & Defourny, 2012; Ponzoni, da Silva, dos Santos, Montanher, & dos Santos, 2014), strong seasonal fluctuations in non-forest vegetation (Ferreira, Yoshioka, Huete, & Sano, 2003; Soudani et al., 2012; You, Meng, Zhang, & Dong, 2013) may be of more importance in the humid tropics. Given the high productivity of even low vegetation during the growing season in tropical regions, maps that emphasize growing-season images could result in overestimation of tropical forests.

This work highlights the occurrence and potential effects of intra-seasonal mixing of images in global forest-cover mapping by focusing on a humid tropical region in western Panama. The first section presents a preliminary assessment of existing global Landsat-based land-cover products in discriminating between forests and low vegetation in the study area. Next, to elucidate the impact of seasonality in potential overestimation of forests in the study area, seasonal fluctuations in spectral indices commonly used to discriminate forests from low vegetation are explored. Various spectral indices are evaluated to assess the length of the temporal window that would most likely result in acceptable accuracy for forest cover mapping in the region, with a secondary goal to determine the best indices for distinguishing forests from low vegetation in Panama.

This work illustrates the usefulness of a Wetness Index to measure and evaluate seasonality. Existence of a correlation between spectral indices such as NDVI and rainfall has been well established for low vegetation (French & Sauer, 1974) with observed lags that suggests that the response is related to soil moisture content rather than direct precipitation (Nicholson, Davenport, & Malo, 1990; Richard & Poccard, 1998). Here a Wetness Index is used as a proxy of stored soil moisture to help identify the conditions under which low vegetation can be reasonably discriminated from forest in the humid tropics.

2. Materials and methods

2.1. Study site

The study area is a heterogeneous landscape of western Panama (Fig. 1) with areas representative of much of the tropics. Based on a Köppen-Geiger climate classification, approximately a third of the study area has a wet equatorial climate with no true dry season (Af) while the remaining area has a tropical seasonal climate (Aw or Am) with three to four months of drought-like conditions between mid-December and mid-April (UNESCO, 2008). The land cover is a mosaic of approximately 36% upland forest, 3% wetland forest, 16% commercial crops or pastures, 43% swidden agriculture in various stages of fallow and productivity, and <1% built area along the Pan-American highway (ANAM, 2000).

2.2. Class comparisons

For the purposes of this study, only the following distinct land-cover classes were included:

- FOREST: Mature trees (at least 25 years) with at least 80% canopy cover, within a patch at least 5 ha in size. Excludes monoculture plantations such as oil palm and teak.
- NO VEGETATION: More than 80% created material (e.g. concrete, asphalt, metal or clay) or bare substrate(rock, sand or dirt) that remains without vegetation for 12 months.
- LOW VEGETATION: Any of the following, or any direct observation of very low vegetation with <20% tree canopy where land use cannot be further distinguished

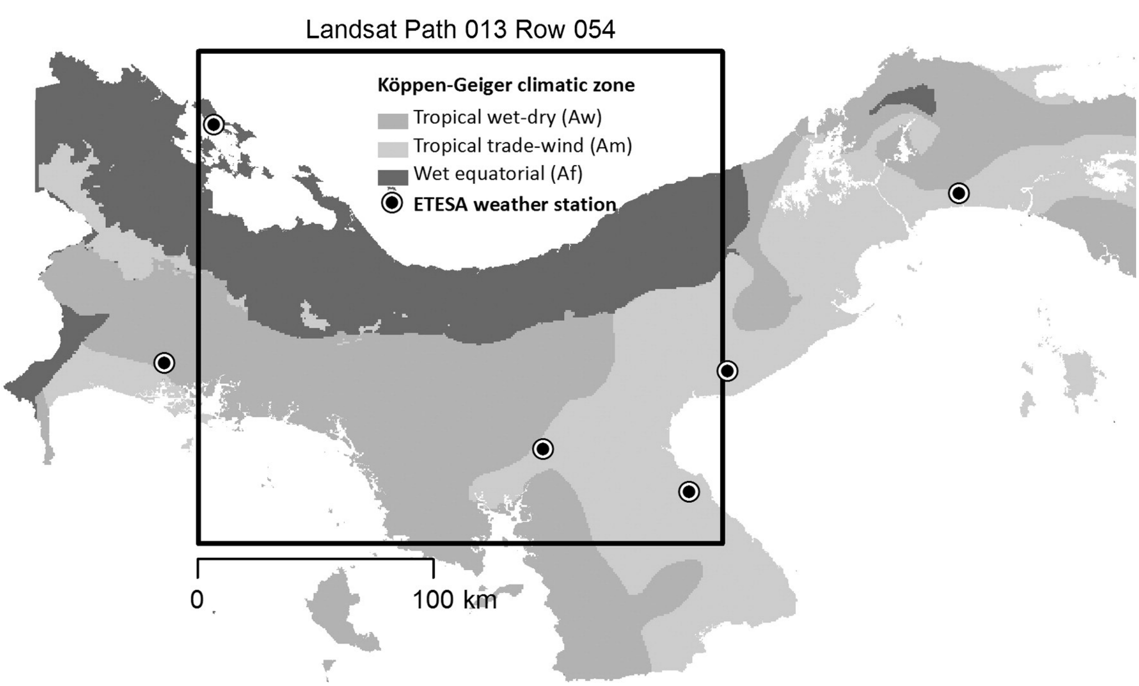

Fig. 1. Study site and location of weather stations for data from Panamanian Empresa de Transmission Electrica (ETESA). Climatic zones digitized from UNESCO (2008). Black square frame shows approximate coverage of Landsat scene (actual coverage varies slightly by date).