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The effect of topographic normalization on fractional tree cover mapping in tropical mountains: An assessment based on seasonal Landsat time series

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ABSTRACT

Free archive of georectified and atmospherically corrected Landsat satellite images create a large range of opportunities for environmental research. However, the topographic effects in images are typically normalized regionally by end-users, and it remains uncertain if this procedure is always necessary. Our objective was to assess the effect of topographic normalization on the fractional tree cover (*Fcover*) modelling in a tropical mountain landscape, in Southeastern Kenya. We carried out topographic normalization by C-correction for all available Landsat images between June 2012 and October 2013, and examined if normalization improves *Fcover* regressions. The reference *Fcover* was based on airborne LiDAR data. Furthermore, we tested several vegetation indices and seasonal features (annual percentiles and means), and compared three digital elevation models (DEM). Our results showed that the fit of *Fcover* models did not improve after topographic normalization in the case of ratio-based vegetation indices (Normalized Difference Vegetation Index, NDVI; Reduced Simple Ratio, RSR) or Tasseled Cap Greenness but improved in the case of Brightness and Wetness, particularly in the period of the lowest sun elevation. RSR was the best vegetation index to predict *Fcover*. Furthermore, SRTM DEM provided stronger relationship with cosine of the solar incidence angle than ASTER DEM and regional DEM based on topographic maps. We conclude that NDVI and RSR are robust against topographic effects in the tropical mountain landscapes throughout the year. However, if Tasseled Cap indices are preferred, we recommend topographic normalization using SRTM DEM.

1. Introduction

The Landsat satellite image archive can currently be freely accessed, creating a large range of opportunities for environmental research (Wulder et al., 2012). Among other things, it has encouraged the use of greater number of images for time-series analysis (Hansen et al., 2013). In most cases, the images can be obtained already pre-processed, excluding the need for further georectification, cloud-masking or atmospheric correction (Masek et al., 2006; Zhu and Woodcock, 2014). However, the topographic effects are typically normalized by end-users regionally, and the need for this procedure usually depends on the characteristics of the terrain, and on the final application (Reese and Olsson, 2011; Vanonckelen et al., 2013, 2015; Chance et al., 2016).

In mountainous terrain, radiometric distortion on the satellite images vary at different levels due to topography, sun elevation angle and sun azimuth angle. The magnitude of this effect also depends on the time of the year because of variations in the sun elevation and vegetation phenology. Topographic normalization removes the dependency of reflectance factors on topographic position. The most common methods for topographic normalization include Lambert cosine correction (Meyer et al., 1993), non-Lambert Minnaert correction (Smith et al., 1980) and C-correction (Teillet et al., 1982), and Sun-canopy-sensor method (Gu and Gillespie, 1998).

Topographic normalization has been shown to improve the accuracy of land cover classification (Vanonckelen et al., 2013; Moreira and Valeriano, 2014), forest cover detection (Vanonckelen et al., 2015) and, although rarely tested, also prediction of continuous vegetation attributes (Törmä and Härmä, 2003). These benefits are particularly relevant in tropical mountains, which are often characterized by heterogeneous vegetation and complex terrain. Tropical mountains are important in terms of biodiversity,

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carbon stocks, water resources, heterogeneous habitat types for endemic plants and animals, and provide diverse goods and services to human (Sandel and Svenning, 2013). Human impact on forest cover are more concentrated on flat plains and some remnant forest are left in the mountains due to extreme slopes where human impacts are moderate (Maeda et al., 2010; Maeda, 2012; Sandel and Svenning, 2013).

Nonetheless, critical challenges exist in addressing topographic normalization of satellite imagery in tropical mountains. One major challenge is environmental seasonality. Tropical mountains are often characterized by fragmented vegetation and seasonal climatic patterns. These factors are associated with a complex spatio-temporal variation in surface albedo, leaf area index (LAI) and spectral characteristics (Maeda et al., 2014; Heiskanen et al., 2015). Another challenge is associated with uncertainties in the accuracy of digital elevation models (DEM), which are a critical component of the topographic normalization. Currently, there are several sources of global DEMs supplemented by regional DEMs based on topographic map data, or occasionally even airborne LiDAR data. However, the viability of different DEMs for topographic correction has been rarely assessed (Frey and Paul, 2012; Szabö et al., 2015).

Solving these issues could, therefore, greatly reduce uncertainties of environmental assessments in tropical mountain ecosystems. For instance, continuous fields of vegetation attributes can be estimated using a multitude of predictors derived from Landsat images. Fractional tree cover (*Fcover)* is an important indicator for biomass distribution and information on *Fcover* is essential for understanding local meteorological processes and hydrological transfers within vegetated environments (Hopkinson and Chasmer, 2009; Wu, 2011; Zhang et al., 2013). However, the topographic effect on different types of predictors can be different. Canopy cover, *Fcover* and leaf area index (LAI) are typically predicted based on vegetation indices such as Normalized Difference Vegetation Index (NDVI) and Reduced Simple Ratio (RSR) (Heiskanen et al., 2011; Korhonen et al., 2013; Majd et al., 2013). With the denser Landsat time series, image compositing and seasonal feature extraction methods have attained popularity over single image processing (Potapov et al., 2012; White et al., 2014; Vanonckelen et al., 2015).

Despite that previous studies have demonstrated that simple topographic normalization methods can remove topographic effects (Richter et al., 2009; Hantson and Chuvieco, 2011; Reese and Olsson, 2011) and improve the land cover and vegetation characterization (e.g., Vanonckelen et al., 2013; Moreira and Valeriano, 2014), the benefits are currently unclear for tropical mountains, which have been studied only rarely (Adhikari et al., 2015). For instance, the following questions have not been comprehensively addressed to date: Is topographic normalization affected by vegetation phenology and sun geometry in tropical mountains? How DEM accuracy affect the results of topographic normalization? Does topographic normalization improve the predictions of vegetation biophysical variables, and how this depends on the vegetation index? In general, the effect of topographic normalization on the seasonal features has not been comprehensively addressed, despite the recent studies on image composites (Vanonckelen et al., 2015), phenological metrics (Galvão et al., 2015) and forest change detection (Chance et al., 2016).

In this study, our objective was to evaluate the impact of topographic normalization on *Fcover* prediction in a tropical mountain landscape using common vegetation indices and statistical seasonal features based Landsat time series of 21 images. In particular, we examined if the results of topographic normalization and fit of the predictive models for *Fcover* vary between images acquired at

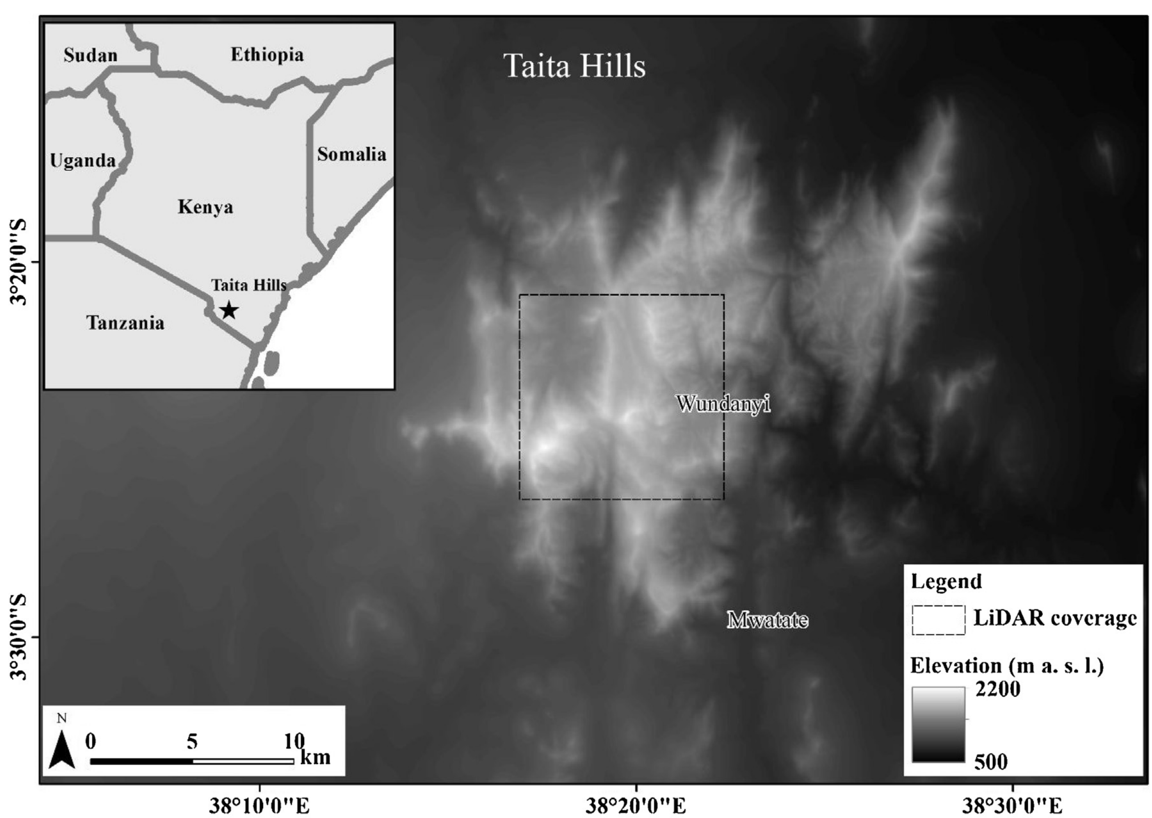

Fig. 1. Location and topography of the study area.