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# Effect of topographic correction on forest change detection using spectral trend analysis of Landsat pixel-based composites

Curtis M. Chance[a,*], Txomin Hermosilla[a], Nicholas C. Coops[a], Michael A. Wulder[b], Joanne C. White[b]

[a] Integrated Remote Sensing Studio, Department of Forest Resources Management, University of British Columbia, 2424 Main Mall, Vancouver, BC V6T 1Z4, Canada

[b] Canadian Forest Service (Pacific Forestry Centre), Natural Resources Canada, 506 West Burnside Road, Victoria, BC V8Z 1M5, Canada

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ABSTRACT

Pixel-based image compositing enables production of large-area surface reflectance images that are largely devoid of clouds, cloud shadows, or haze. Change detection with spectral trend analysis uses a dense time series of images, such as pixel-based composites, to quantify the year, amount, and magnitude of landscape changes. Topographically-related shadows found in mountainous terrain may confound trend-based forest change detection approaches. In this study, we evaluate the impact of topographic correction on trend-based forest change detection outcomes by comparing the amount and location of changes identified on an image composite with and without a topographic correction. Moreover, we evaluated two different approaches to topographic correction that are relevant to pixel-based image composites: the first corrects each pixel according to the day of year (DOY) the pixel was acquired, whilst the second corrects all pixels to a single reference date (August 1st), which was also the target date for generating the pixel-based image composite. Our results indicate that a greater area of change is detected when no topographic correction is applied to the image composite, however, the difference in change area detected between no correction and either the DOY or the August 1st correction is minor and less than 1% (0.54–0.85%). The spatial correspondence of these different approaches is 96.2% for the DOY correction and 97.7% for the August 1st correction. The largest differences between the correction processes occur in valleys (0.71–1.14%), upper slopes (0.71–1.09%), and ridges (0.73–1.09%). While additional tests under different conditions and in other environments are encouraged, our results indicate that topographic correction may not be justified in change detection routines computing spectral trends from pixel-based composites.



## 1. Introduction

The open release of the Landsat image archive in 2008 (Woodcock et al., 2008) has resulted in an increase in the number of spatial and temporal processing and analytical methods (Banskota et al., 2014) associated with large-area analyses from remotely sensed data (Wulder and Coops, 2014). No longer impeded by per-image costs and further enabled by provision of analysis-ready products that have quality geometric co-regisration and calibrated spectral values, users are increasingly empowered (Hansen and Loveland, 2012; Wulder and Coops, 2014), especially for time series investigations (Kennedy et al., 2010). Multiple images with analogous conditions can be combined to create spatially exhaustive image composites based upon individual pixels (Griffiths et al., 2013a,b; Roy et al., 2010; White et al., 2014) rather than a need for cloud-free scenes, with automated algorithms utilized to remove cloud, shadows, and other atmospheric effects (e.g., Zhu and Woodcock, 2012). Access to dense time series and an exhaustive spatial coverage combined with a level of detail that is informative of human and management activities on terrestrial ecosystems has been afforded by Landsat (Wulder et al., 2008). Change detection, with a particular emphasis on forest change, has been a particularly active research area (e.g., Kennedy et al., 2010; Huang et al., 2010), with opportunities to not only capture stand replacing change, but also to relate more subtle changes including magnitude, duration, and preceding and following land cover conditions (Frazier et al., 2014; Hermosilla et al., 2015a).

* Corresponding author.
*E-mail address:* curtis.chance@alumni.ubc.ca (C.M. Chance).

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Currently, analysis-ready Landsat Level 1T (standard terrain correction) products include systematic radiometric and geometric corrections, and include the use of a digital elevation model (DEM) for topographic accuracy (USGS, 2013), noting that there is no standard topographic correction applied for terrain shadows. Topographic correction is an image enhancement used to minimize the impact of shadows or varying illumination caused by terrain (Richter, 1998), the effects of which are not well explored regarding Landsat time series imagery and forest change (Banskota et al., 2014). Pixel-based compositing techniques produce images with a range of pixel acquisition dates, resulting in the possibility of terrain shading differences due to a variation in solar azimuth and zenith. Certain image processing activities can be impacted by differences in surface reflectance values that are not indicative of actual surface condition differences, but rather a manifestation of the physical location (see Tan et al., 2013). Varying terrain shadows throughout the year, as may be the case in a time series based on composites, may disrupt spectral trends, potentially causing errors in change detection results (Banskota et al., 2014). However, studies exploring forest change detection and pixel-based composites have not included topographic corrections (e.g., Griffiths et al., 2013a,b; Hermosilla et al., 2015a), and a study that investigated the effects of topographic correction on a land cover classification of pixel-based composites found only a small increase in classification accuracy (Vanonckelen et al., 2015).

The current capacity for processing of large numbers of images for both large area and dense time series is evident (e.g., Griffiths et al., 2012, 2013a,b; Latifovic and Pouliot, 2014; Hermosilla et al., 2015a; Senf et al., 2015) with the resulting composites supporting monitoring and reporting programs (White et al., 2014). To ensure the quality of these outcomes, additional investigation to determine the possible impacts of spectral differences attributable to topography on land cover and change applications is required. Topographic correction routines remain time consuming, require access to adequate digital terrain models, and can be implemented in a variety of ways (e.g., Soenen et al., 2005; Richter et al., 2009), with no consensus on the most appropriate approaches to follow, some of which may be land cover or location dependent. Knowledge of whether or not to include a geometric topographic correction in an image compositing and subsequent analysis workflow is an important consideration for resultant product quality as well as for time and data management. In this research we explore the effects of topographic correction on change detection outcomes using spectral trends computed from Landsat imagery. Specifically, this research focuses on the differences in the quantity of change detected in forested areas as well as the variation in this quantity across different topographic positions when using uncorrected composites, and composites from two different topographic correction approaches, one correcting each pixel considering its actual acquisition day of year (DOY), and the other considering a single date for all pixels.

## 2. Study area and data

### 2.1. Study area

The study area is 56,000 $km^2$ and located in southwest British Columbia, Canada. The location is well-suited to examine the effects of mountainous terrain on spectral trends as it includes both the Coast Mountain Range and the Cascade Mountain Range with an elevation range from 0 m to 3236 m (mean: 1401 m, standard deviation: 544 m), a mean slope of 20°, and various complex terrain features, such as valleys, ridges, and avalanche chutes (Fig. 1). This study area includes highly productive temperate rainforests of the coast as well as montane forests further east. The mean annual temperature ranges from approximately 10.2 °C in the south to 0 °C in the north and −6.1 °C in high elevations (Fig. 1). The mean annual precipitation ranges from approximately 233 mm in the north to 5883 mm in the north (ClimateBC version 5.10, 2015) (Fig. 1).

Approximately 62% of the area is forest dominated by western hemlock (*Tsuga hertophylla*), western red cedar (*Thuja plicata*), lodgepole pine (*Pinus contorta*), and white spruce (*Picea glauca*). Of the forested area, approximately 77% has a canopy closure of greater than 50%. The area is subject to sustainable forest management (including fire suppression) which allows for a range of harvest scenarios. Fires are also common in the eastern part of the study area.

### 2.2. Data

A digital elevation model (DEM) was available from the British Columbia's Terrain Resource Information Management TRIM, (2014) dataset which covers the entire province, derived from elevation points and lines. The TRIM DEM is a 25 m product, hence for this study, the TRIM DEM was resampled to a 30 m DEM.

The study area is covered by 12 scenes (path/rows) of the Landsat Worldwide Referencing System (WRS-2). We downloaded all available images with less than 70% cloud cover from the United States Geological Survey archive of Level 1 Terrain-Corrected (L1T) Landsat Thematic Mapper (TM) and Landsat Enhanced Thematic Mapper Plus (ETM+) acquired from August 1st ± 30 days from 1984 to 2012. A total of 1279 candidate images were downloaded for inclusion in the annual best-available-pixel composites. August 1st was selected as the central target acquisition date due a to general correspondence with the growing season for the majority of Canada's terrestrial area (McKenney et al., 2006).

## 3. Methods

### 3.1. Methods overview

First, three sets of annual Landsat pixel image composites from 1984 to 2012 were created using: (i) no topographic correction, (ii) a day of year topographic correction (hereafter $TC_{DOY}$) wherein each pixel in the composites are corrected according to their actual acquisition date, and (iii) an August 1st topographic correction (hereafter $TC_{Aug1}$) wherein each pixel is corrected as though it were acquired on August 1st. Second, change detection using spectral trend analysis was applied to each of the image composites (following (Hermosilla et al., 2015a), and we compared and contrasted the differences in the change detection results. The methods are outlined in detail below.

### 3.2. Pre-processing and image compositing

Pixel-based image composites were created from Landsat Thematic Mapper (TM) and Enhanced Thematic Mapper Plus (ETM+) imagery according to the methodology from White et al. 2014). First, the six optical bands of all images were processed through an atmospheric correction using the Landsat Ecosystem Disturbance Adaptive Processing System (LEDPAS) algorithm (Masek et al., 2006). Second, clouds, shadows, and water were masked using the Function of mask (Fmask) algorithm (Zhu and Woodcock, 2012). Following these steps, each pixel was given separate scores for sensor, acquisition day of year, distance to clouds and cloud shadows, and atmospheric opacity, based on Griffiths et al. (2013a,b). For the sensor score, Landsat 5 scored higher than Landsat 7 due to the Landsat 7 Scan Line Corrector (SLC) error (White et al., 2014). Dates of image acquisition were scored based on the number of days from August 1st (Griffiths et al., 2013a,b; White et al., 2014). There were 1279 candidate images for compositing (i.e., acquired within ± 30