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Detecting trends in forest disturbance and recovery using yearly Landsat time series: 1. LandTrendr — Temporal segmentation algorithms

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ABSTRACT

We introduce and test LandTrendr (Landsat-based detection of Trends in Disturbance and Recovery), a new approach to extract spectral trajectories of land surface change from yearly Landsat time-series stacks (LTS). The method brings together two themes in time-series analysis of LTS: capture of short-duration events and smoothing of long-term trends. Our strategy is founded on the recognition that change is not simply a contrast between conditions at two points in time, but rather a continual process operating at both fast and slow rates on landscapes. This concept requires both new algorithms to extract change and new interpretation tools to validate those algorithms. The challenge is to resolve salient features of the time series while eliminating noise introduced by ephemeral changes in illumination, phenology, atmospheric condition, and geometric registration. In the LandTrendr approach, we use relative radiometric normalization and simple cloud screening rules to create on-the-fly mosaics of multiple images per year, and extract temporal trajectories of spectral data on a pixel-by-pixel basis. We then apply temporal segmentation strategies with both regression-based and point-to-point fitting of spectral indices as a function of time, allowing capture of both slowly-evolving processes, such as regrowth, and abrupt events, such as forest harvest. Because any temporal trajectory pattern is allowable, we use control parameters and threshold-based filtering to reduce the role of false positive detections. No suitable reference data are available to assess the role of these control parameters or to test overall algorithm performance. Therefore, we also developed a companion interpretation approach founded on the same conceptual framework of capturing both long and short-duration processes, and developed a software tool to apply this concept to expert interpretation and segmentation of spectral trajectories (TimeSync, described in a companion paper by Cohen et al., 2010). These data were used as a truth set against which to evaluate the behavior of the LandTrendr algorithms applied to three spectral indices. We applied the LandTrendr algorithms to several hundred points across western Oregon and Washington (U.S.A.). Because of the diversity of potential outputs from the LTS data, we evaluated algorithm performance against summary metrics for disturbance, recovery, and stability, both for capture of events and longer-duration processes. Despite the apparent complexity of parameters, our results suggest a simple grouping of parameters along a single axis that balances the detection of abrupt events with capture of long-duration trends. Overall algorithm performance was good, capturing a wide range of disturbance and recovery phenomena, even when evaluated against a truth set that contained new targets (recovery and stability) with much subtler thresholds of change than available from prior validation datasets. Temporal segmentation of the archive appears to be a feasible and robust means of increasing information extraction from the Landsat archive.

1. Introduction

Landsat instruments have witnessed decades of unprecedented change on the Earth's surface (Wulder et al., 2008), and have the spatial and temporal properties needed to capture the processes driving that change (Cohen and Goward, 2004). Traditionally, change detection studies have focused on comparisons between two images: one before and one after a change (Coppin et al., 2004; Lu et al., 2004). To more fully tap the long archive of Landsat data, some studies use multiple two-date comparisons in sequence to summarize multi-temporal trends over time (Cohen et al., 2002; Jin and Sader, 2005; Olsson, 2009). Although these latter approaches are powerful, change analyses based on two-date change detection methods do not fully tap the interrelationships among many multitemporal images, and may not be able to separate from background noise the subtle or long-duration changes in cover condition and vigor that are expected under climate change (Hicke et al., 2006; Logan et al., 2003). Recognizing this limitation, methods that simultaneously consider the signal from

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