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Global, Landsat-based forest-cover change from 1990 to 2000

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ABSTRACT

Historical baselines of forest cover are needed to understand the causes and consequences of recent changes and to assess the effectiveness of land-use policies. However, historical assessment of the global distribution of forest cover and change has been lacking due to obstacles in image acquisition, computational demands, and lack of retrospective reference data for image classification. As limitations of access to imagery and computational power are overcome, the possibility is increased of an automated retrospective classification of forest cover. We used locally fit classification trees to relate hind-cast observations of "stable pixels" of forest and non-forest cover from circa-2000 to Landsat spectral measurements taken from the circa-1990 epoch of the Global Land Survey collection of Landsat images. Based on analysis of nearly 30,000 Landsat images, forest-cover change between 1990 and 2000 epochs was detected based on joint probabilities of cover in the two epochs. Assessed across a sample of areas with coincident reference data in the conterminous United States, the resulting maps achieved 93% accuracy for forest cover and 84% for forest-cover change—comparable or even higher than many previous national efforts. Global accuracy assessment likewise showed accuracy of 88% for forest-cover change. The maps depict the global distribution of gross gains and losses in forest cover, as well as their net change. The initial analysis showed strong effects of extant land use in temperate regions and land-use change in the tropics over the period, while wildfire dominated in the boreal zone. Regions of high net forest loss (e.g., Amazonia) were associated with land-use changes into agriculture, and regions of high gross gains and losses (e.g., southeastern US, Sweden) were associated with intensive forestry. These results, including the global forest cover and forest cover change datasets, will be a basis for the estimation of the efficacy of policies and analyzing correlation between forest cover change and socio-economic factors.

1. Introduction

1.1. Background

Climatological and anthropogenic factors are causing widespread changes in Earth's forest cover. Since the public opening of the USGS Landsat archive (Woodcock et al., 2008), there have been efforts to report global forest-cover and its changes at the 30-meter resolution of the Landsat sensors. Most of these efforts have concentrated on recent changes (2000–present) (Hansen et al., 2013; Sexton et al., 2013a; Townshend et al., 2012). However, historical baselines are needed to understand the causes and consequences of these changes and to assess the effectiveness of land-use policies, most notably for Reducing Emissions from Deforestation and Degradation (REDD) (Olander, Gibbs, Steininger, Swenson, & Murray, 2008).

Consistent with the United Nations Framework Convention on Climate Change (UNFCCC, 2002), United Nations Food and Agriculture Organization (FAO, 2006), and International Geosphere–Biosphere Programme (Belward, 1996), here the term "forest cover" refers to a specified density of trees, and not to land use as pertaining to forestry (Hansen, Stehman, & Potapov, 2010; Di Gregorio & Jansen, 2000). The term "cover" itself generalizes binary (presence vs. absence) as well as continuous (e.g., percent) scales of representation. Forests and forest cover thus defined are relevant to ecosystem processes such as chemical (e.g., carbon) and hydrological cycling, energy budgets, and biodiversity, whereas other definitions might be more applicable to socio-economic phenomena such as land tenure.

Most land-cover changes are small in area, and regional patterns develop over long (e.g., decadal) time scales (Lambin, Geist, & Lepers, 2003; Townshend & Justice, 1988). Consequently, effective monitoring requires longer-term data sets with fine spatial resolution—ideally at sub-hectare spatial resolutions spanning multiple decades (Sexton, Urban, Donohue, & Song, 2013b; Townshend & Justice, 1988). Further, the precision of analyses based on these data depends upon consistency of the definition of "forest" versus "non-forest" over space and time (Sexton, Urban, Donohue, & Song, 2013b). Several geospatial data sets represent Earth's forest cover globally (e.g. Hansen, DeFries, Townshend, & Sohlberg, 2000, Hansen et al., 2013; Loveland et al., 2000; Potapov et al., 2008; Sexton, Song, et al., 2013a), but none have both the spatial

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and temporal scale required for longer-term (i.e., pre-2000), global monitoring of forest-cover change at fine spatial resolution.

Provision of appropriately scaled data has in the past been hindered by two constraints: (1) access to large volumes of satellite imagery and (2) the coincident reference observations required to translate image pixels into estimates of cover. Given their global coverage, spatial resolution (30- to 60-m), and temporal extent (1972–present), the archive of Landsat data is the best source of information for retrieving historical baselines of forest cover (Olander et al., 2008; Townshend & Justice, 1988). But whereas the 2009 opening of the USGS Landsat archive has released the constraint of data access, retrospective mapping of forest cover is still limited by a lack of coincident reference data required for supervised image classifications.

1.2. Objectives

We demonstrate the feasibility of extending global, Landsat-resolution mapping and change detection to 1990. We present a method to retrieve historical maps of forest cover and change from 1990 to 2000 based on archival Landsat images and reference data hind-cast from more recent (i.e., post-2000) periods. We report the first results of this retrospective classification and change-detection algorithm, including: (1) a map of circa-1990 forest cover at 30-m resolution and global extent with a correspondingly scaled layer estimating classification uncertainty and (2) a global map of forest-cover change between circa-1990 and -2000, also with a corresponding uncertainty layer. To assess the quality of the forest-cover and -change estimates, we report error estimates relative to samples of independent reference data collected over the United States and globally, and we compare these validation results to those from previous change-detection efforts. Given the sensitivity of empirical classifiers, special attention is paid to assess the efficacy of methods and to minimize the impact of sampling bias.

2. Methods

2.1. Data and processing

2.1.1. Landsat-based surface reflectance

Landsat images from the 1990 Global Land Survey (GLS) collection (Gutman et al., 2008) were the primary source of imagery of the 1990 "epoch". Representing conditions around the nominal years of 1975, 1990, 2000, 2005, and 2010, the GLS was selected to optimize cloud-free conditions during the growing season for land-cover change studies. The 1990 epoch ranges from 1984 to 1997; images were taken preferentially from years near the target year 1990, but images far from 1990 were chosen by necessity in cloudy or otherwise poorly sampled regions. GLS coverage over the high northern latitudes and over western India and the surrounding region was prevented by gaps in the USGS archive. Also, nearly half of the original GLS-1990 dataset did not have correct radiometric gain and bias coefficients at the time of data acquisition; thus atmospheric correction and conversion to surface reflectance were not possible (Chander, Markham, & Helder, 2009; Chander et al., 2004; Townshend et al., 2012). These uncalibrated GLS images were replaced after the original GLS compilation with substitutes from the updated USGS archive within the epoch wherever possible (Fig. 2). To perform the selection of replacement imagery while minimizing phenological or atmospheric noise, a tool was constructed to query the USGS Global Visualization Viewer (GloVis) database (glovis.usgs.gov/) for appropriate images based on

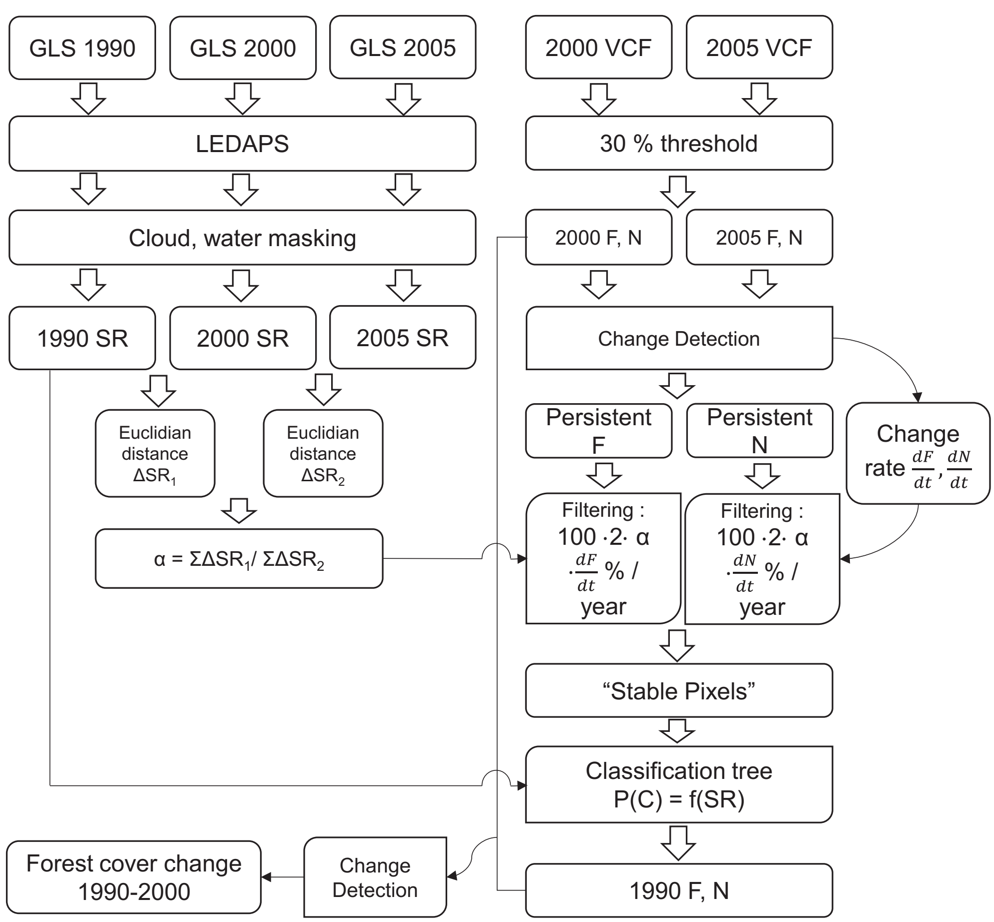

Fig. 1. Hind-cast training and classification procedure to retrieve historical forest cover estimates. SR = surface reflectance, C = cover, $t_1 \approx$ 1990, and $tn \approx$ 2000 or 20005.

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