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Use of Landsat and Corona data for mapping forest cover change from the mid-1960s to 2000s: Case studies from the Eastern United States and Central Brazil

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ABSTRACT

Land-cover change detection using satellite remote sensing is largely confined to the era of Landsat satellites, from 1972 to present. However, the Corona, Argon, and Lanyard intelligence satellites operated by the U.S. government between 1960 and 1972 have the potential to provide an important extension of the long-term record of Earth's land surface. Recently declassified, the archive of images recorded by these satellites contains hundreds of thousands of photographs, many of which have very high ground resolution- 6–9 ft (1.8–2.7 m) even by today's standards. This paper demonstrates methods for extending the span of forest-cover change analysis from the Landsat-5 and -7 era (1984 to present) to the previous era covered by the Corona archive in two study areas: one area covered predominantly by urban and sub-urban land uses in the eastern US and another area by tropical forest in central Brazil. We describe co-registration of Corona and Landsat images, extraction of texture features from Corona images, classification of Corona and Landsat images, and post-classification change detection based on the resulting thematic dataset. Second-order polynomial transformation of Corona images yielded geometric accuracy relative to Landsat-7 of 18.24 m for the urban area and 29.35 m for the tropical forest study area, generally deemed adequate for pixel-based change detection at Landsat resolution. Classification accuracies were approximately 95% and 96% for forest/non-forest discrimination for the temperate urban and tropical forest study areas, respectively. Texture within 7×7- to 9×9-pixel (~13.0–16.5 m) neighborhoods and within 11×11-pixel (~30 m) neighborhoods were the most informative metrics for forest classification in Corona images in the temperate and tropical study areas, respectively. The trajectory of change from the 1960s to 2000s differed between the two study areas: the average annual forest loss rate in the urban area doubled from 0.68% to 1.9% from the 1960s to the mid-1980s and then decreased during the following decade. In contrast, deforestation in the Brazilian study area continued at a slightly increased pace between the 1960s and 1990s at annual loss rate of 0.62–0.79% and quickly slowed down afterward. This study demonstrates the strong potential of declassified Corona images for detecting historical forest changes in these study regions and suggests increased utility for retrieving a wide range of land cover histories around the world.

1. Introduction

The launch of the first Landsat satellite (named the "Earth Resource Technology Satellite", ERTS-1) in 1972 opened an era of monitoring Earth's terrestrial surface by space-borne, remotely sensed imagery. Over the following decades, the medium spatial resolution, global coverage, and potential for time-serial analysis of the Landsat data record have enabled assessments of forest[1] change from local to national scales (Brandt et al., 2012; Huang et al., 2009; Sexton et al., 2013). Recently, global Landsat datasets have facilitated forest change analysis at the global scale (Townshend et al., 2012).

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[1] The definition of forest in this study follows the International Geosphere-Biosphere Programme (IGBP) definition of greater than or equal to 30% tree cover and height exceeding 2 m. Forest loss is defined as conversion from forest to other land cover. Forest gain is defined as growth or recovery of tree cover, such that a previous non-forest location subsequently meets the tree-cover criteria for forests.

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However, in many parts of the world, large-scale forest changes occurred prior to the Landsat era. For example, eastern Paraguay was once covered by intact forests, but only 73.4 ± 4.9% of the original Atlantic forest was left by the 1970s (Huang et al., 2009; Nagel, 1991; Nickson, 1981). In southern Brazil, agricultural developments in the 1960s and 1970s resulted in the consolidation of small farms and a shift from labor-intensive crops to extensive ranching and soy production (Richards, 2011), which resulted in a large forest area being cleared. Knowledge of land cover prior to the Landsat era is important for fully understanding the impact of socioeconomic activities on natural resources, especially in regions where significant development had occurred before the 1970s.

Images acquired by the U.S. Key Hole (KH) missions, which consisted of the Corona, Argon, and Lanyard satellites (collectively referred to as "Corona" images hereafter) that operated from 1960 to 1972 (McDonald, 1995), have the potential to extend historical land cover mapping from the Landsat era into the 1960s. KH-4, including 4A and 4B, was the most successful mission series that acquired most of fine images during from early 1960s to early 1970s. Declassified Corona imagery has worldwide spatial coverage, especially in Eastern Europe and Asia (Fig. 1), and has very high ground resolutions, ranging from 6 to 9 feet (about 1.83–2.74 m). Declassified satellite images have been used to study boreal forest decline (Rigina, 2003), vegetation dynamics (Kadmon and Harari-Kremer, 1999), land resource change (Tappan et al., 2000), forest fire carbon emissions (Isaev et al., 2002), ice sheet change (Bindschadler and Vornberger, 1998), and archaeological features (Beck et al., 2007; Casana and Cothren, 2008; Challis et al., 2002). In these localized studies, Corona images were analyzed mainly through visual interpretation and manually tuned histogram segmentation or were used as stereo image pairs for extracting digital elevation models (DEMs). Although the spatial coverage of available Corona data may allow large-area applications for many parts of the world, such applications would be possible only using more automated digital image analysis methods.

The purpose of this study is to develop an approach for extending forest change monitoring back to the 1960s using Corona data. Focusing on increasing automation relative to earlier approaches, major methodological components of this approach include georegistration between Corona and Landsat images, extraction of texture features from Corona images, classification of Corona and Landsat images, and change detection based on the classification results. The effectiveness of this approach is demonstrated by mapping forest cover change between four epochs—1960s, 1980s, 1990s, and 2000s—in two study areas that have experienced major anthropogenic forest changes: an urbanized landscape in the eastern United States and a forested area in central Brazil characterized by recent agricultural expansion. The following sections provide a brief description of the study areas and datasets, followed by a detailed description of the various methodological components and results derived using these methods. The paper closes with a discussion of potential improvements and applications of the approach developed in this study.

2. Study area and data

2.1. Study area

Two study areas with widely different vegetation properties and human land uses were selected to determine the feasibility of using paired Corona and Landsat images for detecting forest changes (Fig. 2). The sites were selected to represent the range of forest types and change trajectories that impact forest cover classification of high resolution remote sensing images and change detection. The Virginia-Maryland (VM) study area in the eastern United States, centered at 39°02′34.63″N, 77°23′35.45″W and spanning 32.6-by-23.6 km, lies within the temperate mixed forest biome and experienced forest change due to urbanization and managed forest planting. Forests in this region comprise a mix of deciduous (e.g. oak and hickory) and evergreen (e.g. loblolly pine) species. The leaf-on season for deciduous forest normally starts in early April and ends in

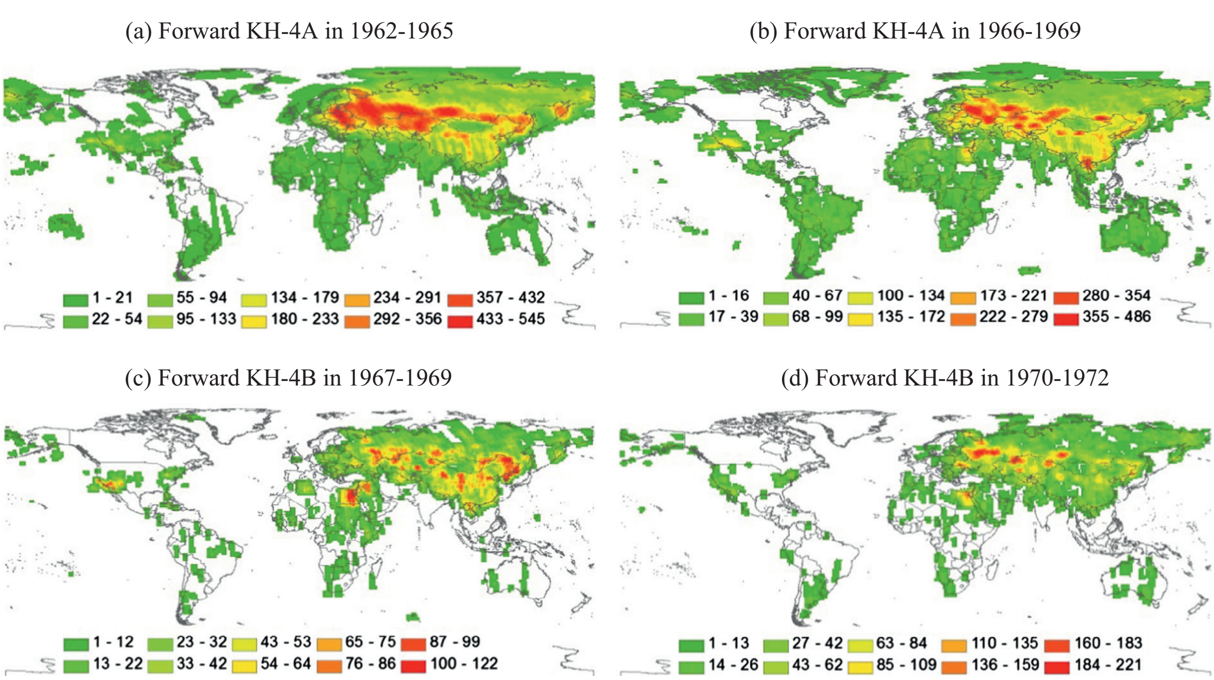

Fig. 1. Global coverage of Corona images acquired by the forward-looking cameras during the KH-4A and KH-4B missions. All coverage maps have been rasterized for display purposes from vector format to 1° geographic grid. (a) KH-4A mission between 1962 and 1965; (b) KH-4A mission between 1966 and 1969; (c) KH-4B mission between 1967 and 1969; and (d) KH-4B mission between 1970 and 1972 (*Source:* https://lta.cr.usgs.gov/declass_1). Metadata was downloaded from U.S. Geological Survey (USGS) Earth Explorer website.

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