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A new generation of the United States National Land Cover Database: Requirements, research priorities, design, and implementation strategies

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ABSTRACT

The U.S. Geological Survey (USGS), in partnership with several federal agencies, has developed and released four National Land Cover Database (NLCD) products over the past two decades: NLCD 1992, 2001, 2006, and 2011. These products provide spatially explicit and reliable information on the Nation's land cover and land cover change. To continue the legacy of NLCD and further establish a long-term monitoring capability for the Nation's land resources, the USGS has designed a new generation of NLCD products named NLCD 2016. The NLCD 2016 design aims to provide innovative, consistent, and robust methodologies for production of a multi-temporal land cover and land cover change database from 2001 to 2016 at 2–3-year intervals. Comprehensive research was conducted and resulted in developed strategies for NLCD 2016: a streamlined process for assembling and preprocessing Landsat imagery and geospatial ancillary datasets; a multi-source integrated training data development and decision-tree based land cover classifications; a temporally, spectrally, and spatially integrated land cover change analysis strategy; a hierarchical theme-based post-classification and integration protocol for generating land cover and change products; a continuous fields biophysical parameters modeling method; and an automated scripted operational system for the NLCD 2016 production. The performance of the developed strategies and methods were tested in twenty World Reference System-2 path/row throughout the conterminous U.S. An overall agreement ranging from 71% to 97% between land cover classification and reference data was achieved for all tested area and all years. Results from this study confirm the robustness of this comprehensive and highly automated procedure for NLCD 2016 operational mapping.

1. Introduction

1.1. History and recent activities in large area land cover database development

The late 1990s to early 2010s witnessed several pioneering and formative developments in global and national land cover datasets using coarse resolution (~1 km) remotely sensed data. The most significant are The International Geosphere-Biosphere Programme (IGBP) DISCover global land cover database (Loveland and Belward, 1997) developed by U.S. Geological Survey (USGS)/University of Nebraska (Loveland et al., 2000), University of Maryland Global land cover data (Hansen et al., 2000), the National Aeronautics and Space Administration (NASA) Earth Observing System's MODIS global land cover (by

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Friedl et al., 2002), Global Land Cover 2000 led by the European Commission's Joint Research Centre (Bartholomé and Belward, 2007), and GLOBCOVER 2005 -led by European Space Agency with International collaborators (Arino et al., 2008). The United States National Land Cover Database (NLCD) was initiated during this era to bring national large-area land cover classification to a medium resolution (30-m) in order to make land cover information more relevant to national applications (Vogelmann et al., 2001). Following the success of NLCD, international communities have continued to advance medium resolution (~30-m) land cover product development at global scales, including the 30-m Global Land Cover (Globeland30) by the China land cover team (Chen et al., 2014, 2015), Fine Resolution Observation and Monitoring of Global Land Cover (FROM_GLC) by Tsinghua University of China (Gong et al., 2013), Global Mangrove Forests Data (Giri et al., 2011), Global Forest Change 2000–2014 (Hansen et al., 2013), Global Landsat Tree Cover (Sexton et al., 2013a), Global Forest Cover Change of 1975, 1990, 2000, and 2005 (Kim et al., 2014), Global Human Settlement of 1975, 1990, 2000, 2014 (Pesaresi et al., 2016), Global Urban Footprint circa 2002 (Esch et at., 2013), Global Impervious Cover 2010 (Song et al., 2016), Global Inland Water Body circa 2000 (Feng et al., 2015), and Global Cropland Extent 2015 (Teluguntla et al., 2017). These activities were driven by an increasing demand for more accurate, higher spatial resolution, and up-to-date land cover datasets required by the global change and land management user communities. The successful completion of those products was attributable primarily to the improved technological and algorithm advancement for land cover characterization, and the ever-increasing availability of multi-temporal and multi-resolution remote sensing and geospatial datasets.

1.2. Emerging trends and challenges in large area land cover monitoring from remote sensing

Until the late 2000s, most large-area (national or global) comprehensive land cover and land cover change monitoring based on medium resolution images (~30-m) was conducted using a conventional change detection method between two points in time. Since 2009, the opening of the USGS Landsat data archive has enabled a new paradigm for advancing land change science (Woodcock et al., 2008; Wulder et al., 2018). The paradigm promotes a new approach to land change monitoring by extending from simple change detection at a bi-temporal scale to a multi-temporal scale (Jin and Sader, 2005; Latifovic and Pouliot, 2005; Kennedy et al., 2007; Huang et al., 2010; Zhu et al., 2012; Sexton et al., 2013b; Franklin et al., 2015). Such an approach can generate land cover products that depict more complex spatial and temporal land cover condition and changes caused by natural or anthropogenic driving forces. The multi-temporal datasets enable a better understanding of land cover dynamics and the implications of these changes on land resources management and ecosystem services.

There are several challenges for realizing this new paradigm as it relates to large-area land cover and change monitoring. From a thematic perspective, it has long been recognized that there is spectral variation within a single land cover type and spectral similarities among different land cover types (e.g., different types and practices of cultivated croplands, and forested wetlands versus upland forest). These have posed great challenges for spectral-based land cover classification. The challenges can be further compounded when a long time-series land cover and change product is targeted. From a temporal perspective, the quality of each individual land cover map in a time series has a direct impact on the accuracy of mapped land cover and change (no-change). The errors and inconsistency in multi-temporal time-series land cover and change maps due to differences in class definition, input data, and methods can lead to illogical and false land cover changes (Latifovic and Pouliot, 2005; Sexton et al., 2013b; Franklin et al., 2015). Consequently, they may yield unreliable estimates of land cover change rate and change trajectory and have a direct and negative impact on the accuracy of the product.

Another challenge is to accurately map various land cover types and changes over vast and complex landscapes subject to various land use and management practices. Some land cover patterns are spatially unique in shape and size, and changes occur at a confined spatial and temporal scale (e.g., a few pixels of water body or a stream), while other types are spatially clustered and confined within areas of certain geometry or terrains (e.g., forest cut or irrigated cropland, objects formed by a group of pixels). Mapping diverse land cover classes and changes in a large region requires spatially and temporally representative training data and a need to achieve a balance between maintaining the spatial coherence of certain land cover types while keeping single pixel level information for other types. In addition, mixed pixels are a challenge for spectral-based classification algorithms. Separating changes between land cover condition and land cover conversion over large and diverse landscapes often requires special treatment and strategies beyond the conventional spectral-only change detection. Under such conditions, geographic ancillary data and local knowledge about the landscape and natural environment, vegetation dynamics, and land use practices can all be used to improve the accuracy of either classification or the post-classification processes (Srinivasan and Richards, 1990; Brown et al., 1993; Jin et al., 2013; Chen et al., 2014). In essence, to achieve a high accuracy in large area time series land cover and change mapping, careful integration of multi-temporal, multi-spectral, and geospatial data and knowledge is necessary.

1.3. Review of U.S. National land cover database development

The United States NLCD had its beginnings in the mid-1990s with the formation of the Multi-Resolution Land Characteristics (MRLC) Consortium by the USGS, the U.S. Environmental Protection Agency (EPA), and the National Oceanic and Atmospheric Administration (NOAA). Additional MRLC partners beyond the three originals now include the U.S. Department of Agriculture (USDA) Forest Service (USFS), National Agricultural Statistical Service (NASS), the Bureau of Land Management (BLM), the National Park Service (NPS), the U.S. Fish and Wildlife Service (USFWS), and the Army Corps of Engineers (USACE) (Wickham et al., 2014). For NLCD, the 1992 product was the first land cover dataset at 30-meter resolution ever produced for the 48 conterminous states with a consistent, coast-to-coast methodology. By the 2001 release, NLCD had evolved to a database concept with multiple products including land cover, percent tree canopy, percent imperviousness, and database derivatives of Landsat imagery, elevation data and derivatives, other ancillary and intermediate datasets, and metadata and other supporting information (Homer et al., 2004). For the 2006 release, NLCD began quantifying land cover change over time (Fry et al., 2011). NLCD 2011, which was released in 2013, represents a decade of consistently produced land cover and impervious surface for the Nation across three periods: 2001, 2006, and 2011 (Fry et al., 2011; Homer et al., 2015). Overall, the USGS, in partnership with several federal agencies, has developed and released four NLCD product databases over the past two decades: NLCD 1992, 2001, 2006, and 2011. These databases provide spatially explicit and reliable information on the Nation's land cover and land cover change.

2. Requirements for a new generation NLCD 2016

Despite several successful data releases, there remains a fundamental need across government and private sectors for more timely, accurate, and relevant products. In addition, there is increasing demand for products that better represent shrub and grass ecosystems than past NLCD land cover classes. Hence, the NLCD team has responded to this need with an NLCD 2016 database design that produces accurate land cover change information more cohesively and consistently by correcting legacy errors in NLCD products; including additional products for shrub, grass, and bare ground and additional forest disturbance