PE&RS

May 2015 Volume 81, Number 5

PHOTOGRAMMETRIC ENGINEERING & REMOTE SENSING

The official journal for imaging and geospatial information science and technology

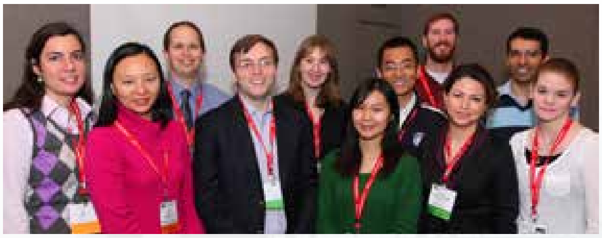
Landsat 5
August 13, 1986

0 5 10 Miles

Landsat 8
August 10, 2014

0 5 10 Miles

The ASPRS Student Advisory Council (SAC) ...
...ensuring Student Member representation in ASPRS and more.



SAC is a group of students committed to serving all of the student members of ASPRS. Our goal is to ensure that ASPRS is a Society that both benefits from student involvement and creates opportunities for those students.

SAC is led by a Council of seven students who meet monthly to discuss issues pertaining to ASPRS Student Members. What do they do?

- **Organize special sessions** of interest to students at ASPRS Annual and fall conferences. http://www.asprs.org/Annual-Conferences/Program/
- **Create networking opportunities** during those conferences and bring together students looking for employment after graduation with potential employers in the industry.
- Inaugurate new programs within ASPRS.
- Design activities such as the **GeoLeague Competition** where students compete in teams using geospatial technology applications to solve a problem. http://www.asprs.org/Students/GeoLeague-Challenge-2014.html.

Promote student involvement in humanitarian projects such as crowdsourcing the manual interpretation of imagery in Somalia to identify shelters that are being used as homes by refugees. http://irevolution.net/tag/tomnod/.

All ASPRS Student Members are encouraged to become involved with SAC. Check out the SAC Social Networking sites and keep up with ongoing news.

Student Newsletter: http://asprssignature.blogspot.com/

Facebook page: https://www.facebook.com/pages/ASPRS-Student-Advisory-Council/117943608233122

LinkedIn Group: http://www.linkedin.com/groups?home=&gid=2487675&trk=anet_ug_hm

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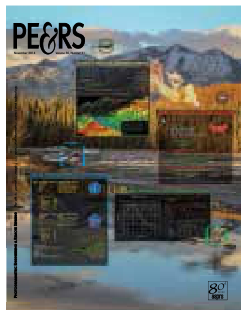
asprs STUDENT ADVISORY COUNCIL
THE IMAGING & GEOSPATIAL INFORMATION SOCIETY

HIGHLIGHT ARTICLES

Proposals Wanted

ASPRS is actively seeking Highlight Articles for publication in *PE&RS*



Highlight Articles are meant to extend the impact of *PE&RS* to an even broader range of readers. These articles are semi-technical or non-technical. Each article should address topics of broader interests with greater impact to the geospatial community, and accommodate the interests of readers with a diverse level of geospatial knowledge. Highlight Articles may: review recent or historical developments in technology, industry or academia; discuss new or unusual approaches to common problems; address topics of common concerns or interests.

ASPRS is interested in articles of varied topics but are most interested in articles on:

- Use of UAS for mapping purposes
- Humanitarian activities/relief efforts facilitated by imaging and geospatial technologies
- Sports applications of photogrammetry
- Microsatellite platforms
- Remote sensing projects by international teams
- Imaging and geospatial information programs/ initiatives in K-12 education
- Machine vision and artificial intelligence applied to imagery
- Remote sensing applications in the following industries; beer, wine, truffles
- Intelligent transportation systems facilitated by photogrammetry, remote sensing, imaging, and geospatial technologies
- Cybersecurity related to geospatial information
- Privacy issues related to geospatial information (must be balanced and thoughtful presentation)

Please note: Highlight Articles are NOT peer-reviewed articles and should not contain lengthy lists of references or complex equations. They should contain high quality photos and graphics.

For more information, contact: Rae Kelley, Assistant Director-Publications at rkelley@asprs.org.

PE&RS

PHOTOGRAMMETRIC ENGINEERING & REMOTE SENSING

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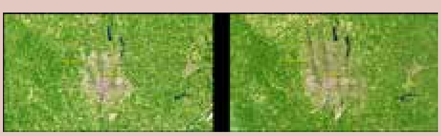
COLUMNS

ANNOUNCEMENTS

DEPARTMENTS



Ohio's capital city, Columbus, is situated along the Scioto River and is one of the fastest growing cities in the state. In 1986, the municipal population was estimated at 600,000. The latest population estimate for Columbus from the U.S. Census Bureau is over 820,000.

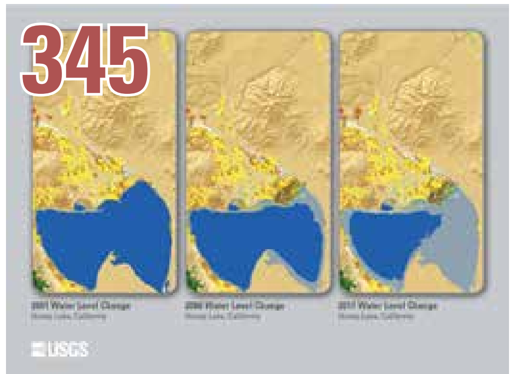
These two images show Columbus and surrounding areas in 1986 and again in 2014. The second image shows the gray urban areas expanding into previous agricultural land, which is indicated by green patchy areas. The bright areas throughout the city are retail and industrial centers. The dark blue spots along the river in the southern part of the city are wastewater treatment ponds and other ponds associated with local sand and gravel quarries.

The historical record provided by Landsat images can be a useful tool for city managers, planners, and scientists who are monitoring and documenting the changes to Earth's land cover caused by urban expansion.

Sensor: L5 TM, L8 OLI
Path/Row: 19/32
Lat/Long: 40.300/-82.600
Category: World Cities
Download High Resolution
Date Posted: 12/16/2014

This Landsat 8 Image can be viewed at landsat.usgs.gov/gallery_view.

HIGHLIGHT ARTICLE



PEER-REVIEWED ARTICLES

FROM THE PRESIDENT'S PEN

Most presidents, I fear, realize that their year was but a walking shadow and is ending with so much to be done and too little to show for their efforts. My term was a challenging one as we laid the foundation to rejuvenate the Society, but it has been a privilege to have been steward of the Society in its 81st year.

First, I must thank the National Technical Program Committee and the Sustaining Members for their efforts to create appealing yet economical events. The Northern California Region ran a magnificent UAS event in Reno last October, attracting more than 500 participants, who were offered a strong technical program including demonstrations of systems in action. This event will continue in 2015. It was quickly followed by Pecora 19 in Denver, which was enhanced by co-location of ISPRS and IAG events. Our 2015 Annual Conference has been re-branded as IGTF 2015 and will open in Tampa around the time this issue is published. For the second year in succession, we are privileged to be joined by JACIE, whose high-quality content enriches our conference.

Many of the Society's activities, of course, are renowned and fruitful. We have fine publications and *PE&RS* is available in both print and digital form and its impact factor is rising. Our manuals are invaluable reference works for our three congregations – academic, government, commercial – but we are moving forward to an all-electronic format, with updates, with the fourth edition of the Manual of Remote Sensing. We are privileged to be working with NASA on a major historical publication about Landsat. The GeoByte webinars have drawn massive attendances. Our student activities and the awards program are prospering. ASPRS certification is sought by employers and under Mike Renslow's energetic, dedicated leadership is expanding into LiDAR; UAS may be next.

The technical work of the Society is done in the Divisions and the committees within them. I remain astonished at the sheer volume of high-quality projects – all done by volunteers to improve the profession. This year we are delighted that two major standards have been published: *ASPRS Positional Accuracy Standards for Digital Geospatial Data* and *ASPRS Guidelines for Procurement of Geospatial Mapping Products and Services*. These will be eagerly adopted. Thank you, Qassim Abdullah, David Maune, Doug Smith, Hans Karl Heidemann, David Stolarz, and Jerry Lenczowski for your contributions to the standard. Perhaps we should remember that it is 15 years since ASPRS took over responsibility for the LAS format. As we redesign and rejuvenate our website as part of our repair of critical infrastructure, we must highlight and proselytize the initiative of the Divisions. In January 2015 the Unmanned Autonomous Systems Division was formally inaugurated and I had the pleasure of appointing Pierre Le Roux as Division Director: the results of an election for Assistant Director will be announced in

continued on page 363

PHOTOGRAMMETRIC ENGINEERING & REMOTE SENSING

asprs THE IMAGING & GEOSPATIAL INFORMATION SOCIETY

Photogrammetric Engineering & Remote Sensing is the official journal of the American Society for Photogrammetry and Remote Sensing. It is devoted to the exchange of ideas and information about the applications of photogrammetry, remote sensing, and geographic information systems. The technical activities of the Society are conducted through the following Technical Divisions: Geographic Information Systems, Photogrammetric Applications, Lidar, Primary Data Acquisition, Professional Practice, and Remote Sensing Applications. Additional information on the functioning of the Technical Divisions and the Society can be found in the Yearbook issue of *PE&RS*.

Correspondence relating to all business and editorial matters pertaining to this and other Society publications should be directed to the American Society for Photogrammetry and Remote Sensing, 5410 Grosvenor Lane, Suite 210, Bethesda, Maryland 20814-2144, including inquiries, memberships, subscriptions, changes in address, manuscripts for publication, advertising, back issues, and publications. The telephone number of the Society Headquarters is 301-493-0290; the fax number is 301-493-0208; web address is www.asprs.org.

PE&RS. *PE&RS* (ISSN0099-1112) is published monthly by the American Society for Photogrammetry and Remote Sensing, 5410 Grosvenor Lane, Suite 210, Bethesda, Maryland 20814-2144. Periodicals postage paid at Bethesda, Maryland and at additional mailing offices.

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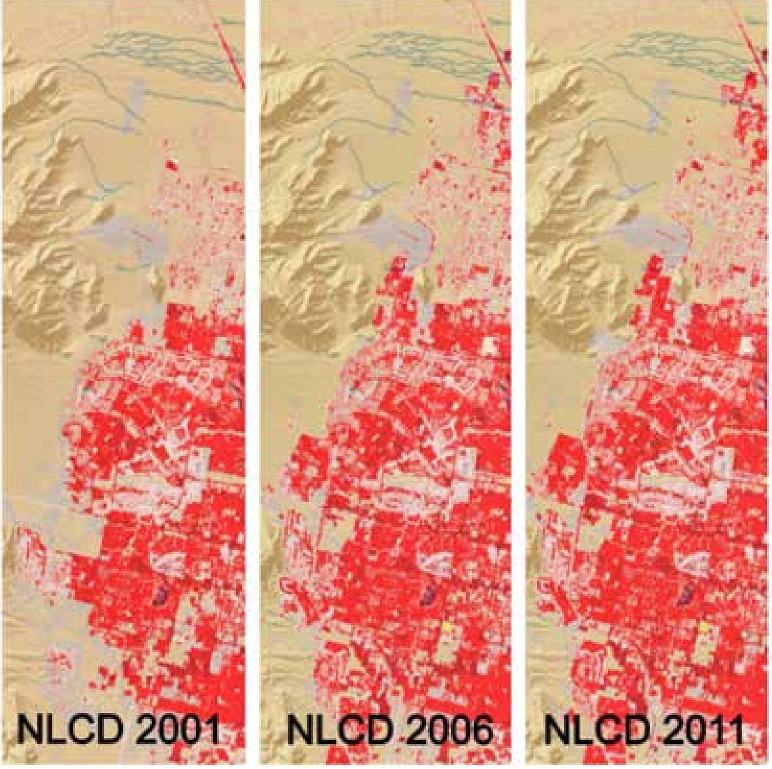
Completion of the 2011 National Land Cover Database for the Conterminous United States – Representing a Decade of Land Cover Change Information

By Collin Homer, Jon Dewitz, Limin Yang, Suming Jin, Patrick Danielson, George Xian, John Coulston, Nathaniel Herold, James Wickham, and Kevin Megown



Introduction

The National Land Cover Database (NLCD) provides nationwide data on land cover and land cover change at the native 30-m spatial resolution of the Landsat Thematic Mapper (TM). The database is designed to provide five-year cyclical updates of United States land cover and associated changes. The recent release of NLCD 2011 products now represents a decade of consistently produced land cover and impervious surface for the Nation across three periods: 2001, 2006, and 2011 (Homer et al., 2007; Fry et al., 2011). Tree canopy cover has also been produced for 2011 (Coluston et al., 2012; Coluston et al., 2013). With the release of NLCD 2011, the database provides the ability to move beyond simple change detection to monitoring and trend assessments. NLCD 2011 represents the latest evolution of NLCD products, continuing its focus on consistency, production, efficiency, and product accuracy. NLCD products are designed for widespread application in biology, climate, education, land management, hydrology, environmental planning, risk and disease analysis, telecommunications and visualization, and are available for no cost at http://www.mrlc.gov. NLCD is produced by a Federal agency consortium called the Multi-Resolution Land Characteristics Consortium (MRLC) (Wickham et al., 2014). In the consortium arrangement, the U.S. Geological Survey (USGS) leads NLCD land cover and imperviousness production for the bulk of the Nation; the National Oceanic and Atmospheric Administration (NOAA) completes NLCD land cover for the conterminous U.S. (CONUS) coastal zones;, and the U.S. Forest Service (USFS) designs and produces the NLCD tree canopy cover product. Other MRLC partners collaborate through resource or data contribution to ensure NLCD products meet their respective program needs (Wickham et al., 2014).

Methods

NLCD 2011 production sought accurate representation of nominal year 2011 land cover condition and the change occurring between 2006 and 2011 through methods and algorithms that were scientifically based, quantifiable, scalable, and repeatable. Product generation followed identical protocols nationally for consistency and accuracy across both space and time. Production protocols spanning source data preparation, spectral change detection, land cover change modeling and mapping, impervious and canopy generation, and post-processing strategies are outlined in the following sections.

Source Data Preparation

Landsat 5 Thematic Mapper (TM) imagery provided the foundation for spectral change analysis, land cover classification, and imperviousness modeling for all NLCD 2011 products. All Landsat images were acquired from the USGS Earth Resources Observation and Science (EROS) Center Landsat archive, where they were radiometrically and geometrically calibrated. All reflective bands were converted from a digital number to top-of-atmosphere (TOA) reflectance through the Level 1 Product Generation System (LPGS). Two Landsat scene pairs were selected for analysis and classification for each path/row in CONUS for each target year of 2006 and 2011. Image date selection objectives included a leaf-on and leaf-off scene pair for each path/row with acquisition anniversary dates within two weeks of each other in order to maintain as much phenological consistency as possible.

Common image extents for each path/row were defined by calculating the intersection area of all Landsat images; this boundary was then subsequently used for clipping all image and ancillary data for each path/row. Ancillary datasets required for analysis included NLCD 2001, NLCD 2006, National Elevation Dataset (NED) derivatives of slope, aspect, elevation, and topographic position, USDA Natural Resources Conservation Service Soil Survey Geographic (SSURGO) database Hydric Soils, National Agricultural Statistics Service (NASS) 2011 Cropland Data Layer (CDL), National Wetlands Inventory (NWI), and nighttime stable-light satellite imagery (NSLS) from the NOAA Defense Meteorological Satellite Program (DMSP). These ancillary data combined with Landsat imagery and derivatives were used as independent variables in the land cover decision tree modeling process. All data were georegistered to the Albers Equal Area projection grid and resampled to a 30-m cell resolution.

Enhanced Spectral Change Detection

For NLCD 2011, two major change detection advancements over previous NLCD methods were implemented. First, unlike NLCD 2006 (Fry et al, 2011), two pairs rather than one pair of Landsat images between 2006 and 2011 (one leaf-on pair and one leaf-off pair) were utilized for spectral change analysis. Use of an additional image pair for land cover change detection reduced commission errors caused by seasonal phenology in agriculture and wetland dominant areas, and reduced omission errors due to limitations of using one image pair in areas with clouds and shadows, fire disturbance, forest cutting, and urban development. Second, the core spectral change detection method used for NLCD 2011 was an enhanced and improved version over NLCD 1992, 2001, and 2006 methods (Homer et al., 2004; Fry et al., 2009; Xian et al., 2009). The 2011 change method referred to as the Multi-Index Integrated Change Analysis (MIICA) model (Jin et al., 2013) uses paired Landsat imagery from 2006 and 2011 to capture a full range of land cover disturbances and land cover changes. The MIICA model accomplishes this by using multiple indices for detecting changes, which recognizes the complementary and sensitivity of each index in detecting various types of land cover changes. Specific indices include the Normalized Burn Ratio (NBR), the Normalized Difference Vegetation Index (NDVI), the Change Vector (CV), and the Relative Change Vector (RCV) (Jin et al., 2013). The four indices were first computed for each pixel of a Landsat scene and then subsequently differenced by 2006 and 2011 scene pairs. During computation, MIICA uses global means and standard deviations from the four spectral indices to set relative image path/row thresholds to determine change areas and to differentiate the change direction (i.e., biomass increase or decrease) between the two time periods (Jin et al., 2013).

For 2011, the MIICA model was also enhanced with a separate process called the Zone model (Jin et al., 2013). This model uses two pairs of NBR change and NDVI change images across a growing season to identify change areas related to forest disturbance and succession. Because the Zone model is more sensitive to the sometimes subtle spectral change from forest cutting and regrowth than the MIICA model, results were used to reduce MIICA omission errors in forest change areas, especially for regions where forests can regrow rapidly.

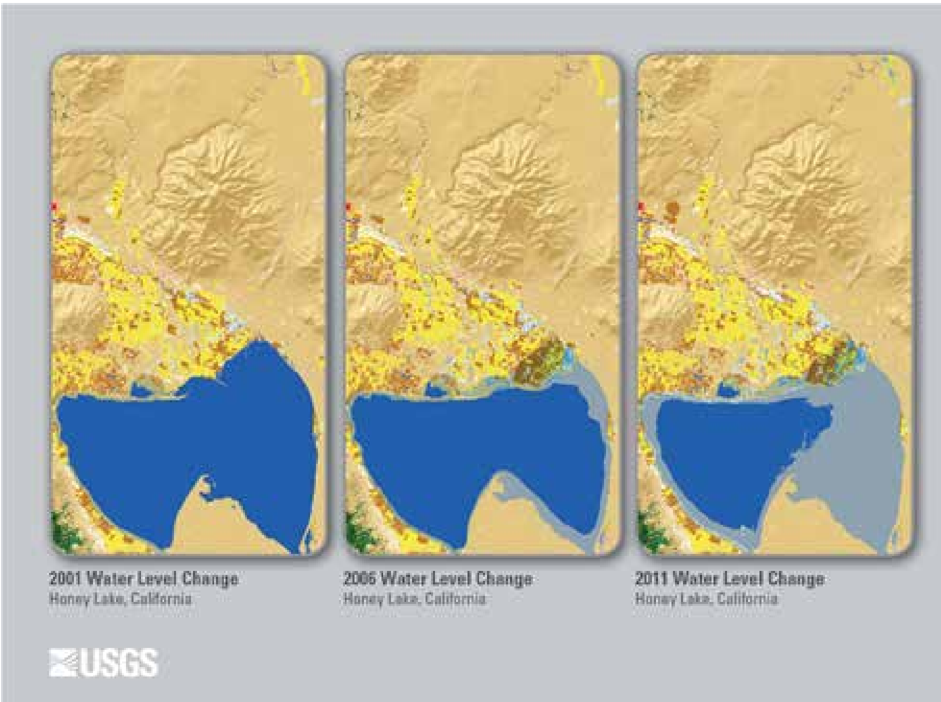
Integrated Land Cover Change Labeling

After the MIICA change detection process identified areas of potential change, additional steps were required to determine if the change was valid and to appropriately label the land cover change between 2006 and 2011. To accomplish this, several steps were required: (1) enhancing and refining training data for land cover classification; (2) improving land cover classification by use of three Landsat images from circa 2011 for each path/row; and (3) establishing a set of knowledge-based rules for land cover labeling within spectral change areas for use in the decision tree algorithm. The goal of labeling advancements was to improve overall classification accuracy and product quality from NLCD 2006 procedures (Fry et al., 2011), which used more simple training procedures, only one date of imagery from each era, and no knowledge-based rules.

An extensive enhanced training dataset was assembled for NLCD 2011 to provide land cover training data for spectral change areas and to provide good balance among different land cover types in the training data pool. The training pool also incorporated several national datasets including NASS CDL (Johnson et al., 2010), NWI data, and hydric soils. A method that integrated these multi-source, multi-temporal training data and information on land cover condition and trajectory into the land cover labeling process was then utilized. This method utilized three Landsat images acquired from 2011 and several geospatial ancillary datasets (e.g., derivatives and a wetland potential index) to generate an initial 2011 land cover map through a classification tree algorithm. Then both the land cover map of 2011 and NLCD 2006 were spatially combined with the spectral change map of 2006–2011 obtained from the MIICA model to derive a land cover change map. This land cover change map contains only those pixels that are identified as change spectrally, and as a class label change between (2006) and (2011) labels.

Post-Classification Processing

Despite extensive efforts in image pre-processing, spectral change detection, and change labeling during NLCD 2011 creation, some mis-classification still occurred, which required correction by post-classification analysis. This analysis typically depends upon knowledge-based rules to refine initial model labeling using the trajectory of land cover history, an estimate of the expected land cover class extent and distribution in the year 2011, and other ancillary data sources. Each specific land cover type required slightly different post-classification analysis. Urban class pixels had top priority, with any change related to newly developed lands always being included in the final land cover change map. For agriculture classes, CDL was used to assist in post-classification refinement. For wetlands, ancillary data including NLCD 2006, SSURGO hydric soil, and NWI were combined to limit both commission and omission errors (e.g., a pixel classified initially



as an upland vegetation class was changed to a wetland class if all three ancillary datasets identified it as a wetland class). For major forest transition areas in the southeastern and northwestern U.S. regions, applying knowledge about forest disturbance, succession stage, and management practice patterns in conjunction with a spectral-ranking approach greatly improved the quality and consistency of land cover change labeling by preventing illogical land cover changes in the final product.

Urban Impervious Estimation

The approach for updating new impervious surface growth and intensification between 2006 and 2011 was similar to the method used to produce the 2006 NLCD impervious surface change product (Xian et al., 2011; Xian et al., 2012). This method employed the NLCD 2006 impervious surface product as the baseline estimate and Landsat imagery pairs in 2006 and 2011 as the primary data source for identifying changed areas. Ancillary data such as DMSP NSLS, slope, and elevation were also used to help develop regression tree models for predicting new percent impervious surface in changed areas. Three major steps were required for this process: (1) modeling an impervious surface, (2) comparison of model outputs, and (3) final product clean-up. In step 1, DMSP nighttime lights imagery in 2006 was superimposed on the NLCD 2006 impervious surface product to exclude low density impervious areas outside urban and suburban centers to ensure only urban core areas be used to provide a stable and reliable training dataset. Two training datasets, one having a relatively large urban extent and one having a relatively small extent, were produced through imposing two different thresholds, ≥ 10 and ≥ 20, of nighttime lights imagery on the 2006 impervious product. In step 2, each of the two training datasets combined with 2006 Landsat imagery was separately applied with regression tree algorithms to build up regression tree models (Xian and Homer, 2010). Two sets of regression tree models were created and used to produce two 2006 synthetic impervious surface products. Similarly, the same two training datasets were used with 2011 Landsat and DMSP NSLS images to create two sets of regression tree models and produce two 2011 synthetic impervious surface products to ensure that only stable predictions are chosen as intermediate products. In step 3 the two synthetic product pairs were then compared to remove false estimates due to strong reflectance from nonurban areas and to retain 2006 impervious values in the unchanged areas. The 2011 impervious surface was updated individually in every Landsat scene over the entire CONUS, with individual scene products subsequently mosaicked together to produce a seamless 2011 impervious surface product.

In addition to identifying new impervious features for 2011, the process was sensitive enough to capture many previously unidentified impervious areas from earlier periods. Identifying these areas as 2011 change would have inaccurately placed the change in the wrong period. To correct this, an intensive combination of hand editing and automated processes was applied to identify and sort potential additions into the proper NLCD period (2001, 2006, or 2011). This approach was dependent on extensive use of high-resolution imagery from each period to accurately identify and sort the additions. All other impervious features were also checked during this process, enabling overall accuracy to be improved. These special edits were focused on the eastern half of CONUS because this area had the most inaccuracies from earlier periods. The additional processing resulted in a much improved impervious product throughout all published years and a more consistent national product.

Tree Canopy Cover

The NLCD 2011 percent tree canopy cover was modeled using photographic interpretation of National Agriculture Imagery Program (NAIP) aerial imagery, Landsat 5 imagery (and derivatives), ancillary data such as elevation (and derivatives), and previous NLCD data (Fry et al., 2011). Approximately 65,000 sample locations were photo-interpreted for percent tree canopy cover using NAIP imagery. These data and corresponding Landsat and ancillary data were used to develop a random forest model (Brieman, 2001) for each NLCD mapping zone (Homer and Gallant, 2001). Two versions of the NLCD percent tree canopy cover were developed: an analytical version and cartographic version. The analytical version is intended to be used for estimating average tree canopy cover in an area of interest and includes both percent tree canopy predictions and uncertainty around those predictions (Coulston et al., 2014). The cartographic version is intended to be used more as a visual backdrop in cartographic applications. Masking procedures and other post-processing procedures were used to reduce commission error and smooth seamlines between mapping zones. The 2011 NLCD percent tree canopy cover differs from the

2001 version primarily in the target definition of trees. In the 2001 version trees were considered to be > 5 m tall, while in the 2011 version trees were based on life-form with no height restriction. The 2011 percent tree canopy product is not designed to be directly comparable to the 2001 version.

Post-Processing And Product Description

Because NLCD components are produced separately, reassembly of these components into a final product is necessary. This process is fairly complex because it not only consists of many independent data layers for 2011 but also incorporates the right version of previous periods. In order to ensure NLCD consistency and direct comparison capability across time, earlier periods of NLCD (2001 and 2006) are re-versioned with the 2011 release. This re-versioning corrects minor inconsistencies with previous periods that would impede direct comparison. This assembly process started with the impervious layers. The previous 2001 impervious layer was updated with the edited impervious areas. The updated impervious change from 2001 to 2006 was added to the full 2001 impervious layer to create a new 2006 impervious layer, and the process was repeated for the 2011 impervious layer. The three completed impervious layers (2001, 2006, and 2011) were categorized into the four corresponding developed land cover types for each period.

The land cover is also assembled starting with the original NLCD 2001 land cover layer. The land cover in NOAA coastal areas was updated to NOAA's current version in all corresponding years. The previous developed land cover classes in both NOAA and NLCD areas were removed and replaced with the updated imperviousness product pixels, creating the "2011" edition of the 2001 impervious layer. These developed pixels were then applied to the 2001 land cover throughout the United States. In order to maintain direct linkage to the imperviousness product, developed pixels were applied to the land cover without further editing or processing. A "smart-eliminate" aggregation algorithm with a minimum mapping unit (MMU) of five 30-m pixels was applied to all other land cover classes besides urban, with an MMU of 12 pixels applied to cropland and hay/pasture pixels to complete the "2011" edition of NLCD's 2001 land cover. The same process was applied to create the "2011" edition of NLCD's 2006 land cover. NLCD 2006 land cover change pixels and updated impervious change pixels were directly applied to the 2001 land cover, and a smart eliminate of a five-pixel MMU for all land cover classes other than urban was again run to complete the creation of the "2011" edition of NLCD's 2006 land cover.

Assembly of the final 2011 land cover change pixels was implemented as an ongoing process during production. As each path/row was completed, results were checked and finalized and then used on adjacent path/rows as training data to develop consistency between path/rows. Following the completion of this process, the 2011 impervious change was then applied to the completed 2011 land cover change pixels to produce the updated "2011" edition of 2006 land cover to create NLCD 2011. A final five pixel "smart eliminate" MMU was again run on the completed 2011 land cover except for the urban class to produce the final product. NLCD 2011 products are represented across nine files, with an additional five files re-versioned for NLCD 2006 and two additional files re-versioned for NLCD 2001 (Table 1).

Table 1. NLCD 2011 product list with approximate zipped file sizes. This includes previous editions of NLCD which were revised as "2011" versions.

All NLCD 2011 Products (For the Conterminous United States)	NLCD 2011	NLCD 2006 (2011 Edition)	NLCD 2001 (2011 Edition)	File Size (zipped)
Land Cover	X	X	X	1.1 GB
Percent Developed Impervious	X	X	X	713 MB
Percent Tree Canopy Cover – Analytical Version	X			10.4 GB
Percent Tree Canopy Cover – Cartographic Version	X			3.2 GB
Land Cover Change, 2006 – 2011 (pixels identified as changed between NLCD 2006 (2011 version) and NLCD 2011)	X			128 MB
*Land Cover Change, 2001 – 2011 (pixels identified as changed between NLCD 2001 (2011 version) and NLCD 2011)	X			74 MB
Land Cover Change, 2001 – 2006 (pixels identified as changed between NLCD 2001 (2011 version) and NLCD 2006 (2011 version)		X		13 MB
Percent Developed Impervious change, 2006–2011 (pixels identified as changed between NLCD 2006 (2011 version) impervious and NLCD 2011 impervious)	X			66 MB
Percent Developed Impervious change, 2001–2006 (pixels identified as changed between NLCD 2001 (2011 version) impervious and NLCD 2006 (2011 version) impervious)		X		8 MB
Land Cover Change Index, 2006 – 2011 (identifies "from" and "to" land cover class values for changed pixels based on a matrix of all possible change combinations)	X			1.4 GB
*Land Cover Change Index, 2001 – 2011 (identifies "from" and "to" land cover class values for changed pixels based on a matrix of all possible change combinations)	X			1.4 GB
Land Cover Change Index, 2001 – 2006 (identifies "from" and "to" land cover class values for changed pixels based on a matrix of all possible change combinations)		X		1.4 GB

* This layer contains less overall change than the sum of 2001-2006 and 2006-2011 products because land cover change can transition twice in 10 years for the same pixel. When this occurs, the latest change class is given.

Results

A total of 464 Landsat path/rows were analyzed across CONUS for land cover and impervious surface change between 2006 and 2011. Image acquisition dates ranged from 05/04/2004 to 10/02/2007 for nominal 2006 imagery and from 02/05/2009 to 11/10/2011 for nominal 2011 imagery. One additional image date was selected for circa 2011 to aid in the 2011 classification protocol, with dates ranging from 04/17/2009 to 11/11/2011. Analyzed change products from 2006–2011 were harmonized to ensure direct change comparison with previous NLCD 2001 and 2006 products, and these products (NLCD 2001 and 2006) were then re-released as the "2011" versions.

For the period 2006 to 2011, 98.23% and 1.77% of CONUS land cover were mapped as unchanged and changed, respectively (Table 2). The largest net losses occurred in the evergreen and deciduous forest classes, covering 20,547 km^2 and 10,491 km^2, respectively. The largest net gains occurred in the shrub/scrub and grassland/herbaceous classes at 17,657 km^2 and 10,005 km^2, respectively (Table 2, Figure 1).

Similar rates of no change (98.37%) and change (1.63%) occurred during the 2001 to 2006 period (Table 2). The largest net losses again occurred in the evergreen (19,905 km^2) and deciduous forest (5,590 km^2) classes, and the largest net gains occurred in the shrub/scrub 13,495 km^2) and grassland/herbaceous (11,655 km^2) classes. The overall change rate for the cumulative period 2001 to 2011 was 2.96% (Table 2, Figure 1).

The total land extent of urban impervious surface for CONUS expanded from 6.04% of the total CONUS area in 2001 to 6.2% in 2006 and 6.34% in 2011. For the period 2001–2006, 7.62% of this impervious surface extent increased in density (changed from a lower impervious value to a higher value), with 4.92% of the impervious extent increased in density during 2006–2011 (Figure 2).

Table 2. Net land cover gains and losses by land cover class across CONUS for the periods 2001–2006, 2006–2011, and 2001–2011 in square kilometers (km2). Net and percentage change for each 5-year time period do not directly add up to the 10-year net change numbers because some land cover categories change more than once during a 10-year period. Numbers in parenthesis represent the numeric name of the class.

	2001 to 2006 Net Gain/ Loss (km²)	2006 to 2011 Net Gain/ Loss (km²)	2001 to 2011 Net Gain/ Loss (km²)
Open Water (11)	-2,268	3,941	1,673
Perennial Ice/Snow (12)	0	0	0
Developed-Open Space (21)	2,563	821	3,383
Developed-Low Intensity (22)	2,689	1,748	4,437
Developed-Medium Intensity (23)	5,441	3,609	9,049
Developed-High Intensity (24)	1,975	1,453	3,427
Barren Land (31)	2,141	567	2,708
Deciduous Forest (41)	-5,590	-10,491	-16,082
Evergreen Forest (42)	-19,905	-20,547	-40,452
Mixed Forest (43)	-4,642	-5,455	-10,097
Shrub/Scrub (52)	13,495	17,657	31,153
Grassland/Herbaceous (71)	11,655	10,005	21,660
Pasture/Hay (81)	-6,356	-3,354	-9,710
Cultivated Crops (82)	-2,312	696	-1,616
Woody Wetlands (90)	-447	-2,608	-3,054
Herbaceous Wetlands (95)	1,562	1,959	3,521
TOTAL	**83,039**	**84,912**	**162,024**
Percent of U.S. that changed	**1.63%**	**1.77%**	**2.96%**

Discussion

NLCD data have remained relevant by sustaining continuous product improvement through ongoing research and development (Homer et al., 2004; Xian et al., 2009; Xian et al., 2010; Jin et al., 2013; Wickham et al.. 2014) and by providing users with products that are regionally and nationally consistent across space and time. Products are also frequently updated (Homer et al., 2007; Fry et al., 2011) and regularly validated (Stehman et al., 2003; Wickham et al., 2010; Wickham et al., 2013). The updated methods employed for NLCD 2011 production resulted in products that include more comprehensive land cover change detection, less commission error, and a reduced production time.

With the release of NLCD 2011, NLCD now provides a decade of land cover change for CONUS over three time periods. A fundamental concept of geodesy is that Earth surface measurements need to be updated routinely because the forces that shape the Earth's surface are constantly changing (Torge, 2001). The same is true for land cover (Wickham et al., 2014), and understanding the spatiotemporal patterns, causes, and consequences of land cover change is now considered a scientific discipline that requires routine measurement (Gutman et al., 2012; Turner et al., 2007). For CONUS, NLCD has shown that 1) change was relatively constant over the two five-year intervals that comprise the 10-year observation period; 2) there has been an non-uniform spatial pattern of change, with change concentrated in the southeastern United States and localized sections of the Pacific Northwest and Northeast (Figure 3); and 3) forests have experienced the highest net losses (-66,631 km^2) through conversion largely to shrub/scrub and grassland/herbaceous (+52,813 km^2), a pattern documented in previous decades (Sleeter et al., 2013).

NLCD 2011 impervious surface products document the continued expansion of the urban footprint extent over the 10-year period and suggest that the rate of urban expansion was not constant over the two five-year intervals. Urban impervious extent increased from 6.04% of the CONUS surface area in 2001 to 6.2% in 2006, but this nearly 0.2% increase declined to approximately 0.1% between 2006 and

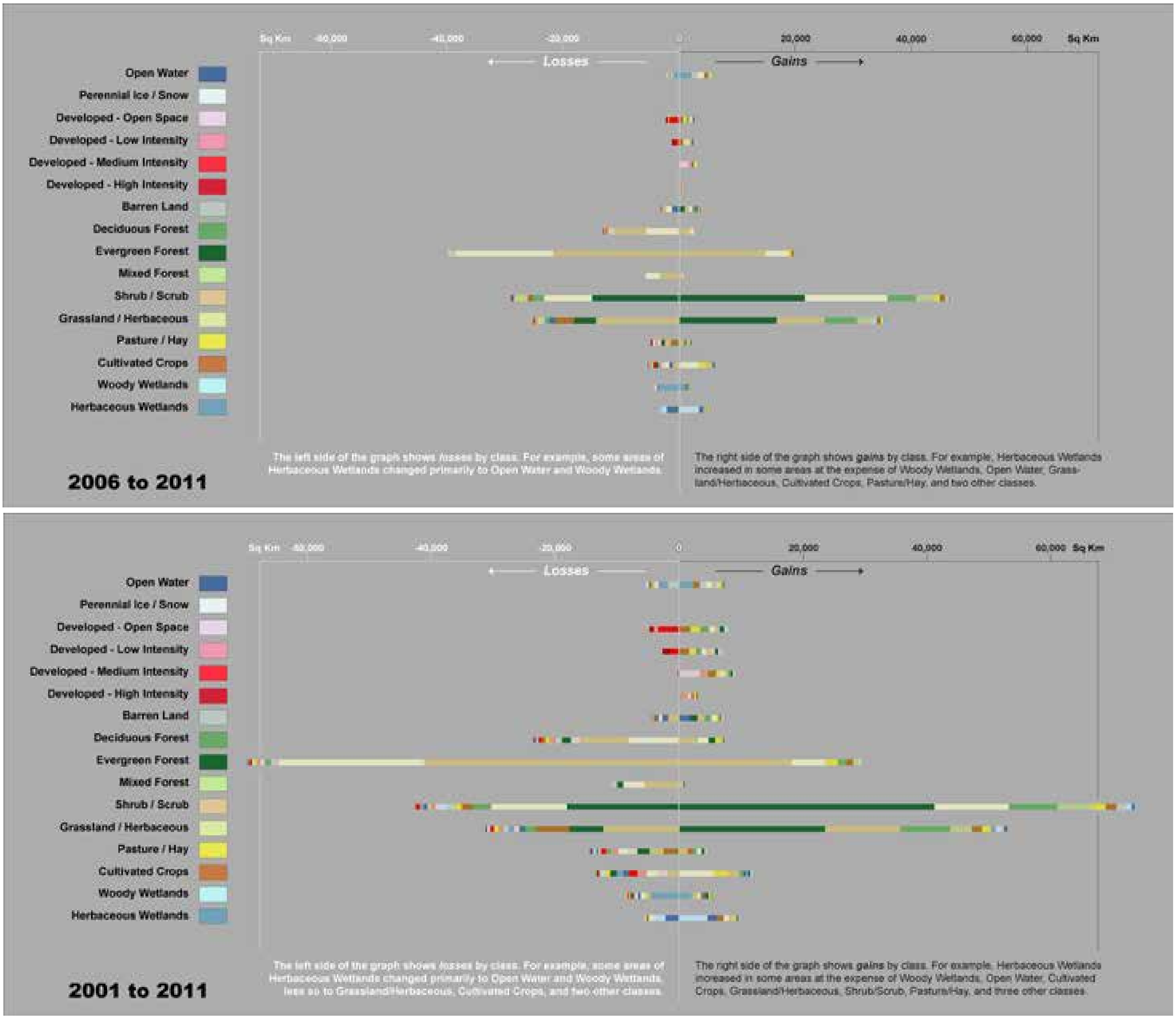


Figure 1 (above). Source and magnitude of land cover class gain and loss for each NLCD land cover class for 2006–2011 and 2001–2011. The length of the bars represents the percent change relative to the total change area with the equivalent area in square kilometers annotated at the end of each bar. Proportions of each bar are colored by the proportional contribution from each land cover class to the total loss or gain. The left side of the chart (white numbers) represents class loss magnitudes and presents which classes a class loss was converted "to" in 2006 or 2011, while the right side of the chart (black numbers) represents class gain magnitudes and presents which classes a class gain was converted "from" in 2001 or 2006.

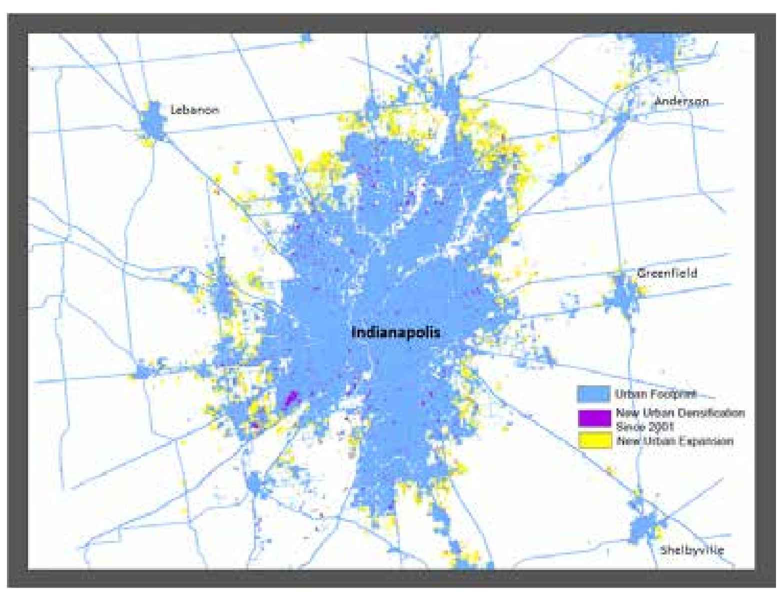


Figure 2 (right). Growth of urban impervious surface for Indianapolis, Indiana, between 2001 and 2011 from the National Land Cover Database. Blue represents the total urban footprint for the city, purple areas show where urban impervious surface increased in density over 10 years, and yellow areas represent expansion of the urban impervious extent into previously nonurban areas over 10 years.

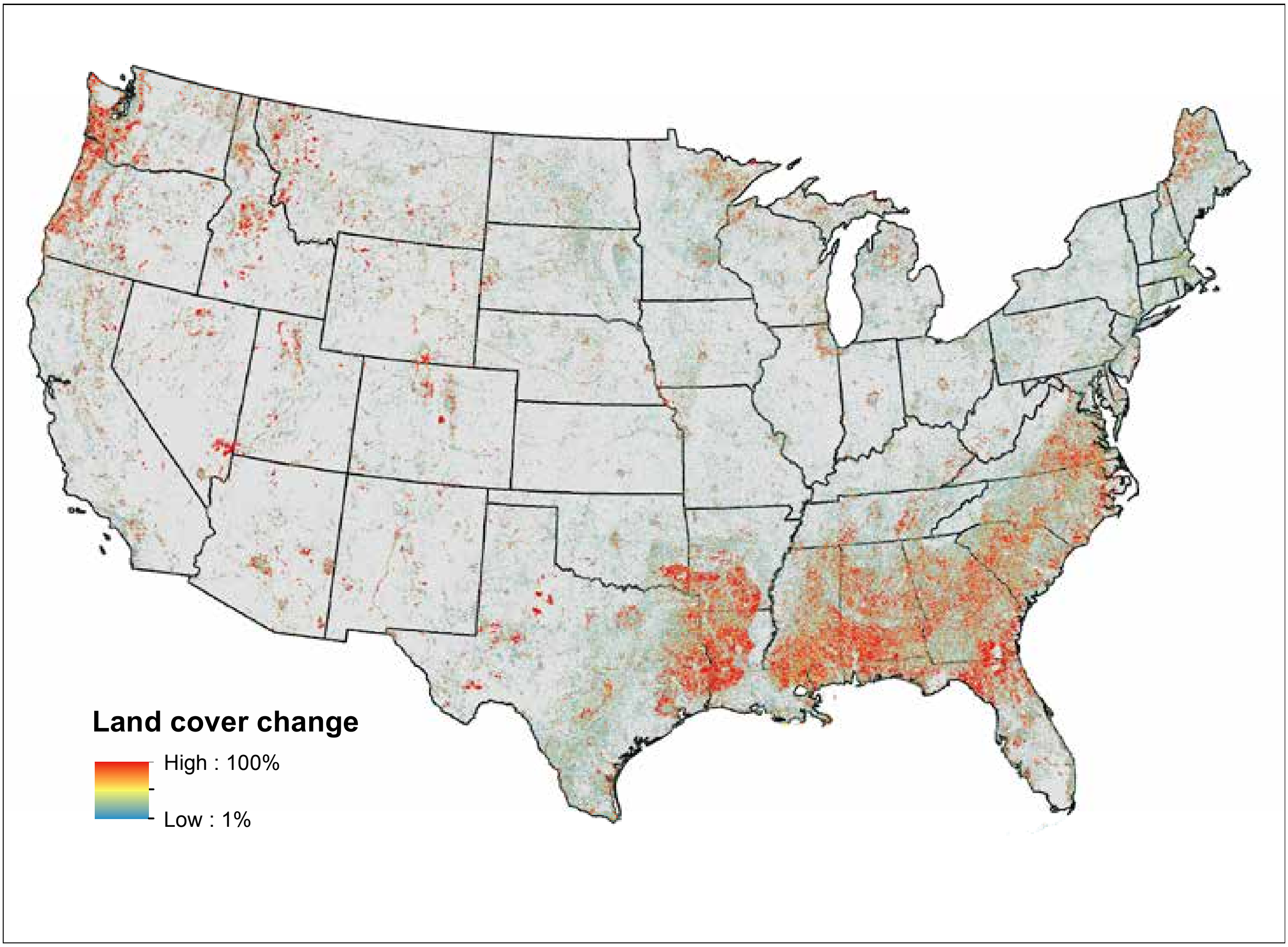


Figure 3. The geospatial distribution and magnitude of land cover change in the conterminous United States between 2001 and 2011 in 1% intervals. Change was calculated as the proportion of 30 m change pixels in a 1 km x 1 km grid. White areas represent places with no land cover change, green tones represent areas with low proportions of land cover change, and red tones areas of high proportional change. Primary land cover change drivers appear to be wildland fire, forest harvesting, urbanization, agricultural conversion, and forest disease.

2011 (Figure 2). This slower expansion of urban growth is also reflected in the densification change rates of the imperviousness classes within the urban footprint—only 4.99% of all impervious pixels increased in density from 2006 to 2011, in contrast to 7.62% of pixels increased in density from 2001 to 2006. The reduction of urban growth from 2001–2006 to 2006–2011 may be partly attributable to the U.S. recession that began in 2008. Although urban growth was expanding, many newly developed areas retained (or established) tree canopy cover. In an example of how the NLCD tree canopy cover product can complement analysis, this product reveals new urban areas converted to the NLCD land cover open space developed class between 2006 and 2011 had an average tree canopy of 22.8%. Similarly, new areas of the low intensity urban class had an average percent tree canopy cover of 14.6% and new areas of the medium intensity urban class had an average of 9.9%.

A formal accuracy assessment of the NLCD 2011 land cover change product is currently underway, with interpretation of sample points expected to be completed early in 2015. Accuracy protocols will analyze the decade of change information from all three NLCD periods and will build on past methods developed for NLCD 1992 and NLCD 2001 (Stehman et al., 2003; Wickham et al., 2010; Wickham et al., 2013) and will depend on independent analysis of high-resolution reference data sources representing the historical date of the products.

NLCD 2011 for Alaska is also now available and includes statewide products of land cover and impervious surface, as well as land cover and impervious surface change between 2001 and 2011. A 2011 version of the tree canopy cover product will soon be available for southeast Alaska. NLCD 2011 land cover products for Hawaii and Puerto Rico will be available later in 2015. The next generation of NLCD is under current research and development and will be produced in 2016. Next generation research to improve accuracy, produce additional periods of NLCD back to the mid-1980s and add additional products will all be considered for the NLCD 2016 product suite.

Acknowledgments

Research, development, and production efforts for NLCD 2011 data products and supplementary layers result from the cooperative efforts of several teams of dedicated individuals. Because of the number of individuals involved, they cannot all be properly acknowledged here. We would like to acknowledge the many organizations that made this work possible especially the support of the individuals and agencies of the MRLC Consortium, in addition to Federal and Federal contractor mapping teams. This study was made possible in part by SGT under U.S. Geological Survey contract G10PC00044 and by ASRC under U.S. Geological Survey contract G08PC91508. The United States Environmental Protection Agency (US EPA), through its Office of Research and Development, partly funded the research described here. It has been subject to Agency review and approved for publication. Any use of trade, firm, or product names is for descriptive purposes only and does not imply endorsement by the U.S. Government.

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THIERRY GREGORIUS

INTERVIEW

Thierry Gregorius is the Principal Strategic Consultant at Exprodat. The interview below was taken from his personal blog, Georeferenced — A blog on all things Geo, Data, Web.

Geospatial careers: 12 things I've learned... so far

Make up your mind: Geospatial vs X

The geospatial profession cuts across many disciplines, so you first need to decide what your professional identity is. If you are committed to a geospatial career you are basically making a choice not to be a geographer, geoscientist, engineer, computer scientist, urban planner or whatever else you might be mistaken for. If you want to be one of those things, go study their subjects and enter their professions proper – it's much harder to get there via the geospatial route. Of course you can also be a bit of both, and such a combination is highly valuable. But the career of a geologist who has GIS skills will probably look very different to the career of a GIS professional who also knows about geology. In fact, as a geospatial professional you need to know about many other things too, being both a generalist and a specialist. You'll work with many disciplines, providing input and joining things up. So you need to be clear: Are you a geospatial professional, or a professional in another field who also has some geospatial knowledge? The difference can be huge.

Build a technical foundation early in your career

Geospatial is a technical profession. Whether you want to be a guru analyst, champion account manager or visionary CEO, in the geospatial domain you will have little success and credibility without a solid grounding in its technical aspects. So resist the temptation of going into managerial or commercial positions too soon. Clients can spot bullshitters a mile off, and so can your staff (but they may be cruel enough not to tell you). Get as much work under your belt as possible, looking for a diverse range of technical responsibilities. It may not pay big bucks now but it's a long-term career investment that will pay dividends later. Besides, once you reach that coveted leadership position you may well find all that glitters is not gold. Doing stuff is often more satisfying than talking about stuff. But, just like teenagers wanting to be adults and adults wanting to be young, you may only learn this the hard way.

Build a unique skillset

You can't be all things to all people. This is especially true in the geospatial domain where many 'geospatial' skills overlap with those of other disciplines. If you dilute yourself too much as a geospatial professional you'll end up becoming the Swiss army knife that people only use when there's nothing better to hand. Also, it's not enough to be good at "programming" or "making maps". These days, any five-year old can do that. Ask yourself, what is unique to you? Where can you make a difference? This could initially be a single skill (say, geoprocessing for environmental workflows), later growing to become a unique combination of skills. The list is potentially endless, hence the need to focus.

Focus

The geospatial arena is very broad and cuts across all industries, so it's very easy to go off in different directions. This brings with it a lot of opportunities – and distractions. Make conscious choices at every step. Ask yourself: What skills am I learning to apply here? What goal will this help me achieve? What development gaps am I plugging? Don't just fall into things unless serendipity is your chosen life philosophy.

Depth vs breadth

As in all technical professions you will, at some point, face an important decision between depth or breadth. Do you want to become a technical guru, or go after a more general role such as project management, sales or leadership? In some scenarios you may be able to hang on to both but that's tough – just ask any geospatial entrepreneur or freelancer. Again, this requires conscious choices. Remember, after you've left the technical track for a while it can be hard to get back on it.

Learn 'the business'

This may sound contradictory to some points above but OK, life is full of contradictions. It's not enough to have geospatial knowledge, you also need to understand the industry vertical in which you are applying it. Your data analysis skills may be legendary but if you don't understand what your clients do for a living and the specific issues they face, you'll only scratch the surface with generic solutions and get nowhere. Google for example has the best map in the world but they have learned to leave market verticals alone – it's a different kind of expertise, and that is where you come in.

Embrace the full geospatial lifecycle

The geospatial data lifecycle is long and varied, and people often get sucked into a particular area such as data management, IT development, or surveying – and end up staying there. Whatever you do, though, make sure you gain exposure to the full lifecycle, not just your immediate area of expertise. Understanding how data flows from data capture to manipulation, analysis and visualisation is critical. So from GPS to geostats, from GIS to JavaScript, stay up-to-date and try to gain knowledge across the board, even if all you can do is learn the basics. Also acquaint yourself with the softer aspects of data including legal, commercial and policy considerations. Whatever your role, you cannot afford to ignore these things.

Go out into the field

Field experience will immensely boost your geospatial understanding and professional credibility. Let's face it, you can't solve the world's problems from behind a computer. Get out there and see for yourself what the real issues are. I started off my career as a surveyor and geodesist, but soon ended up in the office doing 'GIS' for a big oil company. When, years later, I finally got the opportunity to spend a couple of weeks with seismic survey crews in the Libyan desert, it blew my mind. The sights, the smells, the sounds – it all made sense. And it made me have slight regrets of not having done it sooner, and for a longer period of time. If you ever get the slightest chance to take on a field-based role overseas or closer to home, grab it with both hands while you can. The office can wait.

Travel and keep moving

In my opinion travel is still the best way of finding inspiration and learning. If you can somehow combine this with your career, even better. As a young student in Luxembourg and Germany I suddenly saw my whole life flash in front of me, and embarked on a drastic change. I took out a big bank loan and enrolled at a renowned university in Sydney, Australia to continue my geospatial studies there. It was the best investment I ever made, and a turning point in my life that completely changed everything that followed. If you can't travel or relocate physically, at least consider 'travelling' between different industries or working for different-sized organisations – you'll be come a more rounded professional as a result. Just make sure your CV does not end up looking like you're suffering from chronically itchy feet. Don't move on until your learning curve goes flat, and remember that many organisations can offer new roles and challenges internally.

Never stop learning, and look beyond geospatial

In my book, status quo equals decline. You can never afford to rest on your laurels, especially not with the rate of technological change we're seeing. Having said that, don't waste your time following hysterical technology blogs that proclaim "the next big thing" every 5 minutes. Unless you're the next Steve Jobs you're much better off investing your time in learning how to exploit the latest trends for your own needs. Also, find out what you can learn from other, unrelated fields. To me learning is not about collecting badges, diplomas or even CPD points. Learning happens everywhere – you just need to know what to look for. You may learn something in an art museum that you can apply to your cartography. You may learn something from your kids' Lego set that you can use in your geoprocessing workflow. You may learn something from a philosophy book that you can incorporate into your leadership style or negotiation strategy. And most importantly, you can learn a lot from other people.

Learning from people

With all their strengths and imperfections, every boss I ever had taught me something valuable. When I was on placement as a grad student, the chief surveyor showed me the value of delegation by taking a risk and trusting me to do a full building site survey on my own. Another one taught me how to run a team and develop people. And so on. But don't just look to bosses as role models. You can learn something from literally anybody: colleagues, friends, family, children, random encounters. Mentors are obviously useful too, but don't overlook the opportunities that day-to-day interactions bring. Nobody knows everything, but you can piece together a lot by talking to different people and collecting different viewpoints (and in return share with them what you think). Learning from mistakes can also be powerful, but again don't just blindly follow the mantras from fashionable business or technology blogs ("fail fast" etc.). A product flop may well hold useful lessons but some things, like building bridges or positioning oil rigs, are best not done by trial and error. Be open minded, but don't switch off your critical functions.

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Grids & Datums

BY Clifford J. Mugnier, CP, CMS

Datum Origins with Google Earth™

A couple summers ago I decided to see what I could find by keying in the coordinates of various classical datum origins throughout the world. To my surprise, there are quite a number of datum origins that are readily identifiable through archived imagery. I used Google Earth™ software, and the following observations are offered as a sample for those interested in looking these up as well as others. Please note that the maximum difference between various classical datums and the WGS84 datum is usually an East-West displacement due to the past difficulties in maintaining accurate time based on international standards such as Washington, D.C., Paris, Greenwich, Berlin, etc., from long ago. The fact that Google™ uses a spherical approximation to the WGS84 ellipsoid also produces some positional errors, but primarily in the North-South component.

Córrego Alegre is the origin for the primary mapping datum of Brazil, Φ_o = 19º 50´ 15.14˝ S, Λ_o = 48º 57´ 42.75˝ W, referenced to the International 1924 ellipsoid. Since this is a middle 20th century classical datum established with relatively recent technology, the chronometers used were probably calibrated with radio time signals. As a result, there's very little East-West systematic error between the classical coordinates and what is geo-referenced with Google Earth ™. Also see: *(Sampaio, A.C.F., Sampaio, A.d. A. M., Datum Córrego Alegre: o estado da arte de sua existência ou não, **Brazilian Journal of Cartography**, ISSN 1808-0936, 10 pages).*

Carthage is the origin for the Tunesian 1925 datum, Φ_o = 36º 51´ 06.5˝ N, Λ_o = 10º 19´ 20.64˝ E, referenced to the Clarke 1880 ellipsoid. The East-West displacement is minor, perhaps 30 meters, but the North-South displacement is several hundred meters South. Although for decades I knew "Carthage" was the name of the datum origin, it was not until I used Google Earth™ that I realized that it was the name of a cathedral. Furthermore, there is a difference in ellipsoid parameters; the local datum is well known to have some whopping systematic errors from old colonial surveys. Army Map Service contracted with the French Institut Géographique National in the 1950s to model some of these errors, and the non-linearity of the region is legend.

Mirador Tower is the origin for the Belvedere Datum of Vietnam, Φ_o = 21º 01´ 58.5˝N, Λ_o = 105º 50´ 05.95˝E, referenced to the Clarke 1880 ellipsoid. Established by the French back in colonial days, the latitude component (in spite of different ellipsoid parameters) is nearly in perfect agreement with Google Earth™ geo-referencing to a spherical WGS84 "datum," but the East-West displacement puts the Hanoi Flag Tower (Mirador Tower) about a kilometer to the East of the map tack.

The **Aya Sofia Mosque** is the origin for the Balikesir 1934 datum of Turkey, Φ_o = 41º 00´ 30.0709˝N, Λ_o = 28º 58´ 52.7237˝ E, referenced to the International 1924 ellipsoid. Latitude appears about 10 meters off (different ellipsoid parameters), and longitude about 30 meters too far East from the finial of the dome. Although the old grid coordinate system of Turkey is well known to use the Aya Sofia Mosque as an origin point, it is curious that the datum name corresponds to a province quite a distance from Istanbul.

Johnston Memorial Cairn is the origin for the Australian Geodetic datum of 1966, Φ_o = 25º 56´ 54.5515˝ S, Λ_o = 133º 12´ 30.0771˝ E, referenced to the Australian National ellipsoid. There is close correspondence in longitude that is not surprising for 1966, but there's a large disparity in the North-South component (too far south) likely due to the difference in the ellipsoid parameters and meridian distance from the equator. This also marks the spot in the geographic center of Australia.

Bogotá Observatory 1935 is the origin of the Bogotá 1941 datum, Φ_o = 04º 35´ 56.57˝N, Λ_o = 74º 04´ 51.30˝W, referenced to the International 1924 ellipsoid. There is a large circular bare spot in the grass about 50 meters to the southeast from the old coordinates located by the Google Earth™ map tack; perhaps that is where the old observatory used to be located on the top of the hilltop park.

Kandawala is the origin of the Ceylon 1929 datum, Φ_o = 07º 14´ 06.838˝ N, Λ_o = 79º 52´ 36.670˝ E, referenced to the Everest 1830 ellipsoid. The Trigonometrical station is a concrete tower located at the intersection of a North-South road just to the East of the Google Earth™ map tack, and there is very little latitude displacement in spite of the considerably different ellipsoid parameters. There is a ground level image of the tower!

Kandilli Observatory is the origin of the Kandilli datum of Istanbul, Φ_o = 41º 03´ 48.899˝ N, Λ_o = 29º 03´ 55.2˝ E, referenced to the Bessel 1841 ellipsoid. The observatory is located in the forest and on the hill to the west of the map tack location of Google Earth™, and a short distance to the west of the Geodesy Department building.

Helmertturm *(Helmert tower)* in Pottsdam, Germany is the origin of the European Datum of 1950, $\Phi_o = 52^o\ 22'\ 51.4456''$N, $\Lambda_o = 13^o\ 03'\ 58.9283''$ E, referenced to the International 1924 ellipsoid. The tower is located to the southwest of the map tack, and several ground level photographs are associated with its location.

Gellért-Hegy is the origin of Gellért-Hegy 1874 datum and Gellért-Hegy 1908 datum, $\Phi_o = 47^o\ 29'\ 09.6380''$ N, $\Lambda_o = 19^o\ 03'\ 07.5533''$ E, referenced to the Bessel 1841 ellipsoid. The citadel is located to the northwest of the map tack, and is on the top of Gellért Hill overlooking the Danube River in Budapest, Hungary. The citadel is large and the exact spot used for the astronomic position is not obvious.

Quito Observatory is the origin of the Ecuador 1928 datum, $\Phi_o = 00^o\ 12'\ 47.313''$S, $\Lambda_o = 78^o\ 30'\ 10.331''$W, referenced to the International 1924 ellipsoid. Located about 30 meters East and perhaps 150 meters South of the map tack, the observatory appears to still have a conical corrugated metal roof that existed back in the late 1980s in the old city park.

Madrid Observatory is the origin of the Madrid 1853 datum, $\Phi_o = 40^o\ 24'\ 29.7''$ N, $\Lambda_o = 03^o\ 41'\ 14.546''$ W, referenced to the Struve 1860 ellipsoid. The map tack is on the observatory grounds, apparently slightly to the southeast of an observatory building, but there are numerous observatory domes also on the site so which one is the precise dome location is not obvious.

DCS 3 Lighthouse 1955 is the origin for St. Lucia 1955 datum, $\Phi_o = 13^o\ 42'\ 35''$N, $\Lambda_o = 60^o\ 56'\ 37''$W, referenced to the Clarke 1880 ellipsoid. The map tack is located to the South of the lighthouse.

291 Vrcevo is the origin for Vrcevo 1906 datum in Croatia, $\Phi_o = 49^o\ 01'\ 57.834''$ N, $\Lambda_o = 15^o\ 23'\ 40.224''$ E, referenced to the Bessel 1841 ellipsoid. The map tack agrees for latitude; the actual point on the hill top is to the west and has ground level images of the ruins.

Observatorul Astronomic Militar Parcul Tineretului is the origin for New Romanian 1930 datum, $\Phi_o = 44^o\ 24'\ 34.20''$ N, $\Lambda_o = 26^o\ 06'\ 44.98''$ E, referenced to the Bessel 1841 ellipsoid. The old published coordinates place the map tack too far North, and the observatory is actually just East of the double-span bridge in the park. A ground level image shows the observatory. The location differs by some 12 seconds in latitude and 7 seconds in longitude; excessive for a brick-and-mortar observatory and likely more of an error in geo-referencing.

Frauenkirche (North Church Tower), Munich is the origin for the Old Bavarian datum of Germany, $\Phi_o = 48^o\ 08'\ 20.000''$ N, $\Lambda_o = 11^o\ 34'\ 26.483''$ E, referenced to the Bessel 1841 ellipsoid. The old coordinates place the map tack at the Eastern end of the church, latitude being apparently perfect, longitude just perhaps 10 meters off; quite a coincidence.

The National Geospatial-Imagery Agency (NGA) publishes a free software package called GeoTrans that allows one to transform from geodetic coordinates to geocentric coordinates. If one use GeoTrans to convert classical geodetic coordinates of datum origins such as those enumerated above with the appropriate ellipsoid and then does the same with the Google Earth™ coordinates of the actual photo-identifiable point using the WGS84 ellipsoid, … the difference in the geocentric coordinates will serve as a "pretty good" approximation of the datum shift from native datum to the WGS84 datum; at least in the vicinity of the classical datum origin.

Professional Insight
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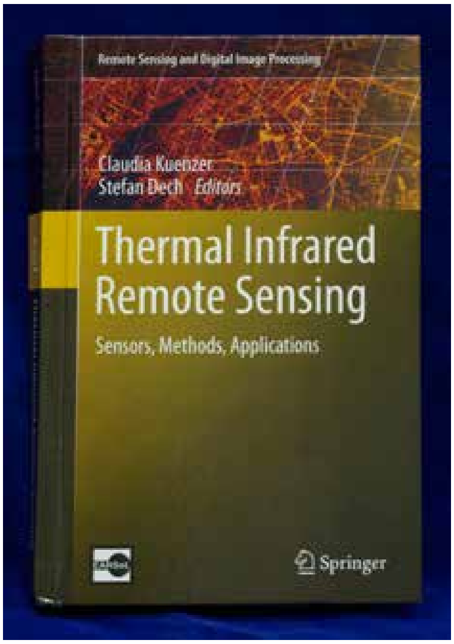
12. It's not about the career, stupid

Finally, let's take a step back and consider this for a moment. We live on a small planet orbiting a star, going round and round in circles. Sooner or later this star will explode in a massive supernova. Whatever you believe in, you were probably not put on this planet to file papers, collect badges, or clock endless miles on a hamster wheel (besides, the Earth's orbit is doing that for you already). So whatever you do, you should do it because you love doing it – not because it has better career prospects in some distant, uncertain future. Career development can take on many shapes and forms (upwards, sideways, deeper, broader) – and then one day the Sun will blow up and destroy everything you ever worked for. You'll never regain the time wasted doing something you didn't enjoy. A career is basically a journey where, one day, you can look back and say, that was fun! Nothing more.

So actually, forget everything I said. Go your own way. Good luck!

For more information on Thierry Gregorius, visit his personal blog, Georeferenced— A blog on all things Data, Geo, Web. Lighthearted and occasionally off-piste, https://georeferenced.wordpress.com/



Thermal Infrared Remote Sensing: Sensors, Methods, Applications

Claudia Kuenzer and Stefan Dech, editors

Springer: 2013. 537 p., 235 illus., 162 illus. in color. $139.00 (eBook, ISBN 978-94-007-6639-6), $179 (Hardcover, ISBN 978-94-007-6638-9).

Reviewed by Doug Rickman, Applied Science Team Lead, Earth Science Office, Marshall Space Flight Center, National Aeronautics and Space Administration.

This book delivers exactly what the title promises. The editors of this book are to be congratulated for an excellent job, as are the publisher and the authors.

What is first apparent is the physical characteristics of book beginning with the clean cover design and quality binding. The paper is esthetically pleasing, acid-free, high whiteness, and glossy. Therefore, the text, equations, and illustrations, especially the abundant color images, are easy to read. The indexing is reasonably thorough. The only deficit, the lack of an editor's preface, could usefully have explained to readers their intent for the book.

Instead, the editors provide an introductory chapter in which they review the basic physics of thermal-wavelength, electromagnetic radiation and introduce several broad topical categories more or less related to subsequent chapters. Your reviewer, who was hired by NASA to work with the future TIMS instrument, has frequently observed that individuals who are not accustomed to working with thermal imagery, frequently slip into thought processes related to remote sensing of reflected energies. Instantaneously, thermal remote sensing is working with two independent properties, the temperature and emissivity of a surface. The former is extrinsic and the latter is intrinsic. This compares to the single intrinsic property, reflectance, used in visible and near-IR remote sensing. Critically, the intrinsic property, emissivity, is essentially independent of environmental variables. This is in marked contrast to reflected spectra, which integrate both the desired intrinsic property and the spectral variation of the illumination. In thermal imagery, the extrinsic variable, temperature, does integrate a substantial number of variables. There are multiple processes for heat gain and loss, and there is also storage and conductivity to consider. For example, heating gains may come from the Sun, vegetation fires, burning coal seams, or geothermal energy. Heat losses may occur through radiation to the sky, evaporation, conduction, or mass transfers. Some of the mechanisms implied in the processes are temporally variable on multiple scales. The obvious example is solar radiation, which varies hourly, daily and seasonally. The processes also vary spatially. Slope and aspect affect illumination. Geology and soils affect conductivity and capacity. The physics provided in chapter 1 definitely helps to set the right conceptual framework, and is likely quite sufficient for many users of the text.

In their introductory chapter and throughout the rest of the text, the editors provide an accurate chapter abstract. Sections and subsections of each chapter are numbered, so following the development of a chapter is easy. With few exceptions, the figures and their contained text are easily legible. In part this is due to the use of high quality paper, but it is also something the editors almost certainly had to demand from some of the authors. Each chapter includes a robust list of references. Significantly, the intellectual content of a chapter is substantially original, rather than modest reworking of published papers, and delivers on what the chapter title suggests. Further, the writing style, which is lucid, and the assumed target audience have both been made consistent across the chapters. I found nothing that I considered opaque or overly simplified. Much of this clearly is to the editors' credit.

Chapters 2, 3, 13 and 25 deal with calibration, spectroscopy, and correction of thermal data. Chapters 5, 6, 8, and 9 deal with sensors. Chapters 4 and 7 deal with platforms. Chapters 10, 11, 12 and 14 discuss data analysis and cross platform comparisons. Together, these fill half of the book. All are topics that often get short shrift, if they get any attention at all, but are very important in practical applications. In this text there is considerably more information on these topics than your reviewer has previously seen in one place. Their

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GIS IN THE ROCKIES — "TODAYS VISION TOMORROWS REALITY" RETURNS TO THE CABLE CENTER IN DENVER

Join us September 23 & 24 in Denver, Colorado for the 28th Annual GIS in the Rockies Conference—the Intermountain West's premier geospatial information and technology conference.

We are pleased to welcome as our keynote speaker Steve Coast, founder of OpenStreetMap - a user created map of the world emphasizing local knowledge. Steve also created the State of the Map conference, co-founded CloudMade, kicked off mapstraction and works at Telenav.

Tracks are being organized by GIS Colorado, ASPRS, Rocky Mountain URISA, and PLSC. Other tracks include GIS in Education, GIS in Government, and Open Source (FOSS4G). Aside from sessions, the opening and closing keynotes, and discussion panels, the conference also features an evening social, vendor showcase, student breakfast, job fair, and more. A preliminary schedule for 2015 is now available at http://www.gisintherockies.org/2015/.

Discounted early registration is available for $250 - a $75 savings - until May 31st!

For more information, visit http://www.gisintherockies.org/2015/.

Book Review

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content and presentation should make them useful both to an applications practitioner and students learning about thermal remote sensing. Many of the illustrations in these chapters are excellent.

The other half of the book illustrates applications of remote sensing using thermal wavelengths. In each chapter, where necessary for understanding, the authors have included enough additional physics to set the context for their particular topic. Where an equation is really needed, it is given in a form that is visually easy to read and is well explained. Illustrations are placed with the topical text, and are sized adequately to be read without strain. The authors of each chapter are clearly knowledgeable on their topic.

Thermal remote sensing may be used in a surprising range of applications. This text explores much of this range. There are chapters on sea surface temperature, soil moisture, vegetation fires, lava flows, volcanic heat patterns, coal fires, hot springs and geothermal areas, urban fabric, and mapping of surficial mineralogy. Topics such as vegetation or agricultural productivity, ecological thermodynamics, atmospheric and weather processes, or lithologic mapping are not addressed. But to cover a meaningful number of additional applications for thermal remote sensing would have required a substantially larger book. The applications selected are adequate to sketch out the scope of the canvas. However, in a revised edition of the book the authors should consider at least enumerating additional applications of the technology with a citation or two. This would serve to put the reader on notice that there is far more out there.

One final observation is pertinent. The editors have chosen authors from a broad range of institutions and backgrounds. This is seen in the international scope of the contributors. The 61 authors are truly international. According to their institutional affiliations there are 11 nations, with no single nation dominating: 16 - Germany, 16 - U.S., 9 - Italy, 6 - United Kingdom, 5 - China, 3 – Spain, 2 – France, 2 – Netherlands, 1 each from Brazil, Austria and Canada. This is not a statistic lacking in meaning. Rather, it illustrates the breadth and diversity of the field; and, it reflects the distinctly different interests for which thermal remote sensing is used.

Thermal Infrared Remote Sensing: Sensors, Methods, Applications is a book I am personally recommending to my colleagues and collaborators, many of whom have worked intensively in the field for three decades. It is also within reach of undergraduates and distinctly useful for graduate students.

NEW SUSTAINING MEMBERS

ASPRS is proud to welcome the following new sustaining members. More information on becoming a Sustaining Member is available at http://www.asprs.org/Join-Now/Corporate-Sustaining-Membership.html

Hexagon Geospatial

5051 Peachtree Corners Circle, Suite 250
Norcross, GA 30092 USA
(720) 381-5654, www.hexagongeospatial.com

Hexagon Geospatial is a part of Intergraph® Corporation. Intergraph Corporation is part of Hexagon, a leading global provider of information technologies that drive quality and productivity improvements across geospatial and industrial enterprise applications. Hexagon's solutions integrate sensors, software, domain knowledge and customer workflows into intelligent information ecosystems that deliver actionable information, automate business processes and improve productivity. They are used in a broad range of vital industries. Hexagon (Nasdaq Stockholm: HEXA B) has more than 15,000 employees in 46 countries and net sales of approximately 3.1bn USD. Learn more at hexagon.com.

SIIS (SI Imaging Services)

441, Expo-ro, Yuseong-gu, Daejeon, 305-714, Republic of Korea
+82-42-341-0401, +82-70-7882-6105 (fax)
www.si-imaging.com, sales@si-imaging.com

SI Imaging Services (SIIS) was founded in April 2014 as a subsidiary of Satrec Initiative (SI) with the mission of "Fair Access to Space". SIIS, which is specialized company in satellite imaging services, is exclusive distributor of KOMPSAT-2 (1.0 m optical), KOMPSAT-3 (0.7 m optical), and KOMPSAT-5 (1.0 m SAR) satellites imagery and also distributes DubaiSat-2 (1.0 m optical) imagery worldwide. SIIS has established the global business network with more than 60 resellers and partners. In the capability of providing both optical and radar imagery as well as the collaborative business with worldwide network, SIIS offers better and fair imaging services to customers.

ASPRS MEMBERSHIP

ASPRS would like to welcome the following new members!

At Large
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Martin Quarshie Semadegbe

Central New York
Tina M. Dorofy
David Nilosek

Eastern Great Lakes
Steven M. Richardson, Jr.
Ryan Smith

Florida
Samira Daneshgar Asl
Roshan Pande-Chhetri, Ph.D.
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Mid-South
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North Atlantic
Ronen Rybowski, GISP

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Matthew Mayo, GISP

Pacific Southwest
Michael Beland

Potomac
Spencer Bolinski
Alexandra Gilman
Li Lin

Rocky Mountain
Reza GoljaniAmirkhiz, GST
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Western Great Lakes
Courtney Blouzdis
Joel Perrington
James Robinson
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HTTP://WWW.ASPRS.ORG/JOIN-NOW/

Your path to success in the geospatial community

To have your press release published in *PE&RS*, contact Rae Kelley, rkelley@asprs.org.

PENNSYLVANIA CELEBRATES NATIONAL SURVEYORS' WEEK

Pennsylvania Society of Land Surveyors (PSLS) is proud to announce its involvement in National Surveyors' Week, March 15-21, 2015, through its Reaching New Heights project. To support this effort, Gov. Tom Wolf has honored Pennsylvania surveyors through a proclamation recognizing surveyors' contributions to local communities across the commonwealth. The proclamation states in part "land surveyors provide exceptional service to our communities, or Commonwealth, and our nation…"

The primary goal of Reaching New Heights is to eliminate or reduce large areas in Pennsylvania with poor elevation accuracy. For the second straight year volunteers from PSLS performed GPS observations on at least 100 bench marks and provide the observations to the National Geodetic Survey who refined the elevation model in Pennsylvania. In 2014, over 70 individuals representing over 45 companies and agencies contributed to the effort resulting in 50 updated bench mark elevations.

Surveyors have played a vital role in the development of towns, cities, and the nation. They provide the client with a wealth of information. The information provided by surveyors is the source from which clients obtain details utilized from commencement to completion of projects ranging from creating residential boundaries to large-scale commercial construction, as well as identifying environmental concerns, and managing floodplain control.

PSLS contacted its members throughout the commonwealth to aid in locating and observing GPS elevations on benchmarks for comparison to traditional elevations. Students from Penn State, Wilkes-Barre and Pennsylvania College of Technology will also participate and be able to use the experience in their projects. The students' involvement in PSLS gives them practical experience and mentorship, and emphasizes the importance of participating in professional organizations.

"PSLS was excited to be working statewide to collect data that will be utilized within the National Geodetic Survey. To help celebrate National Surveyors' Week, the Reaching New Heights project will serve as a tool to actually demonstrate the importance of surveying to the public. We look forward to continuing this project for many years to collect as much data and detail as possible," said Adam Crews, PLS, President, PSLS Board of Directors.

For more information, visit www.psls.org.

ANNOUNCEMENT

Optech is pleased to announce that Lewis Graham, President and Chief Technology Officer of GeoCue Group, and Mark Whorton, Ph.D., Chief Technologist of Teledyne Brown Engineering (TBE) will be the keynote speakers for Optech Imaging and Lidar Solutions Conference 2015.

Mr. Graham will kick off ILSC on June 9 with an in-depth look at the current state of small unmanned aerial systems (UAS) and their practical business use for airborne surveying. While expectations for these versatile systems are rising, their deployment costs can be high and their place in the surveying world remains unclear. Mr. Graham will get attendees up to speed on the rapidly changing small UAS market, including the current state of reliable hardware platforms and the instrument types available for installation. He will then delve into the business aspects of using a small UAS, examining what kinds of problems are amenable to being solved, how they can fit into current workflows, and how companies will need to change their business models to accommodate this quickly evolving technology. This keynote complements a wider discussion of small UAS business cases, processing challenges and trends on June 9, plus two demonstration flights of the Optech XR6 UAV on June 10 and 12.

On June 11, Dr. Mark Whorton will discuss how TBE has worked with NASA to put a facility for swappable earth-imaging systems on the ISS as part of the first generation of commercial space-based earth imagers. The Multi-

User System for Earth Sensing (MUSES) instrument pointing system will host up to 4 separate plug-and-play imaging sensors in its inertial stabilized frame, enabling survey companies, humanitarian organizations, and non-spacefaring nations to send their own instruments into space. From the low-earth orbit of the ISS, sensors will be able to regularly cover the majority of the world's surface, delivering data for projects as diverse as precision agriculture, disaster relief, and urban/regional development and planning. Dr. Whorton will provide historical background on earth imaging from space and some of the resulting systems and applications, then delve into the potential commercial, scientific and humanitarian objectives that can be met using instruments aboard the MUSES facility.

For more information, visit http://www.optech.com/ilsc2015/.

Optech is pleased to announce that long-time client **SAM (Survey And Mapping, LLC)** has acquired a second Lynx Mobile Mapper™ to meet the growing demand for high-accuracy surveying and geospatial services.

Survey And Mapping, LLC (SAM), a leading provider of geospatial solutions, has acquired a second Lynx mobile mapping system. SAM is well known for its experience providing mobile mapping, terrestrial HDS, and aerial mapping for clients in several market sectors, such as Energy and Transportation. The dual-sensor Optech unit has the capability to acquire measurements at a rate of one million lidar points per second at normal highway speeds. Imagery is also collected via high-resolution 360-degree digital sensors synchronized to create high density, survey-grade colorized point clouds. SAM is a national company with completed projects across North America. The additional Lynx unit doubles their mobile mapping capacity and further extends their acquisition capabilities across a greater geographic range.

For more information about SAM, visit www.sam.biz; about Optech, visit www.optech.com.

From the President's Pen

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Tampa, as will my appointment of Greg Stensaas as Director and Allen Cook as Assistant Director of PDAD. I have also been pleased to appoint Karen Schuckman to head the Memorial Address Committee and Bobbi Lenczowski as Secretary of the Society, partly to compose the formal record of our Executive Committee and Board Meetings and partly to provide invaluable support and advice, drawing on the experiences of a glittering career.

Finally, I decided to take action over my concern about committee meetings! I convened a Task Force on Streamlining the Governance and Management of ASPRS and have been humbled by the enthusiasm and dedication of its members, Ryan Bowe, Ekaterina Fitos, Doug Smith and Michael Hauck. We have submitted several reports to the Executive Committee and Board of Directors making extensive recommendations on changes to the Society's structure. We believe the result will be a simpler, more effective, intelligible and economical structure, with volunteers' energies less thinly spread. For example, following the successful merger of St. Louis and Central Regions to form Heartland in 2014, Northern California and Southwest US have merged to form Pacific Southwest and I was able to attend the inaugural meeting of the new Region in Fresno in February.

A Society with thousands of members and over 100 Sustaining Members, there's a lot going on. We are challenged to return membership to a growth path. Whether we do this by one member at a time attracting a co-worker or by campaigns and utilization of social media, we must craft a value proposition that is compelling. We must present our Society as attractive and relevant, in an age where participation in societies is not as natural as it was when I joined in 1973. We are positively impacting the profession, but we have to tell others and draw them into the Society to make their contributions and become part of our network. If I have helped to provide an environment to help us meet these daunting challenges, I shall be content.

Stewart Walker
ASPRS President

CALENDAR

MAY

20-22, The Spatial Data Science Bootcamp, UC Berkeley. or more information, visit http://iep.berkeley.edu/iep?utm_source=GIS_assoc&utm_medium=IEPemail&utm_content=body-top&utm_campaign=spatial2015.

27-28, Geo Business 2015, London, UK. For more information, visit www.GeoBusinessShow.com.

29, GeoByte—A Legal Framework for UAVs: How We Get From Here to There? For more information, visit http://www.asprs.org/GISD-Division/Online-Seminars.html.

JUNE

9-12, Optech Innovative Lidar and Imaging Solutions Conference (ILSC) 2015, Toronto, Canada. For more information, visit www.optech.com/ilsc2015.

19, GeoByte—A Discussion of the USGS Base Lidar Specification, v. 2.0. For more information, visit http://www.asprs.org/GISD-Division/Online-Seminars.html.

AUGUST

23-28, On the Map: American Cartography in 2015, Rio de Janeiro, Brazil. For more information, visit www.icc2015.org/

26-28, 14th International Symposium on Spatial and Temporal Databases 2015 (SSTD 2015), Seoul, South Korea. For more information, visit http://stem.cs.pusan.ac.kr/SSTD2015.

28, GeoByte—USGS Science Data Catalog – Data Visualization, Discovery and Use. For more information, visit http://www.asprs.org/GISD-Division/Online-Seminars.html.

SEPTEMBER

23-24, GIS in the Rockies, Denver, Colorado. For more information, visit http://www.gisintherockies.org/2015/.

28-3 October, ISPRS Geospatial Week 2015, La Grande Motte, France, For more information, visit www.isprs-geospatialweek2015.org.

NOVEMBER

2-5, 10th EARSeL Forest Fire Special Interest Group Workshop, Limassol, Cyprus. For more information, visit, www.ffsig2015.com.

8, Florida ASPRS Symposium, Florida Atlantic University (FAU). For more information, visit http://florida.asprs.org/.

9-13, "COSPAR 2015"—2nd Symposium of the Committee on Space Research (COSPAR): Water and Life in the Universe, Foz do Iguacu, Brazil. For more information, visit, http://cosparbrazil2015.org/.

20, GeoByte—GNSS Derived Heights. For more information, visit http://www.asprs.org/GISD-Division/Online-Seminars.html.

24-27, Bridging Information Gaps by Creating Smarter Maps, Suva, Fiji. For more information, visit http://picgisrs.appspot.com.

JULY 2016

30–August 7, "COSPAR 2016"—41st Scientific Assembly of the Committee on Space Research (COSPAR), Istanbul, Turkey. For more information, visit http://www.cospar-assembly.org.

To have your special event published in *PE&RS*, contact Rae Kelley, rkelley@asprs.org.

Identifying Urban Watershed Boundaries and Area, Fairfax County, Virginia

Tammy E. Parece and James B. Campbell

Abstract

Urban hydrology differs from that of natural environments, and thus urban watersheds require innovative evaluation techniques. Typical geospatial evaluation of urban hydrology begins with identification of water flow and watershed boundaries. This study identifies steps to delineate a highly urbanized watershed in Fairfax County, Virginia. Using standard techniques for natural watersheds and one-meter2 resolution lidar, watershed and flow accumulation raster datasets were derived. Then, modifications encountered within urban landscapes i.e., impervious surfaces, stormwater inlets, pipes, and retention ponds along with high-resolution aerial photos and lidar-derived contour lines were integrated into the analysis. Regions redirecting water flow from stream channels and areas redirecting water flow into the stream channels were identified. These areas were removed or added, reducing the area by almost 17 percent, and the watershed boundary was significantly altered. This analysis illustrates the significance of the distinctive characteristics of the urban landscape in accurate delineations of urban watersheds.

Introduction

Substantial literature, dating back decades, has been devoted to urban hydrology; most specifically to evaluation, management, and engineering of urban hydrologic systems to address changes the built environment has wrought on the natural hydrologic cycle (e.g., McPherson and Schneider, 1974; Debo and Day, 1980; USDA, 1986; Sample *et al.*, 2001; Debo and Reese, 2003; Lhomme *et al.*, 2004; Leonhardt *et al.*, 2014). With the advent of GIS, research has become much more robust in modeling water flow and evaluating water quality issues (Rodriguez *et al.*, 2008). Yet, a better understanding of hydrologic impacts of urbanization is required as current best management practices implemented to address urban stormwater runoff are proving to be inadequate (Burton Jr. and Pitt, 2002). Effective management of urban stormwater runoff and water quality issues can only be accomplished once drainage areas and flow networks in urban settings are identified, with careful attention paid to the urban landscape's distinctive features (McPherson and Schneider, 1974; Burton Jr. and Pitt, 2002; Quinn, 2013).

Urban hydrologic characteristics are unique i.e., quite unlike those of natural environments (Kaufman *et al.*, 2001; Sample *et al.*, 2001; Debo and Reese, 2003; Rodriguez *et al.*, 2003). Anthropogenic changes from land grading, channelization, impervious surfaces, and stormwater sewer systems direct water flows from one catchment area to another (McPherson and Schneider, 1974). Yet, geospatial evaluation of hydrologic impacts begins with identification of overland water flow and watershed boundary areas, and evaluative techniques applied are based on similar techniques used in natural landscapes (Sample *et al.*, 2001; Rodriguez *et al.*, 2003). These conventional approaches fail to account for transfers of runoff across topographic divides, creation of sinks, and disruption by built topography, which modify original natural surfaces and invalidate conventional delineations of drainage systems.

Water bodies experience changes from stormwater runoff with as little as 10 percent impervious surface cover within its watershed (Center for Watershed Protection 2003). Anthropogenic landscape changes due to removal of vegetative cover and increased impervious surfaces have reduced infiltration, amplified stormwater runoff volume and rate, diminished groundwater tables, and decreased evapotranspiration (DeBusk *et al.*, 2010; Welker *et al.*, 2010). Stormwater runoff from impervious surfaces in urban regions degrades water quality through higher water temperatures, and elevated levels of contaminants in surface waters (Slonecker *et al.*, 2001; Davis *et al.*, 2010; Welker *et al.*, 2010). Stormwater runoff not only effects water quality within a specific urban region but also vitiates downstream waterbodies (Bhaduri and Minner, 2001).

On-the-ground surveys in an urban area can produce watershed boundaries that do not compare to those of a natural watershed because they account for grading, and slope changes from impervious surfaces. However, field surveys cannot account for water inflows or outflows without evaluating the stormwater network's inlets, pipes (including location and flow direction), and retention ponds. In large urban areas, field surveys can be quite complex, expensive, and disruptive to daily human activities.

Many researchers recognize that stormwater networks and impervious surfaces have altered urban water flows, and the need to include these and aerial photographs with raster based-delineations (Kaufman *et al.*, 2001; Debo and Reese, 2003), yet few researchers alter standard geospatial methods when delineating an urban watershed. In *Urban Drainage Catchments* (Maksimovíc and Radojkovíc, 1986), when identifying watershed/catchment area, most authors recognized that the built environment changed the natural water flow, and therefore, included these changes in their delineations. However, these delineations were all accomplished without using geospatial software and were completed for relatively small areas. We located four articles evaluating stormwater flow, which included stormwater networks and field data collection with GIS to delineate catchments (Table 1).

While published research is sparse, many government agencies and personnel, and other professionals have long recognized the deficiencies in applying routine methods in identifying urban catchment areas. As such, many of these entities are including impervious surfaces, stormwater networks, and remotely sensed data in analyses in local areas (Mauldin, personal communication, 2014; Quinn, personal communication, 2014). In addition, as more urban infrastructure is recorded as

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Photogrammetric Engineering & Remote Sensing
Vol. 81, No. 5, May 2015, pp. 365–372.
0099-1112/15/365–372

doi: 10.14358/PERS.81.5.365

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Parallel Performance of Typical Algorithms in Remote Sensing-based Mapping on a Multi-Core Computer

Jinghui Yang and Jixian Zhang

Abstract

Typical algorithms in remote sensing-based mapping, such as geometric correction, image fusion, image mosaic, and automatic DEM extractions, are data- and computation-intensive; processing on multi-core computers can improve their performance. Therefore, parallel computing methods that can fully leverage state-of-the-art hardware platforms and that can be easily adapted to these algorithms are required. In this paper, a method with high parallelism is adopted. The method integrates a recursive procedure with a parallel mechanism that is capable of concurrently processing multiple blocks on multiple cores. The parallel experiments of five categories of typical algorithms on two multi-core computers with Windows and Linux operating systems, respectively, were fulfilled. The experimental results show that although the gains of parallel performance vary for different algorithms, the processing performance achieved on multi-core computers is significantly improved. The best case on a computer with two CPUs is able to perform the DEM extractions up to 13.6 times faster than serial execution. According to these experiments, the factors influencing parallel performance on a multi-core computer are discussed.

Introduction

Typical algorithms in remote sensing-based mapping are data- and computation-intensive, such as image fusion, image mosaic, geometric correction, and image matching. In practice, these algorithms usually require not only reading and writing a large amount of data but also several sophisticated computational steps, including interpolating, filtering, orthogonal transformation, convolution, geometric transformation, solving systems of linear equations, optimization, and multi-resolution analysis. The large amount of data and the immense computational costs of these algorithms are a realistic concern. Normally, the entire process of serial execution of complicated algorithms is rather time-consuming.

However, the current computing resources are typically not utilized efficiently for serial algorithms. A serial algorithm is unaware of the existence of multiple CPU cores, and the performance of such an algorithm on a multi-core computer will be the same as its performance on a single core computer. The current serial algorithms are not matched to the developments of computer hardware in which multi-core CPUs are widely available. Hence, parallel computing methods, which not only fully leverage the state-of-the-art hardware platforms but also promote processing speed for mapping, are required.

There are some related works in the field of parallel processing for remote sensing. Lee *et al*. (2011) reviewed recent developments in high performance computing (HPC) for remote sensing. Plaza *et al*. (2011) reviewed recent developments in the application of HPC techniques to hyperspectral imaging problems. Plaza *et al*. (2006 and 2008) have developed several highly innovative parallel algorithms for standard data processing and information extraction of hyperspectral images in heterogeneous networks of workstations and homogeneous clusters. Luo *et al*. (2012) presented a parallel implementation of N-FINDR (Winter, 1999) (a widely used endmember extraction algorithm) which was run on a cluster connected by the Gigabit Ethernet. Generally, these methods mainly concentrate to information extraction of hyperspectral images. These experiments were performed on clusters in which components are largely different from the counterparts in multi-cores computers.

Although there are few high performance software systems, e.g., PHOTOMOD® (Adrov *et al*., 2012), PIXEL FACTORY™ (ASTRIUM, 2013), Correlator3D™ (Rotenberg *et al*., 2013), and PCI GXL (PCI Geomatics, 2009) in photogrammetric and remote sensing community; they are based on either clusters (PHOTOMOD® and PIXEL FACTORY™) or graphic processing unit (GPU) (Correlator3D™ and PCI GXL). The systems based on clusters mostly apply distributed computing, which only dispatches multiple independent tasks to different computers (or cores) and usually cannot subdivide a task into many smaller tasks. Similar to automatic tiling and stitching methods in eCognition® server software, the parallel method adopted in this paper can split a large image into more blocks to enable concurrent processing of multiple blocks. The systems based on GPU mostly need an add-on GPU card. This paper does not compare these HPC methods used in remote sensing field, but aims to provide another insight that the commonplace desktop computing platforms can be employed to improve processing performance.

In a narrower field, i.e., the multi-core based parallel computing for remote sensing, several researchers have done some valuable works in recent years. Christophe *et al*. (2011) compared the relative performance of a multithreaded program run on a CPU and the corresponding program running on a GPU. Remon *et al*. (2011) presented parallel experiments of hyperspectral endmember extraction algorithms on multi-core

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Photogrammetric Engineering & Remote Sensing
Vol. 81, No. 5, May 2015, pp. 373–385.
0099-1112/15/373–385

doi: 10.14358/PERS.81.5.373

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Evaluation of Lidar-derived DEMs through Terrain Analysis and Field Comparison

Cody P. Gillin, Scott W. Bailey, Kevin J. McGuire, and Stephen P. Prisley

Abstract

Topographic analysis of watershed-scale soil and hydrological processes using digital elevation models (DEMs) is commonplace, but most studies have used DEMs of 10 m resolution or coarser. Availability of higher-resolution DEMs created from light detection and ranging (lidar) data is increasing but their suitability for such applications has received little critical evaluation. Two different 1 m DEMs were re-sampled to 3, 5, and 10 m resolutions and used with and without a low-pass smoothing filter to delineate catchment boundaries and calculate topographic metrics. Accuracy was assessed through comparison with field slope measurements and total station surveys. DEMs provided a good estimate of slope values when grid resolution reflected the field measurement scale. Intermediate scale DEMs were most consistent with land survey techniques in delineating catchment boundaries. Upslope accumulated area was most sensitive to grid resolution, with intermediate resolutions producing a range of UAA values useful in soil and groundwater analysis.

Introduction

Topographic analysis using digital elevation models (DEMs) has become routine in soil and hydrologic sciences, and there has been considerable assessment of the effects of grid resolution on topographic metrics. Most watershed-scale studies examined resolutions of 10 m or coarser and tended to use DEMs covering thousands of hectares. For instance, when researchers examined slope computed from DEMs of different resolutions, they observed that coarser DEMs generated lower values (e.g., Isaacson and Ripple, 1990; Jenson, 1991). Quinn *et al.* (1991) compared topographic wetness index (TWI) computed from 12.5 and 50 m DEMs and found higher values for the coarser DEM. Many other studies comparing topographic metric values computed from a range of DEMs reported lower slope, larger upslope accumulated areas (UAAs), and higher TWI values for coarser DEMs (e.g., Hancock, 2005; Saulnier *et al.*, 1997; Wolock and Price, 1994; Zhang and Montgomery, 1994). Variation in topographic metric values computed from DEMs of different resolutions is a result of discretization effects when the size of DEM grid cells is altered (which can affect the algorithm used to compute a topographic metric) and the loss of terrain detail (smoothing) that occurs through DEM coarsening (Gallant and Hutchinson, 1996).

Examination of soil and hydrologic variability of small headwater catchments may be enhanced by higher-resolution DEM data that has only recently become available through light detection and ranging (lidar) technology. Lidar-derived DEMs have been shown to be more representative of field slope measurements (Shi *et al.*, 2012) and field-determined elevations (Vaze *et al.*, 2010) than DEMs created using topographic maps. However, few studies have assessed variation in topographic metric values extracted from a range of high-resolution (10 m or less) lidar-derived DEMs. Sorensen and Seibert (2007) coarsened a 5 m lidar-derived DEM to 10, 25, and 50 m resolutions and found median TWI values increased with DEM grid cell size. Vaze *et al.* (2010) noted changes in DEM-delineated catchment boundaries across five lidar-derived DEMs as resolution decreased from 1 to 25 m.

While lidar-derived DEMs may represent field conditions better than topographic maps, their accuracy has been shown to vary depending on land cover class. For example, previous studies found elevation errors increased under forest canopy compared with open areas (Hodgson *et al.*, 2005; Reutebuch *et al.*, 2003; Su and Bork, 2006). Greater DEM elevation error associated with forest canopy may be related to a decrease in the number of lidar ground returns or off-terrain points incorrectly classified as ground (Hodgson *et al.*, 2005).

Quinn *et al.* (1991) contended that the resolution of DEMs used in hydrologic modeling must reflect topographic features vital to the hydrologic response, suggesting that resolution of early DEMs was too coarse for accurate modeling of some catchments. Two decades later, high-resolution DEMs may offer a level of topographic detail greater than that controlling surface/near surface flow pathways. For instance, Bailey *et al.* (2014) found that a 5 m DEM resulted in UAA and TWI values that were better correlated with soil horizon thickness and groundwater fluctuations than metrics calculated from a 1 m DEM. Gillin *et al.* (2014) showed that digital mapping of soils based on DEM derived topographic metrics was possible with a smoothed DEM. To mitigate landscape roughness, a DEM may be coarsened to a lower resolution through resampling or cell aggregation (e.g., Band and Moore, 1995; Sorensen and Seibert, 2007; Wu *et al.*, 2008) or smoothed through filtering (e.g., Lillesand and Kiefer, 2000; Walker and Willgoose, 1999). Filtered DEMs retain general topographic trends better than coarsened DEMs while reducing local roughness created by individual cells (Hammer *et al.*, 1995). Although filtering is a common technique for smoothing DEMs, evaluations of topographic metrics computed from filtered and unfiltered DEMs over a range of resolutions are limited (e.g., Hammer *et al.*, 1995).

This study had three principal objectives. First, we compared differences in shape and area of a catchment delineated from 1 m DEMs interpolated from lidar datasets, as well as DEMs aggregated from original 1 m resolution to coarser models (3, 5, and 10 m resolutions) and treated with low-pass smooth-

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Photogrammetric Engineering & Remote Sensing
Vol. 81, No. 5, May 2015, pp. 387–396.
0099-1112/15/387–396

doi: 10.14358/PERS.81.5.387

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Refining High Spatial Resolution Remote Sensing Image Segmentation for Man-made Objects through aCollinear and Ipsilateral Neighborhood Model

Min Wang, Yanxia Sun, and Guanyi Chen

Abstract

Man-made objects, such as buildings and roads, which are important targets for information extraction from high spatial resolution (HSR) remote sensing images, often feature straight boundaries. This study employs this knowledge on HSR image segmentation by embedding a straight-line constraint in region-based image segmentation. A new concept called collinear and ipsilateral neighborhood is proposed and applied to hard-boundary constraint-based image segmentation for accuracy improvement. In the experimental areas, the method accuracy measured by recall ratio r increases from 0.036 to 0.048 (on the average) after the refinement, with significantly smaller decreases in precision p that are all less than 0.006. In sum, the proposed technique effectively reduces over-segmentation errors and maintains the same level of under-segmentation error ratio, particularly in man-made areas. It facilitates subsequent object-based image analyses, including feature extraction, object recognition, and classification.

Introduction

Image segmentation is a most important step in object-based image analysis (OBIA); it significantly influences the succeeding steps, including feature extraction and classification. The pioneer OBIA software is eCognition (originally developed at Definiens AG) by Trimble Inc. (2014), which features a multi-resolution segmentation method (fractal net evolution approach or FNEA). This method has wide applicability, high efficiency, and high accuracy. However, FNEA needs to be improved in terms of under- and over-segmentation error ratios, input dependency, and segment boundary precision (Wang and Li, 2014).

In our previous study (Wang and Li, 2014), we proposed a novel segmentation method based on a hard-boundary constraint and two-stage merging (HBC-SEG). This novel method exhibits improved performance when compared with FNEA. In the current study, we design a refined HBC-SEG by integrating straight-line constraints because man-made objects in HSR images often have straight boundaries. The main contributions of this work are as follows. First, we propose and implement a range of techniques, including extracting two types of object primitives (OPs) (segments and straight lines), building their mutual spatial topologies, and comprehensively utilizing these OPs in image segmentation. Second, we propose a new neighborhood model called collinear and ipsilateral neighborhood (Without ambiguity, we refer to it as IPSL-neighborhood). We then confirm that IPSL-neighborhood can improve segmentation accuracy in HSR images. The proposed model and technique are significant to OBIA considering that man-made objects are often the main target of HSR image information extraction.

The rest of this paper is organized as follows. The next section provides a review of related work on remote sensing image segmentation, followed by a detailed discussion of the proposed method, including a brief introduction of HBC-SEG, straight-line primitive extraction, line and segment topology modeling, and refined segmentation method. The next section presents the experiments conducted, followed by a summary of this study.

Related Work

Image segmentation aims to partition an image into several segments, such that each segment is homogeneous, but none of the unions of two adjacent segments is homogeneous (Pal and Pal, 1993). Segmentation accuracy can be measured based on over- and under-segmentation. Over-segmentation indicates that a homogeneous region is divided into several segments, whereas under-segmentation means that different regions are grouped into one segment. Current remote sensing image segmentation methods include point/pixel-based, edge-based, region-based, texture-based, and hybrid. Previous studies (Pal and Pal, 1993; Schiewe, 2002; Shankar, 2007; Dey *et al.*, 2010) have provided systematic reviews of these methods.

In the field of remote sensing applications, FNEA (Baatz and Shäpe, 2000), along with the successful business application of eCognition software, is the most popular segmentation method for OBIA. As an important algorithm parameter, scale is utilized to control the average segment size in segmentations. From scale changes (small to large), segments are merged gradually and hierarchically to allow for multi-resolution segmentation. However, the global scale parameter is limited because remote sensing images contain different types of large and small ground objects. Most ground objects may be over-segmented at small scales. Several small objects may be under-segmented if large scales are specified, whereas several large objects may remain over-segmented. Thus, the co-existence of over- and under-segmentation often results in manual scale tuning to minimize and balance segmentation errors,

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Photogrammetric Engineering & Remote Sensing
Vol. 81, No. 5, May 2015, pp. 397–406.
0099-1112/15/397–406

doi: 10.14358/PERS.81.5.397

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APPLICATIONS PAPER

Lidar Detection of the Ten Tallest Trees in the Tennessee Portion of the Great Smoky Mountains National Park

Chris W. Strother, Marguerite Madden, Thomas R. Jordan and Andrea Presotto

Abstract

This paper describes a method for predicting the locations and heights of the ten tallest trees in the Tennessee portion of the Great Smoky Mountains National Park. Iterative computation tools were utilized to process the data along with the lidar-derived bare earth digital elevation models and digital surface models to create canopy height models for the Tennessee portion of the park. A height threshold of 51.8 meters was chosen as the minimum value for a tree of extraordinary height. Ten potential sites containing tall trees were identified using this methodology, and seven of the top ten ranking trees' heights were field measured using accepted forestry methodology. The trees detected using these methods are potentially the tallest trees ever measured on the East Coast of the United States. These methods show that unique tall trees can be successfully detected in a large, heterogeneous forest area using lidar data.

Introduction

Lidar in Forestry

Airborne lidar (Light Detection and Ranging) data has been used extensively in the past decades to obtain accurate measurements of forest structure (Nilsson, 1996; Maune, 2001; Jensen, 2007; Andersen *et al*., 2006). In the context of forestry, height is defined as the vertical distance between the ground and the tip of the tree crown (Husch *et al*., 1972). Research conducted by the US Forest Service in western Washington State produced sub-meter horizontal and vertical accuracies in a mountainous, forested area dominated by Douglas fir using airborne lidar data in a comparison study with field-collected data (McGaughey *et al*., 2004). The maximum height of tree plots was predicted with R^2 values for accuracy between 85 and 90 percent in a mixed forest area of Appomattox-Buckingham State Forest in Virginia. (Popescu *et al*., 2002). More recently, individual tree detection and characterization has been achieved with some success. Popescu and Wynne (2004) utilized local maxima to delineate and measure individual trees. Sankey and Glenn (2011) fused lidar data fused with Landsat-5 TM imagery to estimate sub-pixel canopy heights in the Western US. Li *et al*. (2012) segmented individual trees from a lidar point cloud data set from the Sierra Nevada Mountains in California. The methodology of subtracting the digital elevation model (DEM) values from the digital surface model (DSM) values to obtain canopy heights has been used by others in measuring forested areas. (Naesset, 1997; Zimble *et al*., 2003; Andersen *et al*., 2006). Specifically, lidar technology has been utilized by Forestry Tasmania, a forest management organization in Australia, to locate a unique eucalyptus tree nicknamed Centurion which measured in at 99.6 m (Lawson, 2010).

Past studies such as Zimble *et al*. (2003) have pointed to height measurement errors created in the lidar data collection process created by the post spacing, or distance between height measurements, that become apparent when ground measurements are made to the highest peaks visible in the tree crown.

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Ground-based Tree Height Measurement Procedures

Andersen *et al*. (2006) point out accurate direct measurement of trees in the field is difficult. Crown overlap in dense canopy as well as other factors such as slope can affect the ground measurements. The US Forest Service (USFS) indicates that the best height measurements are made using an instrument such as a laser rangefinder with a built in clinometer (USFS, 2005). This tool measures the horizontal distance to the tree (hd) from a fixed location as well as angles to the base of the tree (Θ) and the tip of the crown (ρ). The height (h) is derived by the trigonometric equation:

$$h = hd\,(\tan \rho + \tan \Theta)$$

Study Area

The 209,000 hectares of the Great Smoky Mountains National Park (GRSM) straddle the border between the states of Tennessee and North Carolina (Figure 1). The GRSM receives over 10 million visitors a year, making it the most visited National Park in the US. This area contains roughly 1,500 meters of relief ranging from around 250 m at the western border of the park to 2,025 m at Clingman's Dome, the highest mountain in Tennessee and third largest east of the Mississippi (NPS, 2012). The park was created in 1934 from lands donated by Tennessee and North Carolina in an attempt to mitigate the devastating effects nineteenth century timber logging and subsequent erosion. The park is part of the Appalachian Mountain range, one of the oldest mountain ranges on Earth. It is also one of the most biologically diverse areas on the planet, given its

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Vol. 81, No. 5, May 2015, pp. 407–413.
0099-1112/15/407–413

doi: 10.14358/PERS.81.5.407

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Cook, J.D., and L.D. Ferdinand, 2001. Geometric fidelity of Ikonos imagery, *Proceedings of the ASPRS 2001 Annual Convention*, 23-27 April, St. Louis, Missouri (American Society for Photogrammetry and Remote Sensing, Bethesda, Maryland), unpaginated CD-ROM.

Thesis and Dissertations:
Yang, W., 1997. *Effects of Spatial Resolution and Landscape Structure on Land Cover Characterization*, Ph.D. dissertation, University of Nebraska-Lincoln, Lincoln, Nebraska, 336 p.

Website References:
Diaz, H.F., 1997. Precipitation trends and water consumption in the southwestern United States, USGS Web Conference, URL: http://geochange.er.usgs.gov/sw/changes/natural/diaz/, U.S. Geological Survey, Reston, Virginia (last date accessed: 15 May 2002).

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