Recent U.S. Geological Survey Applications of Lidar

by Vivian R. Queija, Jason M. Stoker, and John J. Kosovich

As lidar (light detection and ranging) technology matures, more applications are being explored by U.S. Geological Survey (USGS) scientists throughout the Nation, both in collaboration with other Federal agencies and alone in support of USGS natural-hazards research (Crane et al., 2004). As the technology continues to improve and evolve, USGS scientists are finding new and unique methods to use and represent high-resolution lidar data, and new ways to make these data and derived information publicly available. Different lidar sensors and configurations have offered opportunities to use high-resolution elevation data for a variety of projects across all disciplines of the USGS. The following examples are just a few of the diverse projects in the USGS where lidar data is being used.

Part I: Representative Studies

Dissemination Studies

A goal of *The National Map* is to link base digital-data layers for public distribution. The elevation layer of *The National Map* is maintained through the National Elevation Dataset (NED) at the USGS Earth Resources Observation Systems (EROS) Data Center (Gesch et al., 2002). NED offers seamlessly merged digital elevation models (DEMs) at 1 (30-meter)-, 1/3 (10-meter)-, and 1/9 (3-meter)-arc-second resolutions (Figure 1). As high-resolution data are collected, either by the USGS or its DOI partners, they are incorporated into NED. A bimonthly update is performed to integrate the "best available" DEM data into NED for public availability. Currently, data for the entire nation are available at 1-arc-second resolution, with more 1/3-arc-second-resolution data being completed state by state. The 1/9-arc-second-resolution lidar data are being incorporated into NED as they become available. For certain areas, data are available at all three resolutions, allowing the user to pick the appropriate DEM data for his or her specific application.

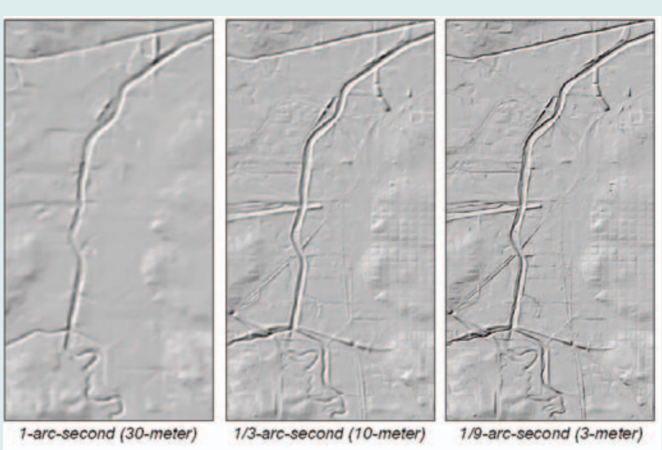

Figure 1. Multiple seamless elevation resolutions in the National Elevation Dataset (Gesch, 2004).

As the lead Federal civilian mapping agency, the USGS ensures that NED makes the base digital elevation data publicly available. The USGS is also a member of the National Digital Elevation Program (NDEP), a consortium of Federal agencies utilizing and maintaining a national elevation dataset (Osborn et al., 2001). As a member of NDEP's High Resolution Elevation Data Panel, the USGS has established a Project Tracking Web page (URL http://mcmcwebmap.usgs.gov/NDEP/viewer.htm) for lidar-data acquisition throughout the country that can be used to assist the scientific community in obtaining available lidar data for critical studies and applications (Figure 2). NDEP partners are considering national lidar coverage to assist in the Flood Plain Mapping Modernization program and other hazard-mitigation studies.

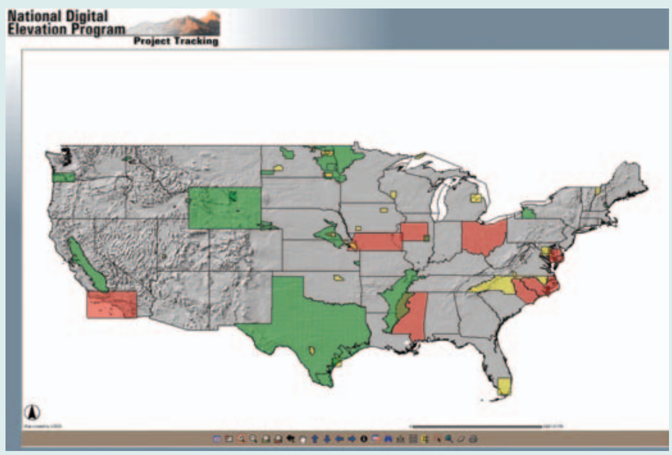

Figure 2. National Digital Elevation Program's tracking viewer (Queija, 2004).

Visualization and Representation Studies

Currently, USGS scientists are investigating a new method of visualizing, representing, and modeling high-resolution lidar data (Stoker, 2004). Instead of representing lidar returns as X, Y, Z points, raster grids, or triangulated irregular networks (TINs), voxels are being used to represent lidar data. A voxel is a three-dimensional counterpart to a traditional pixel. Whereas pixels are two-dimensional raster cells, voxels are three-dimensional "cubes," allowing for three-dimensional representation and visualization of lidar data and for fusing two-dimensional imagery with the three-dimensional elevation data created by lidar. This method makes possible more realistic representations of urban and vegetation structures (e.g., trees) than traditional surface representations of lidar data, as well as visualizations that are superior to simply draping images on a surface (Figure 3). Two-dimensional raster and TIN representations require that surfaces be single valued; i.e., overhangs must be absent. For detailed modeling of urban environments, this representation is unsatisfactory. A voxel-based representation allows representation of the surface and building overhangs, drainage paths beneath bridges, and tree crowns within a single model.

continued on page 6

continued from page 6

Figure 3. Lidar voxel visualization of Lincoln, Nebraska (Stoker, 2004).

The lidar data structure has the potential for modeling in three dimensions because physical information can be passed through filled and empty voxels under certain defined conditions. Examples of this application are fire modeling, where the transition from a surface fire to a crown fire could be simulated and the fire could spread in three dimensions on the basis of more realistic fire-behavior physics (Figure 4), and flood modeling, into which such attributes as subsurface flow and underground drainage could be incorporated. Within a few years, USGS scientists envision being able to walk through "virtual forests" and "virtual cities," using voxel representations of high-resolution lidar data and imagery.

Figure 4. Prefire and postfire lidar voxel visualization of a forested area (Stoker, 2004).

Coastal Studies

USGS scientists are also evaluating the new capabilities of lidar in their recent work in Biscayne National Park, Florida (Brock et al., 2004). For a water-penetrating lidar, National Aeronautical and Space Administration's (NASA) Experimental Advanced Airborne Research Lidar (EAARL) sensor has a relatively small spot size with the potential for capturing significant bottom-surface textural information. These data are currently being evaluated in terms of the ability to discriminate and characterize shallow benthic habitats in various environments.

In the northernmost Florida Keys, the initial emphasis has been on the development of lidar-based measurements of coral-reef "optical rugosity." USGS scientists are utilizing NASA's EAARL, a bathymetric lidar system, in combination with the Airborne Imaging Spectroradiometer for Applications (AISA), an airborne hyperspectral sensor (Figure 5). Each raster scan is treated as a submarine topographic transect, and a measure of rugosity is calculated for each point along transect as the ratio of (1) the terrain-following distance between the transect origin and the point of interest to (2) the straight-line distance between those same two points. A perfectly flat transect has a rugosity of 1, whereas a transect surface with peaks and valleys has a rugosity greater than 1. Mean elevation difference between adjacent points along transect provides another measure of surface roughness. A perfectly flat surface has a mean absolute elevation difference of 0º of slope, whereas a transect surface with peaks and valleys has a mean absolute elevation difference greater than 0º of slope.

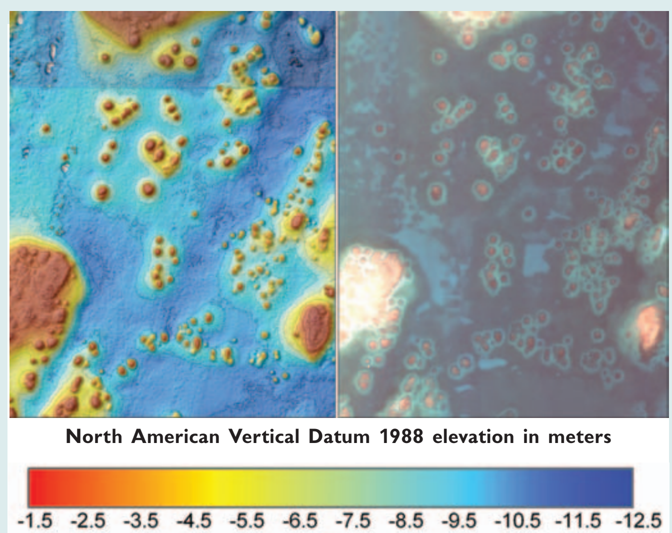

Figure 5. National Aeronautical Space Administration Experimental Advanced Airborne Research Lidar -derived digital elevation model (left) and Airborne Imaging Spectroradiometer for Applications (right) images of coral reefs in Biscayne National Park, Florida (Brock

Among the primary study sites are Alina's Reef, a small patch reef just east of well-known Anniversary Reef, and Pacific Reef, a relatively barren bank-edge reef. These two reefs, distinctly different to the eye and by National Park Service measurements of reef status, can also be discriminated according to lidar-based expressions of optical rugosity (Figure 6). These preliminary results indicate that a high pulse-repetition-frequency, narrow-beam, temporal-waveformresolving green lidar can provide a potentially useful view of coral-reef-habitat complexity, one measure of reef status.

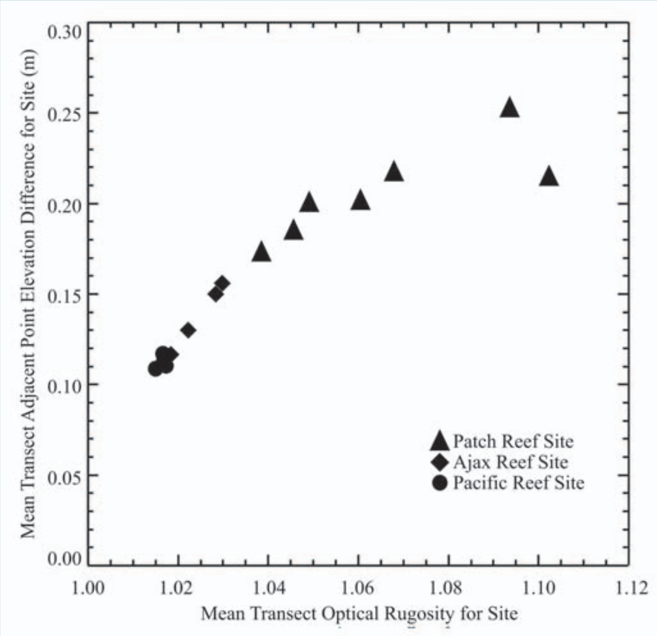

Figure 6. Different textural signatures in National Aeronautical Space Administration Experimental Advanced Airborne Research Lidar data acquired at Biscayne National Park, Florida, August 2002 (Brock et al., 2004).

Biological Studies

USGS scientists are investigating lidar applications for predicting bird-species occurrences derived from modeled vegetation structure (“W. Newton, unpub. data, 2004”). Bird-species occurrences and subsequent bird-species biodiversity depend on both vertical and horizontal vegetation structure (Figure 7). Maintenance of bird-species-diversity across a landscape depends on both natural (e.g., fire) and human (e.g., logging) disturbances to their habitat. Of special interest to forest managers is a need to predict bird species occurrences in relation to various forest-management practices, at both the stand and landscape levels. USGS scientists are currently refining their lidar-derived DEMs, as well as developing lidar-derived vegetation structure estimates at bird-point-count study sites. Their goal is to develop logistic-regression models that will allow the prediction of bird-species-occurrence probabilities across numerous study sites. These studies may prove instrumental in developing models that can then be used to run “what if” or optimization algorithms with respect to various forest-management options.

Urban Biomass Studies

USGS scientists are currently investigating urban-biomass-quantification techniques with lidar. Urban areas are challenging because of their various land uses. Differentiating between vegetation, buildings, cars, and transportation structures presents difficulties with lidar point data (Figure 8). However, merging lidar point data with spectral signatures is proving to be a promising method of distinguishing land cover with accuracy and automation. The ability to quantify specific amounts of biomass will assist in hydrologic modeling, carbon sequestration, and habitat reclamation for endangered species. These lidar and spectral-merging techniques will be utilized

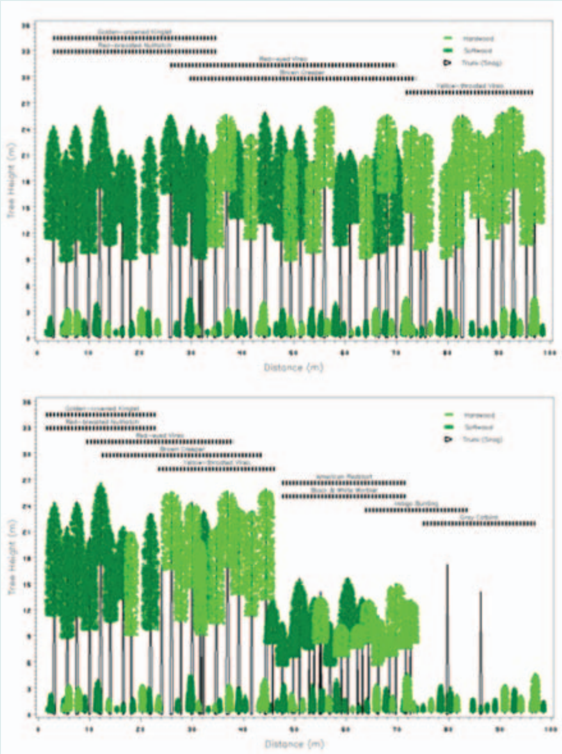

Figure 7. Modeled vegetation structure from lidar (Newton, 2004).

as part of a USGS interdisciplinary science project for hydrologic modeling and geomorphology on the Rio Puerco in New Mexico.

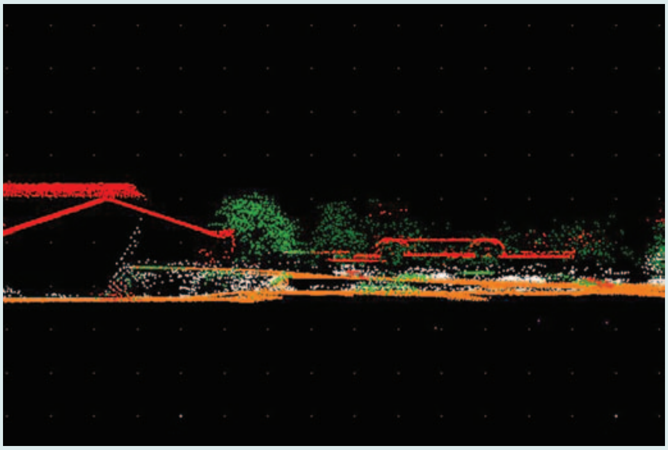

Figure 8. Classification of lidar data in Seattle, Washington (Queija, 2003).

Data Comparison and Transformation Studies

USGS scientists are comparing and quantifying vertical accuracies, using global positioning system (GPS) ground-control points as a baseline, of several lidar and interferometric synthetic aperture radar (IFSAR) high-resolution elevation datasets collected over a study site. In addition to determining the absolute vertical accuracies of these surfaces, USGS scientists are using continuous-surface difference models to visualize the overall comparative characteristics of the elevation surfaces being studied (Figure 9). They are also investigating the use of lidar-based feature extraction tools to help populate *The National Map* base-data themes, such as buildings (Figure 10).

continued on page 8

continued from page 7

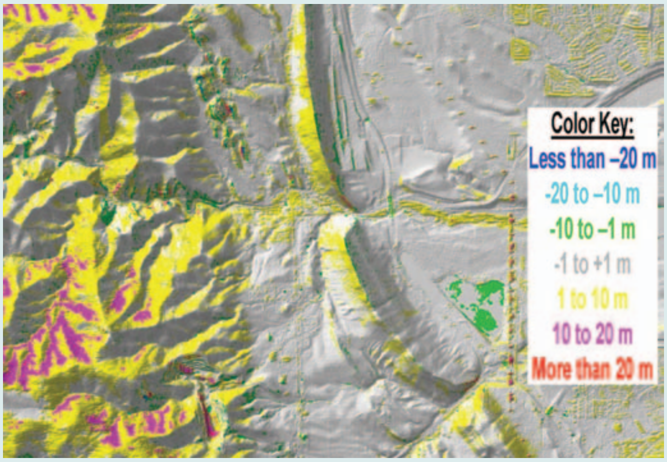

Figure 9. First-surface interferometric synthetic aperture radar versus lidar: colored elevation-difference model (Kosovich, 2002).

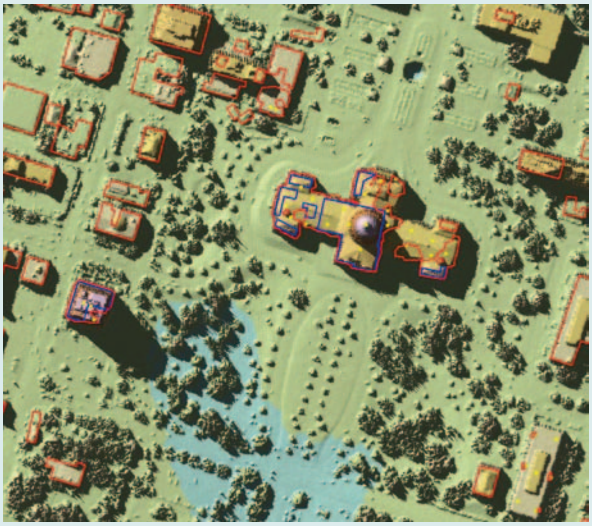

Figure 10. Vector extraction of buildings in Salt Lake City, Utah using lidar data and software provided by U.S. Army Rapid Terrain Visualization Group, Ft. Belvoir, Virginia (Kosovich, 2002).

Part II: Geologic Study- Lidar Survey of Mount St. Helens

In September 2003, the USGS acquired airborne lidar data of Mount St. Helens, Washington, in support of research for volcanic-hazard mitigation. These data were considered to provide an accurate high-resolution DEM base layer for documenting topography. Given the recent 2004 volcanic and seismic activity at Mount St. Helens, the lidar dataset is providing new opportunities for volumetric quantification of lava dome growth.

The Mount St. Helens lidar data were acquired under the Department of the Interior (DOI)'s, High Priority Digital Base Data collection program. The USGS cooperates with other DOI agencies to determine the most critical data needs each year. Once a priority has been established, the USGS contracts data collection, performs a quality assessment, and then distributes the data to its DOI partners. The USGS also translates the data into a standard USGS data format and makes the data publicly available.

As part of DOI's data-collection program, the USGS administers data acquisitions through a Cartographic Services Contract. The lidar data acquisition and processing was awarded to EarthData International in Gaithersburg, Maryland. The lidar specifications were for a bare-earth DEM with a maximum ground sample-point spacing of no more than 5 meters, a horizontal accuracy of 2 meters, a vertical accuracy of 18 centimeters, hydrographic enforcement, and the removal of bridges along the North Fork, South Fork, and main stem of the Toutle River. Given the importance of ensuring a high-accuracy DEM of Mount St. Helens for monitoring volcanic activity, hazard mitigation, and other purposes, rigorous ground surveys were performed to quality-check the lidar data (Figure 11). The U.S. Bureau of Reclamation survey office in Ephrata, Washington, in collaboration with the USGS Northwest Geographic Science Office in Seattle, collected more than 500 survey-grade points for use in the lidar data-quality assessment. The GPS ground-survey methods that were used had a probable error of less than 3 centimeters per point. These survey points were instrumental during the data quality assessment, which established a root-mean-square (rms) vertical accuracy of less than 18 centimeters for the Mount St. Helens lidar dataset.

Figure 11. Tim Casey, a Bureau of Reclamation surveyor, sets up a Global Positioning System real-time kinematic base station near Mount St. Helens, Washington (Queija, 2003).

The bare-earth lidar terrain dataset is helping USGS scientists to document Mount St. Helens' latest volcanic activity. Researchers at the USGS Cascades Volcano Observatory, in collaboration with other USGS and NASA scientists, are utilizing the lidar dataset as a baseline to analyze surface-elevation changes within the crater as part of monitoring the volcanic unrest. Topographic changes between the 2003 survey and a second lidar survey by TerraPoint USA, Inc., on October 4 and 5, 2004, are being used to document volcano deformation with lidar for the first time (Haugerud et al., written commun., 2004). The high resolution of lidar data enabled researchers to visualize and quantify crater-elevation changes with high accuracy. They determined that the new area of uplift within the crater on October 4 was 110 m tall and 130,000 m^2 in area (the height of a 35-story building and the area of 29 football fields). Additional lidar datasets, including those obtained on September 24, September 30, and October 14, 2004, by Sky Research, are being used to document the growth of the new lava dome at Mount St. Helens (Haugerud et al., written commun., 2004). With this DEM time series, USGS scientists are able to determine the rate of growth of the dome. In addition, they are using the lidar-derived DEMs to model volcanic processes and hazards. Color maps depicting elevation changes within the crater, animations, and flythroughs can be downloaded from the USGS Web site at URL http://vulcan.wr.usgs.gov/Monitoring/LIDAR/.

Lidar data for Mount St. Helens are publicly available through the National Elevation Dataset at URL http://seamless.usgs.gov/ or through *The National Map* (URL http://nationalmap.gov/) for order or download as 1/9-arc-second-resolution raster data.

Conclusion

While these are just a few of the many lidar projects being performed by the USGS, they show the amount of varied work in which this highly accurate data is being used. Collaborations within the agency as well as with outside partners has allowed for collection, processing, visualization, and application of this very valuable data. As data cost decreases, technology improves, and scientists' access to this type of data increases, then the more prevalent will become lidar research and applications projects in the USGS.

References

Brock, J., Wright, C.W., Clayton, T., and Nayegandhi, A. (2004). Optical rugosity analysis of coral reef status in Biscayne National Park, Florida: Coral Reefs, 23(1): 48-59.

Crane, M., Clayton, T., Raabe, E., Stoker, J., Handley, L., Bawden, G., Morgan, K., and Queija, V. Reprot of the U.S. Geological Survey lidar workshop sponsored by the Land Remote Sensing Program and held in St. Petersburg, FL, Novermber 2002. U.S. Geological Survey Open-File Report 04-106, 72 p. URL http://erg.usgs.gov/isb/pubs/pubslists/bulopenfile.html.

Gesch, D., Oimoen, M., Greenlee, S., Nelson, C., Steuck, M., and Tyler, D. (2002). The National Elevation Dataset. Photogrammetric Engineering and Remote Sensing, 68(1): 5-11.

"Gesch, 2004" (see fig. 2, p. 4; fig. 3, p. 5)

Kosovich, J., 2002. Mapping Characteristics of LIDAR and IFSAR. Symposium on Terrain Analysis for Water Resources Applications, December 16-18, 2002, Austin, TX.

URL http://www.crwr.utexas.edu/terrainAnalysis/abstracts.cfm

"Newton, 2004" (see fig. 9, p. 11)

"Queija, 2003" (see fig. 1, p. 2; fig. 10, p. 12)

"Queija, 2004" (see fig. 4. p. 6)

Osborn, K., List, J., Gesch, D., Crowe, J., Merrill, G., Constance, E., Mauck, J., Lund, C., Caruso, V., and Kosovich, J., (2001). National digital elevation program (NDEP), chap. 4 of Maune, D., ed., Digital Elevation Model Technologies and Applications: The DEM Users Manual. Bethesda, MD, American Society for Photogrammetry and Remote Sensing, p. 83-120.

Stoker, J.M. (2004). Voxels as a representation of multiple-return lidar data. Proceedings of ASPRS Annual Conference, Denver, CO, 2004. CD-ROM.

Authors

Vivian R. Queija, U.S. Geological Survey, 909 First Avenue, Suite 900, Seattle, WA 98104, vqueija@usgs.gov

Jason M. Stoker, U.S. Geological Survey EROS Data Center / SAIC, 47914 252nd St, Sioux Falls, SD 57198 jstoker@usgs.gov

John J. Kosovich, U.S. Geological Survey Rocky Mountain Mapping Center, PO Box 25046, MS-516, Denver, CO 80225, jjkosovich@usgs.gov