LIDAR MAGAZINE

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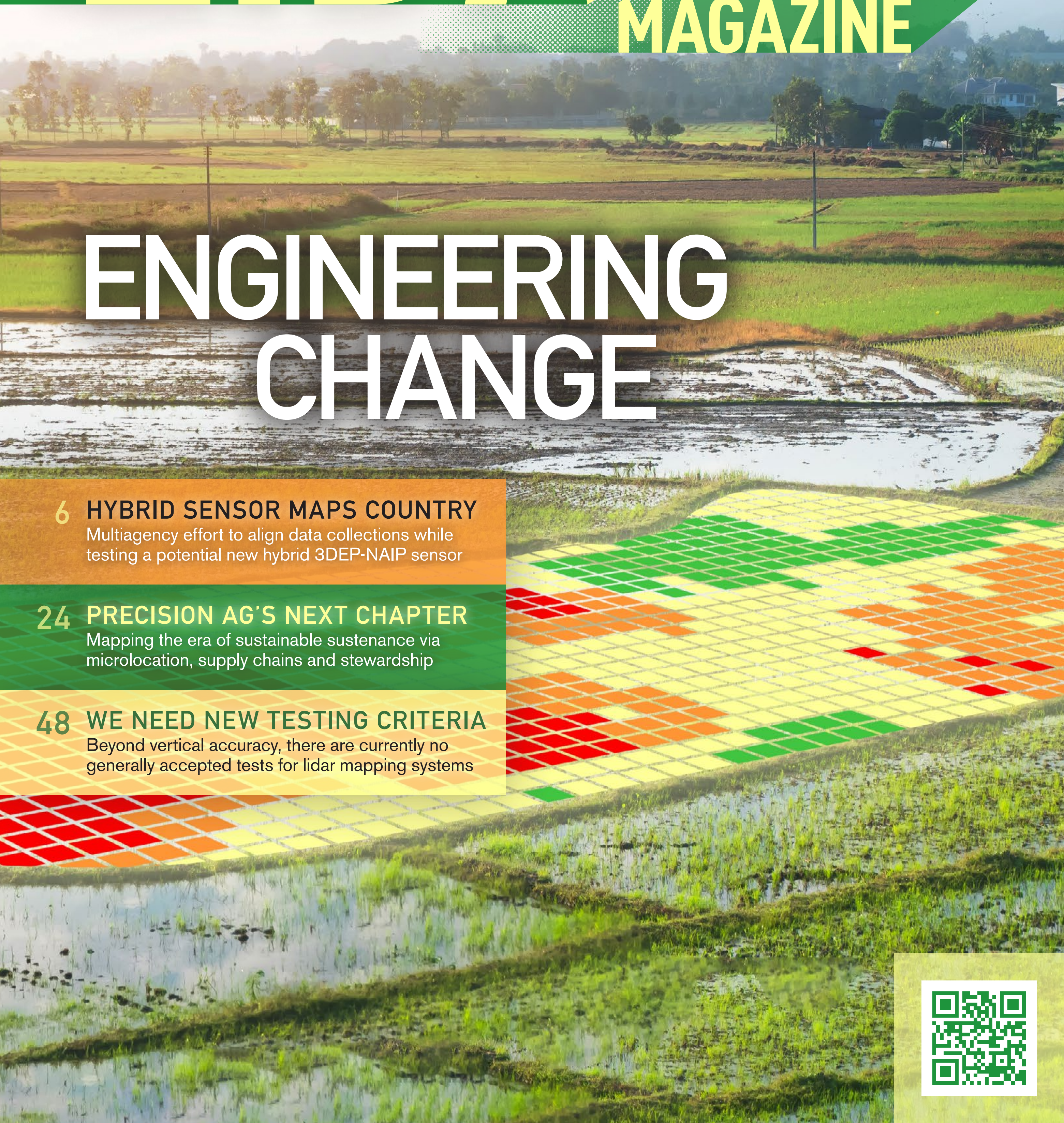
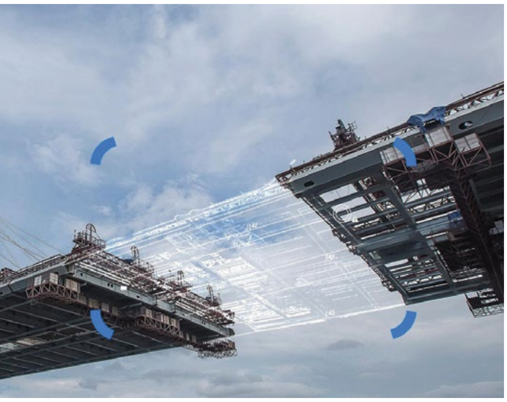
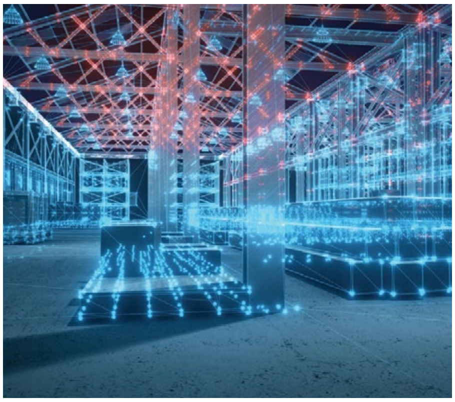
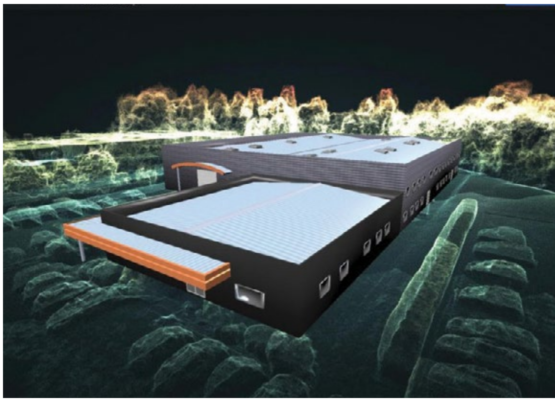


ENGINEERING CHANGE







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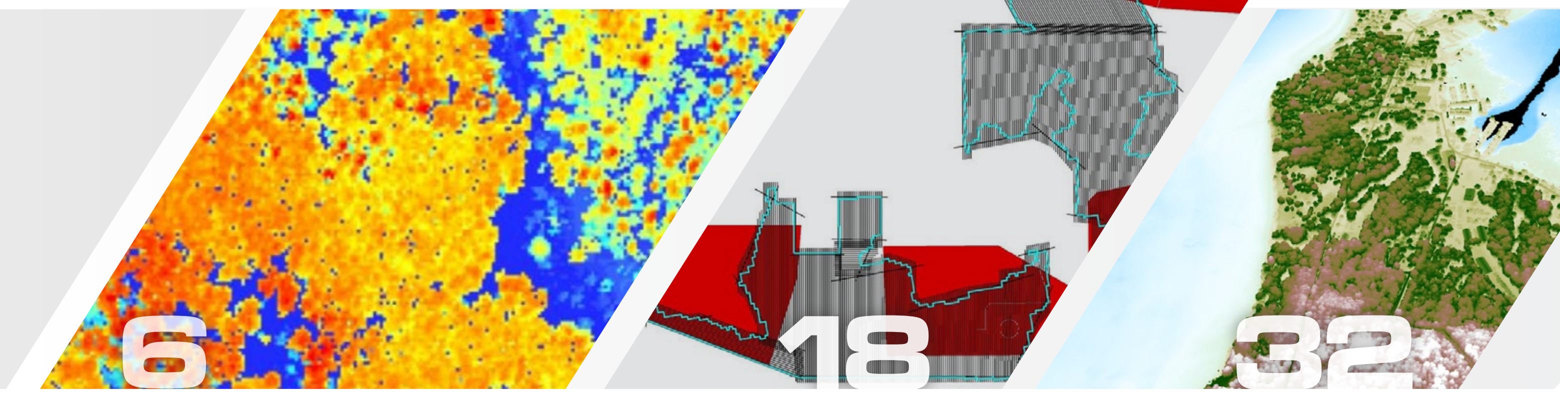

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COLUMNS

◀ **ON THE COVER**
Near-infrared (NIR) images used to create field maps using the normalized difference vegetation index in field rice.

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FROM THE EDITOR

DR. A. STEWART WALKER

Back on the Road

Growing anticipation of face-to-face events

Sometimes I wonder, sitting in my office enjoying the sunset through the California palms, whether it is such a blessing to be back on the road. Those words, of course, belt out the name Kerouac. His view was, "They have worries, they're counting the miles, they're thinking about where to sleep tonight, how much money for gas, the weather, how they'll get there—and all the time they'll get there anyway, you see." I don't think he meant the frequent flyer miles or hotel points. I've written on our digital site about my travels in the Bay Area[1] and to Redlands for the Esri Imagery Summit[2]. I have another trip in the making before the end of the year, but, like many readers, I'm eagerly anticipating the big events of 2022 and hoping they take place face-to-face or hybrid:

Geo Week[3]	Denver	February
XXIVth ISPRS Congress	Nice	June
HxGN Live	Las Vegas	June
Esri International User Conference	San Diego	July
Commercial UAV Expo	Las Vegas	September
Photogrammetric Week	Stuttgart	September
Intergeo	Essen	October
Trimble Dimensions+	Las Vegas	November

I won't rewrite my digital site piece on the Esri Imagery Summit here. Suffice it to say that it was two intense days of well-prepared presentations and discussions. The audience was an eclectic group of 80 with around 1000 remote. It crossed my mind that the sparse audience in the beautiful auditorium in Esri's Q building (which reminded me of the lecture hall in Stuttgart used for the Photogrammetric Week, with its brutalist juxtaposition of wood and concrete) encouraged more uninhibited questions than if it had been full; we forgot that also listening was a big online audience! While the program included numerous updates from Esri experts, the enduring take-home is the daunting role that we geospatial folk are destined to play as we try to save our planet. We are now sitting at the "adult table", i.e. we've come beyond being enablers through the supply of geographic information—we have to do our utmost actually to engineer change. There is consensus also—and,

1 lidarmag.com/2021/09/14/green-green-my-valley-now/
2 lidarmag.com/2021/11/08/esri-imagery-summit-in-redlands/
3 One of the highlights of Geo Week will be the presentation of the Lidar Leader Awards. See gisuser.com/2021/09/2022-lidar-leader-awards-program-announced/

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FROM THE EDITOR

as I write I am reading headlines about the goings on at COP26 in my home city of Glasgow (typical November days there, unfortunately, don't bring global warming to mind)—that the broader world agrees with Jack Dangermond when he said, at the end of his plenary at the 2021 Esri International User Conference, online, this summer, "It's late in the day, but not dark yet". If we act responsibly and fast, we can probably turn things round. There will be terrible depredations as climate events intensify for years to come, but the planet and the human race will survive. Or, indeed, we could call it a day and continue to indulge our love of fossil fuels and various environmentally unfriendly foods and beverages…

The ability of this magazine to bring you up-to-date, relevant articles about lidar and its applications continues to draw on a fruitful relationship with ASPRS. We give opportunities to presenters at ASPRS events to publish with us if they don't want to go down the peer-reviewed route offered by *Photogrammetric Engineering & Remote Sensing*. There is an excellent account in this issue of a new sensor from Leica Geosystems (part of Hexagon) by ASPRS president Jason Stoker and colleagues from USGS, USFS and the Department of Agriculture. This was first given at the online ASPRS 2020 Annual Conference. Charlene Sylvester of USACE enlightens us on mapping the shorelines of the Great Lakes, a presentation first given at a meeting of the ASPRS Eastern Great Lakes Region event entitled "Technology Impacts: What's Next in Mapping?". Thirdly, Al Karlin's article is a backgrounder to and synopsis of the first session of the spring Lidar Workshop given jointly by the ASPRS Florida Region and the University of Florida, the 10^{th} instantiation of this event. This took place in June and further articles are in the pipeline. Since then, these organizers have run both a SAR and the 11^{th} lidar workshop. We have articles from the former being processed and from the latter, being solicited.

We have two articles on very different lidar sensors. Christopher Dollard from Leica Geosystems describes a real-estate application of the Leica BLK2GO handheld laser scanner. Matt Bethel and Andrew Moller recount the experiences of a joint venture of Merrick and Surdex flying the Teledyne Optech G2, a combination of two Galaxy high-end topographic lidar sensors in the same crewed aircraft.

We round off the issue with an article from Charlie Magruder and Matthew Harman of Esri, which gives an overview of the state of the art in precision agriculture with a focus on sustainability. We hope that this is the first of a long series of articles from Esri and its customers, several of which are already being planned.

I want to say a word of thanks to our regular contributor Lewis Graham. How he finds time to contribute something of substance to every issue of this magazine while fulfilling his duties as president and CEO of GeoCue remains a mystery to me, but we're certainly grateful to him. In this issue, he addresses the problem of satisfactorily characterizing the comparative performance of different UAV-lidar sensors.

As always, I like to end with something from the press. In these troubled times, it's not inappropriate that the setting is defense. The US Army, it is reported[4], is spending $22b with Microsoft to equip soldiers with augmented reality goggles, a ruggedized version of the Hololens with significant enhancements. Naturally, there is a FLA (four-letter acronym): IVAS (Integrated Visual Augmentation System). The user will see intelligence information projected into the field of view and the system will remain "locked to the real world", because it is also equipped with sensors to detect the surrounding environment. Center stage are lidar and machine-vision software that perform the operation within the seven milliseconds before dizziness sets in. It's impressive—and other military agencies are looking hard at it. What will be next—contact lenses? Meanwhile, but not yet on sale in the US, Chinese automakers are proud that their new models have built-in lidar sensors[5]. More on automotive lidar developments soon.

Recently we published Howard Butler's fine obituary of Martin Isenburg[6]. We hear, thankfully, that interested parties are in talks to try to continue the activities of Martin's company, rapidlasso GmbH, so that his customers' needs are met and the priceless intellectual property he left behind is preserved and used. The strength of the lidar community shines like a lighthouse.

A. Stewart Walker // Managing Editor

4 Anon, 2021. The future of warfare: through a shimmering looking glass, *The Economist*, 440(9264): 69-70, 25 September 2021.

5 For example: caranddriver.com/news/a35179754/nio-et7-ev-sedan-china/; techcrunch.com/2021/04/13/xpeng-lidar-adas/.

6 lidarmag.com/2021/10/30/in-memoriam-martin-isenburg-1972-2021/.

MOBILE MAPPING

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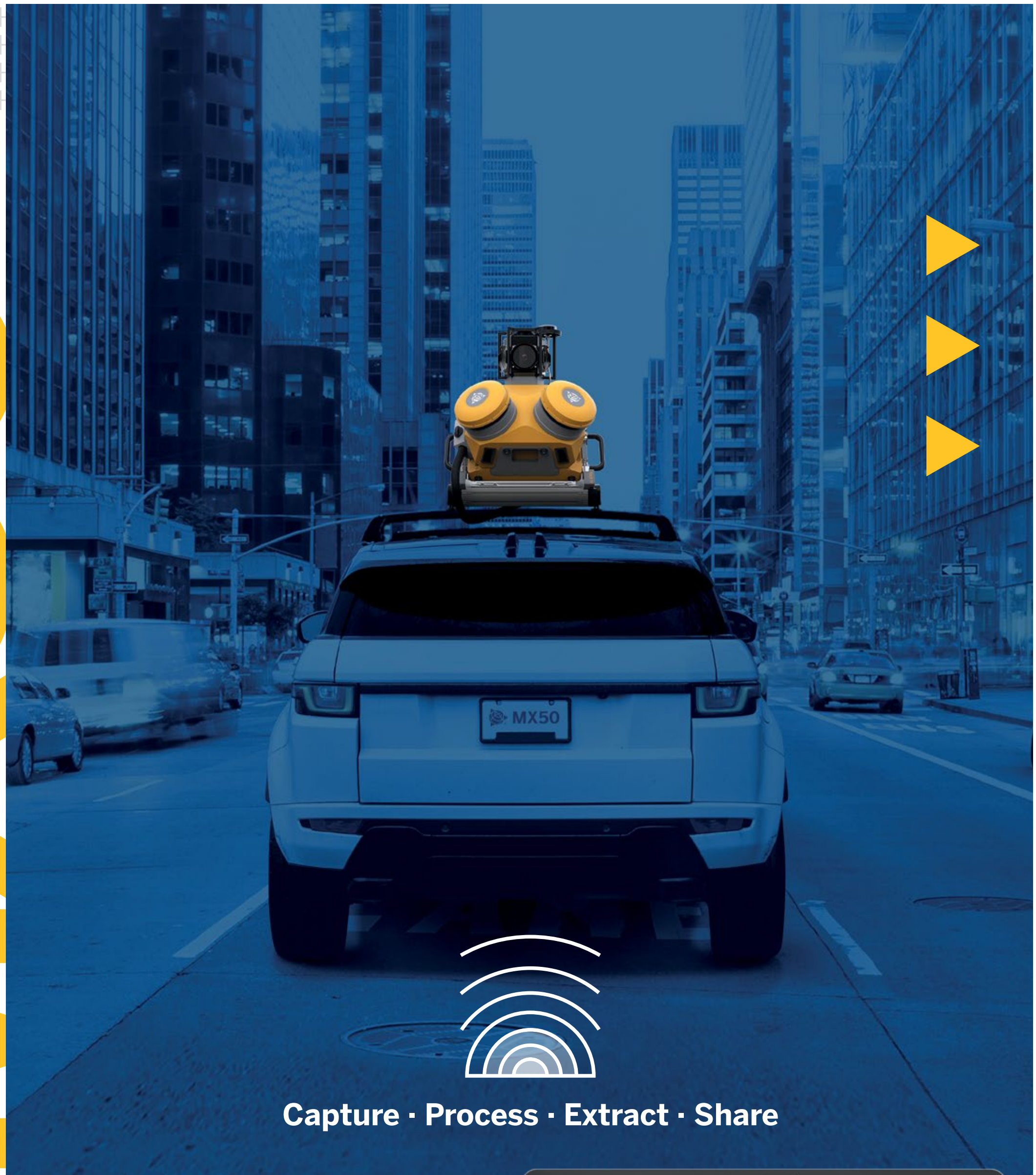

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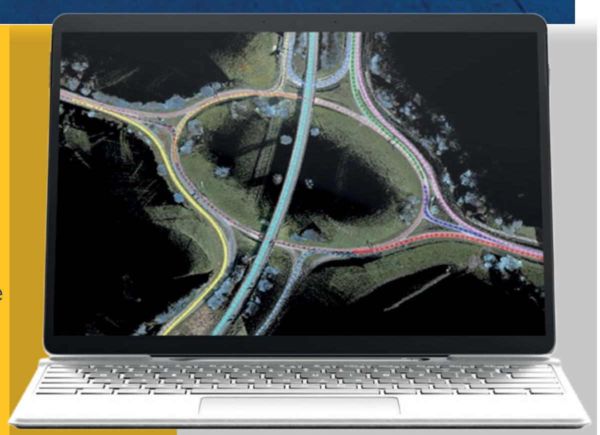

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Airborne Hybrid Sensor Maps the Country

Multiagency effort to test a potential new hybrid 3DEP-NAIP sensor

The 3D Elevation Program (3DEP) is a partnership program with many state, local, and Federal partners, managed by the U.S. Geological Survey (USGS) to respond to growing needs for high-quality topographic data and for a wide range of other three-dimensional (3D) representations of the natural and constructed features in the U.S. 3DEP informs critical decisions that are made across the nation every day that depend on elevation data, ranging from immediate safety of life, property, and environment to long-term planning for infrastructure projects. Our goal is to complete acquisition of nationwide lidar (IfSAR in Alaska) by 2023 to provide the first-ever national baseline of consistent high-resolution elevation data – both bare earth and 3D point clouds – collected in a timeframe of less than a decade. The first full year of 3DEP production began in 2016 and by the writing of this article almost 78% of the nation has elevation data available or in progress that meets 3DEP specifications for high accuracy and resolution. 3DEP must also continue to look forward to the challenges of completing nationwide coverage and meeting growing needs for higher quality data, repeat coverage, and new products and services.

The National Agriculture Imagery Program (NAIP) acquires aerial imagery during the agricultural growing seasons in the continental US. A primary goal of NAIP is to make digital orthophotography available to governmental agencies and the public within a year of acquisition. NAIP is administered by the Farm Service Agency (FSA) of the U.S. Department of Agriculture (USDA) through the Aerial Photography Field Office (FSA-APFO) in Salt Lake City, Utah. This “leaf-on” imagery serves as a base layer for GIS programs in FSA’s County Service Centers

Figure 1: Location of AOIs.

BY JASON **STOKER**, APARAJITHAN **SAMPATH**, MINSU **KIM**, JEFF **IRWIN**, ERIC **ROUNDS**, JOSH **HEYER**, JULIE **DAVENPORT**, GABE **BELLANTE**, TONY **KIMMET**, COLLIN **MCCORMICK** AND JOHN **MOOTZ**

Figure 2: USFS researchers collecting field data.
Credit: Gabe Bellante

and is used to maintain the Common Land Unit (CLU) boundaries.

These two Federal programs, with their distinct needs and goals, have been discussing how to align data acquisitions for potential cost savings. Both NAIP and 3DEP members had been contacted about the potential of a new sensor, the Leica CountryMapper from Leica Geosystems, part of Hexagon[1], to collect imagery and lidar simultaneously for both NAIP and 3DEP. The Leica CountryMapper sensor is currently in development and its specifications are not yet publicly available; but it has been claimed to have the potential to collect data that satisfies both 3DEP and NAIP requirements in a single collection. The Leica CountryMapper is a hybrid sensor that collects imagery and lidar data simultaneously, based on the lidar system from the Leica TerrainMapper and the camera system from the Leica ADS100. This pilot project was designed to help 3DEP determine if this sensor has the potential to meet current and future 3DEP topographic lidar collection requirements, ideally at the same altitudes and leaf-on times that NAIP is flown. The field surveys were performed to evaluate the 3D absolute and relative accuracy of the airborne Leica CountryMapper lidar and to determine if the data met 3DEP specifications.

To test the claims that a sensor could meet both NAIP and 3DEP requirements simultaneously, a multiagency group consisting of USGS, FSA, the USDA Natural Resource Conservation Service (NRCS), Bureau of Land Management (BLM), National Park Service (NPS) and U.S. Forest Service (USFS) began working together to analyze a single collection for the various needs. NAIP was confident about the sensor's ability to meet its imagery needs, so the focus of this study was on the quality and characteristics of the resultant lidar.

The airborne data acquisition for this pilot project was funded by the NRCS National Geospatial Center of Excellence (NGCE) as an add-on to the NAIP acquisition, working with FSA-APFO, now part of the Farm Production and Conservation (FPAC) office. These USDA agencies collaborated to plan and execute the pilot project. Early on, USDA reached out to USGS, USFS, BLM, NPS, and other Federal 3DEP partners to guide and support the project with technical expertise and field work. The latter is a crucial component of the pilot project, enabling the comparison of ground observations with measurements from the remotely sensed imagery and lidar.

This paper discusses the various methods different agencies used to evaluate the same dataset and presents some results. It is our hope that in the future a multiagency evaluation approach to test multiple needs from a single dataset will become more commonplace.

Site selection

Two pilot areas of interest (AOIs) were selected to be flown in north-central Colorado over two different physical settings in order to evaluate the system's performance (**Figure 1**). The western AOI included land managed by BLM, NPS and USFS. The forested land in the western AOI primarily consists of a mixture of lodgepole pine, quaking aspen, Engelmann spruce and subalpine fir. The mountain pine beetle had a devastating impact on the forest, killing many of the lodgepole pines and leaving many of them standing dead or downed. The eastern AOI included agricultural and urban areas.

Hexagon acquired data for this project, operating at an altitude of 3.6 km, a speed of 180 knots, a pulse repetition frequency of 750 KHz and a scan rate of 112 Hz, giving an imagery product of 20 cm ground sample distance and a pulse density of 2.9 points

1 Any use of trade, firm, or product names is for descriptive purposes only and does not imply endorsement by the U.S. Government.

per square meter (ppsm). Its elliptical scan pattern allowed for the separation of the point cloud into forward and backward scanned groups, which enabled intraswath difference analysis.

USFS analyses

The objectives of USFS for analyzing data from the sensor included: 1) evaluate the quality of the lidar data to see if it meets Lidar Base Specification Quality Level 2 (QL2) density specifications (2 ppsm); 2) assess the quality of standard forestry derivatives, such as canopy height and cover rasters; and 3) collect field data and test the efficacy of using these data for forest inventory modeling.

USFS analyzed the Leica CountryMapper data for the western AOI alongside lidar that was previously collected in 2010 in Grand County, Colorado. It derived canopy height (1-meter) and cover (10-meter) rasters from both datasets using USFS FUSION software (version 3.80), then compared the quality of the outputs and interpreted the changes that occurred between 2010 and 2019. Three USFS researchers spent four days collecting 28 forest inventory plots. Field measurements included plot center locations at sub-meter accuracy and individual tree measurements including tree species, diameter, live/dead status, and tree height samples (**Figure 2**). USFS used these field data in combination with the lidar data to create linear regression models for a total of nine forest inventory metrics (Mitchell *et al.*, 2015; Tenneson *et al.*, 2018).

Based on analysis by USFS, the density and vertical distribution of the 2019 Leica CountryMapper point-cloud data appeared to be an improvement over the 2010 Grand County data. **Figure 3** shows a side profile view of a mixed conifer forest, illustrating the higher point density of the Leica CountryMapper data, which results in a better representation of individual trees and understory vegetation.

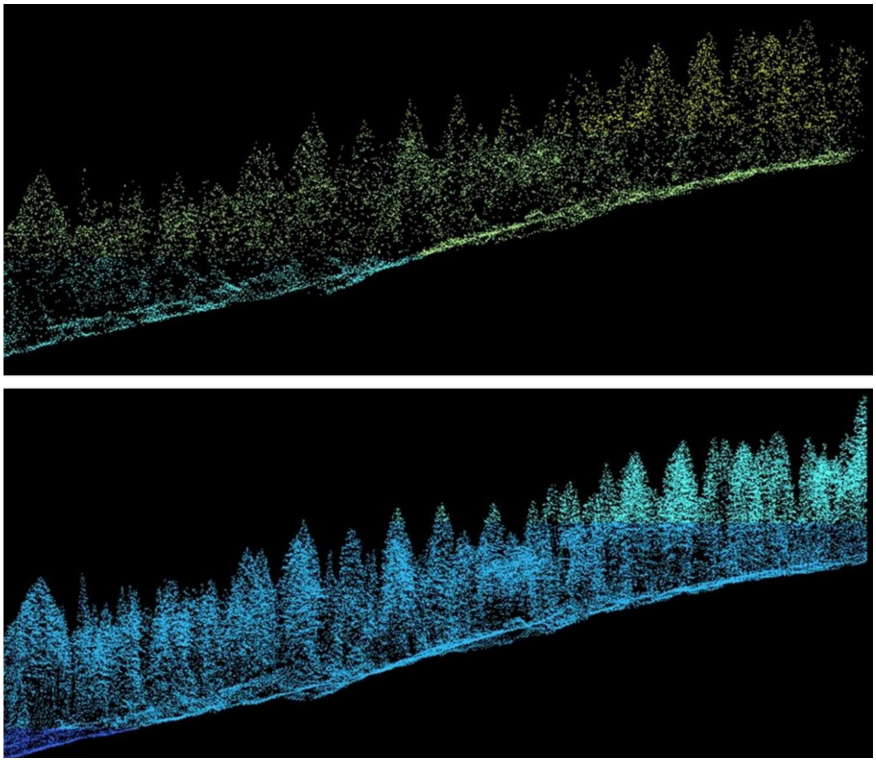

Figure 3: A profile comparison of the 2010 Grand County lidar data (top) and the 2019 Leica CountryMapper data (bottom).

To evaluate the pulse density of the Leica CountryMapper data, USFS produced first-return rasters at two different scales: cell sizes of 1 m and 10 m. For both approaches, the Leica CountryMapper data met or exceeded 2 ppsm, with 99.5% of cells at the 10-m scale and 97.7% at the 1-m scale meeting that threshold. We found that the average first-return pulse density was approximately 5.36 ppsm.

In addition to evaluating point-cloud density, USFS assessed the quality of canopy height and cover rasters derived from the Leica CountryMapper data. These datasets are commonly used in USFS to inform applications such as tree-stand delineation, habitat mapping, and canopy gap analyses. The 2019 Leica CountryMapper canopy height raster, shown on the right-hand side of **Figure 4**, represents the above ground height of all objects in the study area and captures the detail of individual tree crowns. In **Figure 4**, the 2010 and 2019 rasters look very different because of the extensive lodgepole pine mortality throughout the study area. The upper right portions of the images in **Figure 4** are mainly lodgepole pine, and their narrow crowns in the 2019 image are characteristic of the mountain pine beetle damage in this area. The trees that have largely remained the same are aspen: they are tall, with relatively large crowns, and

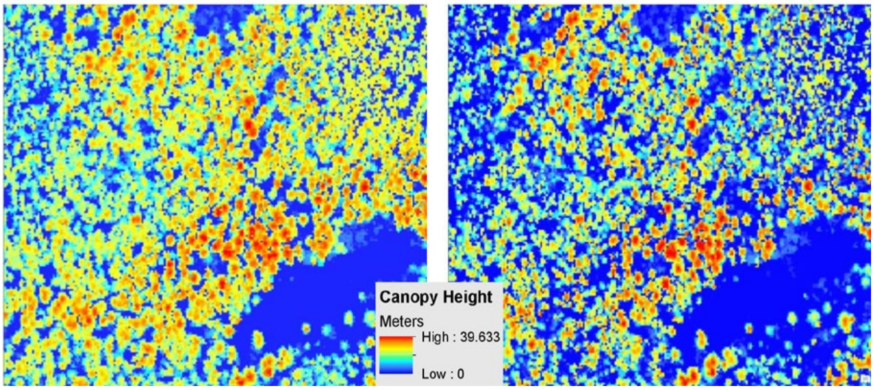

Figure 4: 1-meter canopy height raster from 2010 data (left) and 2019 Leica CountryMapper (right).

can be seen throughout the middle and upper left of both images. In this area, the Leica CountryMapper data appears to represent high-quality canopy height information, as individual crowns are distinguishable and many small-diameter tree crowns are captured in the raster.

Figure 5 juxtaposes the 2010 and 2019 canopy height raster data in a dense aspen stand. In both years, individual aspen crowns are hard to distinguish because the trees have similar heights and the canopies are very tightly knit. The 2019 raster has more gaps within the aspen canopy, which could represent natural gaps during the growing season, or gaps because the data were collected around the time that leaves start falling from aspen stands at this elevation (~9160 feet). The dieback of lodgepole pines, located on the right side of the figure for both years, is also evident in the canopy height data.

Figures 6 and 7 show a zoomed-in view of the 2010 and 2019 canopy cover rasters. Based on a qualitative assessment, the canopy cover values are reasonable, capturing both densely and sparsely forested areas well. Moreover, there are no obvious, widespread acquisition artifacts in the 2019 raster. Such artifacts are related to the variable point density from different flight and scan lines rather than real patterns on the landscape and would appear as parallel lines in the data. These artifacts are relatively common in acquisitions not collected with the flight line overlap specifications that are ideal for forestry derivatives.

Figure 8 shows the differenced canopy cover raster that was created by subtracting the 2010 from the 2019 canopy cover raster. The positive values in red represent areas where the 2019 canopy cover percent was higher than 2010. Conversely, the negative values in green represent areas where 2010 canopy cover percent was higher than 2019. The red pixels are largely associated with areas of forest growth where the trees were below 2 m in height in 2010. The distinct patches of green are primarily associated with lodgepole mortality: the trees in those patches appear dead in the 2010 imagery, and many of them had fallen or been cut down by 2019.

The final component of the USFS analysis was linear regression modeling of forest inventory metrics, including basal area and board foot volume, two metrics that are not directly measurable from a lidar point cloud. USFS produced a total of nine forest inventory rasters for the entire western AOI, most of which had statistically significant R^2 values greater than 0.60 (see **Table 1**). **Figure 9** shows results for the merchantable cubic foot volume and basal area models, which were modeled with R^2 values of 0.82 and 0.71 respectively. Despite the limited number of plots collected and a non-rigorous sample design for the field plot placement, the results of the USFS analysis were very promising. The forest inventory models largely had high R^2 values and a qualitative comparison of the modeled data with NAIP showed good correspondence in relative values of the modeled data with the differences in forest density apparent in the NAIP imagery.

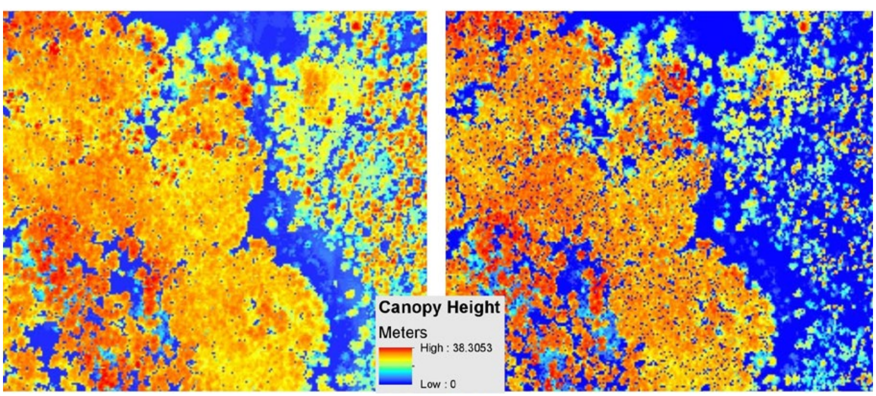

Figure 5: 1-meter canopy height raster from 2010 data (left) and 2019 Leica CountryMapper (right).

Overall, USFS determined that the data exceeded QL2 density specifications at both the 100-m² and 1-m² scales. Nearly 98% of pixels in the 1-m² pulse density assessment met the 2-ppsm threshold, indicating a consistency in pulse density across the study area. The lidar-derived canopy height and cover rasters are suitable for a wide range of forestry applications. The canopy cover values aligned well with 2019 NAIP, and the data showed no prominent acquisition artifacts, which appear as stripes in rasters and are relatively common in acquisitions without 100% flightline overlap. Similarly, the canopy height data appear to be high quality, although the level of detail in individual crowns, particularly in densely forested areas, could be improved. Crown dimensions in some of the dense aspen stands appeared lacking, but this may be due to the tightly knit canopies and similar heights of those stands.

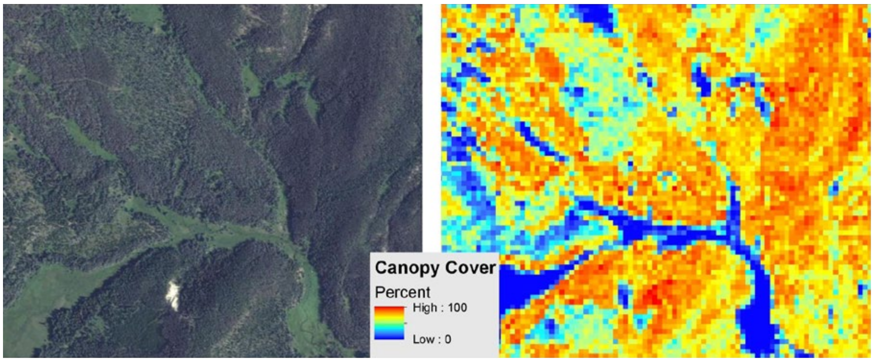

Figure 6: 2010 NAIP (left) and 2010 canopy cover (right).

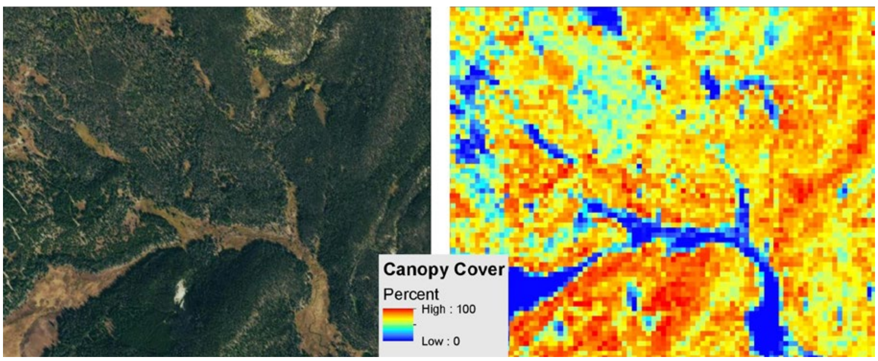

Figure 7: 2019 NAIP (left) and 2019 canopy cover (right).

While the number and locations of sample plots were not ideal, the forest inventory modeling results from this project demonstrate the efficacy of using the Leica CountryMapper data to model forest inventory parameters that are not directly measurable from the point cloud. Even with the limited number of plots collected and the less than ideal plot placement, models performed relatively well. Basal area and quadratic

Response Variable	Linear Model Equation	R^2
Standing Wood	Elev.P25 + Elev.P75 + Elev.maximum + All_1st_cover_above2m	0.83
Merchantable cubic foot volume	*Elev.L1* + *Elev.P75* + *Elev.skewness* + *All_1st_cover_above2m*	0.82
Average dominant height	*Elev.MAD.mode* + *Elev.kurtosis* + *Elev.P25* + *All_1st_cover_above2m*	0.74
Total basal area of live and dead trees	*Elev.P75* + *Elev.P99* + *Elev.skewness* + *All_1st_cover_above2m*	0.71
Quadradic mean diameter	*Elev.L4* + *Elev.P25* + *Elev.CV* + *All_1st_cover_above2m* + *Percentage.first.returns.above.mean*	0.70
Total cubic foot volume of trees	*Elev.P25* + Elev.P99 + *All_1st_cover_above2m*	0.69
Crown competition factor	*Elev.L1* + *Elev.L3* + *Elev.kurtosis* + *All_1st_cover_above2m*	0.65
Stand density index	*Elev.L2* + *Elev.CV* + *All_1st_cover_above2m*	0.58
Total Biomass	*Elev.L1* + *Elev.L4* + *Elev.CV* + *All_1st_cover_above2m*	0.34

Table 1: Forest inventory models were generated for nine metrics using linear equations. The statistical significance is reported for each model in R^2 values. Response variables are included in the left column, and the predictor variables are italicized (e.g. *Elev.P25*) in the middle column. For each equation, the predictor variables are a combination of height, cover/density, and data distribution metrics derived from FUSION's GridMetrics tool (http://forsys.cfr.washington.edu/fusion/fusion_overview.html).

mean diameter models, metrics commonly used by foresters and timber crews throughout the USFS to describe forest stocks, performed well, with R^2 values of 0.71 and 0.70 respectively. The biomass (R^2=0.34) and board foot volume (R^2=0.54) metrics performed poorly, however, which may be due to a few factors, including the high levels of mortality in the study area, the accuracy of allometric equations for the study area, and the limited number of plots.

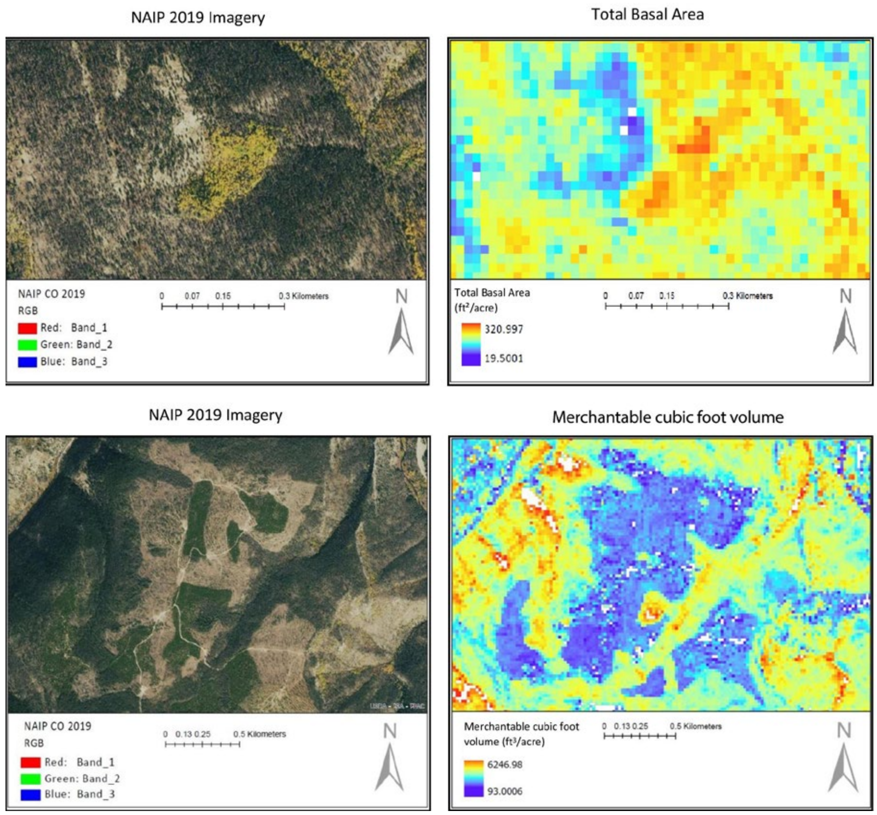

Figure 9: Examples of modeled basal area and merchantable cubic foot outputs juxtaposed with NAIP.

USGS analyses

Field data were collected by USGS in two different field campaigns. The first took place in the western AOI, near Granby, Colorado, on 8–11 September 2019. The second occurred in the eastern AOI, east of Fort Collins, Colorado, on 18–20 November 2019.

The western AOI included six field sites. Four were on land managed by BLM, where BLM had established seven field plots (**Figure 10**). One site was on land managed by USFS and one was at Windy Gap Wildlife Viewing Area. The eastern AOI included four field sites. The first consisted of two houses in the southeastern portion of Fort Collins, Colorado. The remaining sites were Chimney Park, Windsor Main Park, and Eastman Park, all within Windsor, Colorado.

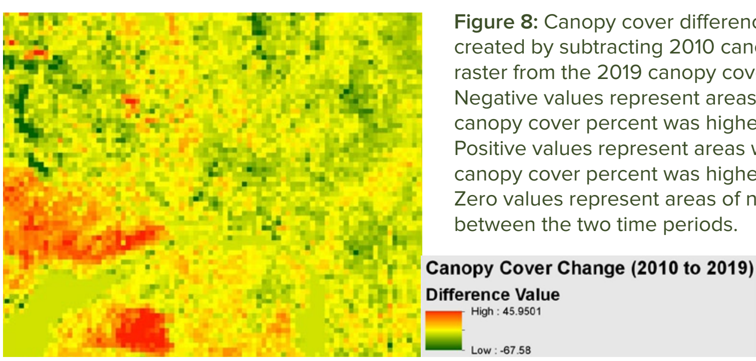

Figure 8: Canopy cover difference image created by subtracting 2010 canopy cover raster from the 2019 canopy cover raster. Negative values represent areas where canopy cover percent was higher in 2010. Positive values represent areas where canopy cover percent was higher in 2019. Zero values represent areas of no change between the two time periods.

USGS collected GNSS data using a Trimble R8 Model 2 base station with a TDL-450H external data radio, in combination with a Trimble R8 Model 2 rover and a Trimble R8 Model 3 rover. The Trimble GNSS equipment has a horizontal accuracy of ±1 cm plus 1 part per million (ppm) root mean square (RMS) 2 cm and a vertical accuracy of ±2 cm plus 1 ppm RMS 3 cm.

USGS also used an Optech ILRIS 3D laser scanner equipped with a pan/tilt base to conduct the terrestrial laser scans. The Optech ILRIS 3D has a raw range accuracy of 7 mm at 100 m and a raw positional accuracy of 8 mm at 100 m. It has a 40° x 40° field of view and scans at the near-infrared wavelength of 1535 nm. Using the pan/tilt base allows the scanner to capture up to 10 FOV scan sections, covering 360° horizontally with 2° of horizontal overlap on each end of a scan section. USGS also collected UAS data for analyses, but for the purpose of this article results are not included. All survey data were published, including the UAS data, and

Figure 10: Collecting data for western AOI site.

can be found at https://doi.org/10.5066/P9CPDWUU (Irwin *et al.*, 2020).

To investigate the quality of the data, USGS assessed absolute accuracy compared to survey ground data as well as absolute and relative accuracy tests using a new method that involves intraswath and interswath comparisons (Kim *et al.*, 2020). Assessing absolute vertical accuracy is a practical choice, because assessing horizontal accuracy is difficult with point cloud data. Checkpoints were surveyed in clear, open areas (which typically produce only single lidar returns) for non-vegetated vertical accuracy (NVA) assessment. Checkpoints for vegetated vertical accuracy (VVA) assessment were surveyed in vegetated areas, which typically produce multiple returns. Both the Root Mean Square Error $RMSE_Z$ and 95th percentile methodologies for NVA and VVA respectively are currently widely accepted in standard practice and have been proven to work well for typical elevation datasets derived from current technologies. Checkpoint survey areas were homogeneous and in areas of gentle slope (<10°).

Intraswath and interswath analyses are another category of accuracy analysis. Intraswath analysis utilizes point cloud data from a single swath. For instance, smooth surface precision measures the consistency of the elevation along a smooth planar object from a single swath, because surface precision is determined mainly by the laser ranging uncertainty and scanner stability. When two lidar swaths overlap and lidar point cloud features extracted from planar features of one swath are compared to the other, it is a relative interswath difference, and the RMS difference can be determined. Interswath overlap consistency reveals the fundamental quality of the lidar point cloud because it establishes the quality and accuracy limits of all downstream data and products. Boresighting or other calibration errors result in substantial interswath differences. USGS used a point cloud-based interswath difference method using geometric features (such as three-plane objects described below) in the overlapping area from two swaths to do the comparisons.

By finding planar surfaces (such as building roofs) with enough sampled points, we can generate a virtual plane through these points. A three-plane geometrical feature creates a unique intersection point at the top. An intersection point determined from a high-accuracy reference dataset over the same features (e.g. TLS) can be used to evaluate the accuracy of an airborne lidar point cloud, such as the Leica CountryMapper data. An intersection point can be computed for planes in both the airborne data and the reference data (**Figure 11**). The difference between two

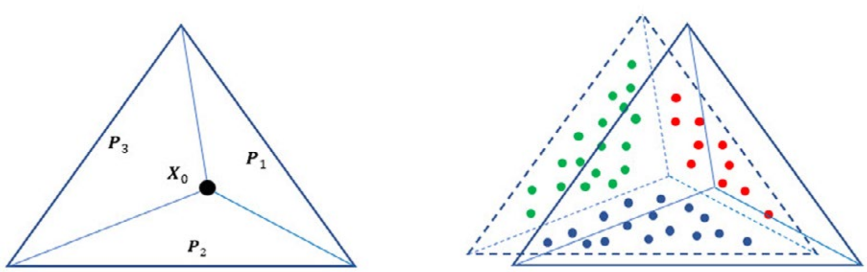

Figure 11: Lidar 3D absolute error based on three-plane intersection using least-squares regression. (a) Three-plane object from reference TLS data; (b) Airborne data with translational error only. The red, blue, and green dots are sampled points for planes P_1, P_2, P_3, respectively. From Kim *et al.* (2020).

intersection points represents the error between the two lidar point clouds in three dimensions. We call this the "generic three-plane" method. We tested this methodology comparing TLS data to the Leica CountryMapper data on the eastern AOI over several houses (**Figure 12**).

We found multifaceted roof objects, then calculated conjugate intersection points from the reference TLS data and from the airborne data. The differences gave error vectors (Dx, Dy, Dz) that were compiled into a table detailed by Kim *et al.* (2020), documenting the mean shift and RMSE for each axis. The mean shift along the X-axis is substantially large (~20 cm) when compared to the shifts along the Y-axis (7–8 cm) and the Z-axis (3–6 cm).

To evaluate intraswath smooth surface precision, USGS used a park office building in Eastman Park, Windsor, Colorado, as shown in **Figure 13**. The example point cloud from the roof plane marked by the yellow cross was sampled. The histogram of the normal distance to the plane is shown, with a RMSE of 2.2 cm. Of the 60 plane features extracted in the 3D absolute accuracy study, each yielded a smooth surface precision value, and the average was 2.5 cm.

The 2.2 cm RMSE intraswath smooth surface precision value (**Figure 13**) is excellent based on the USGS QL2 requirement (<6 cm). Very small intraswath differences between opposite scan directions were observed. Again, compared to USGS QL2 requirements (<6 cm), these results indicate there was minimal systematic error and the quality of the Leica CountryMapper boresighting was high. The differences between two intersection points in the interswath analysis (all 2 cm or less) were also very small, considering the USGS QL2 requirement (<8 cm).

USGS also performed NVA analysis of Leica CountryMapper lidar point clouds on three sites in the eastern AOI. The NVA mean was approximately 2 cm and the RMSE was less than 3 cm, which is also very low compared to the USGS QL2 requirement (<10 cm). Since the mean value (~2 cm) is computed by subtracting the lidar point elevations from the ground truth point elevations, it means that the airborne lidar data are approximately 2 cm lower than the GNSS-measured "true" elevation.

The VVA analysis of the UAS lidar data showed a reasonable mean shift and $RMSE_Z$. The negative VVA mean values are understandable because the lidar return from the low vegetation is a little bit above the ground surface where the survey pole would rest. The VVA mean values from airborne lidar ranged from -3 cm to -8 cm, depending on the BLM sites. The $RMSE_Z$ values were 3–5 cm, which is well within the USGS QL2 requirement (<10 cm).

Conclusion

Both USFS and USGS analyses of the Leica CountryMapper data show promising results. All the results appeared to satisfy the USGS QL2 requirements, although some of the point cloud vector-based methods presented here are new and are different from the raster-based methods suggested in the Lidar Base Specification. USGS used a novel 3D absolute accuracy assessment method, based on geometric features,

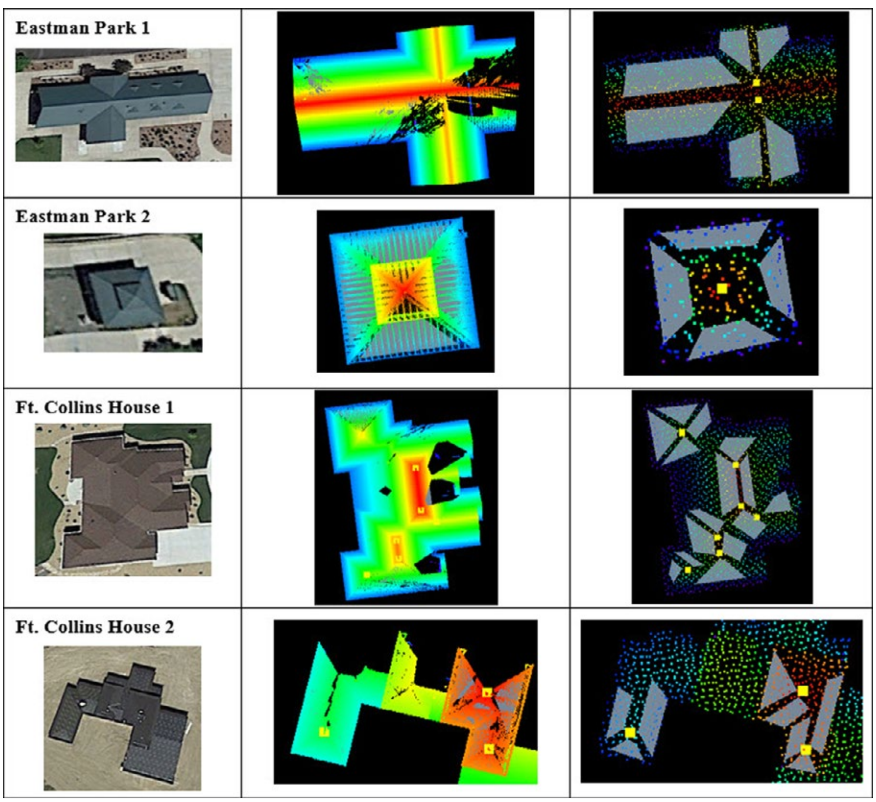

Figure 12: Demonstration of identifying conjugate points from multi-plane intersections from TLS data (center) and Leica CountryMapper data (right).

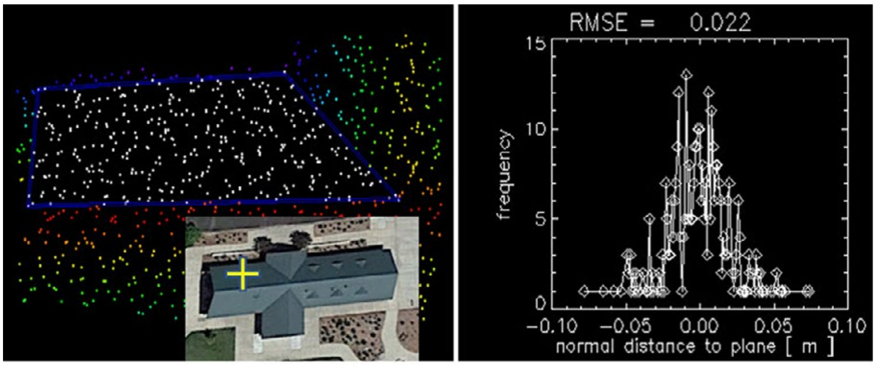

Figure 13: Testing smooth surface precision on one plane of a building roof.

as a potential future standard accuracy assessment practice. Despite some limitations, USGS demonstrated that the practice of assessing the 3D absolute accuracy of lidar point clouds was a viable option during the NAIP/3DEP campaign and will continue to work on improving ground-survey protocols. USFS found the Leica CountryMapper data to be suitable for producing a wide range of high-quality forestry rasters, including canopy height, canopy cover and more complex forest inventory models.

Remember that this pilot project was flown at altitudes to support 20-cm NAIP imagery collection, so no conclusions can be made about the claims of meeting 3DEP requirements from altitudes needed to collect 1-meter imagery for entire states. Also, while this pilot project did pass the test of collecting data leaf-on, these areas in Northern Colorado are sparse in terms of vegetation cover. We hope to attempt another pilot project in the future at higher altitudes over much denser vegetation.

By the time this article is published, many of the specifications of the sensor on which these analyses were based may be obsolete as sensor improvements are continuously being made. The methodology and division of labor to ensure that multiple Federal teams can investigate various requirements from a single dataset, however, provided a very useful exercise. In addition to ensuring that 3DEP technical requirements are met, substantial planning and coordination between agencies is still needed to determine if the technology can be made operational for 3DEP.

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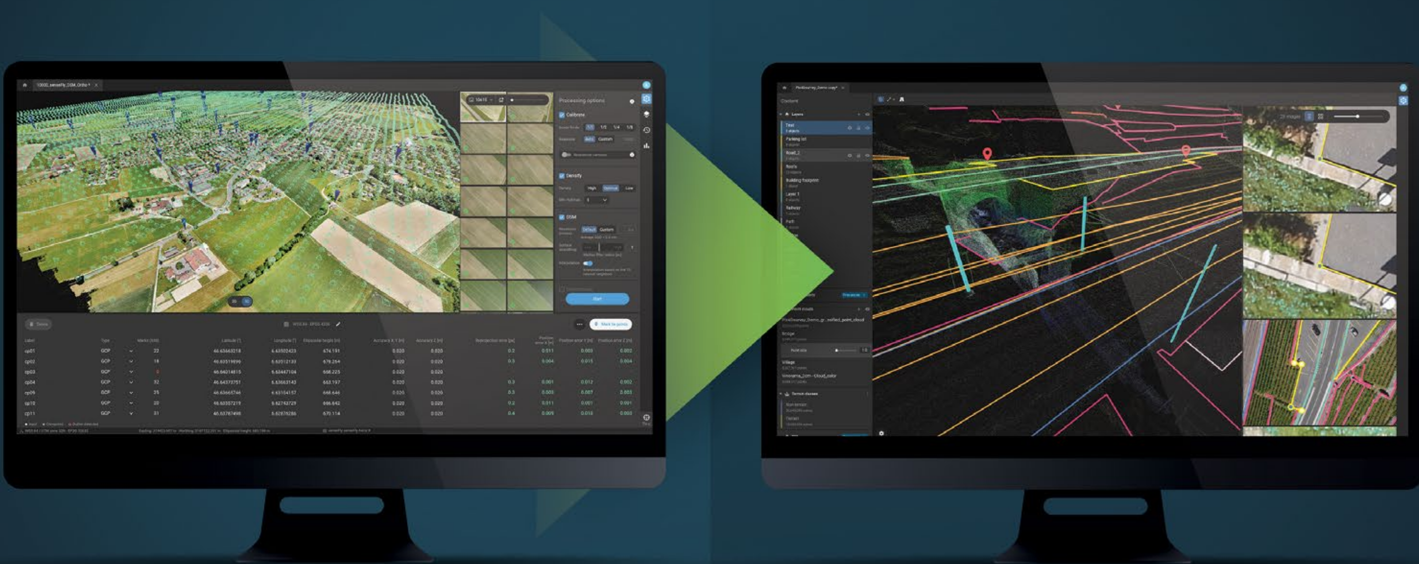
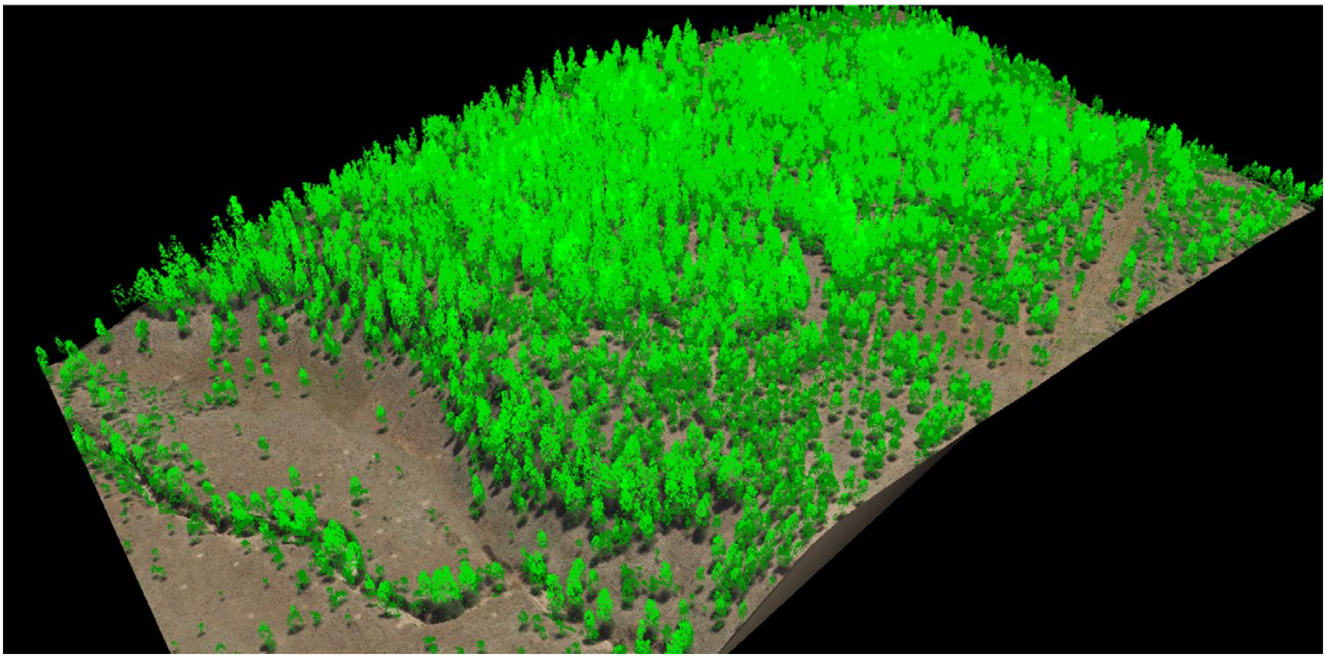


Tough Requirements Call for New Solutions

G2: A solution for difficult terrain, dense vegetation and restricted airspace



When the Merrick-Surdex Joint Venture (JV) saw the call for proposals for a US government 3DEP survey to deliver classified point clouds and lidar-derived forest biomass products in Arizona, they knew it would make for a challenging aerial survey.

As the 3DEP project moves westward toward the Rockies, terrain is getting more and more rugged. For this project, the terrain was four separate areas totalling 5000 square miles of mostly hilly desert with a surprising amount of vegetation (**Figure 1**). In addition, the survey requirements were for USGS QL1 data, which calls for relatively tight point density of 8 ppsm. This would be simple to achieve on the canopy itself, but the point spacing could suffer underneath the vegetation.

The westward trend of the 3DEP project presented another difficulty as more and more aerial survey areas contain special-use airspaces due to nearby military activities (**Figure 2**). Operators can fly such airspaces only at specific times, greatly complicating the flying calendar.

To tackle the terrain, vegetation, and restricted airspace, the Merrick-Surdex JV was eager to employ its Optech Galaxy ALTMs. Their SwathTRAK™ technology would maintain efficiency and point density in hilly terrain, while their small beam size would ensure

BY MATT **BETHEL** AND ANDREW **MOLLER**

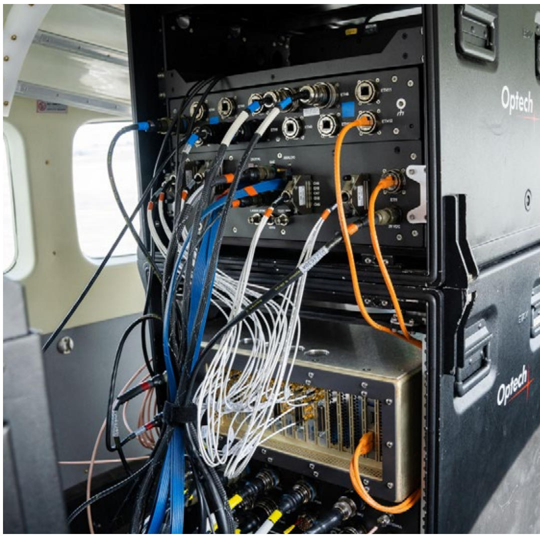


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Figure 1: The project site had considerable vegetation for a desert environment.

penetration of thick canopy, mapping both its vertical vegetation and the ground below it. Finally, the uniquely tough conditions called for an ultra-efficient approach, so Surdex, acting as the collection entity for this JV project, installed two of its Galaxy Primes into a G2 configuration aboard its Cessna 414A (**Figure 3**).

About the G2

In the G2 configuration, two Galaxy systems are installed on a single rigid platform supplied by Teledyne Optech. The dual system requires only a single aircraft hole of standard 19" size, even when integrated with two medium-format cameras. The sensors have a slight yaw rotation between them to make sure the scan lines are interleaved instead of phased atop of each other (**Figure 4**). Each Galaxy can be pitched to the user's choice of either 2.5° or 7° from nadir. This configuration guarantees resolution on vertical targets (such as trees) and a forward and backward pitch for the optimal resolution.

The systems function like a single sensor for the survey. A single flight plan is developed for both sensors at once, and the operator controls the sensors during the aerial survey with a single laptop.

Flight speed benefits of G2 and Galaxy

As noted above, the western movement of 3DEP reaches more areas that can only be flown during particular times. In this case, surveying the restricted areas could only be done on the weekends, so there was a need to accelerate the flight plan. By employing the dual-sensor setup of the G2, the Merrick-Surdex JV team managed to cut the flying time in half compared to a single sensor and the project duration

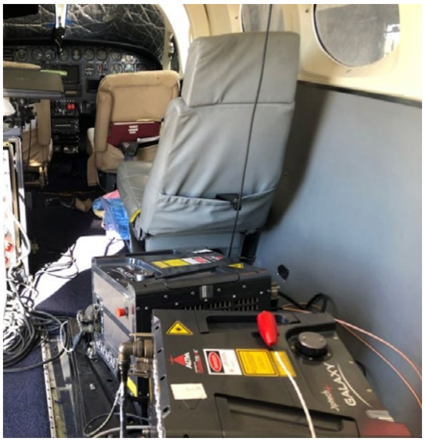

Figure 3: The Galaxy G2 installed in Surdex's Cessna 414A.

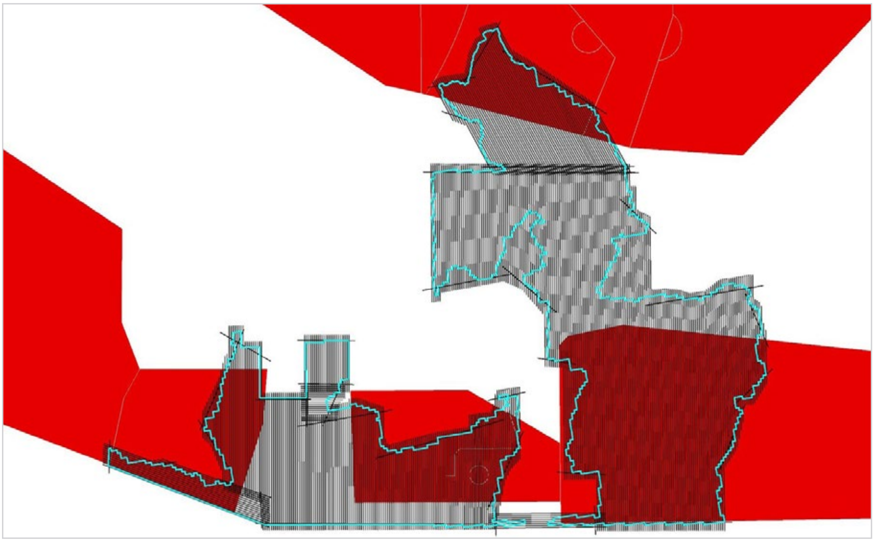

Figure 2: Restricted airspace (red) made it tricky to cover survey areas (blue outline) in a reasonable timeframe.

Figure 4: The G2 gives the Galaxy sensors slight relative rotations in yaw and pitch.

was decreased by several months (**Figure 5**).

The approach towards the Rockies is the other challenge as 3DEP progresses west. In contrast to the plains of the Midwest, the target areas are increasingly hilly. The project areas in Arizona were no exception. Such rough terrain often proves to be a problem for lidars with a fixed field of view, such as those with rotating polygonal mirrors. Flying over a valley widens the scan width on the ground and reduces the scan density; likewise, flying over a hilltop reduces the scan width on the ground, potentially causing gaps between lines. Operators can compensate for this by flying additional flightlines, but this increases the flight time—not an attractive option here given the restricted flying days.

Instead, the team decided to rely on the real-time dynamic FOV adjustments built into the Galaxy systems' SwathTRAK™ technology. As the elevation dropped, the Galaxy systems reduced their FOVs to keep the swath widths and point densities on the ground even. Likewise, as the elevation increased, SwathTRAK widened the FOVs to make sure that they still captured the required swath. In the experience of the Merrick-Surdex JV, this technology reduces the collection costs by up to 40% in sufficiently rough terrain.

Multi-look surveying

Just because 3DEP is heading west, the vegetation is not necessarily lighter. This particular project contained fairly heavy scrub with occasional outbreaks of evergreen forest, and the client required an analysis of the vegetation. In this case, it helped that the G2 sensors were configured with a 7° pitch in opposite directions. Thus one sensor could scan up the front of each vertical surface while the other surveyed down the back of it, resulting in improved vertical fidelity and canopy penetration through the foliage.

They decided to expand on this benefit further by increasing the sidelap between adjacent flightlines to 55%. The flight area, therefore, was covered four times from four separate angles. This improved the vertical fidelity and canopy penetration even more, benefitting the resulting DEMs and point density.

Accuracy

The next challenge was to make sure that the data fulfilled 3DEP's QL1 accuracy requirements. The Merrick-Surdex JV strives to achieve QL0 accuracy requirements on all Galaxy surveys, even when the specifications are less strict. Part of this is the inherent accuracy of the system and its LMS processing suite, but the team takes extra steps to ensure accurate calibration.

Firstly, they focus heavily on the calibration of each lidar's sensor model. LMS automates this well, but must be used frequently and effectively for the dozens of dual-sensor missions

Figure 5: The dual sensor head of the G2 cut surveying time in half and reduced project duration by months.

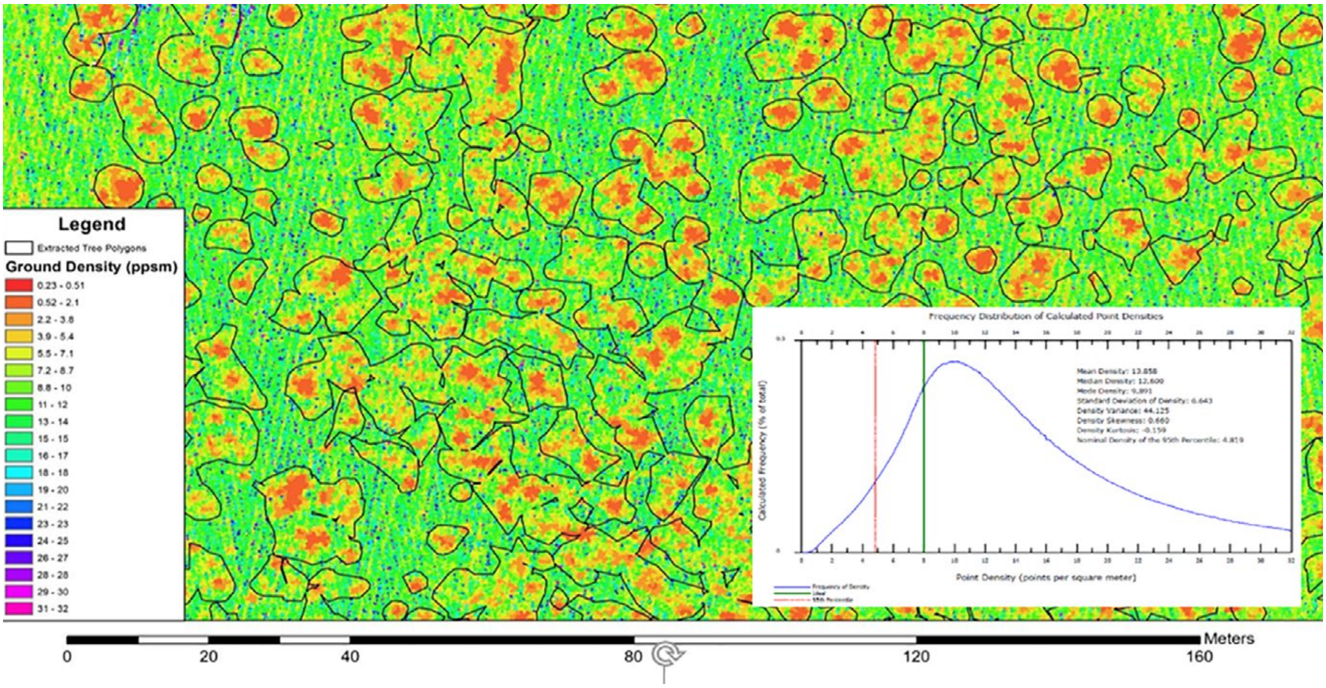

Figure 6: Density of ground points with a median value of 12.6 ppsm — black lines represent canopy extent polygons.

that made up this project. Secondly, a crossline is placed at both ends of all flightlines. Traditionally, a single crossline would be placed across the middle of the flightlines, but this means that the lines can "see-saw" up and down at their ends. Because the autocalibration locks the heights along the crosslines, the crosslines at the ends preclude this see-saw effect. Lastly, they use dynamic adjustment processes to minimize any small, remaining separations between swaths.

The QL1 requirements called for the accuracy for calibration and fitment of all flightlines to be ≤8 cm $RMSD_Z$, while the absolute accuracy measured to checkpoints has to be ≤10 cm $RMSE_Z$. The Galaxy systems achieved 3.5 cm $RMSD_Z$ relative accuracy and under 5 cm $RMSE_Z$ absolute accuracy, easily exceeding 3DEP's QL1 accuracy requirements.

Data production

After calibration was finished, the Merrick-Surdex JV moved on to creating the deliverables. This particular 3DEP project required several items, beginning with point classification into ground and low/medium/high vegetation classes. Automatic classification was run on the data first, then manual cleanup was performed with the MARS lidar software suite, developed in-house, to greatly enhance the classification accuracy.

Another 3DEP requirement was DEMs that would be used for hydrological analysis. Considering the amount of vegetation in the area, the quality of the DEMs would depend on how well the Merrick-Surdex JV could penetrate the canopy and reach the ground underneath. Thanks to the Galaxy's small beam size plus the four-way views achieved by the G2's double pass, excellent ground penetration was achived and the client was pleased with the quality of the resulting DEMs.

The last 3DEP deliverable was tree canopy polygons and tree crown points. To generate these, the team created a multi-step algorithm with both commercial-off-the-shelf and in-house elements. Since imagery collection was not part of the contract, they designed the algorithm to work entirely on lidar points.

Still, the team wanted to check that trees weren't being missed. They verified their lidar-detected canopies against imagery from the National Agriculture Imagery Program (NAIP), which in some areas had been coincidentally collected just a few months before the lidar data. The results of the test showed that their algorithm was effective and very few trees were missed.

Finally, although 3DEP didn't require it for this particular project, the team also produced a canopy height model (CHM) for analysis using the US Forest Service FUSION software. Several characteristics were revealed, such as a distinct increase in tree height in valleys, a result of the extra moisture there.

Point density

While data accuracy was not too difficult to achieve for this project, more care had to be taken to achieve the 8-ppsm point density of 3DEP's QL1 requirement. The Galaxy itself was very useful with its 100%-effective pulse repetition frequency, which ensured that every laser pulse fired could actually reach the ground. As a result, there was no need to increase the PRF to compensate for lost shots.

To achieve QL1 point density, the Merrick-Surdex JV planned for each sensor to achieve about 2.5 ppsm per pass. Since there were effectively four passes over each area (thanks to the G2's two sensors and the 55% sidelap), this resulted in a total planned density of 10 ppsm.

The resulting median point density for all classes was 12.7 ppsm, while density for vegetation was 21 and the density for just the ground points was 12.6 (**Figures 6 and 7**), easily meeting the requirements for the QL1 specification.

Even underneath the canopy polygons, the system still managed 6.5 ppsm, showing that the G2 managed to achieve excellent penetration. Beyond 3DEP, such foliage penetration will become a very pertinent factor in airborne survey, because many clients are adding numerical specifications for sub-canopy point density. This is especially true for heavily vegetated parts of western North America, where one client has required that at least 65% of sub-canopy area be captured with at least 3 ppsm. In this regard, the Galaxy in its G2 configuration already meets and exceeds the most stringent density requirements being issued.

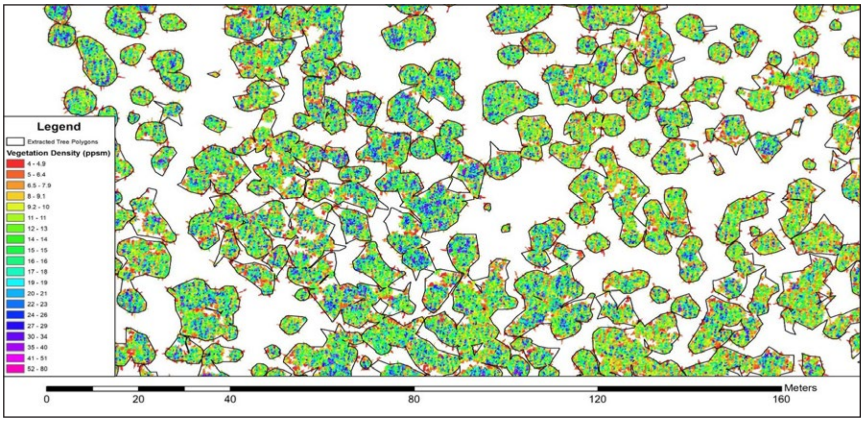

Figure 7: Density of points on trees with median value of 21 ppsm — densities <4 ppsm excluded to prevent improper low-density connectivities between trees.

Conclusion

This project shows that the G2 dual-sensor Galaxy is especially useful for tackling three main tasks, for forest mapping in general and for the 3DEP project in particular, especially as 3DEP moves westward:

- Mapping areas with vertical features like tree trunks with high fidelity
- Collecting efficiently when airspace restrictions limit survey time
- Penetrating foliage to collect high-density data underneath the canopy

In addition, Merrick is also interested in testing another possible use for the G2: powerline surveying in a fixed-wing aircraft. Of course, powerlines are normally collected with a slower rotary-wing aircraft to ensure sufficient point density and to follow the powerline closely. Merrick believes, however, that the very high point output of the G2, combined with its excellent foliage penetration and the Galaxy's line-tracking ability could make fixed-wing surveys a much faster alternative to rotary-wing for some transmission and distribution line projects.

Finally, this survey in Arizona shows the operational flexibility of the Galaxy G2 system. Afterwards, the Merrick-Surdex JV could split up the two Galaxy Primes again and use them separately in survey projects with less strenuous requirements. This gives the Merrick-Surdex JV the ability to match the equipment's capabilities to the project's requirements, making the best use of the lidar systems.

Matt Bethel is Merrick & Company's Director of Operations and Technology for its Geomatics business unit. He has 25 years experience in the aerial mapping industry.

Andrew Moller is a technical writer at Teledyne Optech with almost a decade of experience in writing for the lidar industry.

Near-infrared (NIR) images processed to create field maps using the normalized difference vegetation index in field rice.

Mapping the Era of Sustainable Sustenance

Precision agriculture's next chapter

Agriculture, one of humanity's oldest industries, remained largely unchanged for tens of thousands of years, until a century ago. Then, it underwent a series of revolutions—from mechanization in the early 20th century, to the genetics-based Green Revolution of the 1960s, to the dawn of "precision agriculture" in the 1980s. As a result, the ancient practice of growing, harvesting, and delivering the food on which we depend has become among the most modern of occupations.

Pervasive instrumentation and networking are generating unprecedented volumes and varieties of data about soil, weather, topography, plant biology, fertilizer, and pests. Advanced medicine is teaching us about the human microbiome. We're also hoovering up data on farm machinery, market demand, legislation, regulation, and environmental impact. It's integrated and turned into insight through artificial intelligence.

This is the "precision" in precision agriculture—and it's redefining the science of feeding the planet.

We're seeing new levels of efficiency, societal responsibility, and nutrition through the application of location intelligence and the emergence of a deep geospatial consciousness. It comes not a moment too soon. Not only do we

BY CHARLIE **MAGRUDER** AND MATTHEW **HARMAN**

face the prospect of feeding 9.5 billion people by 2050, but the world has awakened to the unforeseen impacts on our environment and our health of previous revolutions in agriculture—from "factory farms," deforestation, and methane emissions from livestock, to ocean pollution, overfishing, and concerns about the genetic modification of both crops and animals.

Fortunately, we now have promising solutions to these and other agricultural and agribusiness challenges of the 21st century. They are playing out in three key dimensions—microlocation, smart supply chains, and environmental stewardship.

For instance, data-centric companies like farm equipment giant John Deere[1] build sophisticated machines equipped with sensors that capture data on soil, water, and temperature conditions. The company uses satellite imagery to analyze land cover, sizing up how various grasslands, crop fields, or lawns correlate with consumer purchases. A map with 50 billion data points about field conditions and topography gathered from IoT-equipped machines gives Deere and its peers a kind of intelligent nervous system of America's growing spaces.

Welcome to the era of sustainable sustenance.

Microlocation—the nano-geography of precision agriculture

The industrialization of agriculture vastly expanded the volume and productivity of the world's farms by adopting the mindset and methods of mass production—standardizing processes and simplifying products. We got much more food, and much less variety. This impacted the health not only of those consuming the food, but also of the natural systems in which it grew.

Data-centric precision agriculture has made possible a far greater understanding of and attentiveness to the complexity, dynamism, and variety of both natural systems and their abundance.

On a precision-ag connected farm, advanced technology is everywhere[2], and it is location-intelligent: mobile devices combined with smart maps; sensors embedded in both equipment and fields; and pickers equipped with trackable smart devices, so the farm manager can see where that picker was and when they picked that produce. These technologies can help isolate contamination issues so food isn't unnecessarily destroyed, and it can help farmers identify their best produce so they can repeat that success.

Consider the business of berries, which are highly sensitive to their location and surroundings, requiring unique microclimates, air quality, and altitude, among many variables. At Driscoll's, the world's largest berry farmer, every time a new crop is planted, it is mapped and logged in a location-intelligent map. This data serves as a foundation for decision dashboards that fuse information from other departments. A dashboard may show the total acreage planted, a bar chart of forecast production for the coming week, and a map showing which berry varieties are growing where. That information also answers complicated questions about best farming practices and the timing of the supply chain.

Most major meteorological forecasts don't have a high degree of confidence beyond 10 days, while Driscoll's needs to anticipate supply 13 weeks out, tracking and analyzing growing conditions at specific locations across tens of thousands of acres. The company also uses location intelligence to predict when crops will be ready, and in what amounts.

Soon AI-based robots that are spatially aware will navigate through a field to pick produce. Already, insurance companies are flying drones over fields after floods, fires, and tornados to do rapid damage assessment, so they can cut checks, and get farmers back on their feet. Some companies fly their fields with drones or aircraft toward the

1 esri.com/about/newsroom/publications/wherenext/john-deere-market-development-with-location-intelligence/.

2 storymaps.arcgis.com/stories/795fa0328cb2497a8f960b5f3e8d2c7a

end of the growing season to analyze the vegetative index and estimate what the yield will be. That allows them to tell the grain elevator that they're anticipating 5000 bushels of corn, for example. Then they can plan for how many combines and how many tractor trailers they'll need to process it all.

From farm to fork—the new ag supply-and-demand chain

Modern agriculture is highly complex, and farmers today wear many hats. On any given day, they're commodity brokers, bankers, chemists, agronomists, pickers, procurement managers, warehousers, machinists, meteorologists, and long-term gamblers. One thing all farmers must now be is technologists. And despite the Romantic trope of the solitary farmer in the field, all 21st century farmers are inherent members of multipart global supply chains.

"A lot of our work isn't about the day-to-day operations of the business. It's about long-term planning—how you build out your facilities and make investments in order to keep up with the continual changes in the agricultural market," says Josie Taylor of Land O'Lakes' Strategic Asset Management team. Land O'Lakes uses location intelligence and mapping to manage consolidation of facilities to avoid trade area overlaps, gaps, and redundancies. How much capacity does an operation have, and how much is needed to service existing and future customers?

Nespresso has used location intelligence[3] to build a comprehensive view of farming operations and accessibility across regions, recording, mapping, and sharing data about farms, farmers, and coffee crops, including each farm's objectives and performance. But it doesn't stop there. The platform also reveals how farmers deliver coffee beans to central mills to be harvested, a key factor in supply chain productivity. The analysis uncovered areas where the terrain required long rides or walks through the mountains to reach certain farms, making frequent visits impractical. For a company that works with 100,000 farmers, a digital engine of that kind of intelligence is a difference-maker.

UMAP, the self-serve, geospatial digital platform of Agriculture and Agri-Food Canada (AAFC), provides visualization of crop density, field-level cropping patterns, soil moisture, farm locations and agri-environmental indicators across the Canadian landscape—all in one browser. UMAP also allows AAFC staff to mash up key organizational information layers—such as annual crop inventories and historic yield and production statistics—with data from other organizations and third parties. AAFC's maps and apps are informing policy makers on a global scale, from grain brokers looking for new cereal sources to real-estate scouts seeking new investment opportunities.

Mapping the business ecosystem, as well as the natural ecosystem, is also important to the banks that provide farmers with the capital they need to run their businesses. Lenders need a system of record, so they know what's in their portfolios, which clients have what assets and liabilities, and what geographic areas are doing better—creating an automated valuation model to assess agriculture real-estate values and determine which farmers are the best risks.

In the developing world, precision agriculture based on location intelligence offers billions of people the opportunity to leapfrog over millennia of learning, for improvement of productivity, nutrition, and sustainability. Ghana's agricultural industry accounts for about 20% of its gross domestic product and employs more than half of its workforce, mostly on smallholder farms that average 1.2 hectares of arable land. To improve the livelihoods of these smallholder farmers by boosting the productivity of the country's rice, maize, and soybean value chains, the Feed the Future initiative mapped the locations of the country's agricultural value chain, including farms, warehouses, weather stations, tractor service providers, produce aggregators, and processors, and developed a demographic profile of those working at the facilities. The patterns revealed in the data showed that, contrary to expectations, it was not Ghana's changing rainfall patterns but rather the introduction of advanced farming methods—better quality seed, improving water management and properly applying fertilizers and pesticides, for example—that determined the yield for farms.

3 esri.com/about/newsroom/publications/wherenext/sustainability-and-location-intelligence/

Sustaining sustenance

We have learned over millennia that soil and the nutrients and biological ecosystems it supports are a finite resource. Once the soil is gone, there's no more farming. So, applying precision agriculture is crucial to understand how much and what kinds of nutrients to input into the soil, how much water is required to maximize a crop, how much fertilizer, how much seed, and also how much tillage is going on at that exact location—all of which will help us understand how to protect our land for future generations.

Palm oil, the most widely used vegetable oil on the planet, serving as an ingredient in shampoo, lipstick, ice cream, biofuels, and other consumer staples, is big business. Its production accounts for nearly 10% of the world's permanent cropland[4]—and prominent multinationals such as Mondelēz, Procter & Gamble, and Cargill are committed not to source products connected to deforestation. Turning to new forms of location intelligence[5] and daily satellite imagery, they are detecting how many trees have disappeared from an area one week to the next. A new forest monitoring tool called Global Forest Watch Pro[6] (GFW Pro), available through World Resources Institute (WRI), tracks forests cut or lost to fire.

The rise of organic and sustainable agriculture over the past two decades has spawned many new businesses, from Whole Foods to Indigo[7]. Agricultural companies are working on practices such as planting a cover crop, a hedgerow, or riparian plants along a waterway for carbon sequestration. And traditional retailers such as Walmart, along with many other Fortune 500 companies, are committing to a green future. In addition to its own decarbonization goals, Walmart has established sustainability requirements for its suppliers.

Across the Sahel region of Africa, the Great Green Wall[8] reforestation initiative is fighting desertification. Launched in 2007 by the African Union Commission and the UN Convention to Combat Desertification, this initiative aims to restore Africa's degraded landscapes and help improve the livelihoods of millions of people in one of the world's poorest regions. The end-goal is to grow a 5000-mile-long line of trees and plants across the entire width of Africa, to help reverse a long history of desertification, boost food security and build stronger resilience and mitigation against climate change. The $8 billion project is expected to absorb 250 million tons of carbon dioxide from the atmosphere and create more than 350,000 new rural jobs for villagers.

In response to the world's exploding demand for seafood, the aquaculture industry, which emerged in the 1980s, is today helping to provide healthy and environmentally sustainable animal-protein options. Location-intelligence systems such as those created by Innovasea[9] help select prime locations for a responsible fish farm. Farmers can reduce overfishing, encourage aquatic ecosystem restoration, and help endangered species recover. According to the Food and Agriculture Organization of the United Nations, the global aquaculture industry can be pivotal to food security.

Conclusion

In agriculture, location intelligence provides information to both people and machines. When a machine is in a farmer's field, it can know exactly what it's going to see in that space at that time. The soil type is exactly what the equipment says it's going to be. The soil moisture level or the soil health and soil properties are going to be exactly what the equipment says they're going to be at that precise location. Some zones of the field may have better yields historically than other areas that may need more attention, so the application of fertilizer or nitrogen and phosphorus later and after harvest is exactly where it's supposed to be.

It's how precision works hand-in-hand with sustainability.

4 apps.worldagroforestry.org/downloads/Publications/PDFS/OP16401.pdf
5 esri.com/en-us/location-intelligence
6 pro.globalforestwatch.org
7 esri.com/about/newsroom/publications/wherenext/indigo-ag-pursues-innovation-in-the-dirt-and-from-outer-space/
8 greatgreenwall.org/about-great-green-wall
9 esri.com/about/newsroom/blog/innovasea-optimizes-aquaculture/

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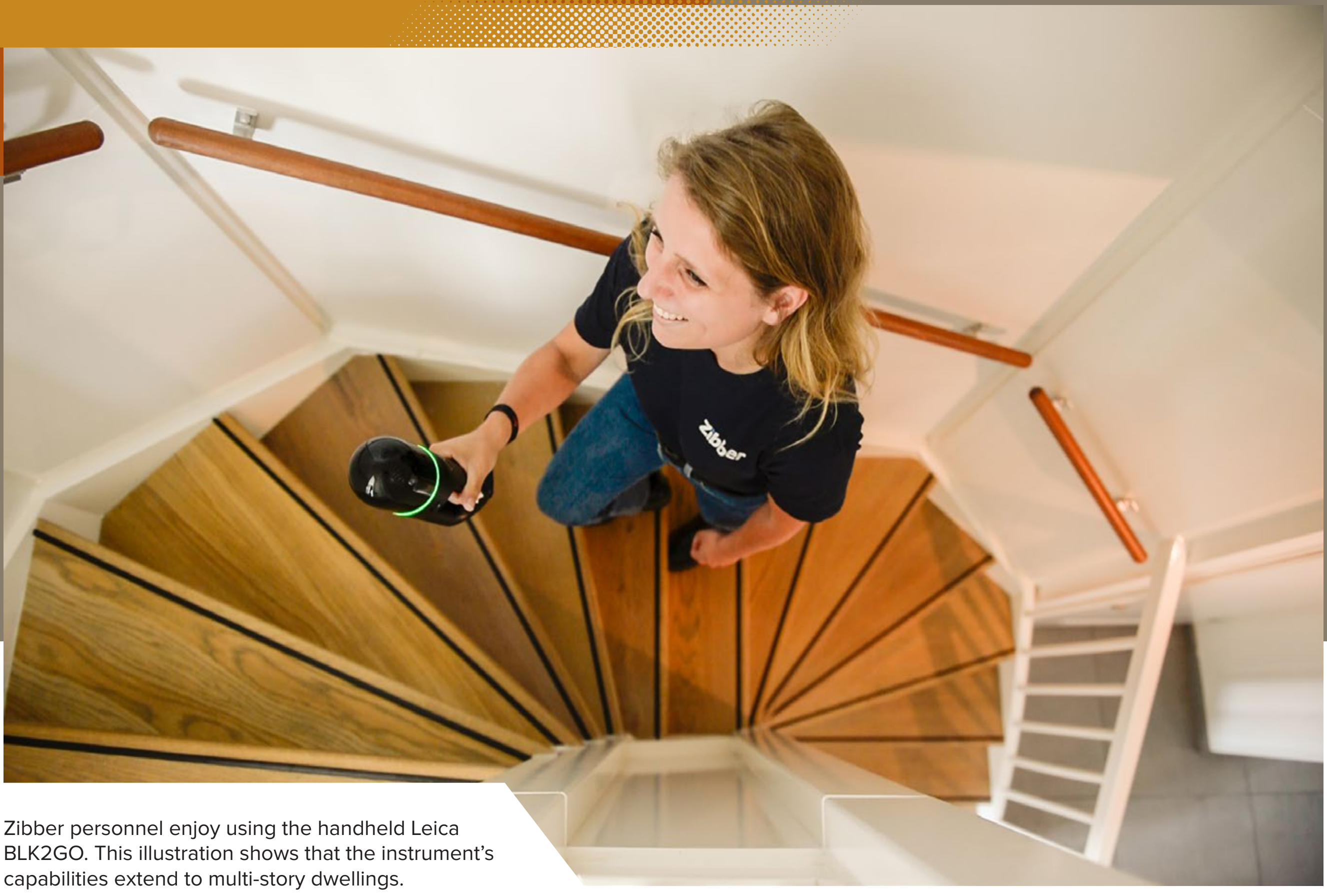

Zibber personnel enjoy using the handheld Leica BLK2GO. This illustration shows that the instrument's capabilities extend to multi-story dwellings.

Lidar for Housing Valuations

Zibber uses Leica BLK2GO to provide fast house measurements to Dutch realtors

Lidar is now being used to address an age-old problem that impacts nearly everybody—real-estate valuations. As accuracy improves and form factors get smaller, there's a growing opportunity to apply lidar-based handheld scanners to capture, document, and measure properties. At first, this may not sound like a big issue. However, when you realize a home is one of the most significant purchases a person makes, accurate valuations are critical. Yet many properties are listed with the wrong dimensions. This impacts valuation, insurance, and taxes, to name just a few of the associated issues.

BY CHRISTOPHER **DOLLARD**

With this in mind, let's take a closer look at how lidar is currently being used for housing valuations.

Accurate measurements to meet real-estate industry regulations

Zibber, a Netherlands-based real-estate documentation and visualization firm, is dedicated to helping real-estate agents, potential home buyers, and other stakeholders in the measurement, design, and transaction process adhere to local standards to ensure homes are properly valued. The firm provides accurate floorplans to real-estate agents to make sure that homes are measured as precisely as possible. While Zibber is based in Europe, the fundamental issues of accurate property valuations are global.

One of Zibber's main missions is to calculate the correct square and cubic meters to meet industry-wide measurement regulations. This process is of utmost importance to real-estate agents because, in the Netherlands, there's a high standard for real-estate measurement. This standard is defined in *branchebrede meetinstructie* (industry-wide measurement instruction), or BBMI[1], a Dutch regulation for "the exchange of uniformly structured information in this field." For example, if a house is sold at too high a valuation based on

1 https://bit.ly/3Elvw30.

inaccurate measurements, the real-estate agent can be held legally responsible.

Zibber's approach relies on a handheld laser scanner. Using the Leica BLK2GO from Leica Geosystems, part of Hexagon, Zibber surveyors scan a home and the entire design, look and feel of the living space. Additionally, they provide immersive visualizations that are derived from high-resolution photography and data from the scanner. By calculating accurate dimensions and quickly providing high-end photography, Zibber helps realtors successfully market each home. Additionally, the process helps potential owners envision living in a space while enabling both agents and buyers to arrive at accurate valuations and fair transactions.

"We distinguish ourselves from our competition by acting as an extension of the real-estate agency," said Hans Meeuwsen, chief innovation officer and co-owner at Zibber. "This allows us to relieve the real-estate agent of work and bring homes to the market faster by processing all media, fully automated, after the appointment and deliver everything to the broker within one working day. These automations in combination with the scanner give us a big advantage over the rest of the market."

How Zibber rises above the competition

The scanner is making an impact for businesses like Zibber due to its ease of use, speed, precision, and ability to produce highly valuable deliverables. "When we started to look for a solution, we saw other companies, but none of them seemed to have such a longstanding commitment to creating the best technology," said Dogan Kahveci, CEO and co-owner at Zibber.

The scanner fits in a briefcase, making it easy for the Zibber team to bring to a house. It also easily integrates into the company's existing workflow. Since it's easy to use, company workers are quickly up and running with the technology.

Zibber currently operates the largest fleet of scanners in the Dutch market, and Dogan and his team were able to train their photographers, who capture and measure properties, to use the scanner so that they only need one person to do the job with the scanner and a camera. This, according, to Zibber, adds a "cool factor" to the process.

"If there are other people at the house, they always think the scanner is a cool device that looks great, and they ask about what it does," Dogan said. "So, we explain how it measures everything accurately by simply walking and holding it, and they're always surprised and amazed. Using the phone alongside the scanner also shows people how it works, and they're flabbergasted with what it does when they see the live visual feedback on the phone."

How scanner technology is changing the real-estate industry

Zibber's process is simple. They turn the scanner on, load the app, and walk through the house. "It's amazing to see the real-time map of the house pop up as you walk," Dogan said. "Then you set it on a table to transfer data to a laptop, and, in the meantime, we take photos of the house."

Once the scanner captures a home, Zibber's team transfers the data into a fully automated data stream from their cloud servers that process the scanner data—Zibber's own creation, their backbone to process all point clouds—and deliver it straight to their production house in Vietnam immediately after the scan is completed.

> "The BLK2GO rapidly advances Zibber's workflow to provide a superior deliverable compared to their competition."

The production house then takes the data, creates an attractive, clean floorplan with exact measurements, and sends it back to Zibber. This process enables Zibber to deliver the floorplan and photos to their clients with a one-day turnaround, and sometimes on the very same day.

The scanner rapidly advances Zibber's workflow with speed and accuracy to provide a superior deliverable compared to their competition. And the BLK2GO also makes sure Zibber's measurements and floorplans meet important industry regulations.

Zibber is taking advantage of highly agile mobile mapping tools and applying them to real estate. As real estate, especially in the U.S., remains a hot market, the opportunities for using lidar-based handheld devices to differentiate and ensure proper valuations are abundant.

Christopher Dollard is a copywriter with the Agile Marketing team of Leica Geosystems, part of Hexagon. Based in Newport, Rhode Island, Christopher has a BA in English from Rhode Island College and an MFA in creative writing and poetry from Syracuse University.


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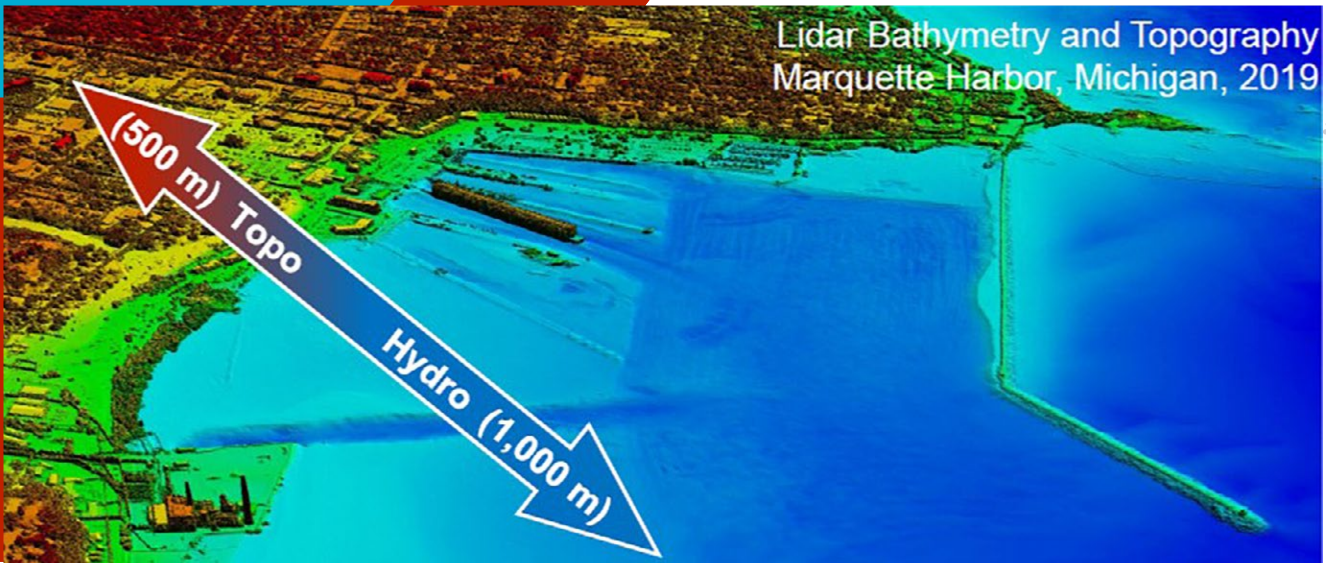


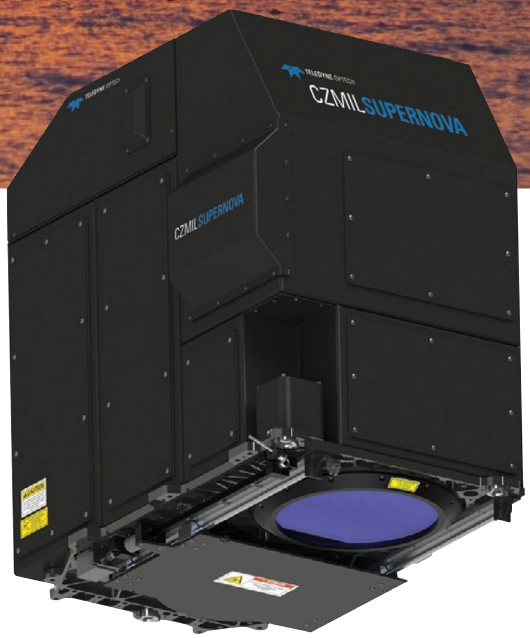
Figure 1: A topobathymetric lidar digital surface model depicting the 1500-m NCMP survey footprint. The data was acquired by USACE NCMP over Marquette Harbor, Michigan in 2019.

Watching the Great Lakes Shorelines

USACE National Coastal Mapping Program provides critical, repeat-mapping data to address regional monitoring needs

BY CHARLENE **SYLVESTER**

Record high water levels in the Great Lakes of the United States increase shoreline erosion, reduce efficacy of natural shoreline protection, and threaten valuable infrastructure related to industry, environment, and tourism. Temporally relevant, high-resolution mapping data is a critical requirement for informing decisions related to managing these threats. The US Army Corps of Engineers (USACE) uses mapping data to support its missions in navigation, flood risk management and ecosystem restoration. Requirements for regional coastal data are fulfilled by the Joint Airborne Lidar Bathymetry Technical Center of Expertise (JALBTCX). The USACE expert in coastal mapping, JALBTCX is a partnership among the Federal government, industry, and academia to perform operations, research, and development in airborne lidar bathymetry and complementary technologies. Federal partners include USACE and US Naval Oceanographic Office (NAVO), both of which acquire mapping data through operational coastal mapping and charting campaigns. Other Federal partners include the National Oceanic and Atmospheric Administration (NOAA) and the United States Geological Survey (USGS), which coordinate their mapping data acquisitions with JALBTCX through the Federal Interagency Working Group on Ocean and Coastal Mapping (IWG-OCM) with the aim of reducing duplicative mapping efforts, allocating resources for mapping in the most efficient manner, and ensuring wide dissemination and interoperability of mapping data. Together with partners



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from industry and academia, JALBTCX has fielded and operationalized three generations of airborne remote sensing platforms for the collection of mapping data in coastal environments. The 23-year partnership continues to coordinate on best practices for data acquisition and data product development, and leads research and development efforts to expand current technologies in support of emerging needs for mapping data that include, for example, needs for bathymetric data in inland and riverine environments.

USACE coastal mapping is executed by JALBTCX under the USACE National Coastal Mapping Program (NCMP). The program's goal is to acquire high-accuracy, high-resolution lidar elevation and imagery data on a recurring schedule along the sandy shorelines of the US. The survey footprint (**Figure 1**) extends from 500 m onshore of the shoreline to 1000 m offshore, or to laser extinction, whichever occurs first. JALBTCX aircraft fly at an operational altitude of 400 m above ground level, producing a swath of data approximately 300 m wide with each pass. Capture of the approximate 1-mile wide NCMP footprint typically requires 5-6 passes of the aircraft, depending on shoreline shape and airspace considerations. Survey coverage includes the important first line of infrastructure, the beach and dune system, and the nearshore out to the depth of closure. The footprint encompasses the "active" portion of the beach profile that plays a critical role in sediment mobility, transport, and deposition. Information gleaned from the mapping data supports the development of regional sediment budgets that USACE uses to understand and manage sediment at regional or watershed scales. The mapping data provides critical, temporally relevant baseline information to inform decisions related to the planning, operation, monitoring and maintenance of coastal flood damage risk reduction, coastal navigation, and ecosystem restoration projects within USACE.

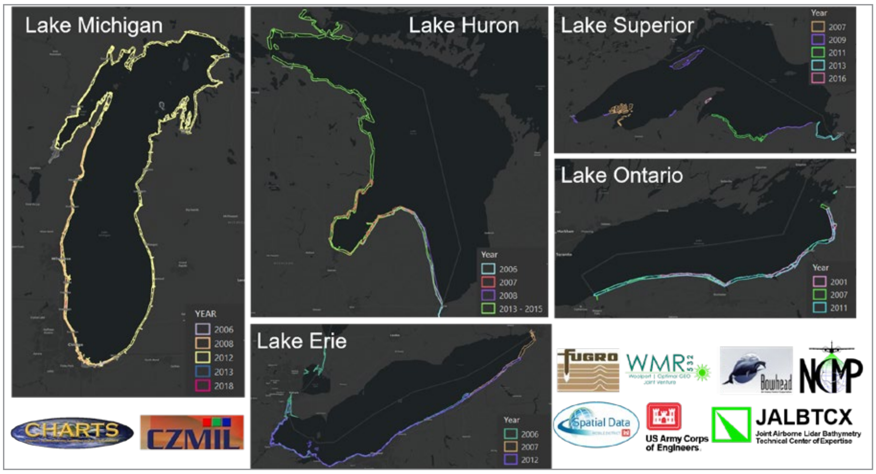

Figure 2: Geospatial extents of NCMP data coverage colored by year of acquisition from 2006 to 2013.

NCMP in the Great Lakes

NCMP completed a third cycle of lidar and imagery mapping data acquisition in the Great Lakes in 2020. Acquisition of this data along the entire US shoreline of the Great Lakes typically takes 2-3 years due to challenging weather and water clarity conditions that limit acquisition windows to summer months. The first regional acquisition occurred during the summers of 2006, 2007 and 2008. Data acquisition was repeated in 2011, 2012 and 2013 to complete the second cycle of NCMP. The first and second NCMP cycles leveraged JALBTCX's in-house survey capabilities, as well as those provided under contract to USACE Mobile District. The most recent, third cycle of data acquisition that was completed in 2020 began in 2018. **Figure 2** depicts the geospatial extents of NCMP data coverage acquired each year for surveys from 2006-2013.

The recent, third cycle of NCMP data (**Figure 3**) was acquired with JALBTCX's Coastal Zone Mapping and Imaging Lidar (CZMIL). This third-generation platform for integrated coastal mapping and environmental monitoring includes a 532-nm (green) wavelength lidar with simultaneous topographic and bathymetric capabilities, a 150-megapixel 3-band digital camera that collects images at 5-centimeter on-ground resolution and a hyperspectral imager that collects 48 spectral bands between 380 and 1050 nm at 1 m on-ground resolution (Wozencraft *et al.*, 2019). Topographic lidar meets the USGS Lidar Base Specification for Quality-Level 2 (QL2) lidar, or two measurements every square meter on ground at 10 cm root mean square error vertical accuracy. Bathymetry is acquired with a vertical precision of 15 cm (one standard deviation) to depths of up to approximately 60 m. NCMP operates CZMIL in a contractor-owned and operated aircraft, including Cessna 406s, Beechcraft KingAirs, and Basler BT-67s, to meet mission objectives. Regardless of airframe, the swath width, which is approximately three quarters of the operating altitude, is constant over the entire operational depth range of CZMIL.

Opportunities for expanding NCMP data coverage

The NCMP planning process includes key personnel from JALBTCX, USACE Districts and partners in the Federal mapping community through the IWG-OCM. Planning meetings are opportunities to discuss additional requirements for mapping data located in areas near the NCMP footprint. Oftentimes, NCMP mission plans can be extended, or added to, at minimal cost to the District or partner to expand data acquisition. Several example projects in the Great Lakes have been accomplished by coordination with local USACE Districts and partners in the Federal Mapping Community. Specific examples include:

- 2021 NOAA Whitefish Bay hydrographic survey requirements met for select areas by the 2019 NCMP Lake Superior dataset
- 2019 NOAA northern Lake Michigan hydrographic survey requirements met by the 2019 NCMP Lake Michigan dataset
- 2018 USACE Buffalo District and the USACE Engineer Research and Development Center (ERDC) partnered with JALBTCX to expand NCMP coverage into wetlands of interest along Lake Ontario
- 2012/2013 USACE Detroit District leveraged Federal Emergency Management Agency (FEMA) funds to partner with JALBTCX to extend NCMP coverage into Green Bay, and extend coverage for inhabited areas to update wave modeling in the Great Lakes
- 2006/2007 National Park Service partnered with JALBTCX to add coverage of Isle Royale, Minnesota and the Apostle Islands, Wisconsin

NCMP data products

Data processing for NCMP lidar and imagery data is accomplished with software from the sensor manufacturers in combination with commercial off-the-shelf software packages. All lidar, true-color imagery and hyperspectral imagery is downloaded from solid-state data collection drives to processing computers, where it is processed from native sensor formats, geo-corrected through the application of GNSS and aircraft attitude data, and developed into industry-standard data formats. For example, the CZMIL lidar data is converted from the raw CZMIL wave-form to a CZMIL point cloud in the industry-standard LAS format. QA/QC of the lidar point cloud is performed in a 3D point-cloud editing environment.

This ensures that the point cloud meets current system specifications and is free of any system biases or navigation errors. Post-processing of the lidar point cloud then continues with the application of an industry-standard ground classification algorithm through which each point is classified as ground (i.e. roads, parking lots, bare and grass-covered ground) or non-ground (i.e. vegetation, trees, buildings). Following QA/QC of the point cloud classification, raster elevation products are generated at 1-m resolution. The digital surface model (DSM) products include points from each classification (non-ground, ground, and bathymetry), whereas the digital elevation model (DEM) products include ground and bathymetry only. A vector product, defined by USACE as the Great Lakes Low Water Datum (GLLWD) elevation contour, is derived from the DEM products, and is manually edited to remove back-bay/back-barrier contour segments and any "islands" landward of the primary alongshore contour. The goal of editing is to produce a single, continuous contour that approximates the shoreline position.

Figure 3: Web map depicting the geospatial extents associated with the 3rd cycle of NCMP data acquisition in the Great Lakes from 2018 to 2020. The extents are colored by acquisition year.

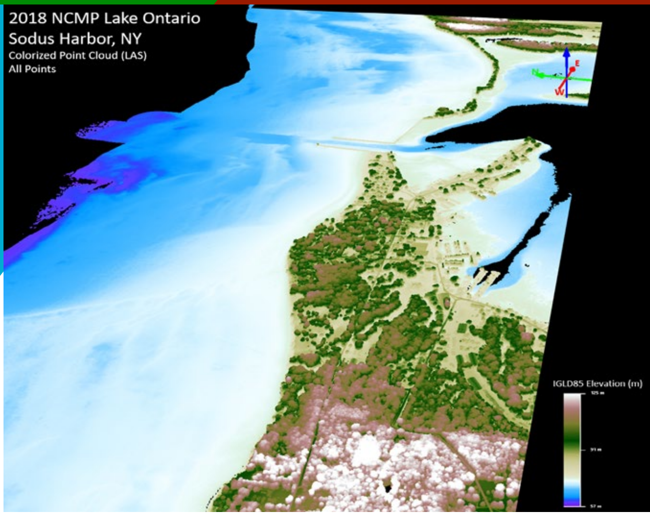

Figure 4: Example NCMP point cloud product colorized by elevation. Points depicted include points classified as non-ground, ground, and bathymetry.

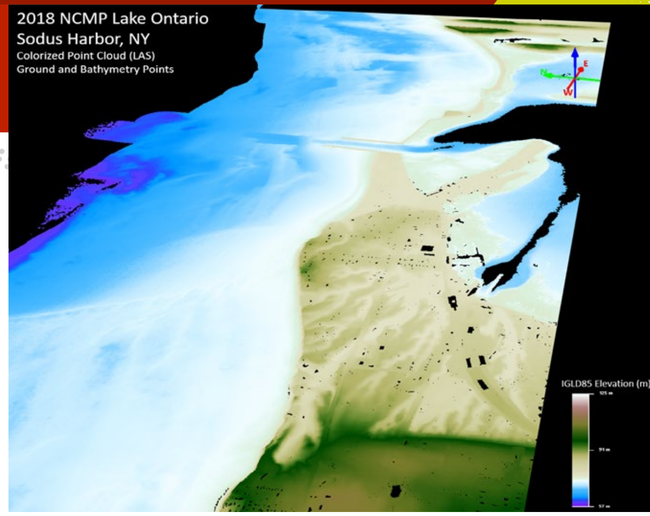

Figure 5: Example NCMP point cloud product colorized by elevation. Points depicted include points classified as ground and bathymetry.

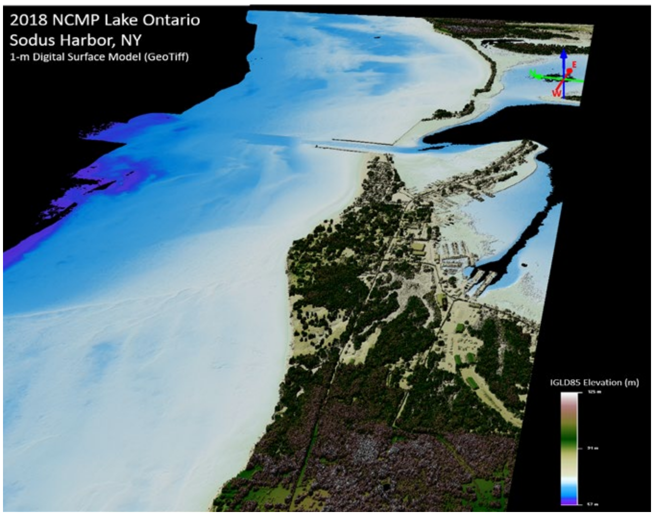

Figure 6: Example NCMP 1-m digital surface model product colorized by elevation.

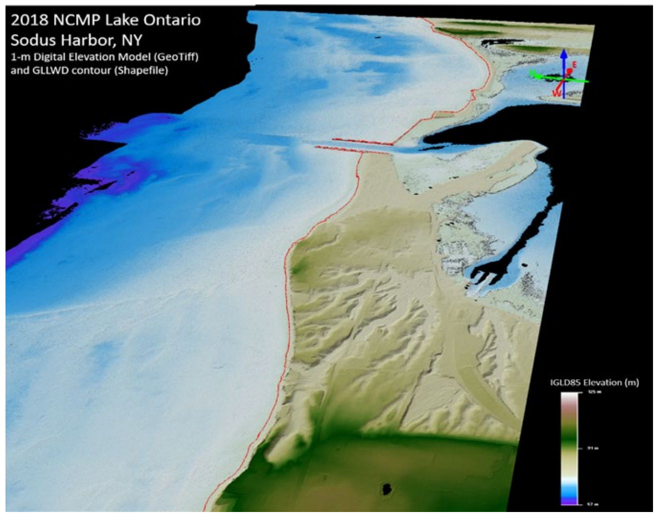

Figure 7: Example NCMP 1-m digital elevation model product colorized by elevation.

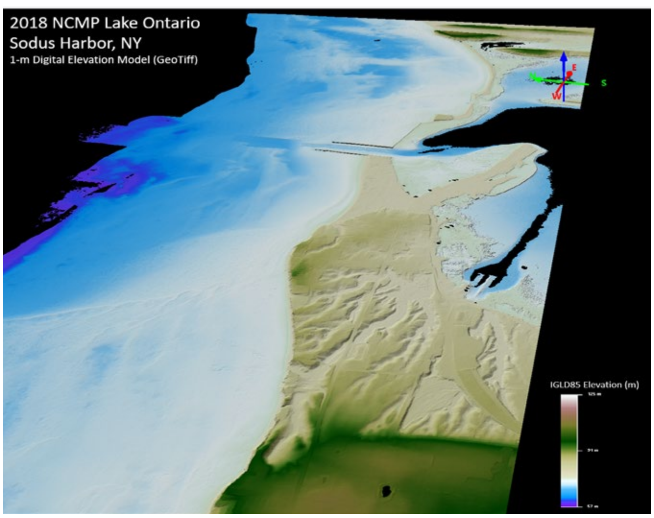

Figure 8: Example NCMP GLLWD contour product overlaid on the DEM product.

Figure 9: Example 5-cm true-color image mosaic (background) and detailed view of the west jetty (foreground).

USACE Project Name	Data Access URL
2001 USACE NCMP Topobathy Lidar: Lake Ontario	coast.noaa.gov/dataviewer/#/lidar/search/where:ID=4700
2006 USACE NCMP Topobathy Lidar: Lake Erie (OH, PA), Lake Huron (MI) & Lake Michigan (Porter County, IN)	coast.noaa.gov/dataviewer/#/lidar/search/where:ID=40
2007 USACE NCMP Topobathy Lidar: Lake Erie (Erie County, PA) & Lake Michigan (Manitou Islands) (MI, PA)	coast.noaa.gov/dataviewer/#/lidar/search/where:ID=115
2007 USACE NCMP Topobathy Lidar: Lake Erie (NY Shoreline)	coast.noaa.gov/dataviewer/#/lidar/search/where:ID=523
2007 USACE NCMP Topobathy Lidar: Lake Huron (Saginaw Bay)	coast.noaa.gov/dataviewer/#/lidar/search/where:ID=550
2007 USACE NCMP Topobathy Lidar: Lake Superior (Apostle Islands) & Lake Ontario (NY, WI)	coast.noaa.gov/dataviewer/#/lidar/search/where:ID=114
2008 USACE NCMP Topobathy Lidar: Lake Huron (Michigan Coastline)	coast.noaa.gov/dataviewer/#/lidar/search/where:ID=587
2008 USACE NCMP Topobathy Lidar: Lake Michigan (Illinois Coastline)	coast.noaa.gov/dataviewer/#/lidar/search/where:ID=563
2008 USACE NCMP Topobathy Lidar: Lake Michigan (Indiana Coastline)	coast.noaa.gov/dataviewer/#/lidar/search/where:ID=588
2008 USACE NCMP Topobathy Lidar: Lake Michigan (Michigan Coastline)	coast.noaa.gov/dataviewer/#/lidar/search/where:ID=518
2008 USACE NCMP Topobathy Lidar: Lake Michigan (Wisconsin Coastline)	coast.noaa.gov/dataviewer/#/lidar/search/where:ID=564
2008 USACE NCMP Topobathy Lidar: Lake Superior (Wisconsin and Michigan)	coast.noaa.gov/dataviewer/#/lidar/search/where:ID=2517
2009 USACE Lidar: Duluth, MN and Superior, WI (Including shoreline in Douglas, Bayfield, Ashland, and Iron Counties)	coast.noaa.gov/dataviewer/#/lidar/search/where:ID=2507
2009 USACE NCMP Topobathy Lidar: Apostle Islands, Wisconsin	coast.noaa.gov/dataviewer/#/lidar/search/where:ID=1392
2009 USACE NCMP Topobathy Lidar: Isle Royale (MI)	coast.noaa.gov/dataviewer/#/lidar/search/where:ID=1391
2009 USACE NCMP Topobathy Lidar: Lake Superior (Duluth, MN)	coast.noaa.gov/dataviewer/#/lidar/search/where:ID=556
2011 - 2012 USACE NCMP Topobathy Lidar: Lake Erie (MI, NY, OH, PA)	coast.noaa.gov/dataviewer/#/lidar/search/where:ID=3662
2011 USACE NCMP Topobathy Lidar: MI/NY Great Lakes	coast.noaa.gov/dataviewer/#/lidar/search/where:ID=1407
2012 USACE NCMP Topobathy Lidar: Lake Michigan (IL, IN, MI, WI)	coast.noaa.gov/dataviewer/#/lidar/search/where:ID=2644
2012 USACE NCMP Topobathy Lidar: Lake Michigan (MI, WI)	coast.noaa.gov/dataviewer/#/lidar/search/where:ID=3663
2012 USACE NCMP Topobathy Lidar: Lake St. Clair (MI)	coast.noaa.gov/dataviewer/#/lidar/search/where:ID=3667
2013 - 2015 USACE NCMP Topobathy Lidar: Lake Huron	coast.noaa.gov/dataviewer/#/lidar/search/where:ID=4844
2013 USACE NCMP Topobathy Lidar: Lake Michigan South (MI)	coast.noaa.gov/dataviewer/#/lidar/search/where:ID=4845
2013 USACE NCMP Topobathy Lidar: Lake Superior (MI)	coast.noaa.gov/dataviewer/#/lidar/search/where:ID=4913
2013 USACE NCMP Topobathy Lidar: St. Mary's River (MI)	coast.noaa.gov/dataviewer/#/lidar/search/where:ID=4748
2013 USACE NCMP Topobathy Lidar: Stamp Sands, Lake Superior (MI)	coast.noaa.gov/dataviewer/#/lidar/search/where:ID=3670
2016 USACE NCMP Topobathy Lidar: Stamp Sands (MI)	coast.noaa.gov/dataviewer/#/lidar/search/where:ID=5187
2018 USACE NCMP Topobathy Lidar: Lake Ontario (NY)	coast.noaa.gov/dataviewer/#/lidar/search/where:ID=8594

Table 1: Inventory of NCMP datasets in the Great Lakes. Direct-download URLs for data access are also provided.

All NCMP data products are provided in geographic coordinates, in decimal degrees of latitude and longitude, that are referenced to the North American Datum of 1983 National Adjustment of 2011 (NAD83 NA11). Elevations are referenced to the International Great Lakes Datum of 1985 (IGLD85) and are provided in meters. The basic tier of data products includes the classified (non-ground, ground, bathymetry) point clouds, DSMs, DEMs, GLLWD contour and true-color imagery mosaics. Example products developed from USACE's 2018 NCMP Lake Ontario project are depicted in **Figures 4-9**.

NCMP data discovery and access

USACE NCMP data is available for free public use from the NOAA Digital Coast's Data Access Viewer (coast.noaa.gov/dataviewer/#/). The site provides capabilities for dataset search by user-defined areas of interest. Once the dataset list is populated from the search, a user is led through a custom data request submission capability that facilitates data format conversions, custom filtering, and coordinate system and datum transformations. Data is then made available as a direct download in a format that is available for use without requiring any additional data processing or manipulation. Direct download URLs to USACE NCMP datasets acquired in the Great Lakes are listed in **Table 1.**

Readers should consult JALBTCX's Production Status Web Map (arcgis.com/home/item.html?id=1d698d610bec432e8374b46ea22db7ac) for the status of the third cycle of NCMP mapping data in the Great Lakes (**Figure 10**).

NCMP data products support regional monitoring efforts

The Great Lakes Restoration Initiative (GLRI) is a multi-year collaborate effort among NOAA, USGS and USACE to inform decisions aimed at mitigating hazards to Great Lakes ecosystems and protecting and restoring the largest

Figure 10: JALBTCX Production Status Web Map. Survey areas (flight blocks) are colored by their status in the JALBTCX production lifecycle. Interactively select any area to view the production status (i.e. processing, QA/QC, products, delivered).

freshwater system in the world (Great Lakes Regional Collaboration, 2005). ERDC is working with the multi-agency team to characterize nearshore geomorphology (i.e. bluffs, sandbars, beach slope, beach width, etc.) in the Great Lakes to support the development of sediment budgets and a coastal resiliency index for each lake. This effort leverages the NCMP DEM products in conjunction with DEMs produced by other entities. Data products for each lake are being integrated into near-seamless DEMs that serve as input to a novel geomorphic feature extraction workflow to detect/delineate nearshore geomorphology characteristics that include bluffs/dunes (bluff/dune crest and toe), sandbars (number of bars, water depth over bars, and distance offshore), beach slope, beach width, and nearshore shape/curvature (**Figure 11**).

These outputs provide the basis for the development of sediment budgets and geomorphic vulnerability indexes in the Great Lakes. Together, both efforts will improve the understanding of key influences on spatially varying rates and impacts of shoreline erosion for each lake. This understanding is key to informing mitigation and restoration efforts related to shoreline erosion and ecosystem degradation in the Great Lakes.

Future NCMP mapping in the Great Lakes

The USACE NCMP operates counter-clockwise around the US on an approximate 5-year update cycle. Future regional-scale NCMP mapping efforts in the Great Lakes will tentatively begin in the 2023/2024 timeframe, contingent upon program schedule elsewhere and agency funding. Stakeholders in the Great Lakes are encouraged to contact JALBTCX, jalbtcx@usace.army.mil, to discuss requirements and opportunities for mapping data during the next NCMP acquisition cycle.

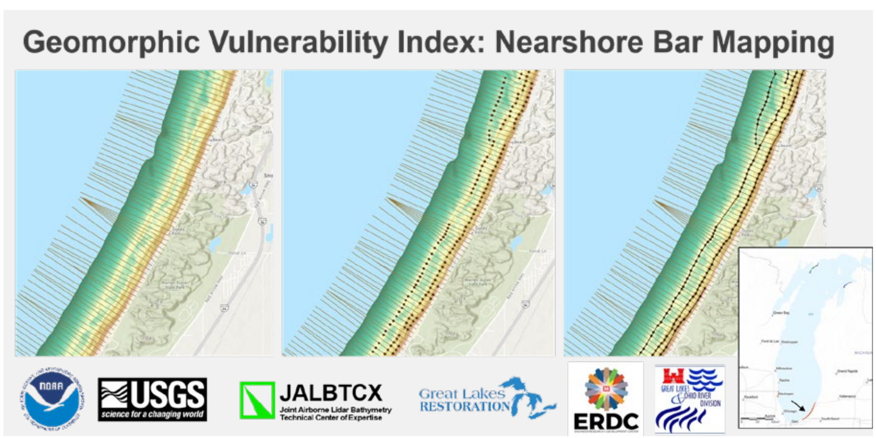

Figure 11: GLRI Geomorphic Vulnerability Index mapping of nearshore sandbars along a series of shore-normal transects, spaced 100 m apart, for a portion of shoreline in southeastern Lake Michigan.

References

Great Lakes Regional Collaboration, 2005. *Great Lakes Regional Collaboration Strategy: To Restore and Protect the Great Lakes*, 70 pp. gsgp.org/media/1847/glrc_strategy.pdf.

Wozencraft, J., L. Dunkin, E. Eisemann and M. Reif, 2019. Chapter 7: Applications, Ancillary Systems, and Fusion, Chapter 7 in *Airborne Laser Hydrography II* (ed. W. Philpot), Cornell eCommons. 279 pp: 207-230. doi.org/10.7298/tbxj-3067.

Charlene Sylvester is a research physical scientist with ERDC's Coastal Hydraulics Laboratory. Charlene supported NCMP with Mobile District and JALBTCX for 11 years, deploying with the field teams for NCMP and Emergency Response survey operations. Charlene recently transitioned to a role at ERDC, where her knowledge in geospatial data analysis, lidar processing and quality control, coastal processes, geospatial metadata and web GIS is applied across a number of R&D efforts that utilize JALBTCX data.

FL-ASPRS/UF SPRING 2021
VIRTUAL LIDAR WORKSHOP

Energetic Data Acquisition in Florida

UPDATES FROM AGENCIES ON LIDAR COLLECTIONS

The spring 2021 FL-ASPRS/UF Lidar Workshop was held remotely on 17 June 2021 and attended by 140 participants. While the majority were from the US (Florida, Georgia and California), other ASPRS registrant countries included Canada, Pakistan, and Brazil. The seven-hour workshop contained recorded technical and application-oriented presentations by state and federal agencies, academia, and private industry. Presenters were available to answer questions live. USGS's Dr. Warren Day, Earth MRI (EMRI) Science Coordinator and Research Geologist, presented the keynote session live and fielded questions about the EMRI program. The biannual workshop was the Florida region's 10th in the series. The plan moving forward was to run a hybrid live/virtual Fall workshop in October 2021.

The workshops traditionally begin with representatives of the five Water Management Districts—Northwest Florida (NWFWMD), South Florida (SFWMD), St. Johns River (SJRWMD), Suwannee River (SRWMD) and Southwest Florida (SWFWMD)—giving short presentations detailing either their recent lidar and/or imagery acquisitions or issues that they have encountered.

Additional state and/or federal agencies also have the opportunity to present. For the spring 2021 workshop, agency briefings were provided by: Florida Department of Revenue (FDOR); Florida Department of Environmental Protection (FDEP); US Geological Survey (USGS); and Dewberry, briefing on the on the Florida State Lidar program.

In 2018 Florida Division of Emergency Management (FDEM), Florida Department of Transportation (FDOT) and the five Water Management Districts entered into a cooperative program with USGS to remap 34,000 square miles of the peninsula of Florida to the USGS QL1 specification. Then, following Hurricane Michael in 2019, USGS authorized remapping of the central panhandle of Florida. The acquisition and processing of the lidar data were discussed in the Dewberry briefing.

NWFWMD

Jesse Gray, a recent addition to the NWFWMD staff who manages all of the District's lidar acquisitions, described the previous lidar collections in NWFWMD. He noted the continuing challenge of obtaining lidar data in the Eglin Air Force Base airspace, indicating that the area was mapped by earlier acquisitions at the QL2 level. He concluded by illustrating the 2020 USGS QL1 post-Hurricane Michael lidar acquisition currently in progress (**Figure 1**).

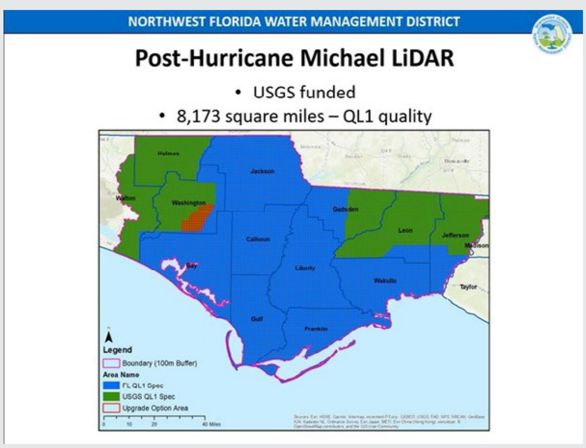

Figure 1: Lidar collections in the central-panhandle counties of Florida mapped following Hurricane Michael.

COMPILED BY AL **KARLIN**

SJRWMD

Sandra Fox contributed a map showing the status of SJRWMD's review of the current USGS/FDEM Peninsular lidar (**Figure 2**). Most of the coastal counties in SJRWMD have been reviewed, while the inland counties are awaiting review.

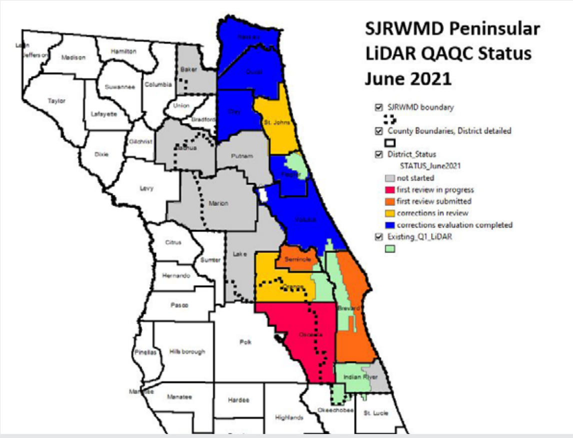

Figure 2: 2018/19 Peninsular Florida lidar surveys in review by SJRWMD.

SRWMD

Paul Buchanan, GIS Manager, reported on the lidar remapping for Gilchrist and Bradford counties and a topobathymetric (CZMIL) project in the Suwanee Sound area (**Figure 3**). He also presented SRWMD's 360° image mapping project of the Suwannee River and its primary tributaries, known as the Riverview Project (**Figure 4**).

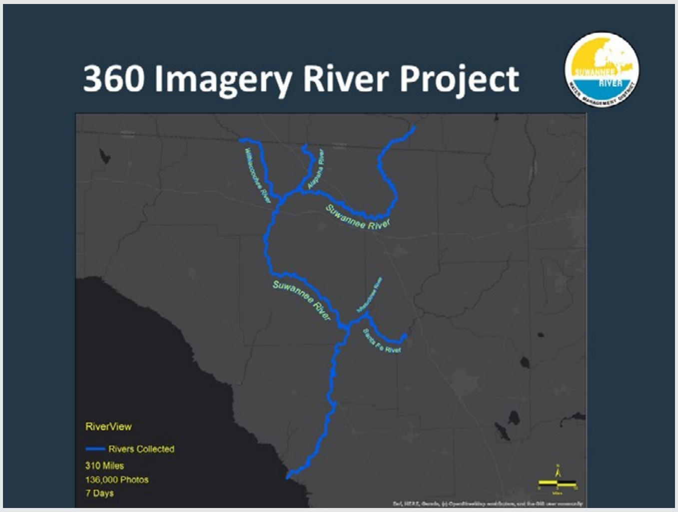

Figure 4: Areas of the Suwannee River imaged by 360° photogrammetry in spring 2021.

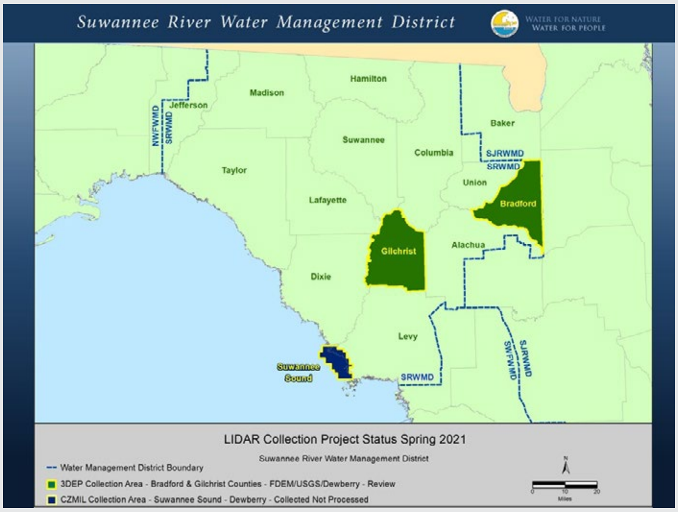

Figure 3: 2018/19 Peninsular Florida lidar surveys in review by the SRWMD.

SWFWMD

Nicole Hewitt cited a discussion with James Van Rens in the Spring 2021 issue of *LIDAR Magazine*[1] regarding the future of artificial intelligence (AI) in lidar processing. Nicole presented several "challenges for classification", including building misclassifications as well as bridge and seawall misclassifications, which could potentially be resolved through AI coupled with high-resolution orthophotography and/or oblique imagery (**Figure 5**).

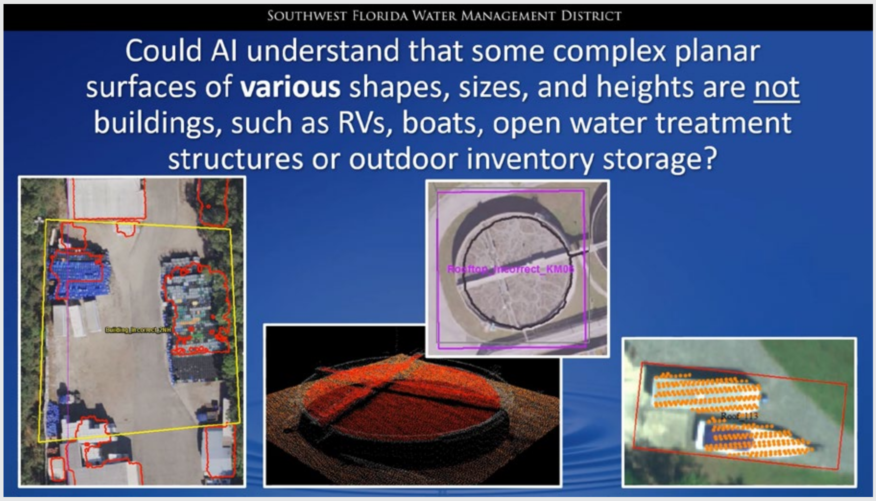

Figure 5: Lidar classification challenges raised by SWFWMD.

1 Walker, S., 2021. The next decade with lidar: *LIDAR Magazine* interviews James Van Rens, SVP, *RIEGL* USA, *LIDAR Magazine*, 11(1): 12-16, Spring 2021.

FDOR

Charles Russell contributed a map showing the orthoimagery acquisition scheduled for fall 2021/winter 2022 and the links to the FDOR website for the Florida orthoimagery standards and tile index (**Figure 6**).

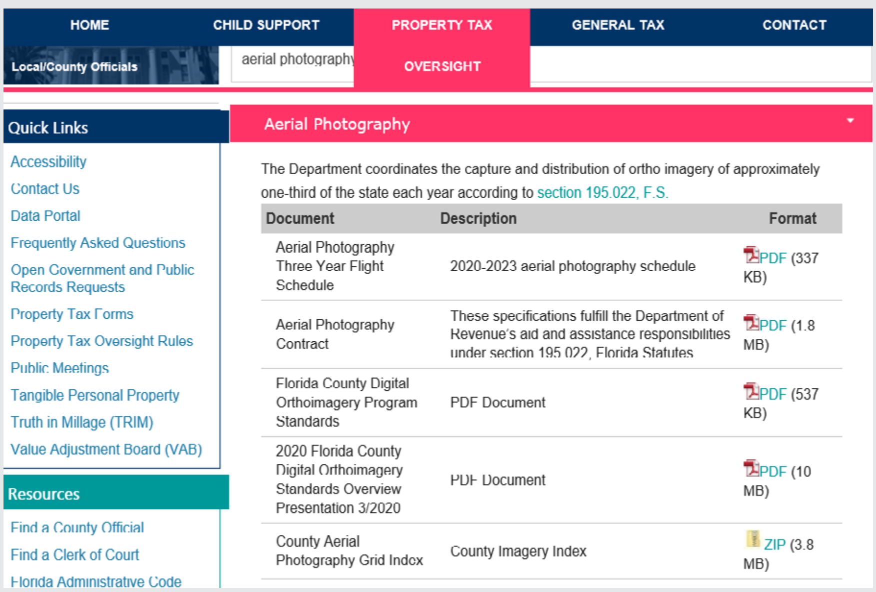

Figure 6: FDOR website access to Statewide Photography Grid Indexes.

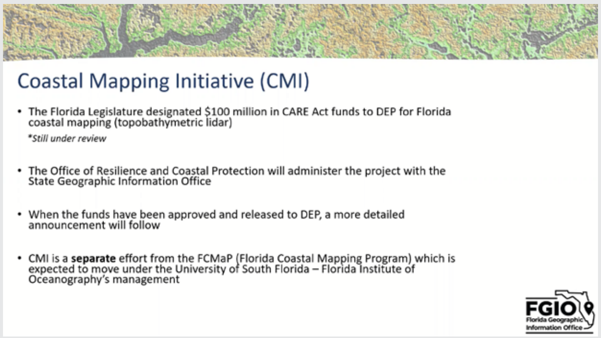

Figure 7: FGIO summary of the upcoming CMI.

FDEP

Parker Hinson represented FDEP and the Florida Geographic Information Office (FGIO). He discussed two major FDEP/FGIO updates, including the newly announced Coastal Mapping Initiative (CMI) (**Figure 7**), as well as additions to the FGIO Hub (floridagio.gov) (**Figure 8**). CMI will assist State efforts in mapping Florida's coast using topobathymetric lidar, and updates to the FGIO Hub include new partners, content, and lidar projects and resources such as the Florida Peninsular LiDAR County Delivery Dashboard.

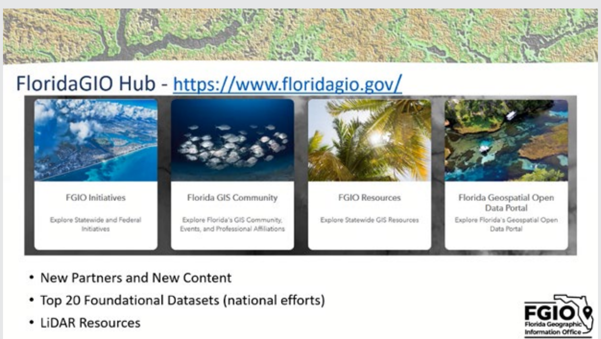

Figure 8: FGIO announcement of the new FGIO Hub.

USGS

Alexandra "Xan" Fredericks provided an update on behalf of the National Geospatial Program about the 3D Elevation Program (3DEP) and the FY2021 Broad Agency Announcement. She displayed several new features and datasets available on the USGS/The National Map (**Figure 9**) and illustrated how to use the webmaps for planning and coordination of topographic and topobathymetric efforts in Florida, as well as the Florida Coastal Mapping Program Hub (**Figure 10**).

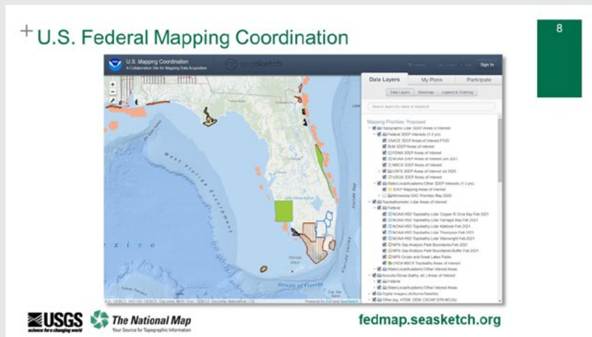

Figure 9: USGS link to seasketch.org showing U.S. Federal Mapping Coordination.

Figure 10: Link showing the Florida Coastal Mapping Program StoryMap.

Florida Statewide Lidar

Elise MacPherson presented the Florida Statewide Lidar Mapping Project on behalf of Dewberry. She started with an overview of the Florida Peninsular Lidar Project, then discussed the challenges and issues encountered (**Figure 11**). She outlined problems with calibration, classification, and breaklining, along with the complexities of having multiple data collectors, compilers, and multiple levels of external review. Since October 2020, 29 (out of 34) counties' QL1 lidar data has been delivered. Moreover, lidar collections of the northern counties, which were delayed owing to flooding and calibration issues, have been conflated and are in final stages of completion by dedicated staff.

With more counties nearing completion, edge-matching has been a continuing challenge. Marion County, which borders on seven other counties, has been particularly problematical, but, thanks to past experience, these issues are being resolved.

She concluded with a description of the review process, the project status map (**Figure 12**) and an updated project completion schedule.

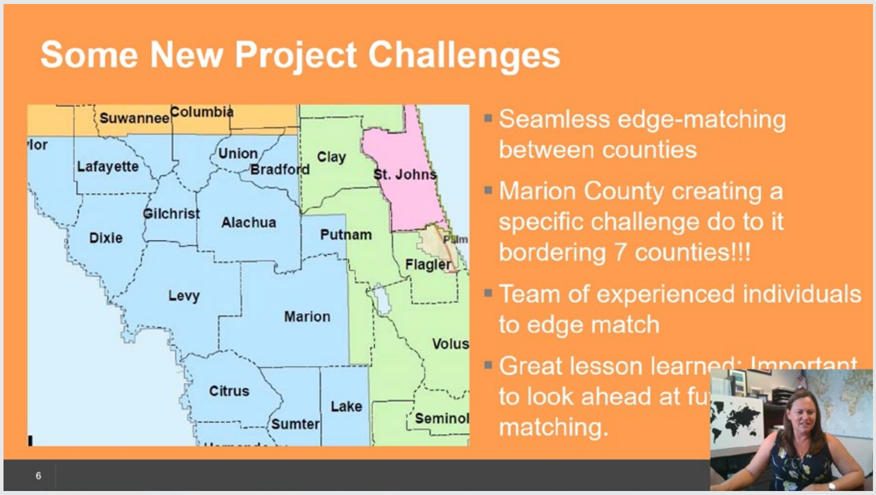

Figure 11: Recent challenges to the Peninsular Florida lidar mapping program.

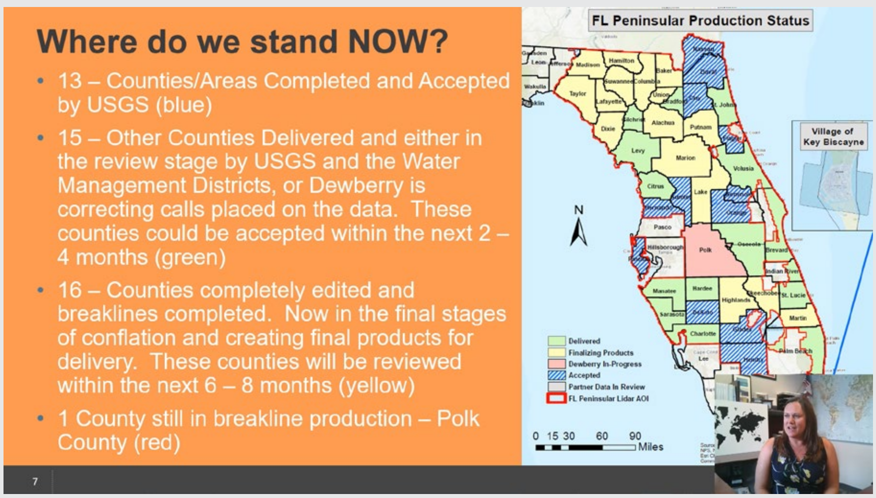

Figure 12: Status of the Peninsular Florida lidar mapping program.

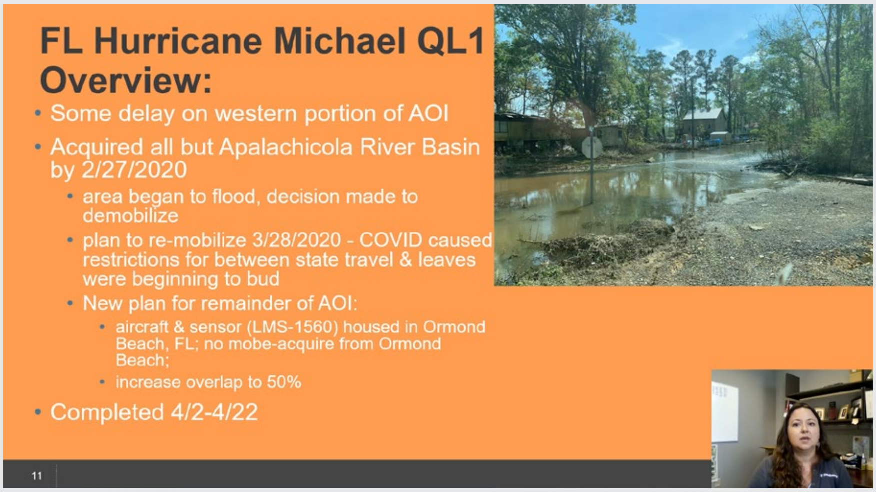

Figure 13: Summary and plan for the Florida Hurricane Michael QL1 Supplemental project.

Emily Klipp completed Dewberry's presentation by discussing the status of the Florida Hurricane Michael Project (**Figure 13**). She summarized the damage resulting from the hurricane and the rationale for the USGS Supplemental project. The QL1 lidar collection was accomplished by the end of February 2020, but flooding along the Apalachicola River, combined with covid-19 restrictions in early 2020, delayed acquisition in the area until late April 2021.

Emily ended with an update map of the Hurricane Michael Supplemental Project (**Figure 14**).

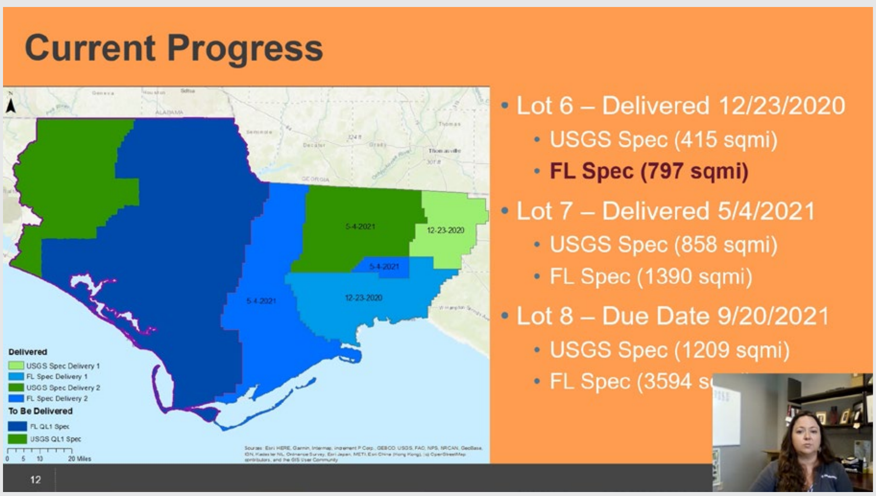

Figure 14: Status of the Florida Hurricane Michael Supplemental project.

Alvan "Al" Karlin, PhD, CMS-L, GISP is a senior geospatial scientist at Dewberry, formerly from the Southwest Water Management District (SWFWMD), where he managed all the remote sensing and lidar projects in mapping and GIS. With Dewberry, he serves as a consultant on Florida-related lidar and imagery projects, as well as general GIS-related projects. He has a PhD in computational theoretical genetics from Miami University in Ohio. He is a past president of the Florida Region of ASPRS, an ASPRS Certified Mapping Scientist – Lidar, and a GIS Certification Institute Professional.

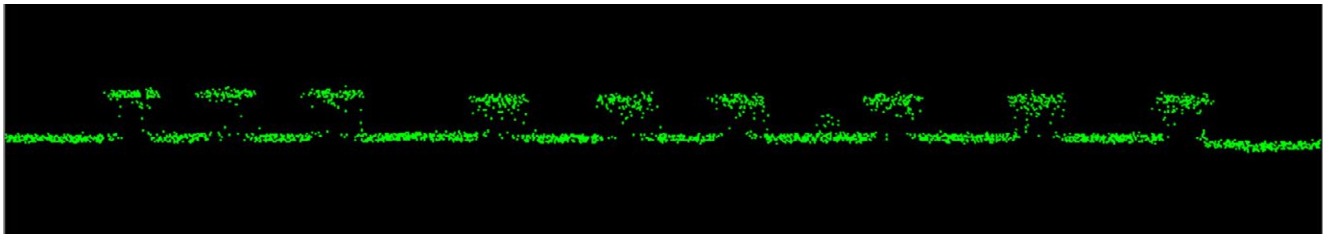

Figure 3: HVAC unit scan by True View 515 - 75m AGL.

Graham, *continued from page 48*

distribution wires, compute stockpile volumetrics, model rail lines, monitor construction sites—you get the idea. One of the major concerns is what I call point-cloud "conformance." Conformance is a measure of how well the point cloud fits the true object space. For example, if we are modeling something lumpy such as a gravel or coal stockpile, do we have some amorphous blob or does the point cloud closely follow the true shape of the object being modeled?

Consider a row of HVAC units beside our new GeoCue main building (**Figure 2**). These units are rectangular with some transparency to the interior via the fan guards. We would expect to see rectangular peaks in the lidar data with a few stray interior points across the mid-section from penetrating rays.

If we examine data from a True View 515 3D Imaging System (3DIS), we see just what we expect (**Figure 3**). These data were captured during a lidar QC flight at 75 m above ground level (AGL).

We are testing a new, low-cost lidar system based on the Livox Avia (I'll call this system "X"). This system is showing (among other issues) poor performance in the conformance area. Consider the same scan of the HVAC area using X (that is, 75 m AGL, all-flight-lines scan). As you can see in **Figure 4**, the conformance of X is really terrible. The rectangular HVAC units are reduced to a series of hay piles! I would be reticent to use this system for anything except perhaps a few very well-known scenarios (clear area; hard, flat surface) owing to this obvious gross inaccuracy in conformance. Now it could be that these errors are being introduced by the proprietary post-processing software, such as a poor data smoother; more investigation is needed.

An interesting note is that the vertical accuracy of X measured on flat, hard surfaces is in the neighborhood of 4.5 cm root mean square error (RMSE)—by the old vertical accuracy standards, a fine lidar sensor. In a feature article scheduled for a Q1-2022 issue of *LIDAR Magazine*, we will present a detailed overview of this sensor.

The takeaway message here is to look holistically at the performance of lidar, camera and 3D imaging systems. Vertical accuracy, expressed as RMSE against a set of check points, is a very important lidar parameter, but if conformance is as bad as shown in **Figure 4**, do you really have a useable system? I would say, for most applications, probably not. Today there are no generally accepted tests beyond vertical accuracy for lidar systems. Perhaps it is time we begin collaborating on some assessments that provide a better overall picture of sensor performance.

Lewis Graham is the President and CTO of GeoCue Corporation. GeoCue is North America's largest supplier of lidar production and workflow tools and consulting services for airborne and mobile laser scanning.

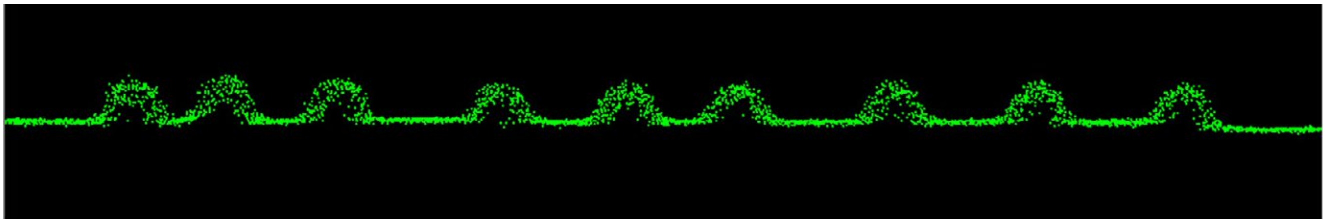

Figure 4: System X HVAC row conformance.

LEWIS GRAHAM

We Need New Lidar Testing Criteria

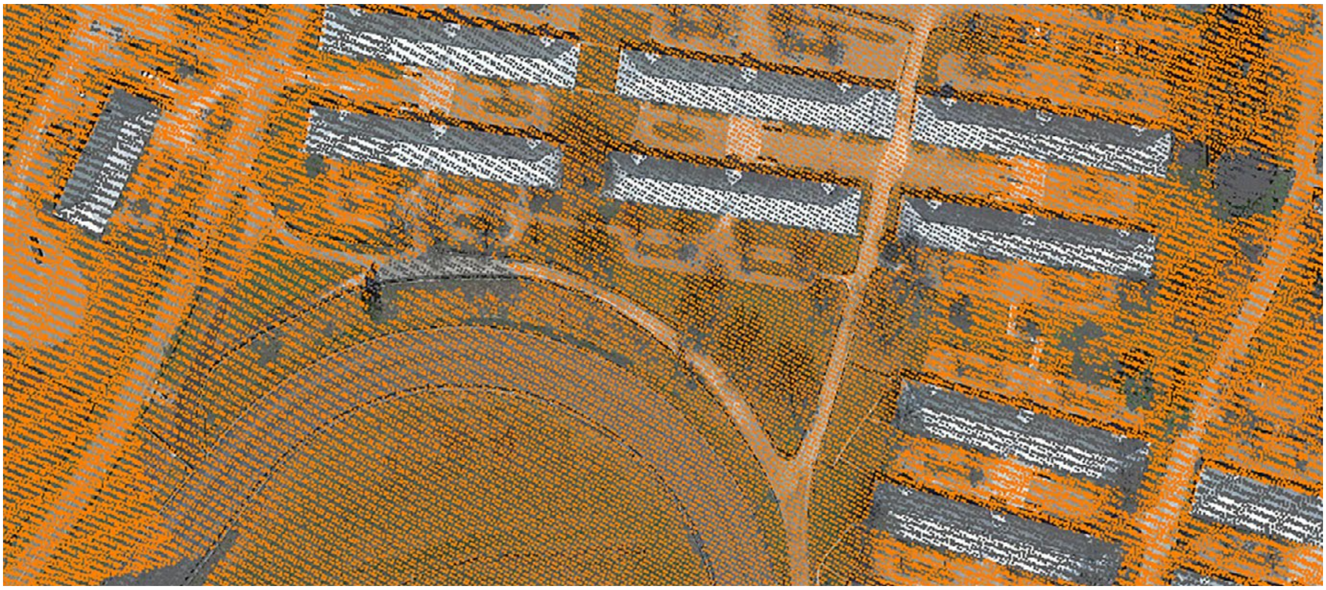

Figure 1: Keenland data set, circa 2005.

Figure 2: Row of HVAC units.

I have been in the business long enough to watch lidar point density go from single-line profilers with perhaps a point every few meters to the incredible density we get now with drone lidar systems such as our own True View 3D Imaging Sensors.

In the beginning, the technical focus of the community was firstly on vertical accuracy and secondly on vegetation penetration. If you think about it, a vertically accurate point on the ground every few meters is a big step up from boots-on-the-ground topo collection. No wonder the Federal Emergency Management Agency (FEMA) was one of the first to mandate lidar for flood-plain mapping: lidar made cyclic updates of Digital Flood Insurance Rating Maps (DFIRM) a reality. **Figure 1** shows a lidar project from circa 2005 with a single-flight-line nominal point spacing (NPS) of 1 m (~3 feet). This was a fabulous data set for its time.

Nowadays we use lidar for direct 3D imaging with a variety of applications as broad as your imagination. However, we really have not moved much beyond the original assessment of lidar data quality.

We now use lidar for myriad tasks beyond constructing a topo map. We routinely collect transmission/

continued on page 46

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