LIDAR MAGAZINE

VOLUME 11 ISSUE 1
SPRING 2021

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LIDAR MAGAZINE

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◀ ON THE COVER

The state of Florida shown via Moderate Resolution Imaging Spectroradiometer (MODIS) image, acquired by NASA's Aqua satellite.

Source: Jacques Descloitres, MODIS Rapid Response Team, NASA/GSFC

LIDAR To Go!
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DR. A. STEWART WALKER

Florida Open for Lidar Business

The focus of this issue is lidar in Florida. I wrote earlier about the lidar workshops series run by the ASPRS Florida Region and the University of Florida, of which the first online one took place last October. After the event, I approached the organizers and suggested publishing some of the presentations in the magazine. I am enormously indebted to one of our regular contributors, Dr. Al Karlin, who helped me with the project and acted as a conduit to the authors. No less than 13 articles emerged! Al himself provided a short history of the workshops to give a perspective, then he and Matt LaLuzerne compiled a summary of a session in which the various Florida organizations that collect lidar described what they had been doing. There are ten articles from the commercial sponsors, one of which is an interview with *RIEGL* USA senior vice president, James Van Rens, based on his keynote at the workshop. Finally, one of the academic presenters chose to publish with us and we're pleased to print Allison Senne's study of seagrass, where airborne imagery was used but future work will benefit hugely from topobathymetric UAV-lidar. We hope you enjoy these articles. They go well beyond Florida—Jamaica and Tonga, for example—and reflect the energy and imagination of the workshop organizers in assembling a high-quality program.

We've been able to prevail upon Jeff Lovin, senior vice president at Woolpert and president of ASPRS (until Dr. Jason Stoker takes over on 31 March 2021) to give us an industry outlook. This embraces not only technology but also the effects of the pandemic—valuable insights from an industry veteran. And, of course, we have Lewis Graham's "Random Points", yet more well thought out advice from an acknowledged expert.

We appear—in the US at least—to be reopening after covid. The lidar community has high hopes that the Geo Week conferences take place as scheduled in Denver in February 2022. The ILMF Advisory Committee has been working hard with Diversified Communications on the program. We look forward to the fourth incarnation of the Lidar Leader Awards. In the short term, however, continuing caution is recommended, even by those who have been vaccinated. I'm writing this just after a week of celebrations, with Pi Day on Sunday and St. Patrick's Day on Wednesday. Let's hope the former doesn't turn out to be a geospatial superspreader, as its festivities will have attracted the sort of uninhibited throng who'll put a samurai sudoku to one side in order to attack Dave Lindell's "test yourself" puzzles in *The American Surveyor*. Fortuitously, a less cheerful event fell between the two and we hope that the admonitory spirit of *cave idus martias* spread through the week…

As I noted in my previous comments on the excellent online events that have emerged during the pandemic, one of the highlights was the

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Geospatial Summit run by the Spatial Sciences Institute (SSI) at the University of Southern California, which took place on 26 February—the 11th such event and the first online. SSI was assiduous in inviting me to attend in order to report on the day[1]. The number of attendees varied thoughout the day, to a maximum of 130. The goal of the meetings over the years has been to present some of the ongoing geospatial activity in the greater Los Angeles area and in particular to give students opportunities to present both verbal and poster papers and to learn about employment opportunities. After an opening session on “Data and Dashboards: Using GIS to Communicate in Crises”, with an emphasis on covid, came, for me, the best part of the day—the student poster session and the discussions with the presenters. One of them had surveyed oyster beds using remote sensing, but admitted that topobathymetric lidar was her dream sensor. Next were three student lightning talks, with well known respondents from Esri, USGIF and Maxar Technologies. No less than seven sessions were available called “lunch and learn”, then the main session of the afternoon was Zoom rooms to talk to 17 companies and organizations. The final session was “Customizing your applications: making the data work for you”, with expert speakers from Northrop Grumman and Maxar Technologies. If you’re anywhere near LA, think seriously about attending next year’s event, on 25 February. There was rather little lidar on this year’s program, but I’m confident next year will be different!

More recently, I joined a packed one-hour event, “How to utilize 3D mesh models for smart city and AEC applications,” sponsored by Aerometrex and hosted by Gavin Schrock of Geospatial Media. This topic shows how we are moving forward, i.e. beyond merely creating the mesh models but actually using them. Chris Andrews of Esri spoke about 3D mesh in ArcGIS, then the session entered a vigorously international component. Christian Doehring, speaking from Calgary, presented Pureweb’s approach to publishing and streaming, then a presentation, by Ray Henry in Ireland, from the start-up Ambiflo, discussed applications for mobile telecommunications. Gavin rightly pointed out that it’s nevertheless important to understand the “heavy lifting” that must go on before the digital twin can exist and be exploited and Matt Walker, from the Aerometrex office in Brisbane, Australia, took up this theme. With good planning so much can be packed into an hour! The bimonthly meeting of the ASPRS LAS WG will be reported by Evon Silvia on the website and it’s gratifying that revision 16 is ready to go. ASPRS is limbering up for its annual conference, once again virtual. This will be rather a marathon, because it’s packed with excellent presentations, with a five-day program starting on 29 March 2021.

As a result of my involvement with *LIDAR Magazine*, I have had the great honor of being invited by Underwriters Laboratories to participate on their Standards Technical Panel 4700, “LiDAR and LiDAR Systems”. The goal is a standard concerned with lidar safety. I find myself privileged to be amongst a group of top engineers from lidar sensor manufacturers, automotive companies and safety organizations. I may have to request your help on this, so will report again once the group gets going.

How’s this for a one-paragraph description of our science? “Using laser light in the same way that sonar uses sound and radar uses radio waves, ‘lidar’ technology is used to build digital models of all sorts of environments. Ecologists use it to estimate forest biomass, film-makers to produce simulacra of famous cities that can then be trashed in spectacular computer-generated mayhem. Would-be-autonomous vehicles use lidar to spot obstacles. If your phone recognises your face in the dark, it is because it is running its gentle infrared lidar across your features. Thanks to their precision, lasers can pick up movement, too. Some lidars measure wind speeds by tracking dust motes in the air. Spies use lasers reflected from windows to snoop on conversations; the tiny vibrations in the glass caused by voices on the other side create measurable variations in the wavelength of the reflected light.”[2] This makes it sound exciting, to be sure, but omits mapping and charting, surely the bedrock of many of lidar’s spectacular achievements. These applications are special, not only to the readership of *LIDAR Magazine*, but also because they excel when lidar data is fused with that from other sensors—and this is performed at scale. Nevertheless, as I never weary of saying, it means we lidar folk are mainstream and will have plenty to do…

A. Stewart Walker // Managing Editor

1 The program can be found at https://spatial.usc.edu/los-angeles-geospatial-summit-events/2021-full-program/.

2 Anon, 2021. Lasers: outshining the sun, *The Economist*, *Technology Quarterly*, 9 January 2021, page 10.

The Florida ASPRS Lidar Workshops

9TH IN SERIES GOES VIRTUAL

The five Water Management Districts (WMDs) in Florida—Northwest Florida (NWFWMD), St. Johns River (SJRWMD), Suwannee River (SRWMD), South Florida (SFWMD), and Southwest Florida (SWFWMD)—along with the Florida Division of Emergency Management (FDEM) and the Florida Department of Transportation (FDOT)—have played a major role in acquiring and distributing high-quality elevation data to the State. Beginning in the 2001/2002 flying season, lidar missions started to replace traditional on-the-ground survey for water modeling by the WMDs, and, by 2007, the FDEM and WMDs partnered with USGS to conduct a massive coastal lidar program.

The 2007 FDEM/USGS mission was designed to capture what would become "USGS QL3" data for coastal regions from the western panhandle (NWFWMD) through the Big Bend (SRWMD), along the Gulf of Mexico (SWFWMD) and along the Atlantic Coast (SFWMD and SJRWMD). Although the original intent of the project was to serve coastal areas for storm surge modeling (Sea, Lake, and Overland Surges from Hurricanes, SLOSH), many counties, with the aid of the WMDs, "bought up" the lidar for more inland areas to be used for watershed and surface water modeling.

The project, of course, took longer than anticipated to complete, but as the data trickled into the WMDs for surface water modeling, other, inland counties could see the benefits of the lidar-based DEMs. Several of those inland counties cooperated with the WMDs to secure American Recovery and Reinvestment Act funding to acquire lidar data in the 2009/2010 flying season.

Finally, with the results of the USGS National Enhanced Elevation Assessment (NEEA) in 2011, the creation of the 3D-Elevation Program (3DEP), and the Broad Agency

BY AL KARLIN

Announcements (BAA) that followed for 3DEP funding partners, there was renewed interest in updating the "QL3" data from 2007 with newer technology and higher density lidar-derived DEMs. Several of the WMDs, counties, and municipalities responded to the BAAs that followed and started acquiring new lidar data. This resulted in a patchwork of elevation data, collected at different times, with different technologies, at varying accuracy levels, to meet different needs, and a general need to coordinate WMD activities.

In the fall of 2015, as I was the newly installed President of the Florida Region of ASPRS and on staff at SWFWMD, several colleagues from the other WMDs approached me for guidance on how to review lidar point clouds and breaklines that they were receiving from the 3DEP program contractors. We conferred among ourselves, started a small working group under the umbrella of the Florida Region of ASPRS, and included our USGS state-liaison and a few selected academic members from around the state. After a few phone conferences (this was all before Zoom and/or Teams), it became apparent that we were discussing so many lidar-related topics that our phone calls were not sufficient. Thus we landed on the idea of a "Lidar Workshop" for the spring of 2016.

That first University of Florida/FL-ASPRS Lidar Workshop was a one-day event held at the University of Florida, Institute of Food and Agricultural Sciences, Mid-Florida Research and Education Center (IFAS/MREC). The venue, in Apopka in central Florida, was convenient to most of the participants and easily accessible by highways in the Orlando area. To help defray rental and lunch costs, the Florida Region involved corporate sponsors and, in return, provided an opportunity to network with the state agency representatives in attendance. The program was incorporated into our biannual ASPRS regional meeting and included the four major components that persist today: state agency updates, a "keynote" topic speaker, a "workshop" of industry innovations, and academic research.

The workshops have registered consistently around 100 people (the fire marshal's limit on the IFAS/MREC is 110 persons). The participants have represented the three major ASPRS sectors: government, including several of the state agencies, the five WMDs, the US Army Corps of Engineers, Jacksonville District (USACE/SAJ), Natural Resources Conservation Service (NRCS), and USGS; private enterprise (over 15 different sponsors, including Dewberry, GeoCue, GPI GeoSpatial, Quantum Spatial[1], Riegl USA, Surdex, and Woolpert; and academic representatives, including University of Florida, Florida Atlantic University, University of South Florida, and Embry-Riddle Aeronautical University. Selected topics have evolved over the nine workshops and have spanned the lidar/remote sensing spectrum. Workshops have been focused on diverse topics such as topobathymetric lidar and sonar; UAV-based lidar platforms; forestry lidar applications; and laser scanning for historical preservation.

While the workshops are open to ASPRS members and non-members alike, over 60% of the attendees are ASPRS members, who are eligible to receive six professional development hours (PDH), while Florida Surveying and Mapping Society members are eligible for two Continuing Education Unit (CEU) hours.

The first eight workshops were in-person meetings at IFAS/MREC, but, as a result of the pandemic, the spring 2020 meeting was abruptly cancelled. The Fall 2020 FL-ASPRS/UF Workshop, the 9th in the series, was the first "virtual" workshop offered by the Florida Region and was conducted on the Zoom platform on 22 October 2020. As usual, there were six "sessions" beginning with a General FL-ASPRS Business Meeting and followed by nine state and national agency updates. The keynote address was delivered by James Van Rens of Riegl USA, discussing a vision of lidar technologies for the next ten years. Sessions 3, 4, and 5 featured technologies and projects by our sponsors, and Session 6 showcased academic presentations by faculty and students from Florida Atlantic University, University of Florida and University of South Florida. Riegl USA and NEI-GPS provided technology updates of their sensors and opted not to publish synopses of their presentations. Similarly, the academic presenters from the University of Florida and Florida Atlantic University opted to submit their research for publication in other outlets. All the remaining presentations are represented in the following articles.

There were 166 unique logins for the event and eight phone-callers. The maximum number of attendees at any one session was 137 and the average, 83. Moreover, in addition to out-of-state attendees, there was a handful of non-US ones, from Brazil, Canada and Netherlands. The attendance, therefore, exceeded in number what could have been accommodated in IFAS/MREC and the geographical reach was vast compared to previous years. Even as vaccines are rolling out and the fight against the pandemic has a chance of success, this broad appeal may suggest merit in running a hybrid event in the future.

"The attendance exceeded what could have been accommodated in IFAS/MREC and the geographical reach was vast compared to previous years."

1 Quantum Spatial, Inc. announced its change of name to NV5 Geospatial on 10 December 2020.

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 of the remote sensing and lidar-related 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 the immediate past president of the Florida Region of ASPRS, an ASPRS Certified Mapping Scientist—Lidar, and a GIS Certification Institute Professional.

Lidar Actors in Florida

UPDATES FROM AGENCIES ON LIDAR COLLECTIONS

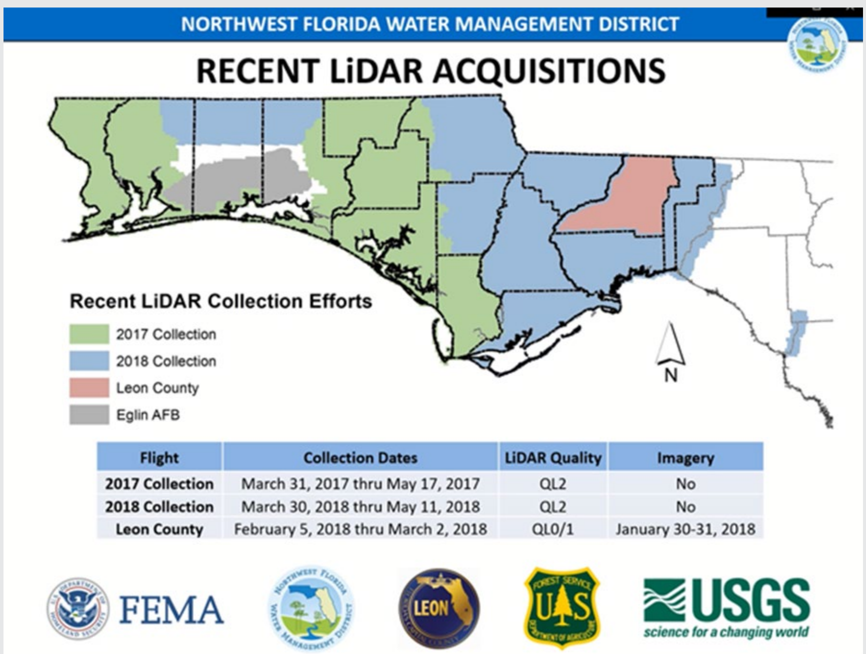
The workshops traditionally begin with representatives of the five Water Management Districts (WMDs)—Northwest Florida (NWFWMD), South Florida (SFWMD), St. Johns River (SJRWMD), Suwannee River (SRWMD) and Southwest Florida (SWFWMD)—giving short presentations detailing either their recent lidar and/or imagery acquisitions or issues that they have encountered regarding those products. The Fall 2020 Workshop heard from: John Crowe (NWFWMD); Christine Carlson (SFWMD); Bill VanSickle (SJRWMD); Paul Buchanan (SRWMD); and Nicole Hewitt (SWFWMD).

Additional state and/or federal agencies also have the opportunity to provide briefings pertaining to their activities. For the Fall 2020 workshop, briefings were provided by: Parker Hinson (Florida Department of Environmental Protection—FDEP); Jason Kirkpatrick (US Army Corps of Engineers, Jacksonville District—USACE/SAJ); Xan Fredericks (US Geological Survey—USGS); and Elise MacPherson (Dewberry; Elise briefed on the Florida State Lidar program).

In 2018, Florida Division of Emergency Management (FDEM), Florida Department of Transportation (FDOT) and the five WMDs 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 USGS/Dewberry briefing.

NWFWMD

John Crowe highlighted the previous lidar collections in NWFWMD and indicated that they were not in the process of collecting additional data at this time. He continued to note the challenge of obtaining lidar data in the Eglin Air Force Base airspace. John concluded by indicating that NWFWMD would be responding to the USGS 3DEP/BAA with a request to lidar survey the counties in the western panhandle to bring them to the QL1 level to match the remainder of the state.

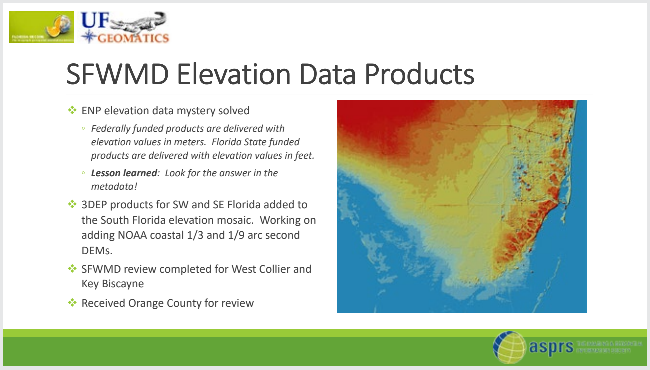


2017–2018 USGS/3DEP QL2 lidar acquisitions in the Northwest Florida Water Management District. Leon County (in pink) was collected to the USGS QL0 specification.

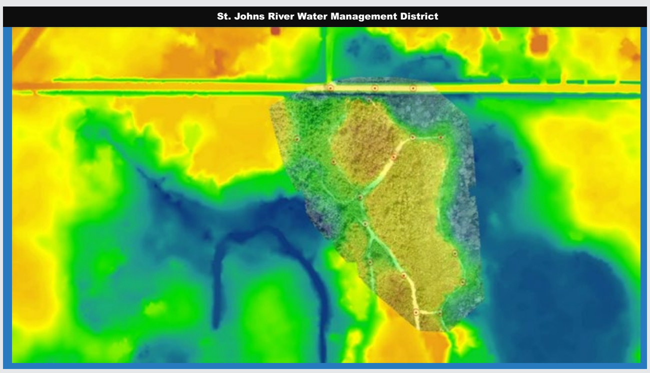
COMPILED BY AL **KARLIN** AND MATT **LALUZERNE**

SFWMD

Christine Carlson provided an update on the status of the South Florida elevation mosaic and highlighted the portions of the FDEM/USGS project that she has reviewed for Collier County and Key Biscayne. She noted that the issue presented and discussed at the previous workshop regarding an elevation difference between the Everglades National Park and Miami-Dade lidar surveys was resolved (see graphic to right). She is working on a new version of the South Florida elevation mosaic that incorporates NOAA 1/3 and 1/9 Arc Second DEMs. She showed an image of the remaining data gaps in the western Everglades area and inquired about the processing status of that 3DEP collection.



Updates to South Florida Water Management District distributed elevation products. An elevation difference between the Miami-Dade and Everglades National Park datasets has been resolved.



SJRWMD

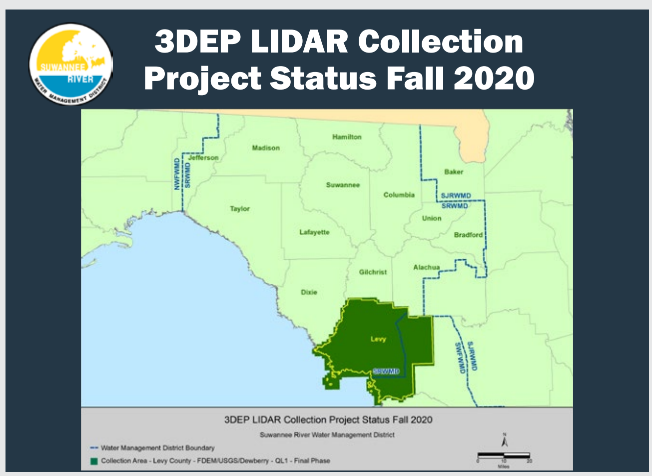
Bill VanSickle discussed SJRWMD's plans for the next round of districtwide land cover mapping and highlighted a UAV project in which lidar and drone mapping were used in combination to assess and manage Florida scrub-jay habitat near Orlando.

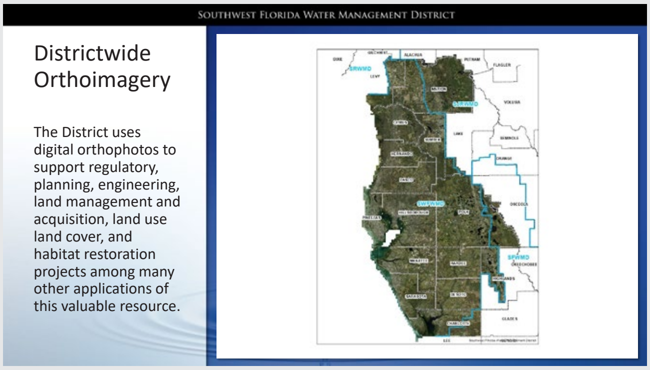
St. Johns River Water Management District Digital Elevation Model (DEM) basemap with inset portion of scrub-jay habitat surveyed with UAV. The positions of trail intersections in the lidar DEM were used as ground control points for the photogrammetry.

SRWMD

Paul Buchanan reported on the progress of the lidar re-mapping and SRWMD quality control review of Levy County. A portion of the county is in SWFWMD, but SRWMD did the review. As part of the Florida Peninsular FDEM USGS lidar project, Levy County is the first and only county delivered so far for SRWMD review.

Levy County, on the border of the Suwannee River and Southwest Florida Water Management Districts, has been the first county delivered by the Florida Peninsular Lidar Project to SRWMD for review.





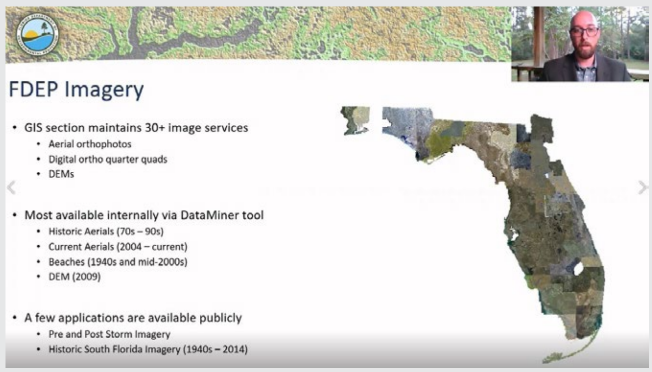
SWFWMD

Nicole Hewitt presented three projects in her update: topographic lidar, SWFWMD-wide orthophoto and seagrass imagery. She discussed how the 2017 Hillsborough County and 2018 Pasco County projects combined with the 2019 USGS Florida Peninsular lidar project will provide seamless coverage with high-quality topographic lidar throughout SWFWMD.

The Southwest Florida Water Management District recently completed and accepted the 2020 digital orthophotography for the 16-county area shown in the figure.

FDEP

Parker Hinson represented FDEP and the Florida Geographic Information Office (FGIO). He provided historical context for FDEP's internal and external imagery services and applications, and outlined the timeline to distribute the remaining county imagery services acquired in 2020. As GIS lead for FGIO, he described ongoing efforts to identify an online platform to store state imagery, lidar datasets, and bathymetric data that is not under existing stewardship—for example historic imagery related to hurricane flights. He also relayed statewide initiatives and community events, in addition to a new lidar resource page available at the Florida GIO hub site, *floridagio.gov*.



Florida Department of Environmental Protection maintains image services for multiple image datasets as shown on this figure.

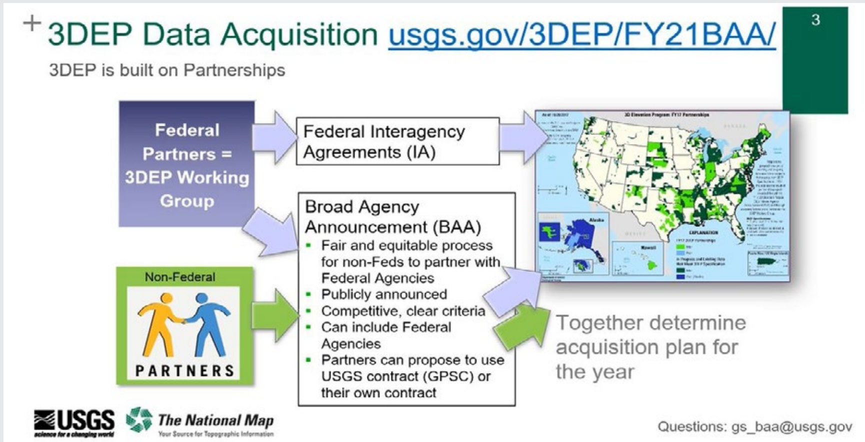
The US Army Corps of Engineers, Jacksonville Office offers instructions on the procedures to start a UAV program.

USACE/SAJ

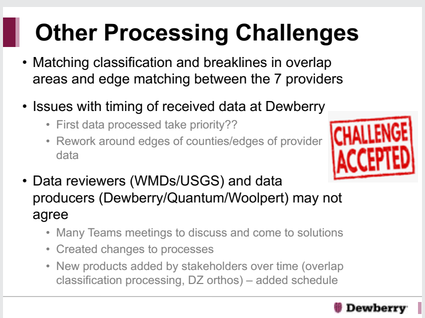
Jason Kirkpatrick's briefing covered the Corps' UAS program and discussed the steps involved in starting a local program. He emphasized the advantages, disadvantages and risks involved with maintaining a UAS program and showed a user-focused planning application (MARS) used by the Corps. He offered the Corps' standards, training, and mission management system for use by other organizations and can be reached at HQAviation@usace.army.mil.

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. Xan indicated that a new Florida 3DEP Fact Sheet is in preparation, along with a National Digital Trails Project update that highlights the addition of Florida trails in the TRAILS Decision Support Tool. Her briefing concluded with a message about the Florida Coastal Mapping Program (FCMaP) Virtual Forum on 3 December 2020.



USGS uses the Broad Agency Announcement solicitation method to put federal, state and local partners together for funding opportunities.



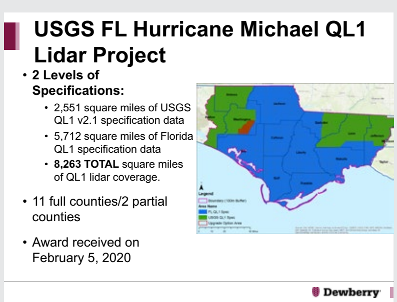
Slide showing some of the issues encountered during the lidar processing stages of the Florida Peninsular lidar program.

Florida Statewide Lidar

Elise MacPherson presented the Florida Statewide Lidar Mapping Project on behalf of Dewberry. The presentation started with an overview of the Florida Peninsular project and proceeded to discuss the challenges and issues encountered with the project. She outlined problems with calibration, classification, and breaklining, along with the complexities of having multiple data collectors, compilers, and levels of external review.

Dewberry responded to the challenges and Elise gave details of the current processing and updated delivery schedule and presented the plan for the Florida Peninsular-phase of the project to be delivered and accepted by USGS in mid-2021. Given the uncertainties of the pandemic, however, the schedules remain flexible and subject to modification.

She finished the briefing with the introduction of the recently awarded USGS Hurricane Michael QL1 lidar acquisition in the central panhandle of Florida. She indicated that data acquisition was completed in April 2020, and the pilot area was delivered in May 2020. Project completion is anticipated in late May 2021. ∎



Alvan "Al" Karlin's biographical notes are on pg 7.

Matt LaLuzerne, PSM is vice president and strategic growth director at GPI Geospatial, Inc. and has over 15 years of experience managing and performing various types of survey and geospatial products, ranging from traditional boundary and control work to multi-platform remote sensing services. He has worked closely with public and private clients to establish clear and concise methods for data collection, processing, and final deliverable products. Matt has given countless presentations and continues educational classes and technical seminars for ASPRS, FDOT, FSMS, ACEM, TUC and TEAMFL, and is contributing to the continued growth of the geospatial industry.

The Next Decade with lidar

LIDAR MAGAZINE INTERVIEWS KEYNOTE PRESENTER JAMES VAN RENS, SVP, *RIEGL* USA

The keynote at the Workshop was given by James Van Rens of *RIEGL* USA. *LIDAR Magazine* (**LM**) interviewed James (**JVR**) and put questions to him drawn from his keynote, which was entitled, "The next decade with lidar".

LM: James, thank you for taking the time to talk to us. Our questions are based on your keynote at the Workshop. I'm sure almost all of our readers know you, but, in case some don't, could you please tell us a little about yourself? How did you become involved in the geospatial world? You are currently Senior Vice President with *RIEGL* USA, Inc., headquartered in Winter Garden, Florida. When and why did you join *RIEGL*?

JVR: Most familiar to your readers is my role at *RIEGL* USA as Senior Vice President. Additionally, I serve *RIEGL* International as a strategic advisor and as *RIEGL*'s Board Member to the World Geospatial Industry Council.

RIEGL's early product application was in hydrography. Involvement with the geospatial world is part of the *RIEGL* DNA. In the 1990s, *RIEGL* developed its first airborne scanner—this led directly to involvement with ASPRS. I was quite active with ASPRS during development of the LAS data exchange format. This

James Van Rens, senior vice president, *RIEGL* USA

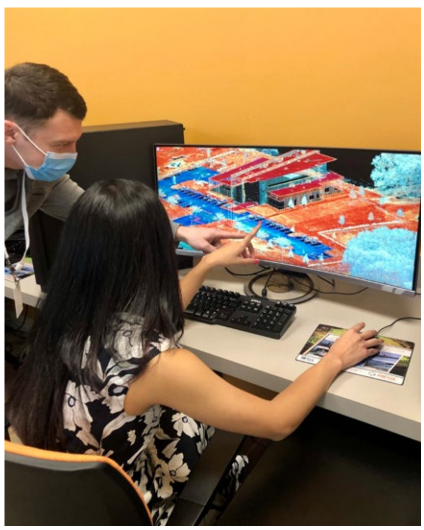
BY STEWART WALKER

Entrance of *RIEGL* USA's new headquarters

standard was critical to lidar producers, surveying and mapping firms, and their clients.

My attention was drawn to the world of laser rangefinding during the 1980s. Motorola was an innovator that I followed closely. It developed a method that monitored the environment for signals of technological change. Laser rangefinding was clearly a signal of change. So, in 1993, I started a business applying laser rangefinders to commercial and industrial situations. It was a very small field and led me to *RIEGL*. By 1997, it was clear that the instruments *RIEGL* produced were innovative, very robust, and accurate. This was critically important as those early applications would set the tone for further business. The rest, as they say, is history.

LM: Your presentation began with a historical review of lidar. What do you think are the most important innovations that *RIEGL* has contributed to the development of the technology?


RIEGL USA team members processing data captured over *RIEGL* USA's new headquarters

JVR: Dr. Johannes Riegl, founder and CEO of the *RIEGL* Group of companies, has been visioning the *RIEGL* path since 1978 and still is one of the most forward thinking and innovative entrepreneurs in our industry.

In the 1990s, Dr. Andreas Ullrich joined the company. He would become chief technical officer, principal product development leader and the leading light of our digital waveform signal processing. And, of course, Dr. Martin Pfennigbauer, who heads up many of the current development and research projects at *RIEGL*, has also made important contributions.

Dr. Riegl's foundational work with avalanche pulse generators in the 1960s and the application of the principles of radar measuring provided the critical start. This led to the development of a pulsed laser rangefinder in the 1970s. The 1980s featured new applications and products suited to them. In the 1990s, scanners with rotating polygonal mirrors were realized for important new applications such as airborne scanning. 1998 saw the arrival of the first 3D scanner. An important development occurred in early 2000 with the introduction of the LMS-Q560 digital full-waveform airborne scanner. By 2010 the digital signal processing regime had found its way from airborne to terrestrial to mobile platforms. In 2012, *RIEGL* fielded its first bathymetric system for coastlines and shallow waters. In 2013 the LMS-Q1560 was introduced. The importance of this design was to be seen with the "crossfire" scan pattern to minimize range shadows. This important design set the stage for high-density airborne mapping with superb data visualization. This was quickly followed by the introduction of the VUX-1 system for UAVs. Currently, we are introducing the VQ-840-G bathymetric system for UAV and helicopter applications.

LM: Let's move straight into what is a thorny problem, perhaps, for traditional geospatial lidar suppliers. A great deal of ongoing development of the technology is taking place in the automotive world, funded by the deep pockets of the car and truck manufacturers, especially those involved in autonomous vehicles. One result has been the appearance in the geospatial market of very competitively priced sensors, suitable for mounting on both UAVs and vehicles carrying mobile mapping systems. Do you see this as a good thing for the geospatial world? How has *RIEGL* responded?

JVR: There is a website called "Our World in Data"[1] that illuminates the issue. It features charts of technological change in various areas over the years. You can plot the development of lidar in a very similar fashion. A higher number of shots per second leads to greater productivity, which leads to better information and to new applications. The investment by the automotive companies is a natural development. For instance, there has been discussion that crowd-sourced transportation mapping with these onboard automotive sensors is the future of mobile mapping. It is an intriguing question. The car companies need sensors that are in the range of hundreds of dollars, not thousands. The intermediate sensors at the product development stage look for other applications to sell into. They are looking for new markets and new applications. Does this mean that they are "good enough" for surveying and mapping? The professionals in the industry will answer that question.

> "The role of geospatial in managing our world is at an all-time high. Airborne acquisition for a wide range of customers is increasing."

LM: The other side of the coin is that some people have suggested that the airborne lidar market, i.e. systems flown on manned aircraft and helicopters, is stagnant or declining. Yet we have noticed that the large US geospatial services companies seem to be prospering despite the pandemic, with plenty of contracts and a customer base that demands more data, more detail, more accuracy, and more repeat collects. What is your view?

JVR: The role of geospatial in managing our world is at an all-time high. Airborne acquisition for a wide range of customers is increasing. The marketplace, however, is changing in a very natural way. The forces of market maturity have led to various segments being emphasized at one time or another. As end users of the data become more sophisticated, they need better information for analysis and decision making. This leads to more data, requires better accuracy and involves repeat collects. This trend will increase.

LM: What are the most popular applications of lidar at the moment, first of all in the manned aircraft/helicopter case, then in the UAV case? What are the drivers behind this picture? How do you think the deliverables, supplied by the geospatial services companies to their clients, are changing?

JVR: The clients of our geospatial service companies need actionable information. That is driving many changes. Lidar point clouds are the base, but analytic information is what is required. Final deliverables from geospatial service companies are constantly changing to meet the needs of their clients. High-accuracy, high-density lidar provides innovative new visualizations and deliverables for many areas, such as forestry as an excellent example.

For traditional airborne mapping, the segment leaders are wide-area mapping, project mapping, corridors, and emergency response. However, they all have sub-segments within them that ebb and flow. For wide-area mapping, there are urgent needs for forestry mapping and shoreline mapping. In corridors you have different types of powerline mapping, and transportation has many different requirements.

For UAVs there are overlaps, but the dominant users are surveying and mapping firms for everyday projects. The world of construction is using drones in an increasing fashion to raise productivity and provide the job site superintendent with an overall view of the project. Electric utilities are chasing UAV mapping for beyond visual line of sight (BVLOS) to better manage their extensive networks. UAVs are here to stay with an increasing role in many areas. As with any new technological improvement, there is an initial period of exuberance, which settles into a solid growth path.

LM: In your keynote, you spent some time discussing accurate, authoritative

1 https://ourworldindata.org

data. Would you like to expand on that?
JVR: The key issue with data is veracity, reliability, and trust. The need for standards that are developed in conjunction with academia, industry and government is paramount. Who is to say that the data is correct and right? Do we rely on everyone to do their best or do we have standards? This is evolutionary. As the technology and the data change—so too must the standards, which must be authoritative and relevant. *RIEGL* is supporting the industry-university collaboration on fundamental matters of geospatial data referencing, standards, and analytics. We believe it will propel technological progress across private and public sectors and favorably impact the US's strategic position in the global geospatial enterprise. A consortium of universities (The Ohio State University, Purdue University and St Louis University) is proposing an Industry-University Cooperative Research Center (IUCRC)[2], the central goal of which is to accelerate technology development and commercialization.

LM: One of the developing applications that has generated special excitement has been smart cities. Could you please say more about this application and give some examples of how *RIEGL* and its customers are involved?
JVR: Authoritative surveying and mapping information is a planning requirement for the transportation network of the future. For example, New York City contracted with Tuck Mapping to provide high-density lidar mapping of various areas of the city for its planning database. Tuck Mapping used the latest *RIEGL* VQ-780 II to meet the requirements.

2 A National Science Foundation initiative: https://iucrc.nsf.gov

RIEGL's additional new production facility on campus in Horn, Austria

Technology and geospatial location data are at the heart of smart cities. As the world's burgeoning population pours into major urban areas, it is difficult for city managers and planners to stay on top of all the issues necessary to provide livable conditions. The Internet of Things is a part of this new approach. Real-Time traffic information is critical for effective emergency response and smart cities. High-fidelity mapping information regarding the transportation network of the city and the implementation of a network of sensors to assess congestion is an example of the reliance on location information. Ford Motor Company has been issued a patent that combines blockchain technology, digital assets, and smart contracts to enable autonomous vehicles to communicate with each other. If there is an emergency vehicle trying to get to a location, all of this will enable faster response.

LM: During the Workshop, there were several presentations prior to yours about the wealth of public sector lidar data being collected in Florida. The whole country, moreover, is benefiting from the massive USGS 3DEP program. *RIEGL*'s customers are heavily involved in the data collection efforts. Do you think that open data is a healthy development, or is the "fly once, use many times" business model not ideal for system suppliers and their customers?
JVR: "Fly it once, use many times" was a slogan to address the redundancy of Federal Agency data collection. 3DEP has been effective in eliminating that problem. The 3DEP open data approach has created many more opportunities because of the strategic vision of the program and its importance to managing our country.

3DEP should be viewed in the light of being an open data geospatial utility. It is authoritative. The collection of the data is held to ASPRS-developed standards. Its data format is reliant upon the ASPRS LAS format. Anyone can download the data without a license or a cost. For instance, a satellite company downloaded the data to measure its products' correctness. Distribution and trucking firms have used the information for route planning to save energy. Cities have used the information to recalculate vegetation mowing requirements due to the improved data.

LM: The next theme in your keynote was "information at the point of work". Please elaborate.
JVR: The dominant industry players, Esri for GIS and Autodesk for CAD, are collaborating at unprecedented levels to

improve product integrations and ensure *information* from one world can *easily* be leveraged in the other. *RIEGL*, which is a supplier to both, has embarked on a development program to improve the ease and efficiencies of importing lidar and image data into Esri's ArcGIS platform. Benefits include improved storing, managing, analyzing, visualizing, and sharing of the scanner data.

During 2020, Esri and *RIEGL* partnered to demonstrate how the companies' technologies could be combined in an AEC environment to store and manage a wide variety of different data sets in both 2D and 3D. Data types such as lidar scans (terrestrial, airborne and mobile), BIM (Revit models), CAD (architectural plans), UAS orthophotos, and field-collected information were included. A key benefit is that the information is available on any internet-connected device (with proper permissions), including desktop computers, smart phones, and tablets, whether in the office or in the field.

One potential example of utilizing these combined and more closely integrated technologies is the municipality inspector's ability to perform a "virtual" review of as-builts of the project's status to date, highlighting points of interest and adding comments so field inspections can zoom in on critical issues. With that, identified problem areas can be shared universally. Hence the phrase "information at the point of work".

LM: What do you think are the critical lidar trends right now in terms of evolving technology? We hear a great deal about artificial intelligence, machine learning and, in particular, deep learning. What will be their role in the lidar world? Where will they be most successful? Is *RIEGL* involved in this?
JVR: *RIEGL* is heavily involved in AI and machine learning at various levels. In the workflow of our customers, one spot of processing congestion is the classification of point-cloud data. Machine learning will be highly effective at speeding up that effort. Object recognition is another area that will greatly benefit.

For AI/ML to be more successful and have faster adoption, high-fidelity image information is critical. High-fidelity lidar systems with advanced image sensors allow the algorithms to see the assets and learn correctly. Machine learning will handle many mundane tasks very effectively. Artificial intelligence will provide us options to analyze and assess the correctness of the models we use to define our world.

LM: I understand that *RIEGL* is expanding its campuses, both its headquarters in Horn, Austria, and its US headquarters near Orlando. Could you please tell us more about what's happening?
JVR: *RIEGL* is investing in the future and expanding globally. *RIEGL* is determined to meet the sales, support, and service requirements of its customers.

In Horn, Austria, expansion is underway. 2019 saw the completion of a new assembly area for mobile mapping solutions. Currently underway is a new 100-meter indoor test range for *RIEGL* systems dubbed the "bunker". The current summit of the expansion is the brand new production facility for manufacturing the latest PCBs and assembling instruments. This state-of-the-art facility is nearing completion.

Here in Winter Garden, Florida, *RIEGL* USA has moved into its new North American Headquarters. It is designed with future growth in mind. This multi-million-dollar headquarters and training facility features modern training rooms, service areas including climate chambers, laser test ranges for equipment testing and calibration, a customer support center, a distribution hub, and sales and administration offices.

LM: Like its competitors, *RIEGL* has been a strong and consistent supporter of ASPRS and its counterparts round the globe. It is heartening to listen to senior figures such as yourself speaking at regional events. How do you think the relationship with ASPRS works for *RIEGL*?
JVR: *RIEGL* has been a strong supporter of ASPRS, which is a critical linchpin in the geospatial ecosystem. The last slide of my presentation was a group picture of the last "in person" ASPRS Florida Region meeting. The title of the slide was "Who creates the future of lidar?". The people in the picture are responsible for guiding us to new applications, new requirements, refinements of the processes and products. ASPRS plays a critical role in the development of standards, certification of experts, a peer-reviewed publication source and being The Imaging & Geospatial Information Society.

LM: James, thank you very much indeed for these full and fascinating responses. We look forward to hearing you speak again soon, both at ASPRS Florida Region events and, as covid recedes, on the wider conference circuit.

Stewart Walker is the Managing Editor of the magazine. He holds MA, MScE and PhD degrees in geography and geomatics from the universities of Glasgow, New Brunswick and Bristol, and an MBA from Heriot-Watt. He is an ASPRS-certified photogrammetrist.

Our 3D Life in 3D GIS and Digital Twins

SANBORN ILLUSTRATES THE NEXT DIMENSION

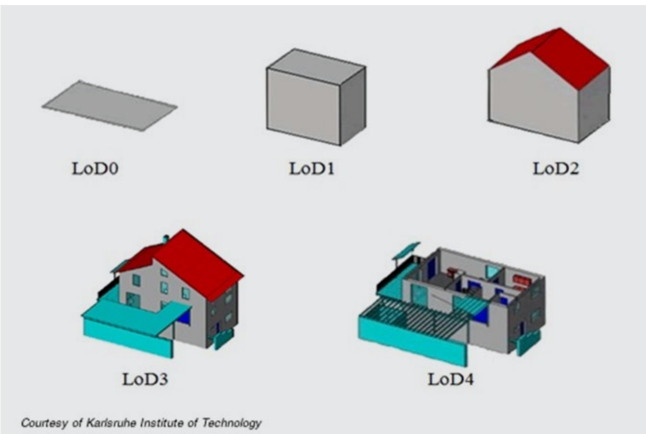


Figure 1: Schema showing the different Levels of Detail (LoDs) for building models.

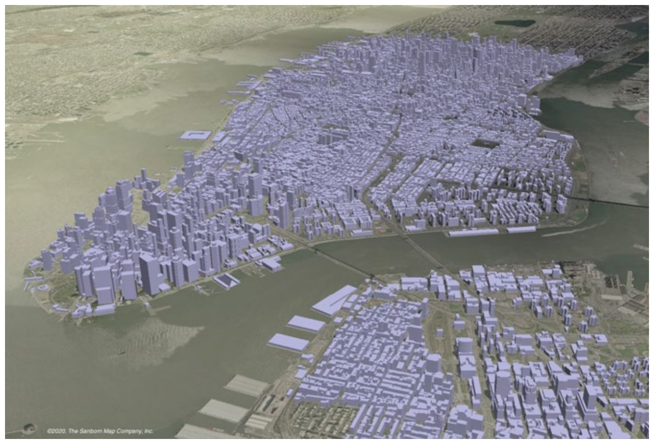


Figure 2: LoD1 building model of Manhattan and Brooklyn, New York.

Although physicists have recently determined the theoretical possibility of a two-dimensional (2D) universe, most of us are perfectly happy living in our three-dimensional (3D) world. It is a natural progression, therefore, for our GIS data to evolve from traditional 2D maps to a 3D representation—essentially creating a duplicate of the physical world by creating a 'digital twin' base map. There are numerous capabilities and advantages related to working in a 3D virtual environment. For instance, imagine a 9-1-1 dispatcher who receives a call and is then able to enter a digital twin 3D virtual environment to access real-time video feed from rooftops or other lines of sight; or to use a floor-by-floor geospatial reference for a multi-story structure, providing emergency personnel with information to better respond. This scenario just touches the surface of capabilities represented by 3D data. Sanborn has developed an array of 3D building modeling and digital twin/visualization products and services, deliverable in several formats and available for a wide variety of uses. This article provides an overview of the following:

BY KRYSIA SAPETA

- Types of architectural building models
- Building model generation
- Additional features to enhance a building model for development of a digital twin
- Applications

3D models are designed for 3D visualization, GIS applications, architectural modeling, 3D modeling, 3D graphic design, and 3D simulators.

Types of architectural models

Sanborn uses an enhanced version of City Geography Markup Language (CityGML) to classify the unique Levels of Detail (LoDs) for building models. The various LoDs display different levels of building architecture and are delivered as accurate, geo-registered (X,Y,Z) models ready for seamless integration into most 3D application software. The complexity and detail of the model increases with each level, and the five (5) standard LoDs are described below (see also **Figure 1**). Please note that each LoD type model can be void of texture, have a computer-generated texture, or have actual or photo-realistic imagery texture applied.

- LoD0 is actually a 2D footprint/outline—many of us are familiar with these and already have them in our GIS datasets—but is the basis for building the other LoDs.
- LoD1 uses the elevation of the top of the building and the ground level LoD0 footprint to construct a simple 'sugar cube' model type (**Figure 2**). Although it does not have detailed architecture, it provides the highest point of the building, which can be used for some limited line-of-sight analysis or simple modeling.
- LoD2 provides additional architectural detail. For example, the Empire State Building would be a simple block if defined according to a LoD1 model. The LoD2 model would illustrate the tiered roofline or 'wedding cake' components of the building. Domes are also modeled, as well as slanted rooftops.

LoD3 has increased complexity, and provides additional detailed modeling that includes all small building appurtenances such as exterior stairways and rooftop component details (**Figures 3** and **4**).

LoD4 is more complex yet and includes modeling the interior of the building (**Figure 5**).

Figure 3: LoD3 building model of United Nations building in New York, with computer-generated texture.

Figure 4: LoD3 building model of part of Denver, Colorado, with photo-realistic texture.

Model generation

There are three primary sources for developing a 3D model: nadir imagery, oblique/nadir imagery, and lidar.

A 3D model can be developed from a vertically oriented imagery sensor in a photogrammetric 3D environment. Features and buildings can be extracted using automated methodology, and verified/enhanced by experienced stereo-compilation technicians.

Oblique imagery typically provides five views created by four cameras each tilted at 45 degrees and arrayed in 90° arcs around one vertically mounted camera. It provides views of the sides of the structure additional to the familiar nadir one.

Lidar is very successful for creating 3D models. Typically, a density of 2 to 4 points per square meter produces a relatively good result, but a higher point density can increase the quality of the 3D geometry. Automated software can provide an acceptable base model but will also need review/enhancement by experienced technicians to repair errors in the model where buildings and vegetation or other anomalies overlap.

Figure 5: Views of an LoD4 building model of an office building showing interior detail of cubes, furniture etc. The floorplan is shown for reference.

If photo-realistic texturing is desired, imagery will also need to be obtained.

Texturing

There are multiple sources of computer-generated textures to provide exterior detail to models—anything from very simple shading to more customized façades indicating brickwork, mirrored surfaces, colors, etc (**Figure 3**).

The ideal texture source is oblique imagery, since it provides multiple building views, and the imagery can be used to show the actual façade of the buildings (**Figure 4**). In some instances, for example in extreme urban canyons, additional imagery may be acquired using ground-based or drone sensors.

Additional features to enhance a building model into a digital twin

Using a high-quality and accurate building model as a base, we progress to a more robust "digital twin" by expanding/adding other significant vector features and attribute data. A digital twin combines different assets and their information in one place, facilitating improvement of operational efficiency and expanding the practical applications of a building model. It also enables users not only to view the geospatial complexities of a 3D model, but also to simulate future environments and aid in strategic planning—thus making the physical area represented more resilient and manageable.

Sanborn uses multiple techniques to extract additional features using semi-automated processes from either imagery or lidar data. Features are extracted in 2D and/or 3D and enhanced with information from the

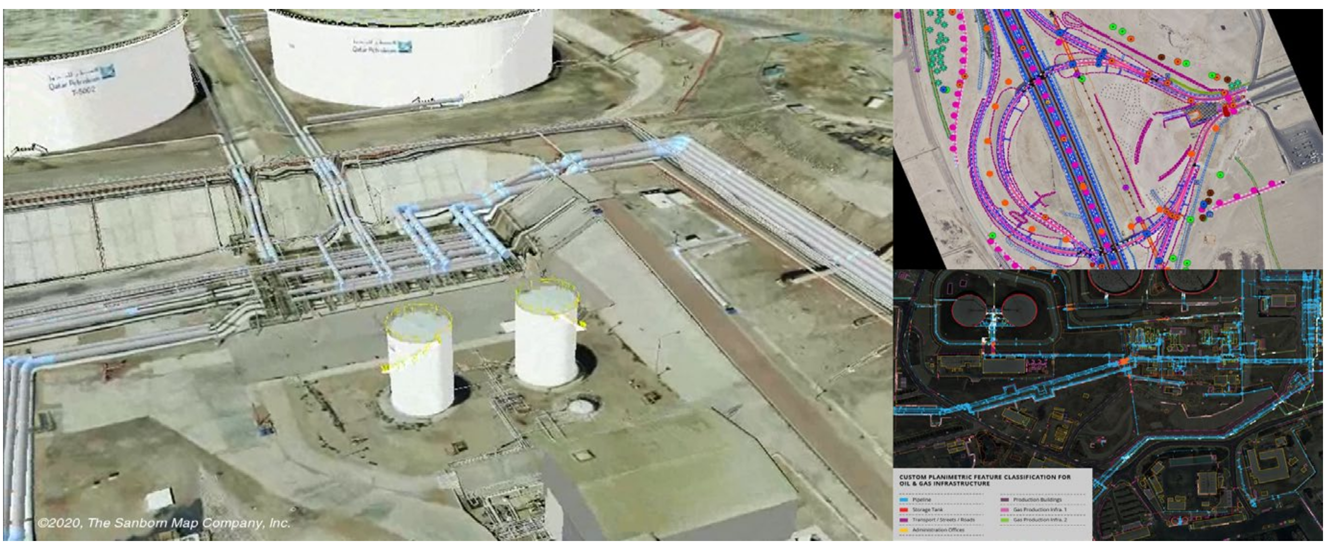


Figure 6: Views of oil and gas infrastructure. LoD3 building model with photo-realistic texture (left), orthoimagery with stereo-compiled features superimposed (top right) and incorporation of asset information (bottom right).

sensor or other auxiliary data sources such as as-built drawings and databases of information/attribution. An example of a digital twin for utility asset mapping is illustrated in **Figure 6**.

Applications

3D models and digital twins provide a wide variety of enhanced applications. Examples include:

- Emergency response—A digital twin provides the X, Y, Z location for 9-1-1 responders and is especially valuable in high-rise or multi-unit complexes. It can aid in coordinating evacuation plans, real-time video surveillance, operation planning for coordination/line-of-sight analysis/dissemination, and crime analysis (**Figure 7**).
- Building information modeling—The digital twin aids in determining optimal occupancy and facilities management for large commercial complexes. It provides the capability for urban design, where new construction design can be integrated into the existing model, and provides site analysis from an accurate virtual environment.
- Finance/Insurance—The digital twin improves an agency's ability to calculate value based on location and proximity to desirable features such as shopping and schools, and to assess vulnerability from natural hazards such as floods, fire, hurricanes, etc.
- Property investment/management—Attributes can be added to the model for property valuation, environmental hazards, and community trends. The digital twin model provides a tool to determine and track tenant acquisition and retention, especially in high rise buildings, whether commercial or residential. It allows real estate transactions to occur more easily without an onsite visit.
- Asset management—The digital twin improves the efficiency of asset management, including maintenance, tracking, and upgrade.
- Real-time directories—A digital twin model has extensive practical applications in education, marketing, advertising, tourism, etc., especially for virtual tourism and other opportunities to view locations and buildings remotely.

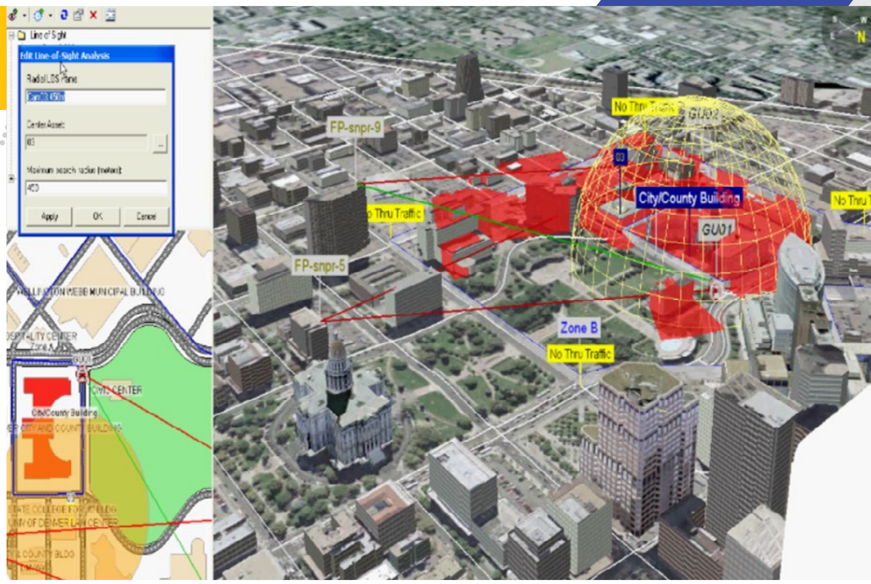


Figure 7: The use of a digital twin in operation planning related to the City and County Building, Denver, Colorado.

Conclusion

3D modeling and enhanced digital twins will continue to expand our GIS capabilities and open up opportunities for applications that make our lives better and safer, and GIS data more robust. Digitizing our 3D world can aid us in decision making and planning with advanced GIS simulation environments to provide vital information for line-of-sight analysis for high-profile route planning, strategy preparation, property management, engineering, urban design, contingency planning and safety concerns, etc. Making geographic information more accessible, including the ability for additional ecological analysis, will help our communities improve their resiliency and environmental sustainability.

With over ten million buildings modeled for locations across the US and around the world, Sanborn is an industry leader in the 3D visualization field.

Krysia (Chris) Sapeta, CP, PMP, SP, GISP has over 30 years of experience working in the geospatial industry. Her background includes a strong technical foundation as well as 18 years as a full life-cycle program manager. Ms. Sapeta continues to enhance her technology expertise through continuing education opportunities, and shares her experience and knowledge with the geospatial community through conference presentations, workshops and publications.

Ms. Sapeta is a director, strategic accounts for The Sanborn Map Company, Inc. (Sanborn). Sanborn is the oldest map company in the US, established in 1866 and originally producing extremely detailed and valuable fire insurance maps. It is now a 21st century industry leader in geospatial solutions and technology and its primary business function has expanded to providing all types of professional geospatial mapping and GIS services to organizations around the world.

Please visit www.Sanborn.com for additional information, or contact the author at ksapeta@sanborn.com or (321) 613-2809.

UAV Drone Lidar—Improving Point Cloud Data Quality via Smoothing

GEOCUE REFINES DATA FROM AUTOMOTIVE-GRADE LIDARS

Figure 1: Cement pad used for planar fit analysis (1.5 cm GSD orthophoto from True View cameras).

Drone lidar—the use of compact, lightweight lidars on small unmanned systems—is an active area of research and commercial development. The use of drone lidar has accelerated over the past five years with the opening-up of the air space to commercial drone work. These changes in the regulatory environment, along with advances in lower-cost lidars, primarily developed for the automotive industry, the availability of multi-channel lidars (8-16-32-64-128 channels) and the development of alternatives to mechanical, rotating or oscillating mirror systems, have made drone-based lidar mapping affordable and efficient for many projects that would not be cost-effective with traditional fixed-wing or helicopter surveys. Drone surveys also offer advantages over static scanning in terms of coverage and remote accessibility for many project sites. This latest innovation in lidar is a continuation of the ongoing shift in the commercial lidar industry from "big, heavy, expensive" to "small, light, cheap".

BY MARTIN **FLOOD**

At GeoCue Group we design integrated lidar/camera payloads for use on small commercial drone platforms such as the DJI M600 or the Harris Aerial H6. Our focus is on high-accuracy data collection and processing for base mapping using tightly integrated lidars and mapping cameras in a single sensor. We refer to this as a 3D Imaging Sensor (3DIS) for its combination of high-accuracy elevation data with high-resolution oblique imagery, facilitating the simultaneous generation of a true 3D colorized point cloud and corresponding orthophoto. We focus our research and field testing on how to achieve the highest-accuracy results using relatively low-cost technology, with the goal of making this technology as widely accessible as possible to the survey and mapping community. Under our True View brand, we provide the results of our research and field work as end-to-end hardware and software solutions for researchers and commercial survey and mapping firms.

Any preliminary analysis of the drone lidar market will reveal that there are several classes of drone lidar sensors in today's market with clear price/performance trade-offs. One of the

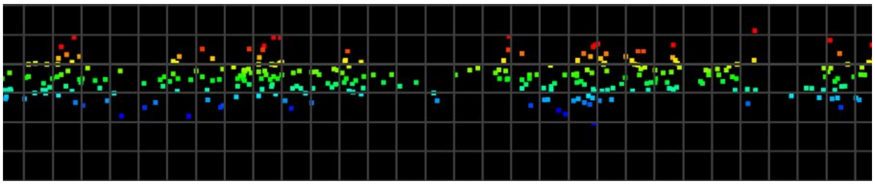


Figure 2: Point-cloud profile before smoothing.

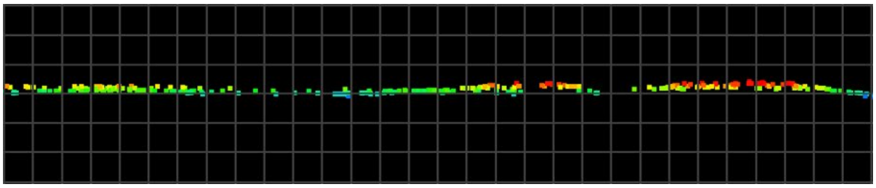


Figure 3: Point-cloud profile after smoothing.

key differentiators in both price and performance is between systems that use an automotive-class lidar (cheaper, but noisier) as opposed to what we consider a survey-grade lidar (more expensive but much less noisy). Another major price differentiator in drone lidar systems is the choice of the inertial navigation system that combines the GNSS position and on-board IMU orientation data to generate a precise trajectory for the lidar and camera. At GeoCue Group we focus on systems intended for high-accuracy data collection for professional survey and mapping projects. We have standardized on the Applanix APX series for direct georeferencing of our sensors.

A drawback to using automotive-class lidars, such as the Quanergy M8 Ultra we use in our True View 410, is that such lidars have more shot noise and larger peak-to-peak noise than lidars used in traditional airborne sensors. This noise may be acceptable for inspection and visualization applications or for low-accuracy mapping projects, but is detrimental to any survey or mapping project where accuracy is a key requirement. On a flat, hard surface such as a concrete pad or parking lot, for example the GeoCue test site in **Figure 1**, there may be upwards of 20 cm peak-to-peak (±10 cm) noise from this class of lidar. This compares to less than 5 cm (±2.5 cm) or even better from a survey-grade system. Many automotive-class lidars are also multi-channel designs with 8 to 128 separate beams in a fan-shaped scan pattern. Compared to the single-channel transceiver designs more common in survey-grade sensors, this increases the sampling rate but at the expense of introducing even more noise in the point cloud. Channel-to-channel calibration requirements for automotive applications are usually not rigorous enough for mapping and can further contribute cross-channel noise to the lower-quality data sets collected with such systems.

To address this noise challenge, GeoCue has developed smoothing routines in the True View EVO software to reduce the peak-to-peak noise in the point cloud while maintaining the overall accuracy and preserving the detail of fine features and above-ground structures. Typically, this smoothing is done after applying a final debias to the data to correct any residual systematic error in the vertical, but prior to any classification of the point cloud. Debiasing is valid for data sets where the standard deviation of the mean is small compared to the mean. Examples of the results of this smoothing for a Quanergy M8 Ultra (True View 410) point cloud measured over a flat cement pad are shown in **Figures 1–3**. **Figure 1** shows the test pad in a 1.5 cm orthophoto generated from the True View 410 mapping cameras' imagery using Agisoft's Metashape. **Figures 2 and 3** show a profile of the point cloud data across the pad from west to east before and after smoothing. The graticule in the profile is 5 cm.

By using a planar fit analysis to measure the deviation from the surface of the target, we can quantify the results of the smoothing as shown in **Table 1**.

By comparing to known field check points, we can measure the vertical RMSE error and any residual Z bias (residual systematic vertical error) of the point cloud both before and after smoothing to verify that the smoothing algorithm has not introduced any additional error into the point cloud. Note that since we debiased the data

	Point Cloud	Smoothed Point Cloud
Standard deviation to the plane (cm)	2.6	0.7
Minimum below (cm)	-11.7	-2.3
Maximum above (cm)	9.9	2.8
Peak-to-Peak range (cm)	21.7	5.2

Table 1: True View 410 planar fit analysis to cement pad.

	Point Cloud	Smoothed Point Cloud
$RMSE_z$ (cm)	1.5	1.3
Mean (cm)	0.0	0.0
Standard deviation of mean (cm)	0.4	0.3
Range (cm)	4.7	3.9

Table 2: True View 410 vertical accuracy analysis pre/post smoothing.

prior to smoothing, the mean error is zero. The results are shown in **Table 2**.

Qualitatively we are also able to assess that the planar smoothing has left above-ground features preserved, as can be seen in the profiles of tree canopy and telephone wires in **Figure 4**.

Smoothing noisy point cloud data from automotive-class drone lidars also improves the results when running a ground classification/bare-earth extraction using an adaptive TIN algorithm. This approach to ground classification is a robust method used in many lidar production software tools, including GeoCue's True View EVO and LP360 software suites as well as industry-standard tools such as Terrasolid's TerraScan. The adaptive TIN algorithm uses a spatial angular and distance test to densify a seed surface created from low points in the point cloud. The dense, noisy point-cloud data generated by most automotive-class lidars introduces bias in the selection of low points for the seed surface. The noise in the data also increases the number of false negatives—true ground points left unclassified—due to the larger angles and distances introduced by the greater peak-to-peak distribution. Smoothing the point cloud to reduce this noise on planar surfaces allows the adaptive TIN algorithm to start with a better seed surface and converge faster to a higher-fidelity ground surface. As a result, we have adopted the practice of smoothing point-cloud data prior to ground classification in all cases except where preserving the structure of low ground cover or fine terrain features on the same scale as the lidar point cloud noise envelope is the primary research interest. In such cases smoothing is detrimental to preserving those features and alternative approaches to dealing with the noise from an automotive-class lidar must be considered. Alternatively, the use of a survey-grade drone lidar sensor with inherently lower peak-to-peak noise, such as GeoCue's True View 615/620, based on the Riegl miniVUX-2, should be planned.

In summary, there is a range of price/performance options available when selecting a drone lidar sensor. When paired with comparable high-accuracy INS systems, a primary differentiator between these systems is the shot-to-shot noise introduced into the point cloud by multi-channel automotive-class lidars. Using a robust planar smoothing algorithm to reduce the peak-to-peak noise while preserving accuracy and above-ground features is an effective technique for improving the quality of such data sets on most survey and mapping projects.

Martin Flood is vice president, special projects for GeoCue Group, Inc., a technology company dedicated to creating innovative hardware and software tools for improving geospatial data production processes. Martin's primary focus is on UAV payload development and related data-processing workflows. He also works with GeoCue Group's enterprise consulting group to deploy cloud-hosted data management solutions built using GeoCue's Earth Sensor Portal web-publishing technology. Martin began his career in 1991 working on lidar sensor hardware development at Optech, Inc. and was involved in the development of the first commercial airborne lidar terrain mapping systems released by Optech in 1995. He is a member of the American Society for Photogrammetry and Remote Sensing (ASPRS) and a past chair of the ASPRS Lidar Technical Committee. He currently serves on the ILMF Advisory Board. Martin received his undergraduate degree from the University of Waterloo and his M.Sc. in physics from the University of Western Ontario. He has over 30 years' experience in the design and construction of advanced laser systems and optimizing data-processing workflows for remote sensing applications.

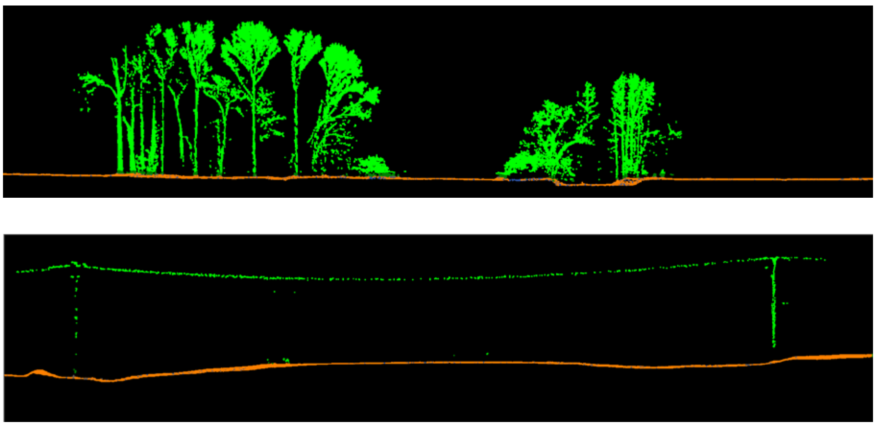
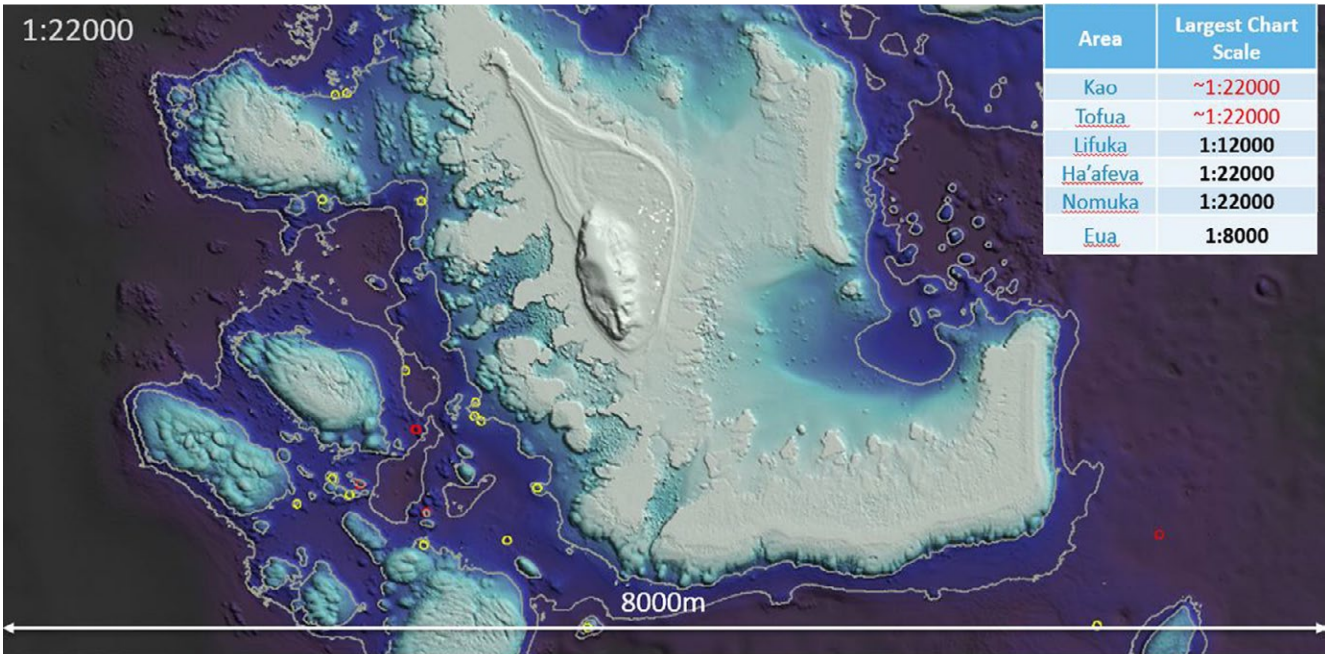


Figure 4: Canopy and telephone wires after smoothing/ground classification in True View EVO.



Area	Largest Chart Scale
Kao	~1:22000
Tofua	~1:22000
Lifuka	1:12000
Ha'afeva	1:22000
Nomuka	1:22000
Eua	1:8000

Figure 1: Multibeam sonar data and bathymetric lidar data are combined to detect hydrographic objects larger than 2 m by 2 m on the navigation surface of Nomuka, an island in the South Pacific. Difference locations are circled.
Image courtesy of Woolpert.

Topobathymetric Lidar Fits Well with Hydrographic Survey

WOOLPERT USES OBJECT DETECTION TO COMPARE TOPO-BATHYMETRIC LIDAR AND MULTIBEAM SONAR IN TONGA

BY CAROL LOCKHART

In 2018, Woolpert and iXblue teamed up to map the coastline of Tonga in support of nautical charting for Land Information New Zealand (LINZ). The project was part of the Pacific Regional Navigation Initiative (PRNI), the goal of which is to allow safe and reliable passage through Pacific waters, while protecting fragile ocean environments and allowing the economies of Pacific island countries to develop.

Tonga is comprised of hundreds of islands in the South Pacific Ocean, but, for this LINZ project, the team set out to detect hydrographic objects with dimensions of at least 2 meters by 2 meters around six main islands—Kao, Tofua, Lifuka, Ha'afeva, Nomuka and 'Eua. The project used a combined sensor approach, with satellite-derived bathymetry results generated first, followed by Woolpert providing airborne topobathymetric lidar with its Leica Chiroptera 4X system, followed by iXblue acquiring multibeam sonar data.

Figure 2: This aerial photo of the coastline on the island of Lifuka, Tonga, depicts one of the areas surveyed. The project consisted of surveying a wide variety of environments, from coral reefs and complex seabed surfaces to steep, sloping volcanic islands.
Image courtesy of Woolpert.

The topobathymetric lidar data, collected four to five months ahead of the multibeam, was planned to provide coverage to a 20 m depth, with the sonar targeting greater depths. The lidar was acquired to extinction in most locations, however, and the multibeam data came in shallower where it was safe to do so. This resulted in a large overlap between the two datasets, from a depth of 5 m to 45 m over approximately 50 square kilometers, allowing for valuable statistical analyses.

Methods and processes

Since lidar can survey shallow water more efficiently than multibeam, analyses were conducted to assess how reliable the lidar hydrographic object detection was with a modern sensor.

In the past, object detection analyses have been conducted by examining specific objects at the point-cloud level, but this can lead to tunnel vision, focusing on differences that have no impact on the final product. It's also very difficult to scale this approach to large areas. To identify differences that would have meaning for a mariner, the team wanted to do the analyses on the chart product, or a proxy for that product.

A proxy for the largest-scale production chart in each area was used. Focal statistics were used to interrogate the lidar and multibeam final bathymetric surfaces to determine where the multibeam-only chart would differ from one derived from lidar data. If the lidar and multibeam surfaces agreed to within the allowable vertical uncertainty, within 2 mm horizontally at the largest production chart scale, then the charts were considered to match. Otherwise a difference location was generated (**Figure 1**).

A closer look at difference locations

The terrain covered was challenging and widely varied, from coral reefs comprising a complex seabed to volcanic islands that sloped steeply into the ocean (**Figure 2**). The difference locations were initially assessed to see if there was any correlation to water depth or seabed type, but no strong correlation was found.

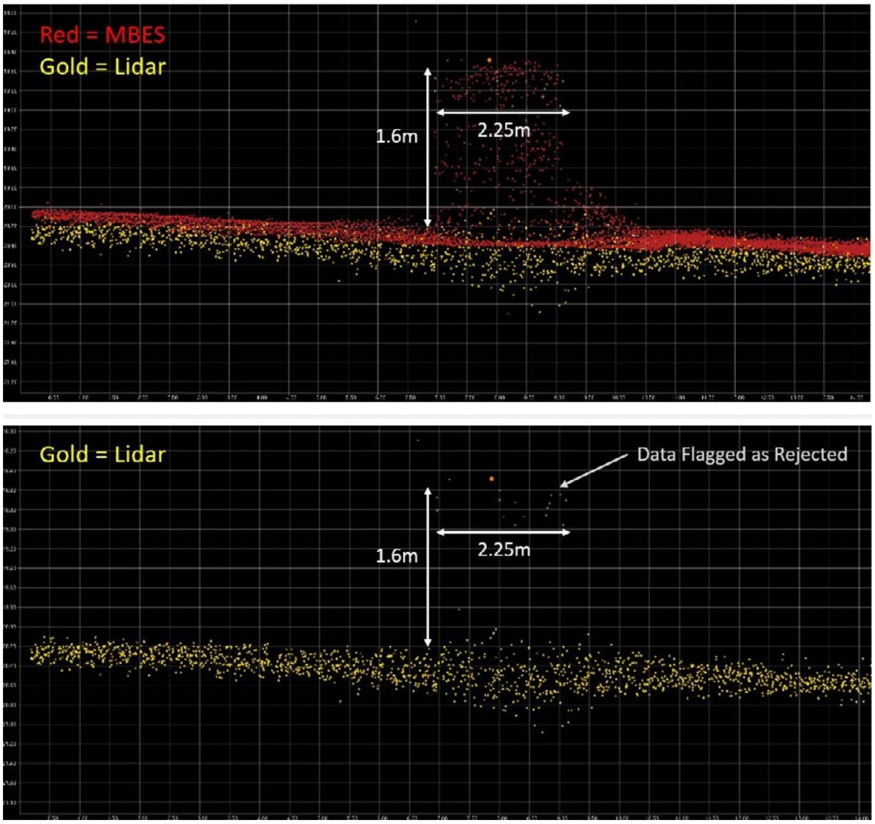


Figure 3: The lidar points in these images indicate that an object was detected, but the faint points at the top were flagged in the editing process and removed, which caused a difference between the lidar and multibeam datasets.
Images courtesy of Woolpert.

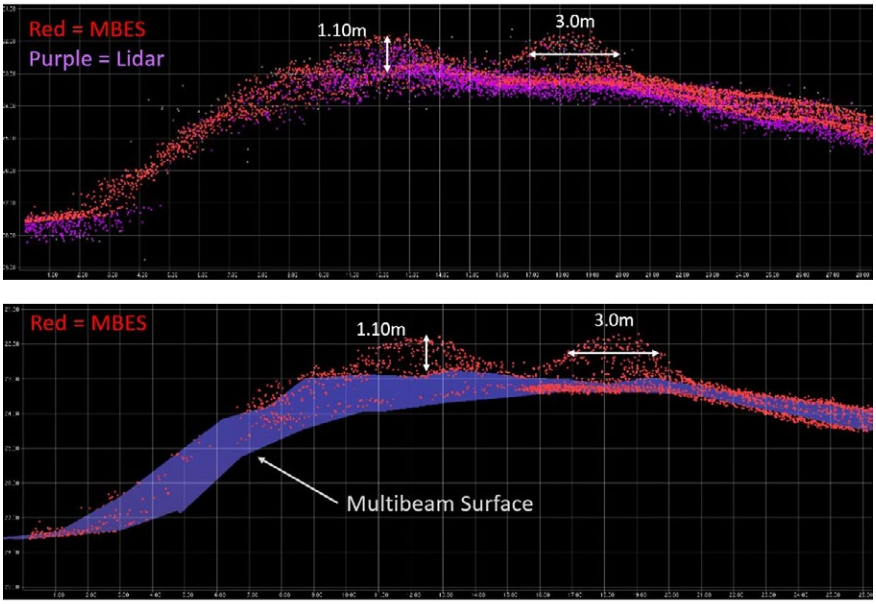


Figure 4: This final multibeam surface is not pulled up to the shoalest points in the point cloud. This discrepancy highlights the importance of knowing the largest-scale chart for which the surface will be used, since the surface is the basis for charting.

Images courtesy of Woolpert.

The comparison surface used for analyses comprised 12,625,000 grid cells at 2 m resolution. There were 71 grid cells in which multibeam identified something where lidar had no correlating object, and 76 grid cells in which lidar identified something where multibeam had no correlating object. Over 12.6 million grid cells, or 99.9994%, had no discrepancy.

When analysts looked more closely at the locations where the two datasets did not match, two types of discrepancies were apparent. In the first example from Nomuka, multibeam clearly detected the object. Lidar also detected the object, but the data on the top of the object had been flagged as rejected. This is an editing error. The team also saw examples of this in reverse where multibeam was flagged as rejected (**Figure 3**).

In the second example, it appears that the object was represented correctly by both the multibeam and lidar point clouds. However, the multibeam surface was not pulled up to the shoalest sounding. This was by far the most common discrepancy found and highlights the importance of knowing the largest-scale chart for which the surface will be used, as the surface is the basis for charting (**Figure 4**).

There are techniques to highlight potential surface representation issues at a given scale, prior to finalizing the surface for client delivery. But that scale must be known and communicated early. This enables a full workflow to be established with the end product in mind, specific to its use and scale. This approach would likely result in far fewer discrepancies in the quality control and acceptance phases of future surveys. It would also provide greater confidence in the dataset for allocating Zones of Confidence classifications.

Using the right tool at the right time in the right location

Being able to analyze the data in the overlapping areas of the two collections revealed some new considerations for surveyors. It is important to distinguish between object detection and object recognition. In most cases, the sensors detected the objects, but they weren't always recognized as such during editing. There were editing anomalies in both lidar and multibeam, because there is still a human factor present in the processing of these complex datasets.

Scale still matters. Once raw data is acquired, it can be processed and classified very differently depending on the required project scale and purpose, with potentially very different levels of effort required. In the case of hydrographic surveys, it directly affects shoal sounding designation.

Even with the differences identified, it's important to note that the two datasets showed agreement across the overlap area to near absolute certainty, with a 99.9994% success rate.

Lastly, the combined multi-sensor project approach was very successful in achieving the goals of PRNI. Using the right tool at the right time in the right location allows survey to be collected more efficiently and effectively. These analyses show that lidar is the right tool to provide efficient, high-resolution surveys in many hydrographic environments.

Woolpert vice president and chief hydrographer **Carol Lockhart** is a world-renowned expert in the hydrographic and bathymetric surveying industry. Lockhart is known for developing process workflows for new technology and adeptly managing large-volume datasets, and her technical background is unparalleled in the industry.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Elevation-Derived Hydrography in Florida

NV5 GEOSPATIAL MEETS THE CHALLENGES

The exponential growth of lidar coverage across the nation has sparked considerable discussion on how to leverage this data to create Elevation-Derived Hydrography (EDH). Moving from a lidar bare-earth DEM to high quality, usable hydrologic line and polygon vectors, however, is more difficult than GIS manuals suggest. Running an algorithm is easy. More difficult is producing a data set that meets the requirements and standards of hydrologists and the data programs that support their work, the two most notable being the National Hydrography Dataset (NHD) and the Watershed Boundary Dataset (WBD). The key is to produce data sets that are both consistent and accurate enough to provide the information that users need to make decisions. Each region of the US has its own unique challenges due to its particular topography, land use, and geology. This article focuses on some of the challenges of developing EDH in Florida, which is generally flat and has widespread karst geology.

To understand the challenges, we first need to understand the process for creating EDH. There are two main approaches

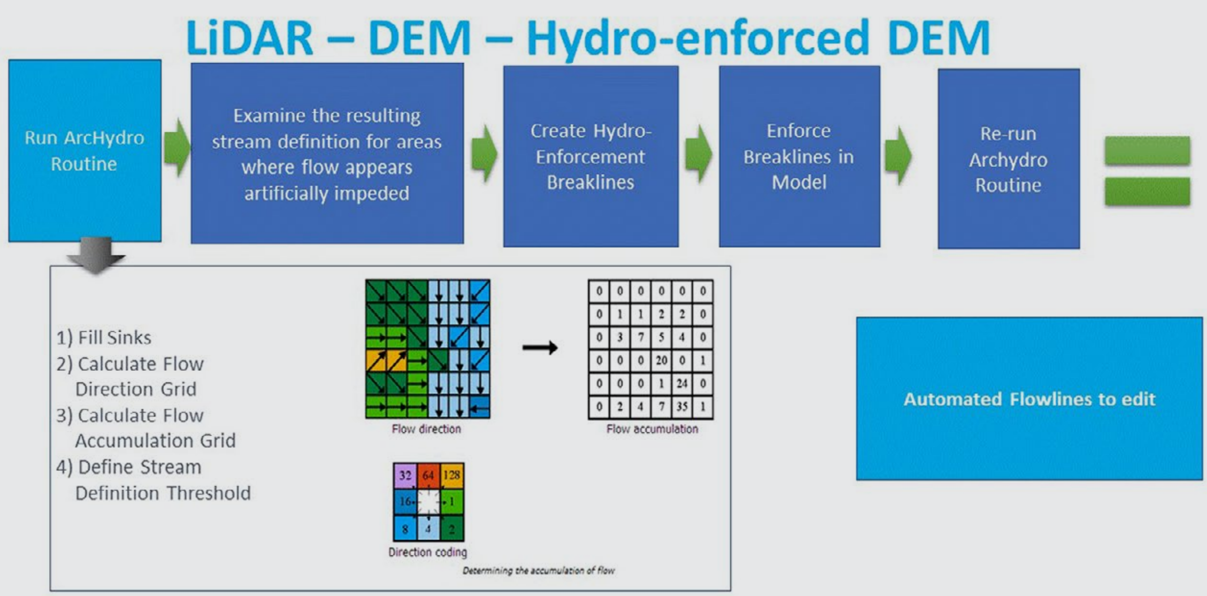

Figure 1: Basic workflow to map flow accumulation across landscape.

BY ANDREW **BRENNER,** CATHY **POWER** AND MISCHA **HEY**

to developing hydrography. The first involves mapping the slope and aspect of the landscape to obtain flow direction and then simulating the accumulation of flow across that landscape. A stream is then formed when a certain flow accumulation threshold is reached. This process is shown in **Figure 1**. The second approach is to analyze the shapes and formations within a landscape and how they relate to one another to classify features into what are called geomorphons. When this analysis is conducted at multiple scales it can be used to characterize large valleys and small stream channels (**Figure 2**). Both these approaches have their advantages and disadvantages and so are often best used in conjunction.

Regardless of the extraction technique or combination of techniques, a critical first step in any hydrology extraction from a lidar DEM is hydro-enforcement. For this process, the bare-earth lidar DEM is modified so that the tops of selected drainage structures (bridges and culverts) are removed to depict the terrain under those structures. Hydro-enforcement enables hydrologic and hydraulic models to depict water flowing under and through these structures, rather than appearing in the computer model to be dammed by them. Although hydro-enforcement can be largely automated, it does require manual quality control to ensure that the automated processes produce accurate representations of the reality on the ground. This manual review can be time-consuming, so an efficient workflow is required. Focusing on where errors are most likely to occur and directing editor reviews to those locations has proved to optimize results. NV5 Geospatial (formerly known as Quantum Spatial) achieves this by overlaying ancillary data such as depression depth and road networks on the derived stream network. In **Figure 3** the areas that require enforcing are shown in red circles. Ancillary data allows the reviewers to focus their efforts at these points in the map.

Once the DEMs have been hydro-enforced, processing can move on to

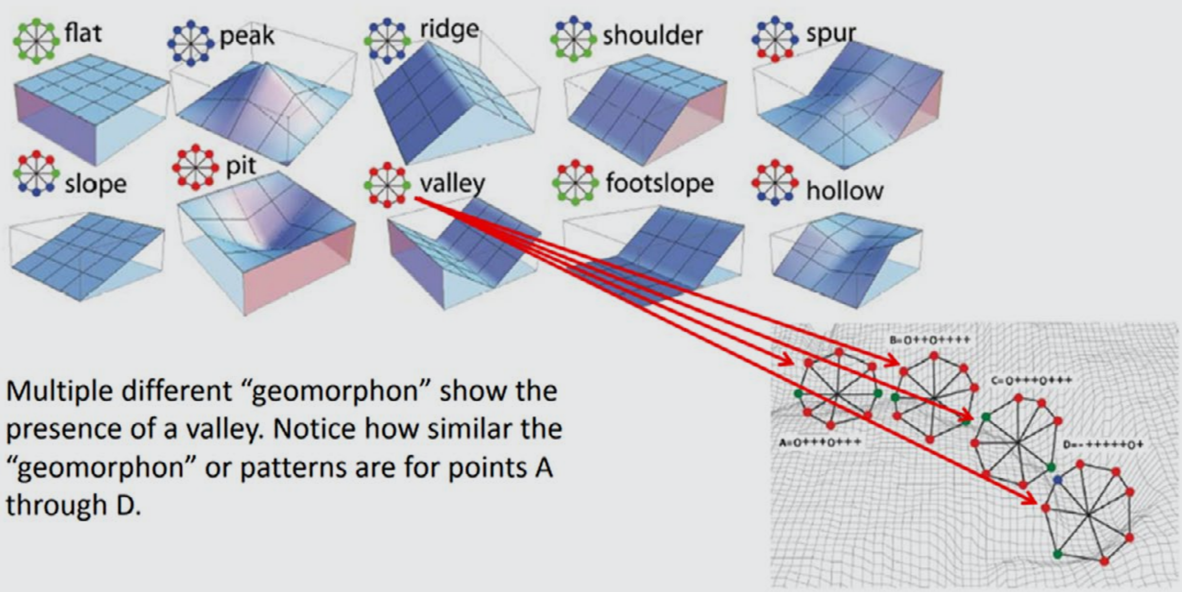

Figure 2: Characterization of landscape features using geomorphons.

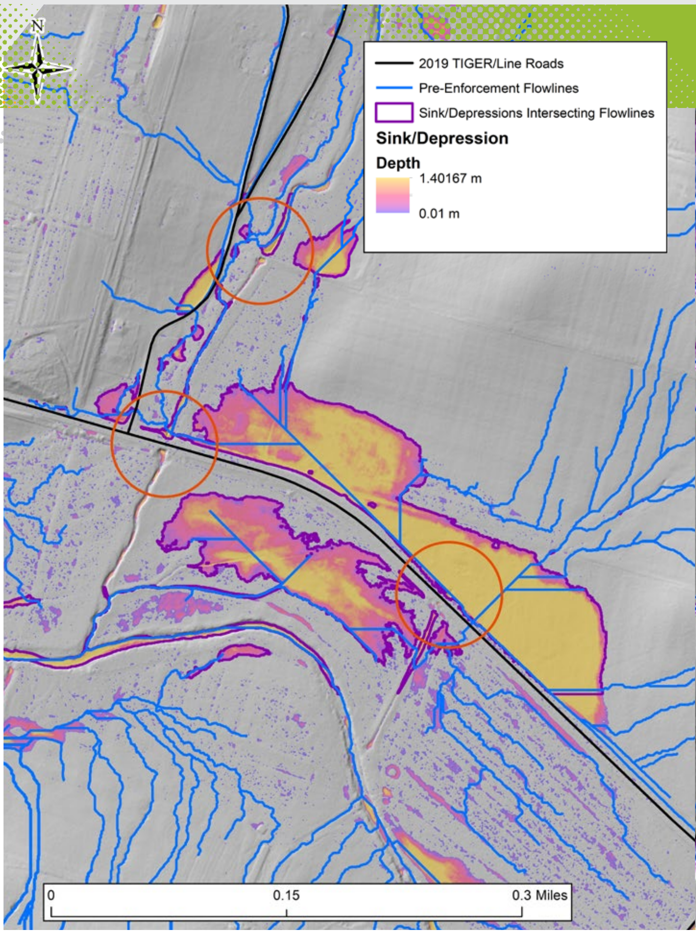

Figure 3: Ancillary information helps focus the attention of data reviewers where automated hydro-enforcement fails.

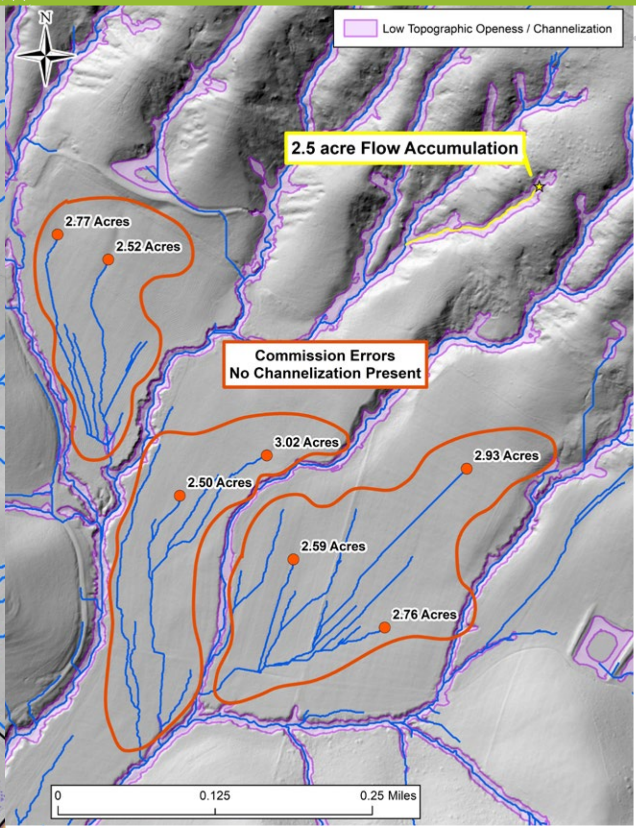

Figure 4: Streamlines intersected with a topographic openness layer to show where they should be retained and dropped.

stream extraction. Traditional stream delineation is predicated on the principle that stream flow occurs when a minimum threshold of contributing surface area is exceeded. Although this is true, this threshold will vary depending on climate and landscape conditions. Streamlines are required to meet both a minimum length criterion and fall within a channel. Depending on the environment, very different stream definition thresholds may be needed to meet these requirements. Inspection to make sure that all streamlines clearly follow visible channelization in the ground model is critical to creating an accurate and therefore useful data product. This is a particular problem in Florida, where the area is flat and there are large areas of agriculture. We have found that topographic openness is a good indicator of true stream channelization in the bare earth. This can be superimposed on the streamlines to quickly distinguish commission errors and identify which streamlines should be retained (**Figure 4**).

Another problem with stream extraction in Florida is that there are many large sinks or true depressions in the landscape (think swamps and gators!). Flow direction and geomorphons do not perform as well in areas of low slope and so great care is needed to prevent hydrologically linking areas where there are no true above-ground connections. The karst landscape of the state often means there are underground connections, but this is not something that can be interpreted from lidar. In **Figures 5 and 6** we show how the flow lines would be derived if we relied purely on flow directions and flow accumulation rules. In **Figure 5**, NV5 Geospatial avoided this problem by eliminating these sinks incrementally, thus preserving the slightly higher area circled in yellow that maintains the separation of the two hydrologic systems. In **Figure 6**, the main stem of the river flowing through low relief swampy areas is not identifiable through the flow accumulation approach. It can, however, be discerned using the lidar intensity image based on the low reflectivity of the infrared lidar over this area and the total absence of returns from the middle of the channel.

Each region in the US will have its own characteristics when it comes to developing EDH. Although automated

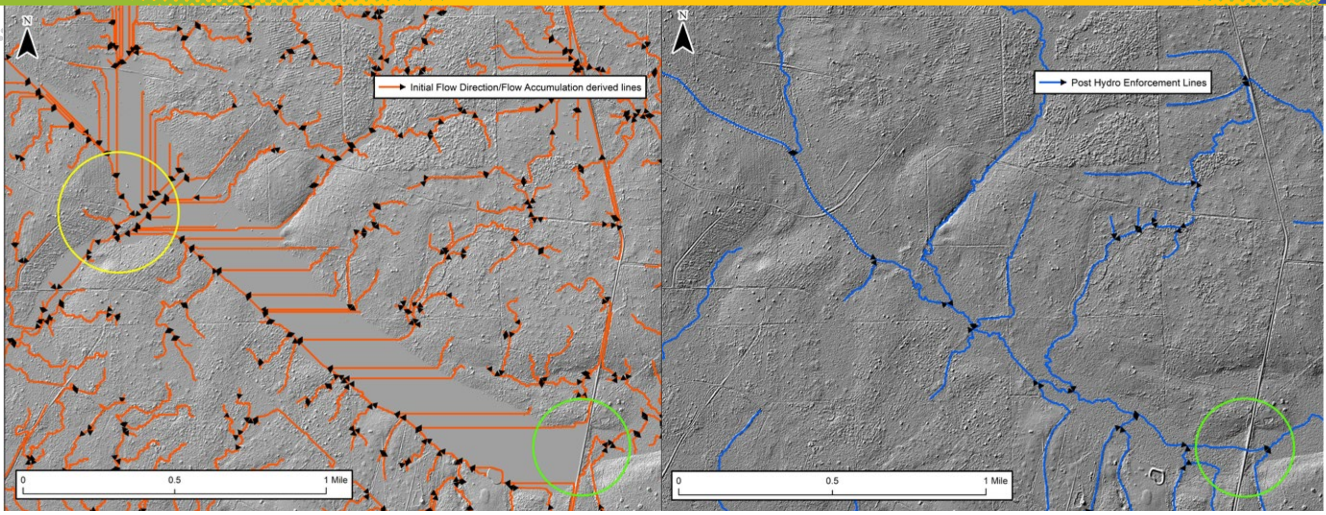

Figure 5: Streamlines created using the flow accumulation approach (left)—note the errors in flow across areas circled in yellow; streamlines created using the flow accumulation approach thinned for EDH rules using an iterative sink removal approach (right).

tools are essential to ensuring a cost-effective creation of these data sets, NV5 Geospatial has found that creating consistent and high-quality hydrology is not easy—and has developed processes to meet the challenge.

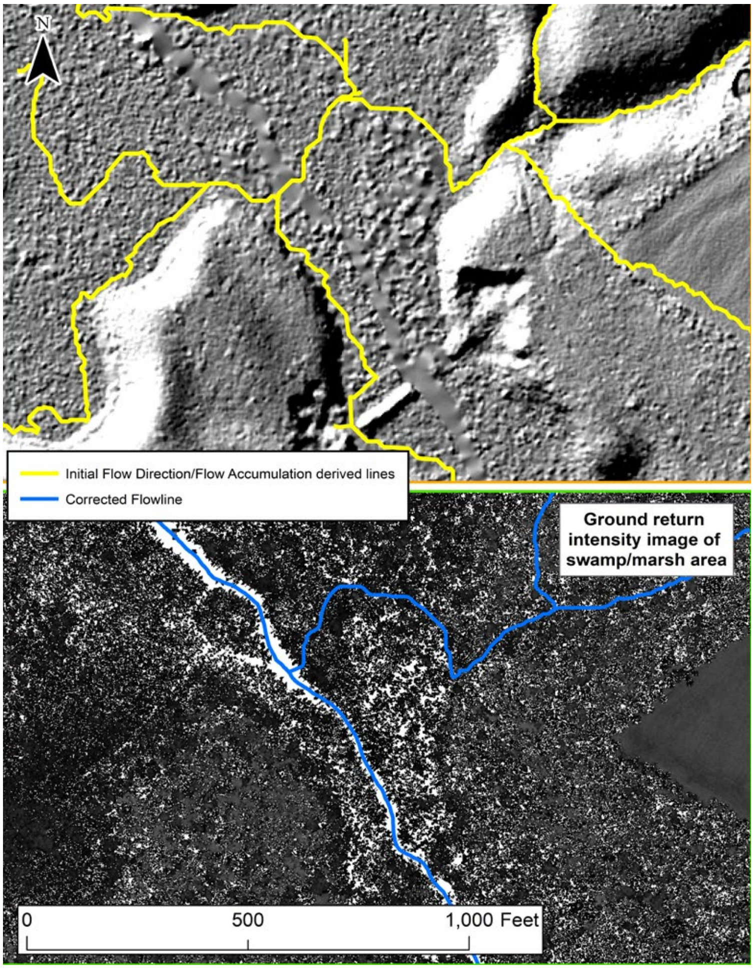

Figure 6: Automated flowlines within a wetland that need to be corrected by hand using the lidar intensity image as a guide to where the open water is. The white represents where there are no returns from the lidar because of water.

Andrew Brenner directs water programs for NV5 Geospatial. He has worked on geospatial data analysis for over twenty years. His focus in on the application of geospatial technology to resolve real world challenges. Andrew has developed hydrographic data using imagery and lidar, led watershed management projects and run hydrologic modeling initiatives. He has a Ph.D. in environmental physics and an undergraduate degree in agriculture.

Cathy Power lives in Corvallis, Oregon and serves as a technical expert for NV5 Geospatial. Cathy has been working with lidar and lidar derivatives for over a decade. Her principal focus in recent years has been the derivation of high-resolution hydrologic networks in support of national and local hydrology programs.

Mischa Hey lives in Corvallis, Oregon and serves as NV5 Geospatial's senior technical domain expert with over 15 years of direct experience developing applied GIS solutions. Mischa works primarily in development and deployment of biophysical modeling analytics derived from remote sensing data.

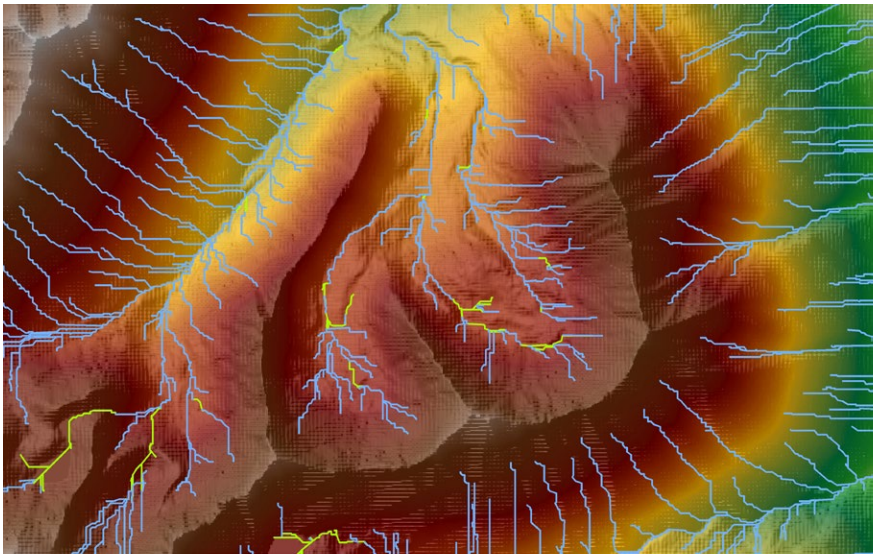

Figure 1: Small area of Upper Kobuk River, Alaska watershed with elevation-derived hydrography (blue lines) for updating the National Hydrography Dataset (NHD).

Dewberry Assists Federal, State and Local partners

RECENT TOPOGRAPHIC AND TOPOBATHYMETRIC LIDAR PROJECTS

Dewberry's Geospatial Technology and Services has been a gold sponsor of the FL-ASPRS/UF Lidar Workshops since the first one in 2016. The sponsorship and participatory support from Dewberry has been well received by the FL-ASPRS Region and workshop attendees. Multiple Dewberry staff have presented remote sensing projects contracted through several of the water management districts, the National Park Service, and the US Geological Survey (USGS), giving updates about ongoing lidar and related projects, as well as providing insights on other aspects of remote sensing and lidar activities. Dewberry is a major geospatial firm in Florida and maintains a large presence with 18 offices and over 350 staff in the state.

As a corporate ASPRS sponsor, Dewberry partnered with ASPRS to edit and publish *The DEM Users Manual*, which is now in its 3rd edition[1]. Amar Nayegandhi and David Maune, the primary authors and editors, were assisted with contributions from several Dewberry industry experts. The 3rd edition has already sold 500 copies. The editors have held book-signings for the Florida ASPRS Region at previous workshops.

For the Fall 2020 "virtual" Lidar Workshop, Amar Nayegandhi presented several recent topographic lidar projects. These emphasized successes that Dewberry has achieved through partnerships at the national, state and local levels.

BY AMAR NAYEGANDHI, NICK KULES AND AL KARLIN

Topographic lidar at the national level

Dewberry is actively engaged as a USGS Partner in the 3D National Terrain Model. This partnership has resulted in Dewberry conducting the National Hydrography Requirements and Benefits Study. This "follow-up" to the National Enhanced Elevation Assessment is designed to determine the benefits for the 3D National Terrain Model. In addition, Dewberry is engaged in pilot studies for extracting

1 Maune, D.F. and A. Nayegandhi (eds.), 2018. *Digital Elevation Model Technologies and Applications: The DEM Users Manual*, 3rd edition, American Society for Photogrammetry and Remote Sensing, Bethesda, Maryland, 652 pp.

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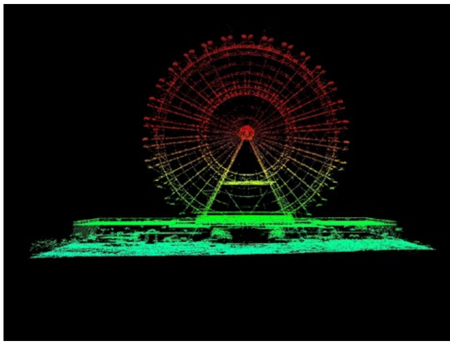
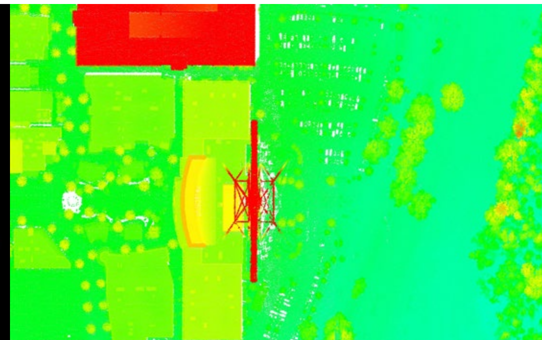
Elevation Derived Hydrography (EDH) from lidar and IfSAR data in Colorado (South Platte Watershed), Virginia (Lower Chesapeake Watershed), Delaware (Mid-Atlantic Watershed), and the 15,000+ square mile Ikpikpuk Watershed in Alaska (**Figure 1**).

Topographic lidar at the state level

In late 2018, Dewberry partnered with USGS, Florida Division of Emergency Management, Florida Department of Transportation and all five of the Florida Water Management Districts to collect QL1 data and compile high-quality breaklines for over 34,000 square miles of the peninsula of Florida. While the sheer magnitude and complexity of this vast project was challenging as a result of unseasonable rain and water levels, data acquisition was completed by late 2019 and the processing has been progressing in an orderly manner. This collaboration has produced some extraordinary data and images (**Figure 2**), such as The Wizarding World of Harry Potter at Universal Studios (note the fantastic luck of seeing the dragon's breath in the lidar). The Florida Statewide Peninsular project will





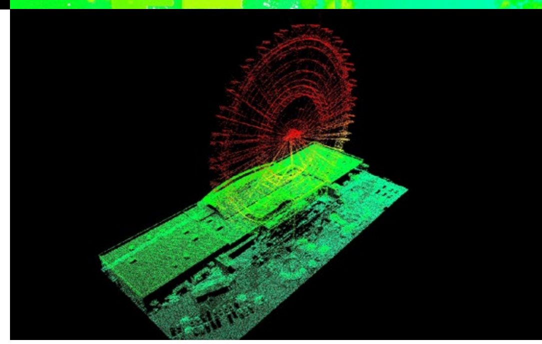
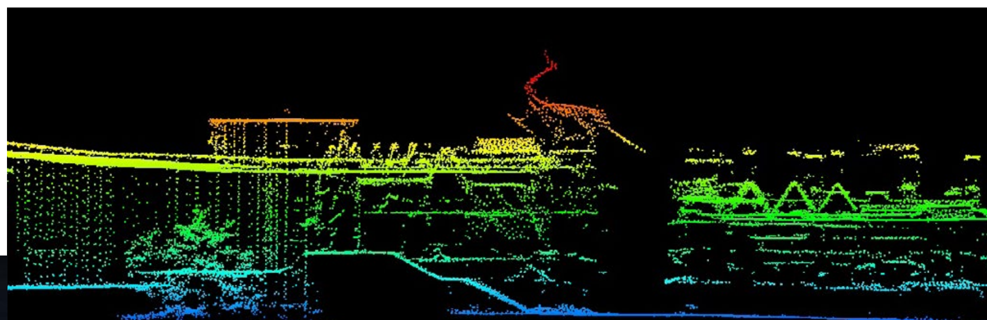


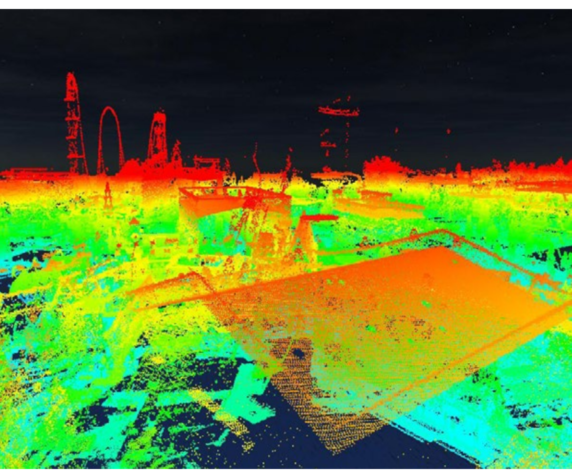
Figure 3: The Wheel at ICON Park, Orlando.

be in production through mid-2021 and is already producing high-quality QL1 lidar point clouds, DTMs and DSMs as seen in this and the following images.

The lidar point-cloud scene of "The Wheel" at ICON Park, the QL1 point cloud, in excess of 12 points/m^2, shows the detail of the wheel, including the infrastructure and gondola seating (**Figure 3**).

Further amazing views of the Incredible Hulk Coaster at Universal's Islands of Adventure within the Universal Orlando





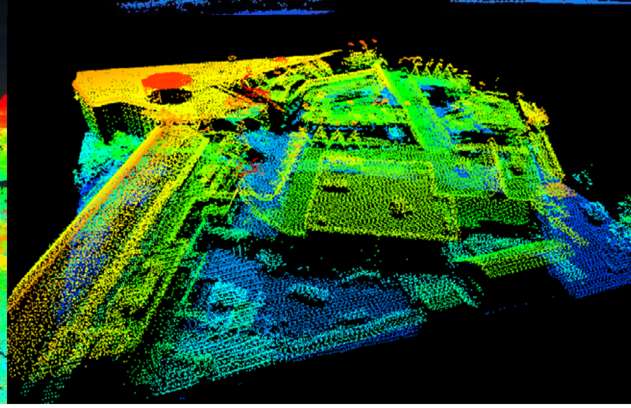


Figure 2: Hogsmeade at The Wizarding World of Harry Potter at Universal Studios, Orlando.

Resort were collected (**Figure 4**). With the background of the lidar-derived DSM, the profiles through the lidar point cloud show the elevations of the roller coaster. Deliverables for the Florida Statewide Peninsular project include the classified point cloud, high-quality hydrographic breaklines, and DTMs.

Topographic lidar at the local level

Dewberry has been providing lidar services to Leon County, Florida, since 2018. The county's requirement for high-density, high-accuracy lidar to serve multiple county agencies led to the first ever countywide USGS QL0 lidar survey. In coordination with both USGS and Leon County, Dewberry acquired high-accuracy ground survey and lidar in 2018 (**Figure 5**), then processed and delivered the QL0 data to the county specifications in 2019[2].

2 Karlin, A., R. Miller, A. Nayegandhi and G. Mauldin, 2020. Florida-Based land surveyors achieve QL0 lidar scan for GIS landbase update, *Point of Beginning*, 45(12): 21-26, October 2020.

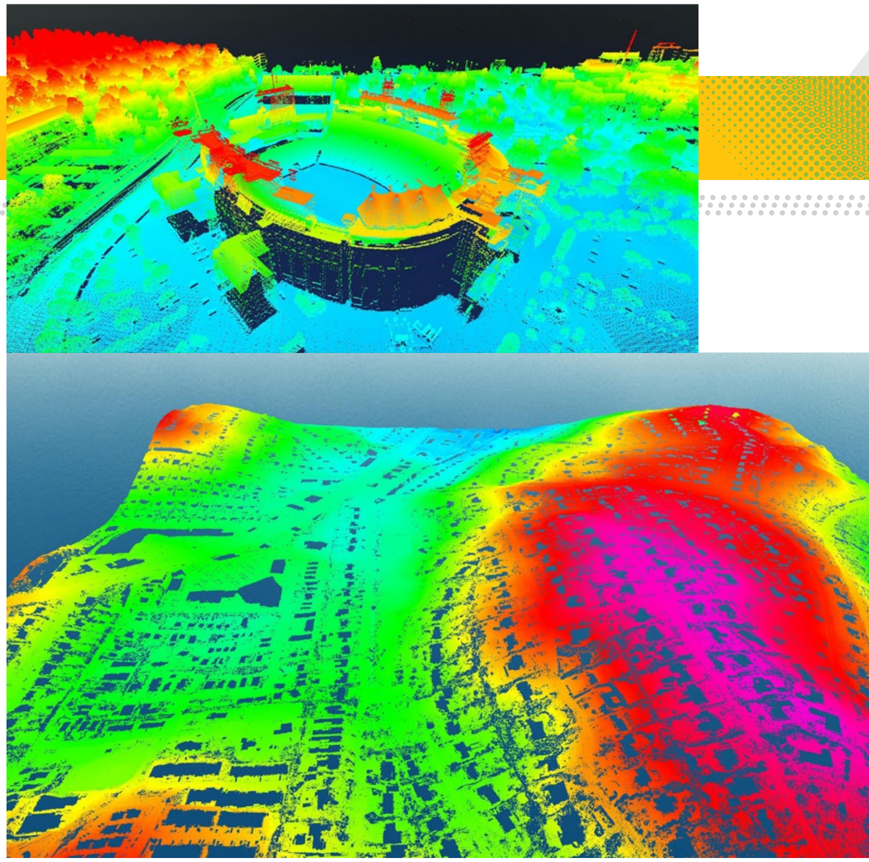
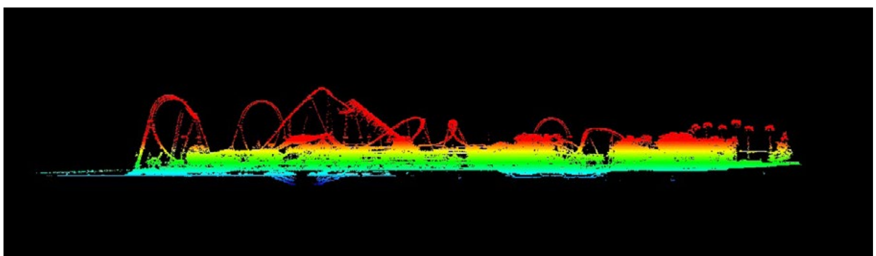
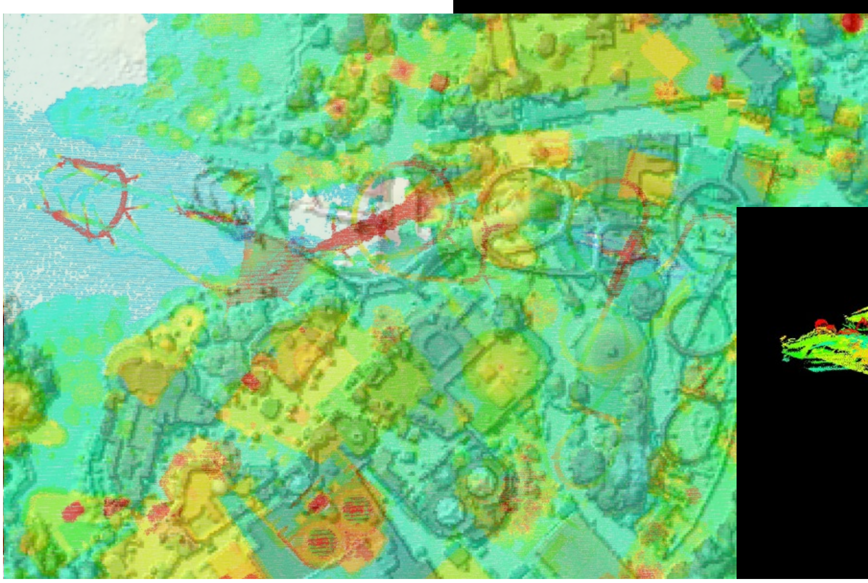


Figure 5: Lidar collections from the Leon County project—QL0 lidar point cloud showing Doak-Campbell Stadium, Tallahassee (top); QL0 bare earth (Class 2) point cloud looking northward from Thomasville and Bradford Roads, Leon County (bottom).





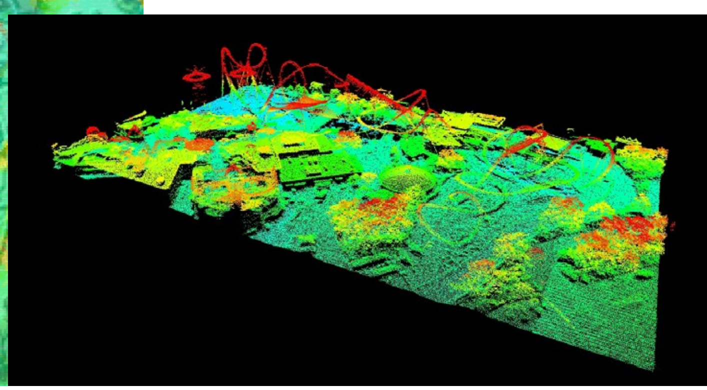


Figure 4: Views of Incredible Hulk Roller Coaster at Universal's Islands of Adventure, Orlando—3D, nadir, profile and DSM.

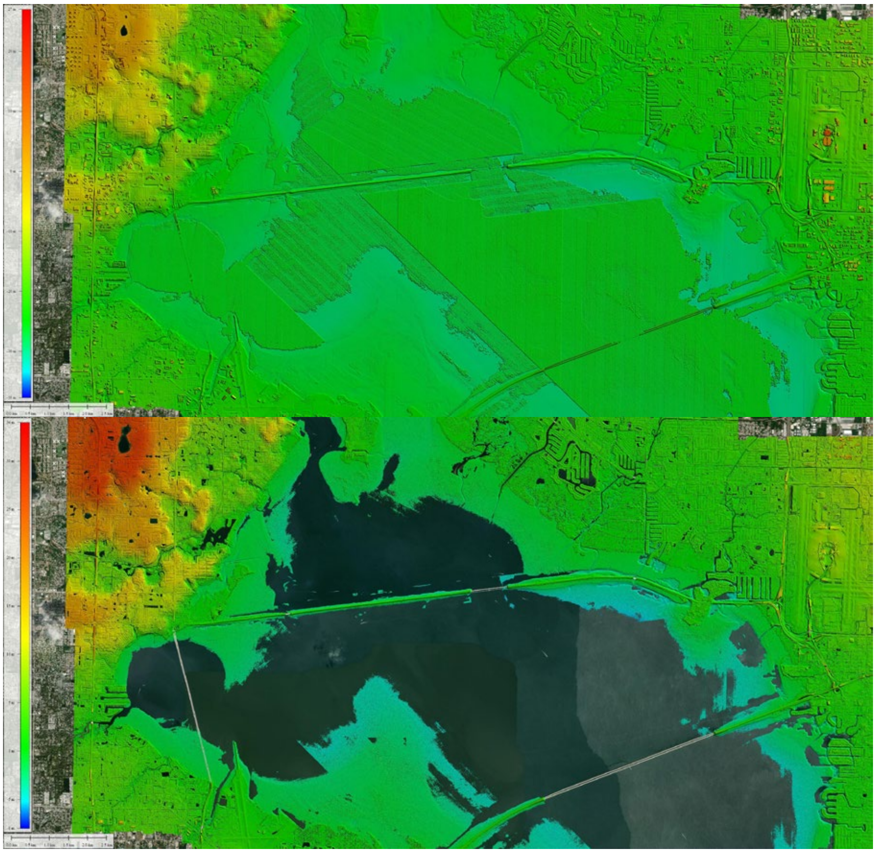


Figure 6: Digital terrain models (DTMs) of North Tampa Bay constructed from topobathymetric lidar collected with Riegl VQ-880-G II sensor in 2019. Open water surface returns were removed in the lower view.

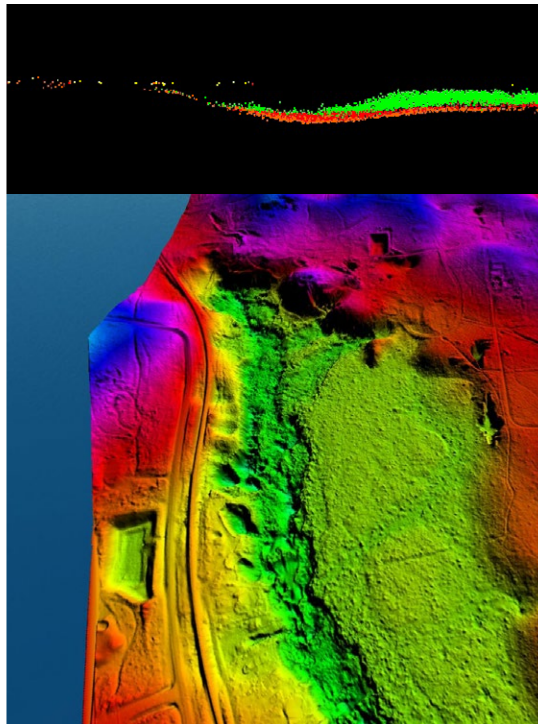


Figure 7: Lidar study of Rainbow Springs Aquatic Preserve, Marion County. Map (bottom right) shows location of the Preserve (DSM lower left). 3D DSM of the Preserve (top)— the springheads are seen in the darkened, northern portion of the Preserve. Classified lidar topobathymetric profile (center right), with water surface depicted in yellow, vegetation in green and bathymetric bottom. Location of the profile is shown on aerial photo (center right).

Topobathymetric lidar

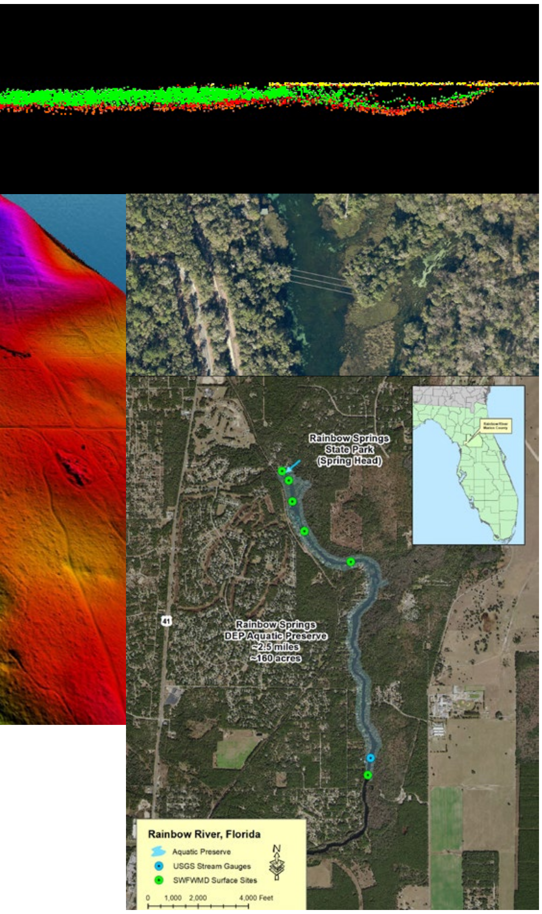
Nick Kules, a technology manager with Dewberry, presented several topobathymetric projects, again emphasizing the value of partnerships and the breadth of projects in which Dewberry has engaged. As a prime contractor on the USGS Geospatial Products and Services, the NOAA Coastal Geospatial Services Contract, and several state-level service contracts, Dewberry has conducted multiple topobathymetric lidar projects.

Topobathymetric lidar at the national and state levels

As part of a larger project on the Gulf Coast of Florida, Dewberry is assisting NOAA to map the bathymetry of Tampa Bay. In 2019, Dewberry used the Riegl VQ-880-G II to map the northern portion of the bay (**Figure 6**). The mapping was accomplished after several missions and included multiple re-flights to ensure complete coverage given the tidal and water clarity constraints. Additional mapping is scheduled for winter 2021 to map the southern portion of the bay.

Topobathymetric lidar at the state level

The Southwest Florida Water Management District contracted with Dewberry to investigate the potential of using topobathymetric lidar to map submerged aquatic vegetation and the bathymetry in the Rainbow Springs Aquatic Preserve. This project was captured with NOAA's Riegl VQ-880-G in the spring of 2018. Refraction corrections were made based on a water surface determined by USGS water level gages and the results were delivered as both a DTM (**Figure 7**) and a classified point cloud. Profiles through the point cloud were used to determine vegetation canopy.



Topobathymetric lidar at the local level

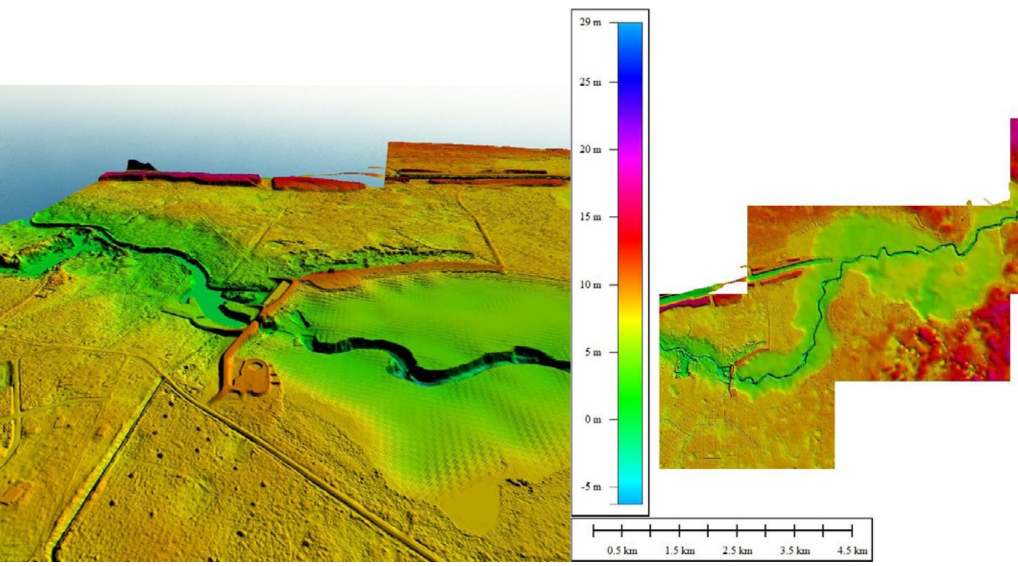
Dewberry has been working with several state agencies to integrate elevation data from multiple sources into seamless DTMs. For the Lake Rousseau-Withlacoochee River minimum flows and level (MFL) modeling, Dewberry used multibeam sonar to measure the bathymetry of a dredged river channel and area near the Ingles Lock and Dam that formed Lake Rousseau (western area on the figures below); conventional single-beam hydrographic survey sonar and advanced surface modeling techniques along the flooded lake outside of the channel; and USGS QL1 terrestrial lidar through the floodplain. These data sources enabled the firm to construct a seamless elevation model for the MFL along the seven-mile length of the backwater lake (**Figure 8**).

The above projects demonstrate the value of partnerships between federal, state, and local agencies and municipalities with Dewberry, as well as the range of projects and uses for topographic and topobathymetric lidar.

Amar Nayegandhi, CP, CMS, GISP is vice president and director of remote sensing at Dewberry. He oversees the Geospatial and Technology Services line for Dewberry's contracts with federal, state, and commercial clients. With over 20 years of experience, he is a recognized expert in topographic and bathymetric lidar data acquisition and processing. Amar has a bachelor's degree in electrical engineering from the University of Mumbai and a master's degree in computer science from the University of South Florida. He is the director of the ASPRS Lidar Division, an ASPRS Certified Photogrammetrist and Certified Mapping Scientist – Remote Sensing, and a GIS Certification Institute Professional.

Nick Kules is a geospatial technology manager in Dewberry's Tampa office, responsible for overseeing geospatial process development, tool and scripting development, and providing technical guidance for remote sensing projects. Mr. Kules is experienced in geospatial software and tool development in C++ and Python, as well as systems integration of software and hardware solutions for processing workflows. He is experienced in processing and calibrating both topographic and bathymetric lidar sensors and data. Mr. Kules also has extensive experience with ArcGIS, MicroStation, POSPac, Inertial Explorer, and with extraction software related to Teledyne Optech, Leica Geosystems, and Riegl sensors. Mr Kules is currently a director of ASPRS Florida Region.

Alvan "Al" Karlin's biographical notes are on page 11.



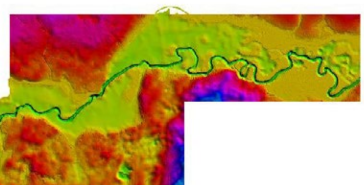
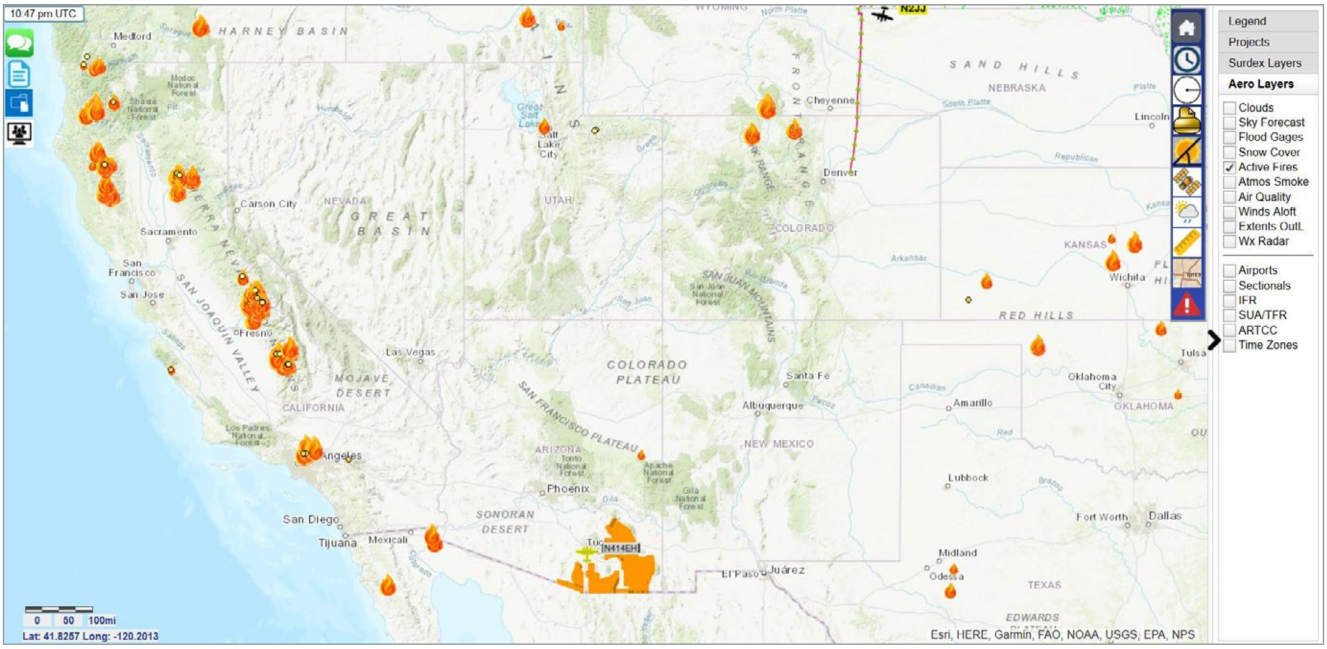


Figure 8: Left-hand image shows DSM constructed from aerial lidar and single- and multi-beam sonar of the Ingles Lock and Dam, which forms Lake Rousseau on the Withlacoochee Rover, Citrus County, Florida. Right-hand image shows DTM constructed from the same sources, showing the dredged channel in Lake Rousseau, the remains of the Withlacoochee River channel.



FlightTracker wildfire layer

Optimizing Lidar Collection with Advanced Flight Management Tools

SURDEX PERFORMS SUCCESSFUL OPTECH G2 DUAL-LIDAR ACQUISITION IN ARIZONA

The success of an aerial acquisition project, whether lidar or imagery, depends on taking advantage of acquisition days to turn around the project quickly. Surdex accelerates schedules by using a collection of flight management tools to make the most of suitable flight conditions and re-routing aircraft around poor conditions, thereby reducing the time the fleet is on the ground.

For a recent lidar GPSC3 Task Order from USGS, the Merrick-Surdex Joint Venture collected 5032 square miles of QL1 lidar data in Arizona. The acquisition was complicated by 2020 west-coast summer and fall wildfires adding atmospheric issues that affected aircraft operations across the US. Using its flight management tools, including a near-real-time aircraft tracking tool called FlightTracker, Surdex flew the project with optimal efficiency. The hallmark of the Merrick-Surdex Joint

BY WADE **WILLIAMS**

Venture is on-time delivery for USGS GPSC Task Orders.

Surdex's flight management system includes real-time monitoring and communications measures to direct aircrews to the most advantageous acquisition conditions:

- *Flight conditions*: online weather forecast, satellite feeds, leaf-on/off predictions, fire/smoke obfuscation to ascertain real-time flight conditions
- *Continuous monitoring*: Flight Operations monitors conditions of all flight areas every day to apprise air crews of changes in conditions
- *Rapid communications*: aircrews are informed via text messaging to divert from problematic areas to areas of favorable conditions, reducing the need to land for updated directions

Contending with wildfires and smoke

For the USGS Arizona lidar project, the significant number of wildfires exacerbated issues with visibility and data collection. Heavy smoke over a project area and other atmospheric conditions weaken the intensity of lidar returns, sometimes requiring re-flights to ensure sufficient point density is achieved.

The time delay between acquisition and data inspection creates a domino effect, since additional delay may arise before re-flights can be planned. Re-flights impact schedule during the project flight window. The solution is to work around smoke-affected areas to reduce re-flights.

During the first few days of the Arizona project, Surdex experienced sit days, creating concerns that the project schedule would fall behind. The project area included restricted airspace, adding another complication.

First G2 mount dual-lidar acquisition in US

Surdex flew the USGS Arizona project with an Optech G2 sensor system, based on two Optech Galaxy Prime lidar sensors, in a Cessna 414 piston twin. This was the first operational mission in the US for this Teledyne Optech system with dual collection.

The Optech G2 sensor system was specifically designed for USGS 3DEP collection, combining both Optech SwathTRAK technology and two lidar sensors for high-density collection in varying terrain. The system is proving its reliability.

Building the solution

To better manage flights around impacted areas, Surdex's R&D staff searched for real-time or near-real-time sources to incorporate a wildfire prediction layer into the FlightTracker system to improve mission planning. The size of the Arizona project area demanded better information to make informed decisions for areas impacted by wildfire smoke.

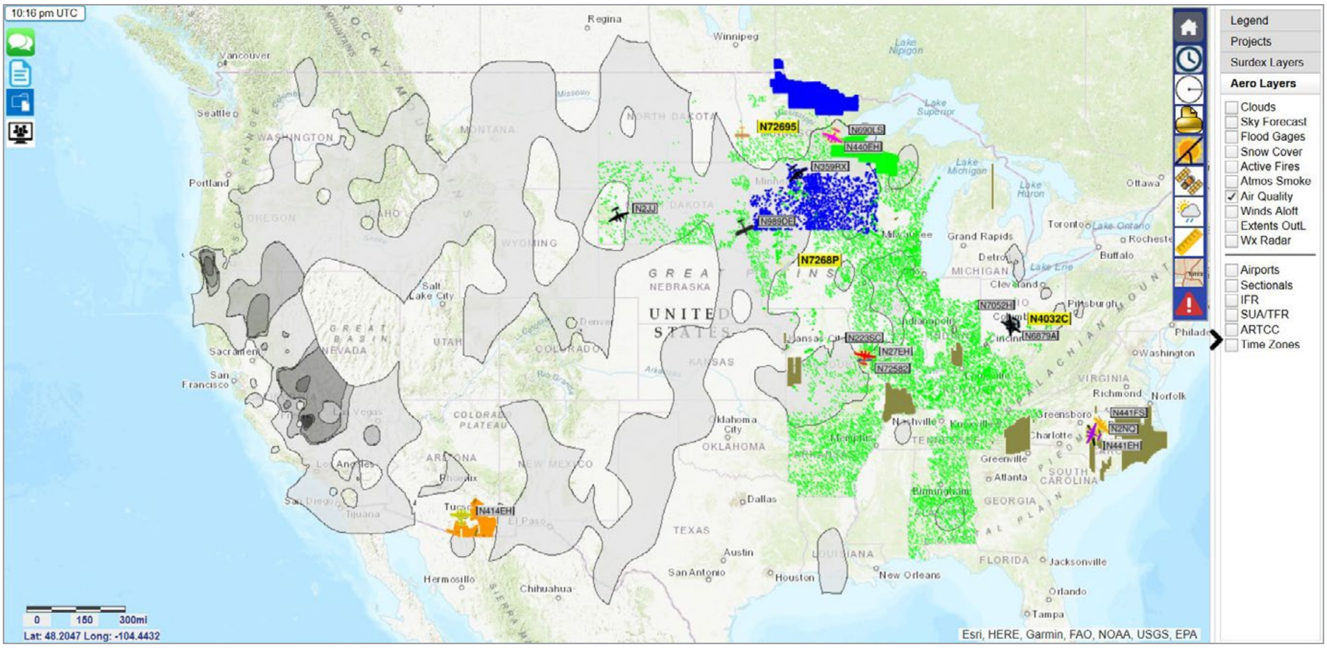
The solution was to incorporate a near-real-time layer of fire data into the FlightTracker system, which allows for data layers to be added, providing additional valuable data for analysis and flight planning. In this instance, we identified three data layers that would address issues pertaining to fires and smoke.

- *NASA Fire Information Management System*. This layer provides active fire data within three hours of satellite observation from both a moderate resolution spectroradiometer and a visible infrared imaging radiometer suite. The data is available in multiple formats compatible with FlightTracker's multilayer scheme.
- *NOAA Smoke Forecasting* data feed. The data provides 48-hour predictions for smoke dispersion and concentration used for air quality forecasts from the NOAA GOES satellite observation.
- *AirNow*. This data was added to indicate air quality, which factors in wildfire smoke. AirNow was originally developed by the US Environmental Protection Agency. It is now a partnership of seven US agencies and Environment Canada, which are responsible for updating the US Air Quality Index (AQI). AQI is forecasted for major cities across the US with wildfire smoke included as a variable in air quality. AQI predictions are based on ground observations and satellite data.

The smoke and fire data sources in FlightTracker appear as layers that can be toggled on or off if smoke is a factor during collection. All the other FlightTracker features such as aircraft location and cloud conditions contribute to successful mission planning and execution. This brings reassurance to a client with a FlightTracker link and improves decision-making for aircraft movement by Surdex Flight Operations.

Implementing the tool

These three data layers were identified and quickly added into the FlightTracker system, and Flight Operations and flight crews were trained on their use. The prevalence and severity of wildfires had created conditions that affected



FlightTracker air quality layer and locations of Surdex aircraft across the whole US

many areas other than Arizona, and the solution could be instituted across the country. During mission planning, the fire and smoke layers viewed in FlightTracker proved extremely valuable, and Flight Operators could text air crews, notifying them when shifting winds moved smoke into planned flight lines.

The layers also proved extremely useful during numerous projects in southern Florida, where post-harvest burns in sugar-cane fields often occur on days that normally would have been ideal for data collection.

How Surdex's flight management works

Clear flying time is a limiting factor in every project, and aircraft operations are expensive. To optimize collection efficiency and manage costs, it is imperative to keep aircraft operational—and that means flying in conditions good for lidar collection.

Surdex's answer is a coordinated system of data collection, analysis, communication, and redirection.

- Twice daily, Surdex Flight Operations reviews the location of all Surdex aircraft to evaluate conditions within each project area and identify favorable acquisition conditions for the next 24 to 72 hours.
- Flight crews are directed via text messaging after each Flight Operations meeting to remain on their current mission, change locations within the project area or mobilize to a different project with optimal collection conditions to avoid downtime.
- Project managers use FlightTracker for interim status checks throughout the day, either from the office or via a smart phone app developed for FlightTracker. In cases where it is not necessary to land and refuel, Surdex flight management has extended the average annual on-line time for Surdex aircraft up to 30% in the past several years.
- FlightTracker, in addition to onboard texting by flight crews, allows movement within a project AOI or to other projects, eliminating the need to land and get instructions. This maximizes acquisition time when conditions are optimal.

Client FlightTracker

Internal use of FlightTracker has proven so successful that Surdex adapted a version for client use. Many clients have a sense of urgency about acquisition, and this tool enables them to follow individual aircraft during the acquisition of their projects. The system continuously reports an aircraft's status, whether it is over the project area, headed to the site, returning from the site, or stationed at a local airport. It also provides airborne data such as the aircraft's airspeed and flight altitude.

With FlightTracker, clients can see precisely how much of the project has been completed and how much has yet to be flown. In conjunction with satellite data, it is easy to see areas of current and upcoming cloud cover.

The system is configured to allow users to see only their own project areas and allows Surdex to manage multiple projects across the country, relocating aircraft and sensors to capitalize on ideal acquisition conditions.

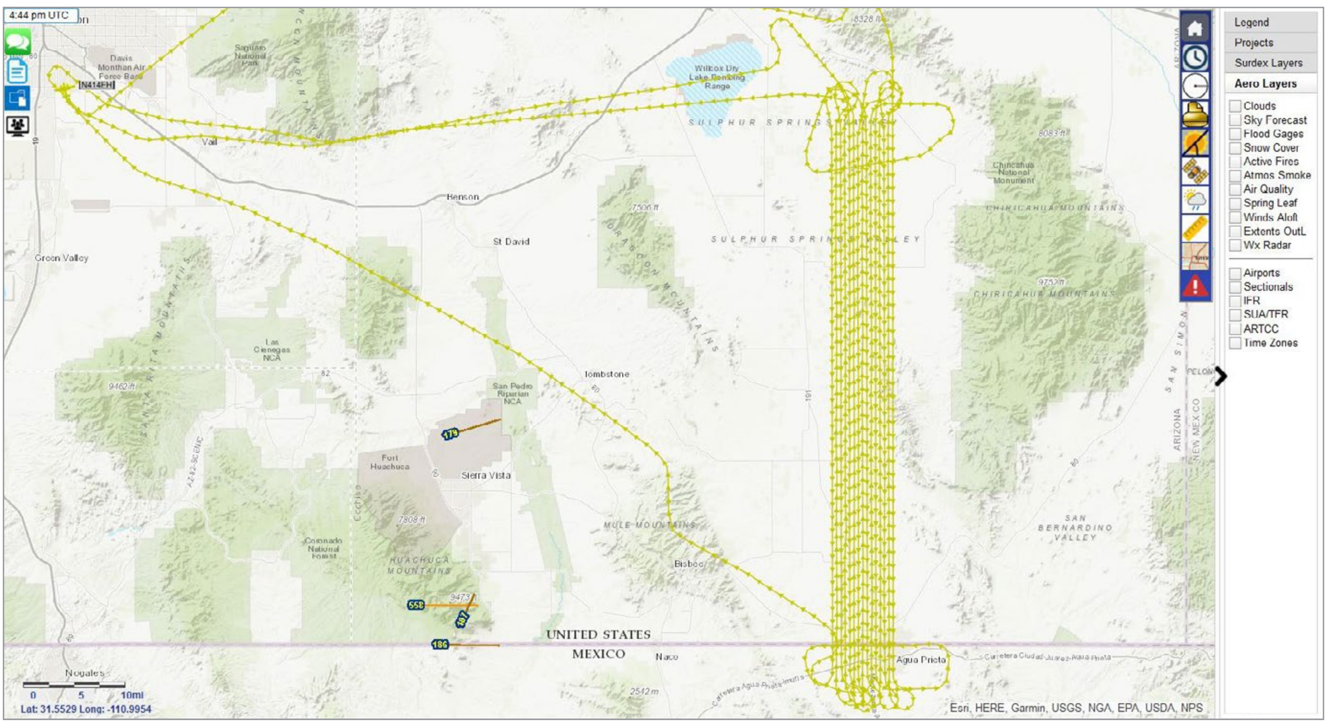
Clients view Surdex FlightTracker as another communication tool during acquisition, eliminating doubts as to progress and expected completion. FlightTracker's advanced weather predictions, including cloud movement coupled with other environmental issues impacting data collection, provide status, improve efficiency, and contribute to flight crew safety.

FlightTracker helps completion of Arizona acquisition

Surdex Flight Operations included smoke predictions to manage aircraft location within the Arizona AOI for each mission to reduce or eliminate sit days and minimize downtime and re-flights. The smoke tracking feature incorporated into FlightTracker contributed to successful completion of data capture at the end of November 2020. The Merrick-Surdex Joint Venture completed collection on time.

FlightTracker is a custom online tracking tool that incorporates data feeds from several federal agencies into a cohesive framework to display all issues that affect airborne data collection. It is a client "feel good" value-added service as well as a critical Surdex Flight Operations management tool. In the Arizona project, the smoke detection feature of FlightTracker in conjunction with the use of the Optech G2 sensor system during acquisition had positive results. ∎

Wade Williams has 25 years of industry experience. He joined the Surdex project management group in 2002 and went on to become director of project management, supervising a team of project managers, and monitoring schedules and progress of the production pipeline. Wade holds a BS in geography and cartography from Southwest Missouri State University and is an ASPRS Certified Photogrammetrist.



FlightTracker view of detailed mission flight path fpr the Arizona project, indicating lines flown plus mobilization to and from the collection area

Taking Flight in the Caribbean

KUCERA PERFORMS LIDAR SURVEY FOR JAMAICAN AIRPORT

Coast of Jamaica as captured by Kucera's flight crew from the Piper Navajo Chieftain aircraft.

Some of most interesting yet logistically difficult work for US suppliers of aerial lidar data are flyovers beyond the continental United States. In 2020, Kucera International, an experienced international lidar provider based in Ohio, tackled multi-country flight logistics and customs to deliver lidar data and aerial imagery to CEAC Solutions, a Jamaican civil and environmental engineering company.

CEAC was contracted by the Airport Authority of Jamaica (AAJ) to perform various environmental, zoning, and other baseline studies for the Norman Manley International Airport (NMIA/KIN) in Kingston, Jamaica. This work included creation of high-accuracy topography covering the immediate Airport Property and defining the obstacle limitation surface (OLS) of the airport to ensure obstacle clearance for airport approaches and departures and to define the extent of development allowable in the highly-populated surrounding area (designated "Area 2C"). Aerial lidar was recognized as a primary support technology for this work. Following internet research and contact referral of aerial lidar providers, Kucera was chosen for its understanding, experience, and confidence of a successful outcome, according to Kris Freeman, CEAC civil engineer.

Since starting into aerial lidar surveying as a primary in-house service in 2003, Kucera has successfully performed lidar surveys covering hundreds of thousands of square miles throughout the US and abroad, including major projects in Poland and in Haiti following the 2011 earthquake. Kucera currently has seven twin- and single-engine fixed-wing aircraft outfitted for large-area and corridor lidar capture with latest-generation lidar sensors and is one of the few companies that has flown aircraft across the Atlantic Ocean and throughout the Caribbean region to perform aerial lidar surveying.

BY BARBORA UBAR

Pre-flight preparation

In the months leading up to the flight, CEAC prepared for Kucera's flyover by making hosting arrangements with the local air authority and conducting the ground control survey work. Kucera carefully selected a flight crew of Drew Walker, a pilot with international and open-water flight experience, and Joe Pocs, a highly skilled sensor operator.

Walker used his knowledge of flying to the Bahamas to prepare for the project. He filed much of the preliminary paperwork and arranged for the rental of lifeboats and personal flotation devices at the airport of exit, Fort Lauderdale-Hollywood International Airport (FLL). His research informed Kucera's decision to hire an international handler, based in Canada, to provide fueling services, preparation of customs paperwork, approval of crew lists, and coordination of in-bound and

Sensor operator Pocs servicing the Vexcel Eagle UltraCam sensor at Fort Lauderdale before departure to Jamaica.

out-bound flyovers, including permits to enter Cuban airspace.

Immediately before scheduled departure to Jamaica, the twin-engine Piper Navajo Chieftain aircraft used for the project was flown to Kucera's hangar facility in Willoughby, Ohio for a major inspection. Every effort was made to minimize in-country maintenance needs as local repair stations in Jamaica were unavailable. In the case of an issue, Kucera's senior aircraft mechanic would have flown to Jamaica to conduct the repairs himself using the common spare parts included in the initial cargo. Extensive documentation of these extra parts, as well as the sensors and peripheral equipment, including drives, download stations, and computers, was gathered to present to customs. Any items with no immediately clear purpose (drives external to the sensors, for example) had the potential to be flagged in international customs.

The initial plan for the project was for the aircraft to be based out of NMIA/KIN, with the flight crew staying in Kingston. Due to on-site ground surveying and other work being performed directly at NMIA/KIN, however, along with increased air traffic congestion, AAJ requested Kucera to base from Ian Fleming International Airport (OCJ) at the north end of the island. This had the advantage of hotels in closer proximity to the airport base (OCJ being located in a popular tourist area), but ultimately created a tighter constraint on the aerial capture window due to the increased flying time need to reach NMIA/KIN (approximately 20 minutes) combined with restrictions on flying during non-daylight hours. It became almost impossible to perform the lidar capture at night as was planned. Kucera's crew was able to adjust and to work within the reduced capture window, nevertheless, by making sure to be "wheels-up" at daybreak on each flight day.

On-site work

Walker and Pocs travelled from Willoughby, Ohio to Fort Lauderdale, Florida, from which they exited the country. The flight to Jamaica included Cuban airspace, which required a permit, as well as stretches of open ocean without radio contact. "There were periods when we were not being watched, tracked, or communicated with," said Walker. Loss of contact with local air traffic control was an atypical experience for the crew, as they usually fly over contiguous land with constant contact. Kucera Flight Operations also had an unusual experience during the water crossing when the flight's satellite tracking path was interrupted with data gaps. Still, the crew arrived safely in Jamaica after a four-hour flight.

Upon arrival, Jamaican customs inspected the extra gear and aircraft parts thoroughly. Walker and Pocs picked up their rental car that night and planned the rest of the week.

For each day, the flight crew had to submit a flight plan to the air traffic controllers. Typically, Kucera flies its surveying work under spontaneous visual flight rules (VFR). VFR is conducive to aerial surveying as it allows the pilot to maneuver freely in the sky, given clear conditions and a position outside restricted airspace. Instead, Jamaican air traffic control requested daily flight plans with specific, orderly routing from point A to point B for every flight, similar to instrument flight rules (IFR) flight plans.

The expectation of destination-focused flight plans, as is typical with IFR, caused difficulties for the flight crew to relay flight manifests to Jamaican air traffic control, especially in the first days of flying. The flight plans submitted by Kucera, to take off, fly in repetitious lines over and around Kingston, and then return to the point of origin at an unspecified time, were novel. Walker and the OCJ airport manager filled out the forms together, by hand, and submitted them by fax. Multiple flight plans were submitted and rejected, then submitted and rejected again. The flight plans that were ultimately accepted required the crew to navigate across the island through a series of predetermined waypoints and bore most of the characteristics of an IFR flight plan. Once the aircraft was in the air, however, the controllers were informed and understanding of the atypical flight plans.

While in the air, Pocs flagged lines of imagery affected by clouds in-real-time to perform same-day re-flights where possible. After each day's flying, the hard drives of lidar data and imagery were collected from the flight crew in northern Jamaica and driven back to Kingston for shipment to Kucera headquarters. Amazingly, the data arrived in Willoughby for quality control (QC) within 24 hours each day.

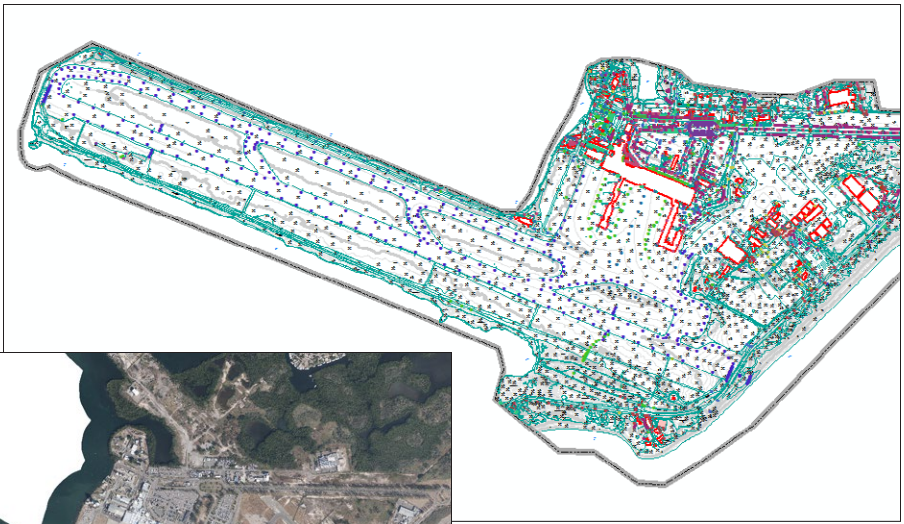
Window of acquisition

Jamaica has only a six- to eight-week window of clear weather conditions that are suitable for aerial survey because of persistent, heavy clouds. Due to concerns about the availability of clear weather, the original plan was to capture the imagery and a portion of the lidar during the day and to return at night, after the clouds dissipated, to complete lidar collection. Instead, lidar acquisition was captured in concert with the imagery because of OCJ's limited hours of operation. Despite being handicapped by lighting restrictions, Kucera's well-planned approach using advanced sensor technology and some luck with the weather allowed for timely data acquisition.

The mountains surrounding Kingston create a microclimate, resulting in fewer clouds obstructing the city and airport area compared to the rest of the island. The clouds gather in the mountains and roll toward the coast throughout the day, so acquisition on and near the mountainous northeastern portion of the AOI was given first priority each morning. Even so, only one or two lines could be acquired at higher elevations before clouds began to appear. An average of two to four hours of on-line flying (along the plotted flight lines) was possible each day.

The aircraft used for the project, a Piper Navajo Chieftain, has a large cabin and dual fuselage holes, which can accommodate two sensors for simultaneous capture. Kucera's Chieftain was outfitted with a Leica ALS80 lidar sensor and a Vexcel UltraCam Eagle camera for the project. While simultaneous capture of lidar and imagery was possible and is regular practice, two separate flight plans were used and the crew collected on only one plan at a time, using the corresponding sensor.

The flexibility of being able to switch between sensors allowed Pocs to take advantage of changing conditions. Imagery, flown at a greater altitude and with collection specifications more affected by cloud cover, was given priority over lidar. When cloud cover increased, Pocs switched sensors, Walker decreased aircraft altitude, and lidar acquisition began. The prioritization of data capture and the ability to switch from imagery to lidar quickly with the appearance of more clouds maximized efficiency and increased cost-effectiveness.



Left: Orthoimage of the NMIA/KIN area at image pixel resolution of 7.5 cm/3 inches.

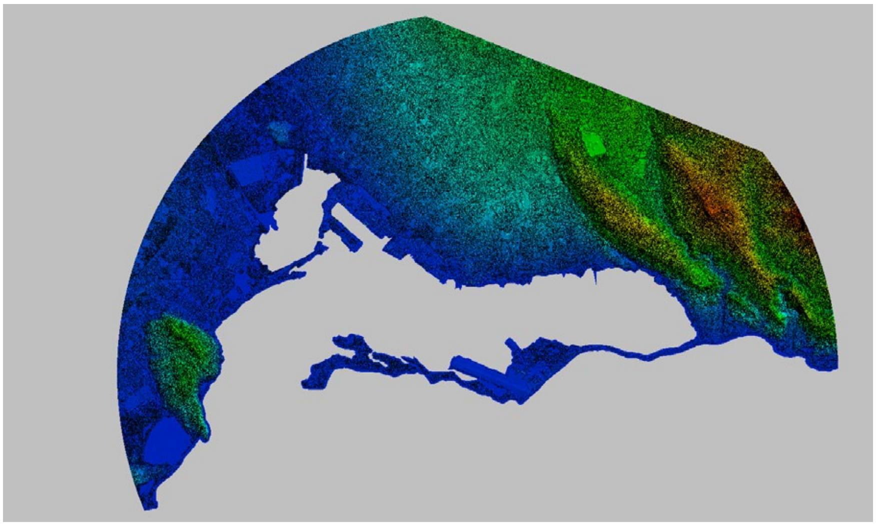
Above: Planimetry and topography of the NMIA/KIN area.

Product outcome

The data products Kucera created from the acquisition with the Leica ALS80 and Vexcel UltraCam Eagle sensor systems were georeferenced orthoimagery, lidar surface representations of Area 2C, and a topographic base map of the immediate airport property. The 43-square-mile Area 2C encompassed a wide range of environments, including coastal mountains with terrain variations of over 800 meters, dense vegetation, and complex urban development. A lidar capture resolution of 10 ppsm was determined as optimal for project work in terms of allowing the flyover to be completed within the short time frame needed while providing sufficient data density for the OLS and topographic survey work in the varied project terrain. A narrow field of view (<20°) was chosen to better penetrate the vegetation and the flight altitude was limited to keep under the daily occurring clouds as much as possible.

Since the Leica ALS80 captures lidar data at near vertical or nadir, the lidar was captured and processed with high (~50%) overlap, to make sure that all obstructions were captured in the data, including small and vertical features. Optimizing the laser footprint and flying the sensor with double coverage and high density ensured that all the features of interest that the client tasked to be located by the lidar as potential obstructions were identified in the lidar data. The result was confirmed, as the data was paired with "ground truthing," and orthoimagery comparison for feature verification.

The lidar data was carefully processed and checked to separate ground and non-ground features/surfaces, with particular attention to obstruction features. The fully classified lidar dataset was further processed and furnished to CEAC as a GeoTIFF raster along with a digital surface model (DSM) and point-cloud lidar products.



Project-wide DSM derived from the lidar data.

After receiving the data, CEAC sent a team of local surveyors to verify the obstructions indicated in Kucera's data and to identify any missed features. "This blended approach [between aerial and ground surveying] worked well," said Marc Henry of CEAC. "The lidar did capture what it should—poles and antennae—and it was shown in the DSM as well as in the point clouds." In some areas of limited ground access, Kucera's lidar data alone was used for the obstruction identification.

By means of the finalized lidar, AAJ's existing database of obstacles was verified and updated to create the Area 2C OLS. For the Airport Property, Kucera merged the lidar bare-earth return with stereo-compiled break lines to create a design-grade digital terrain model (DTM) and 0.3 m contour topography. The lidar data is also being used for planning purposes by the local development regulatory agency to create building height codes in Kingston and for drainage mapping and flooding analysis.

Another international success

The success of the NMIA/KIN project has encouraged CEAC and Kucera to jointly pursue other engineering projects with lidar support services in the Caribbean region and build Kucera's résumé of international aerial acquisition experience. "With our staff's can-do attitude and knowledge of international aerial flight requirements, open-water flying, and island/country hopping, there are many more places outside of the US we can reach for aerial survey work," commented John Antalovich, Jr., Kucera's President.

Barbora Ubar is Kucera South-Tampa office manager. She joined Kucera in 2010 after serving as photogrammetrist for Hillsborough County, Florida. As a project manager, she oversees numerous aerial mapping projects. Barbora holds an M.Sc. in civil engineering—geodesy and cartography from Slovak Technical University and has been an ASPRS Certified Photogrammetrist since January 2017.

Setting a New Standard for Topobathymetric Surveys

ASTRALITE FACILITATES UAV LIDAR SURVEYS OF LAND-WATER INTERFACE

Water is a vital resource for all cultures, and many people live, work, and play near the intersection between water and land. This resource has a powerful effect on our livelihood, but not always for the better. Over 300 million people reside in low-elevation coastal zones and are susceptible to coastal storms causing damages of tens of billions of dollars per year (Kron, 2013) with the expectation that the occurrence and severity will increase with increasing sea-level rise (Hinkel *et al.*, 2014). From 2000 to 2018, costs associated with river flooding included $830 billion in economic losses and over 6200 deaths in the United States (Truhlar and Bergstrom, 2019). Coastal zones have complex bathymetry that can alter the dissipation of wave energy (Gomes *et al.*, 2016) and create complex beach erosion and accretion events. These events represent dynamic and sometimes catastrophic change caused by the interaction of rivers, lakes, estuaries, and oceans with bounding land. Such interactions take place in critical shallow-water zones where a high fraction of aquatic bio-life, human-life activities, and infrastructure exist and, as a consequence, are altered.

Figure 1: ASTRALiTe EDGE lidar sensor flying on a hexacopter sUAS.

Traditional topobathymetric airborne lidar systems have demonstrated the capability of mapping such regions and have served as a critical technology for understanding land-water interactions for several decades. These systems observe only a portion of the temporal-spatio spectrum of change, i.e., wide-area coverage with a few points per square meter resolution and infrequent revisits, typically measured in years.

Expanding our understanding of critical shallow-water zones and improving our ability to safeguard water infrastructure requires data at higher resolution and more frequent refresh rate. This is particularly relevant in

BY ANDY **GISLER** AND JEFFREY **THAYER** cases where detecting and identifying weaknesses for small areas can prevent large-scale damage by implementing solutions prior to major disruptive events. A localized weak point in a levee, berm, dune, bridge pylon, or dam can lead to large-scale changes of a region or damage to infrastructure if not identified and repaired. When such damage occurs, repair and restoration procedures must be undertaken to prevent future issues; these operations require detailed and targeted maps of the affected areas. In particular, shallow waters exhibit dynamic bathymetry, with shifting currents leading to large changes in location of sediments, rocks, and other hazards.

The convergence of rapidly advancing technologies in lidar and in autonomously operated, uncrewed aircraft systems has opened up the possibility to expand the utility of topobathymetric lidar surveys into this more detailed temporal-spatio observing capability. The observing platform places constraints on the payload capacity and consequently requires miniaturization of the lidar system and supporting navigational components.

To meet these demands, ASTRALiTe™, Inc. has developed the EDGE™ lidar, an ultra-lightweight scanning topobathymetric lidar system. EDGE is capable of mounting on above-water platforms to retrieve detailed geospatial information (>100 pts/m^2) of land-water interfaces on a routine basis at much lower cost than traditional fixed-wing bathymetric flights. The lidar has unprecedented capability in 3D mapping of littoral-zone bathymetry with centimeter-level precision in waters shallower than 10 m. The system provides next-generation capability for day or night operations on a variety of platforms, such as watercraft or small unmanned aerial systems (sUAS), allowing for unique shallow-water capabilities (**Figure 1**). Eye-safety engineering control measures provide 3R laser light output, making the lidar beam equivalent to laser pointers sold in the United States. Preliminary data can be viewed immediately in the field upon return of the sUAS to enable rapid assessments of the surveyed area and of the data coverage[1].

1 Visit www.astralite.net for more information.

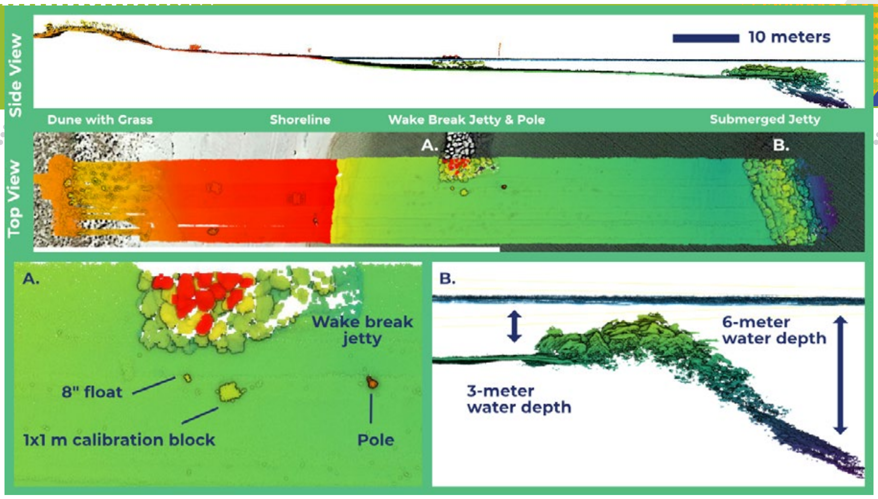


Figure 2: Multiple views of lidar data showing the dune crest covered in grass, through the shoreline transition, into shallow water, and along a portion of the jetty, some of which protrudes above the water line. Orange and red colors indicate above-water objects, while green to purple indicate increasing water depth. In the middle panel, the lidar data are superimposed on a photograph of the scene, showing the grass-covered dunes, the shoreline, the wake break jetty and pole. The tide was lower when the lidar data was collected, causing a slight mismatch between the satellite image and the lidar point cloud. The lower-left panel shows detail of some objects in the water, highlighting the high-resolution feature detection capability of the ASTRALiTe EDGE lidar.

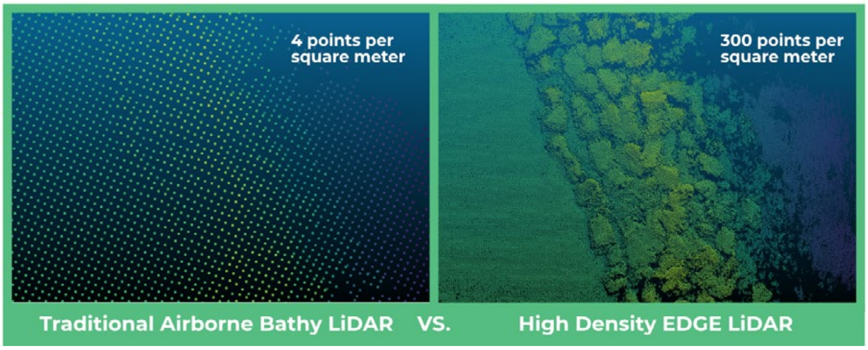


Figure 3: The comparison with traditional airborne bathymetric lidar, which has a typical resolution of single-digit points per square meter, demonstrates the high resolution of the ASTRALiTe EDGE lidar, which can resolve individual rocks. The water surface has been removed from the data for clarity.

Three use cases are provided to demonstrate the ability of the ASTRALiTe EDGE lidar to survey infrastructure for change detection and remediation in the aftermath of damage.

Coastal use case—jetty

The first use case comes from Panama City, Florida, where a jetty protecting a beach was damaged by Hurricane Michael in 2018. In the wake of the storm, the jetty had become a navigational hazard to small boats and was less effective in protecting the shoreline from erosion and sediment transport. To prepare for remediation and repair of the jetty, a high-resolution survey was required to determine the location of displaced riprap, estimate the volume of relocated sediment, and identify underwater hazards.

The ASTRALiTe EDGE was deployed on a commercially available, multi-rotor (hexacopter) sUAS by Juniper Unmanned to survey a 10-acre area covering portions of the beach dunes, down through the land-water transition, and into water depths of 7+ meters. The deployment was quick and easy, requiring minimal coordination to secure the necessary permits.

The topobathymetric capability is evident in **Figure 2**, with the seamless transition from grassy dunes to 7-meter water depth. The high-resolution capability is illustrated by the significant detail in the jetty rocks captured in the lidar data (<5 cm resolution; **Figure 3**). Combined, these two features in the data highlight the benefits of using the AstraLiTe EDGE in such a survey. The high-definition lidar data was collected at 300 pts/m² and was digitally georeferenced and classified to identify water surface, bottom, and land elements.

The data obtained from the survey shows precise locations and orientations of rocks and other hazards, providing remediation crews with knowledge to more effectively scope the effort required to repair the damaged jetty. Future work is scheduled to conduct a post-remediation survey to validate the completed restoration and assess whether it meets specifications.

Coastal use case—harbor

Another coastal use case is inspection of jetties, piers, and navigational hazards off the coast of Norway. In particular, the local government required information on the status of a dredging project around two of the local piers, as well as the current state of an underwater pipe that provides power to two harbor lights (**Figure 4**). Flights were conducted by Nordic Unmanned AS using its Staaker BG200 drone, capable of carrying the lidar payload for 30+ minutes on a single battery charge.

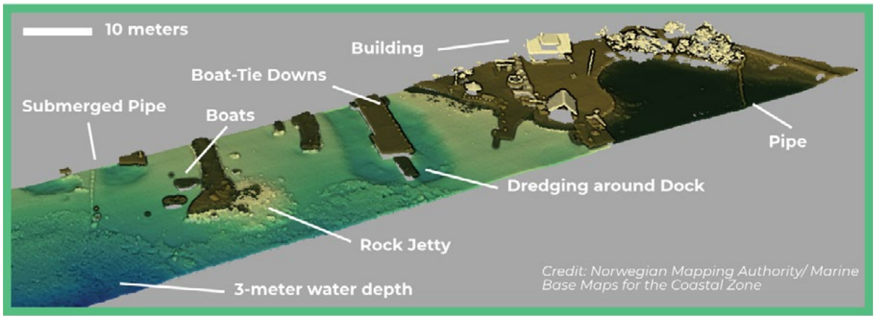


Figure 4: Lidar data from coastal Norway, with tan-brown indicating topographic features, and yellow-blue the bathymetry. Features shown in this set range from dredged areas around piers to individual rocks separated from a jetty, to a pipe running out to two harbor lights.
Image courtesy of Norwegian Mapping Authority/Marine Base Maps for the Coastal Zone.

The flight plans were designed to achieve 300 pts/m² and cover 1.5 hectares per 15-minute flight, which enabled detailed depiction of the jetty rocks, many of which posed navigational hazards, because they had been displaced by waves. These rocks can now be recorded and tagged for removal/repair. Frequent surveys in this area will continue monitoring the status of jetty rocks, the 30 cm pipe, and the dredged area surrounding the piers, providing valuable insight for harbor authorities.

River use case

The third use case is a riverine survey on the Nabari River in Japan. Infrastructure surrounding the river is protected from high river flow rates by levees and other bank cladding strategies. Local governments require frequent inspections of river systems that experience dramatic change as a result of destructive typhoons and seasonal flooding. These flood events can cause significant sediment transport and deposition, damaging infrastructure such as bridges and levees.

Resource managers require up-to-date information on the state of the river and how to remediate effects of the previous storm event. A drone-based high-resolution survey of the area using the ASTRALiTe EDGE provides tactical data on specific problem areas, such as bends, confluences, or critical infrastructure, including the underwater portion.

Lidar data captured by Mirukuru Co. Ltd. indicated that sediment had built up at the confluence of these two rivers, primarily at the output of one of the side rivers (**Figure 5**). This was deposited on the left side of the river channel (shown in overhead view as shallow green area). Near-real-time visualization allowed for quick, actionable decision-making and strategic revisits to areas of interest. The flight altitude above ground level was 30 m, the sUAS traveled at 4 m/s and the river's turbidity was measured at 4-8 Nephelometric Turbidity Units (NTUs).

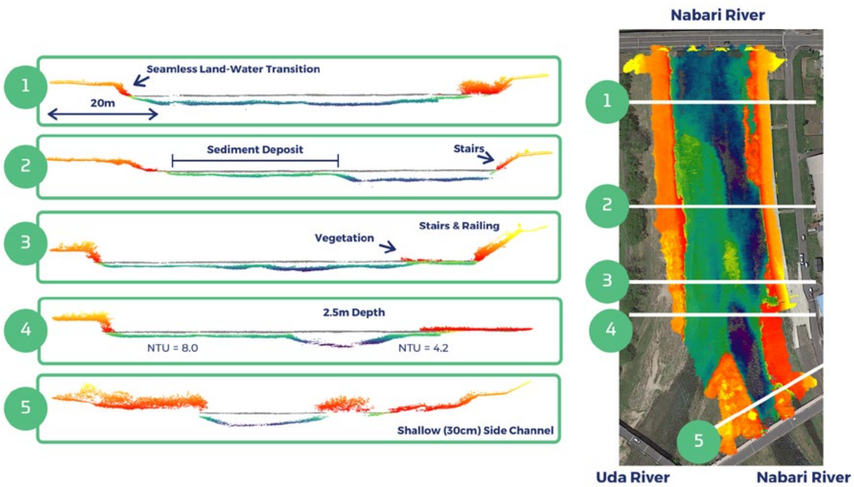


Figure 5: River transects and full map showing topography (red-orange) and bathymetry (green-purple) in a 5-acre area at the confluence of two rivers. Five transects include detail of stairs, vegetation, riverbank location, water depth, sediment deposition, and channel location.

The data extracted from the 3D point cloud includes cross-sections of the river, encompassing water surface, water bottom, vegetation, land, and man-made objects such as stairs and rails. Waters as shallow as a few centimeters are observable and vegetation near the water's edge is clearly distinguishable. The ASTRALiTE EDGE provided seamless transitions from land to water and measured depths of 2.5 m in this river system when the Secchi depth was estimated to range from 0.8 to 1.4 m.

Summary

The new standard for topobathymetric lidar is a more detailed, more frequent set of observations in land-water transition regions that can be deployed at dramatically lower costs. These measurement attributes enable users to improve planning and prevention efforts, and/or repair and restore damaged areas – whether environmental or man-made. The ASTRALiTe EDGE offers this capability and places highly coveted, detailed data in the hands of users, as shown in the examples above, to enable rapid and targeted investigations, including maintenance and restoration operations. Surveyors can use this innovation of topobathymetric lidar in combination with sUAS to work in areas that are difficult for boats or divers to reach, rapidly assess the data, and increase the frequency of surveying areas of interest to dramatically improve the effectiveness of data products for their customers.

For example, underwater infrastructure can be more easily evaluated than with current methods (diver, sonar), facilitating a more informed situational assessment. The generation of highly detailed maps enables change detection assessments at centimeter levels and captures this change on short timescales rather than the hydrographic "climatological" scale of past airborne topobathymetric surveys.

The convergence of lidar and sUAS technologies combines previously unavailable high-definition topobathymetric lidar data with increased flexibility of data acquisition, resulting in dramatically improved decision aids for end users who must adapt to the ever changing, dynamic environment where land and water meet. Users are just beginning to learn how best to implement the new capability for a variety of use cases like the ones shown here.

Andy Gisler is director of lidar at ASTRALiTe and leads the research and product development programs. He has over a decade of experience working with laser systems and spearheads the development of the EDGE lidar system.

Dr. Jeffrey Thayer is CTO of ASTRALiTe, is the inventor of the patented techniques used in the EDGE, and has over two decades of lidar experience. He is also a professor of aerospace engineering sciences at the University of Colorado.

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Seagrass Changes in St. Joseph Bay

HURRICANE MICHAEL AND BIOLOGICAL DRIVERS OF CHANGE IN CRITICAL FLORIDA ECOSYSTEM

Seagrass's role in Florida

Contrary to their common name, seagrasses are technically marine monocotyledons, which means that they are a flowering plant that moved into the water around 70-100 million years ago. Despite their low species diversity and distinct physiological characteristics, seagrasses have successfully colonized every ocean, save for the poles (Orth *et al*., 2006).

Their importance is derived from the priceless natural services that these plants provide for the anthropocentric world as well as entire ecosystems. As a result, these grasses are worth over $19,000 per hectare, making them the third most valuable ecosystem in the world. Indeed, they are intrinsically priceless, as they promote and directly support much of the biodiversity that is characteristic of coastal and marine ecosystems. They are "ecosystem engineers" due to their strength and "coastal canaries" due to their vulnerability.

Seagrasses are representatives of the health and status of both their own and surrounding ecosystems, including human environments and economies. Seagrasses also support marine life by acting directly as a food source, or as a nursery and habitat for a diverse array of species.

BY ALLISON **SENNE**

Commercial as well as recreational inshore fishing in Florida relies on many of these same species, such as tarpon, snapper, and grouper (Matz, 2015). Tourism centered around species which are considered megafaunas, such as manatees and sea turtles, is equally important to the economy of Florida (FWC, undated).

Since seagrasses are so important, they also experience a wide array of stressors and disturbances. These include but are not limited to herbivores, competing producers, tides, air exposure, hurricanes, storm surges, water quality, and turbidity (*ibid.*). Perhaps the greatest global threat to seagrasses is humans and their various exploits. The world's population has historically resided, developed, and polluted near the coast, including bays and estuaries—the areas where seagrasses are most abundant and biogeographically important to the environment (Griffiths *et al*., 2020).

St. Joseph Bay "is dominated by large monospecific stands of *Thalassia testudinum* interspersed with smaller patches of *Halodule wrightii*, unvegetated sand flats, and small amounts of *Syringodium filiforme*" (Heck and Valentine, 1991, 217). The variegated sea urchin, "*L. variegatus*, previously observed defoliating large expanses of seagrass in the northern Gulf of Mexico, is commonly found within vegetated areas of St. Joseph Bay with population densities as high as 140 individuals/m2" (*ibid.*, 216). These events are classified as overgrazing when urchin populations overwhelm and impair ecosystem services. The causes include eutrophication due to runoff from various point and non-point sources, overfishing of the sea urchin's natural predators, and rising water temperatures. A 2019 study of sea urchin populations in St. Joseph Bay after Hurricane Michael suggests that vegetated areas averaged about 13-14 individuals/m2 (Challener *et al*., 2019). The same study noted that sea urchins here are "remarkably" resistant even to intense storms. They also noted that smaller individuals were likely swept away by the strong wave action during the hurricane and left the larger individuals behind to repopulate.

While all these factors influence the status, health, and productivity of seagrass meadows, this study focuses on quantifying seagrass loss after Hurricane Michael as well as potentially related sea urchin grazing. Hurricane Michael in October 2018 is ranked as the third most intense of all recorded hurricanes to have struck the continental United States up to that point. It traveled north up the Gulf of Mexico and hit the Big Bend region of Florida's panhandle, including St. Joseph Bay, causing 30 billion dollars in catastrophic damage to multiple coastal towns. While property and infrastructure losses have been calculated, the effect of

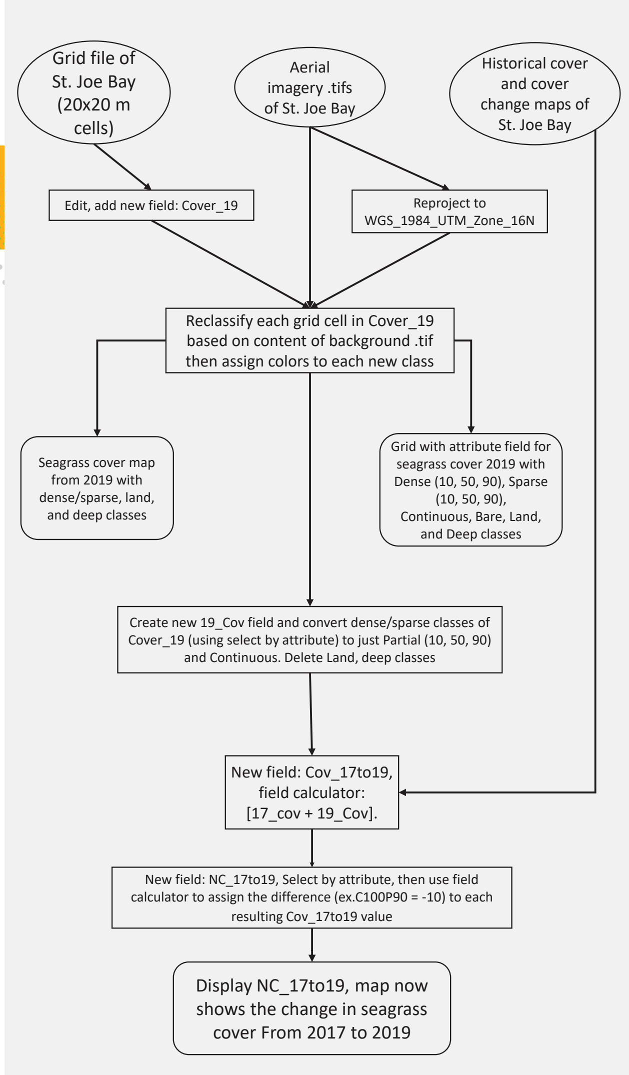


Figure 1: Flowchart of GIS procedure used for mapping and data collection. Circles represent input data layers, rectangles represent processing, while rounded rectangles represent produced map layers.

this storm on the environment and its natural ecosystem services has yet to be fully assessed. To quantify and analyze the seagrass loss caused by these processes, seagrass meadows in the waters of St. Joseph Bay were mapped using aerial imagery taken in March 2019.

Three main layer groups were manipulated within Esri ArcMap 10.3.1 for this analysis. Kucera International provided over 40 aerial imagery tiles, taken with a multispectral sensor at high resolution (10215 x 10215 pixels) with 8-bits-per-band depth. These were added to the working ArcMap document, one layer per .tif file. The tiles do not overlap each other and cover the full extent of the bay, so they function as the first layer group that is manipulated in this study. The second layer group consists of six different 20 x 20 m grid shapefiles with both cover and cover change attributes for each cover study completed by the Fish and Wildlife Research Institute (FWRI). These will be merged later with the Cover19 grid (the numerals refer to 2019, the date of the data). The third, topmost layer is a 20 x 20 m grid shapefile with an empty Cover19 field. The properties of this grid are changed so there is no color fill to the cells, and the aerial imagery can be clearly seen beneath. This layer is to be edited the most and will contain the completed cover change analysis maps. The first and third layers remain active during data collection while the second and third layers remain active during data processing and analysis. All layer groups were projected to the geographic coordinate system WGS 1984 UTM Zone 16N. The workflow, process, and methods for this analysis are depicted in **Figure 1**.

Currently there is not an accurate automated method to detect the presence of seagrass and then classify it as such—only manual photointerpretation and supervised, semi-automated methods. Lidar and remote sensing abilities are limited due to the functioning of light underwater with suspended particles, turbidity, and swaying motion of seagrass that is dictated by underwater currents. This study area includes a very complex water column, since it is located in the salty Gulf of Mexico, so for these reasons aerial photography was utilized in this study and not lidar. As topobathymetric lidar capabilities increase and intertwine with neural networks and deep learning, it is highly likely that the current method will be accurately replicated without a user-intensive process and instead utilize multiple sensors, models and algorithms at once to automate the process.

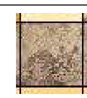
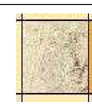
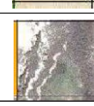
Class	Code	Example
Dense Continuous	DC100	
Dense Patchy 90%-50%	DP90	
Dense Patchy 50%-10%	DP50	
Dense Patchy 10%-1%	DP10	
Sparse Continuous	SC100	
Sparse Patchy 90%-50%	SP90	
Sparse Patchy 50%-10%	SP50	
Sparse Patchy 10%-1%	SP10	
Bare	BARE	
Land (above sea level)	LAND	

Figure 2: Photointerpretation key with examples from imagery

Cov_YEARtoYEAR	NC_YEARtoYEAR
C100C100	0
C100P90	-10
C100P50	-50
C100P10	-90
C100BARE	-100
P90C100	+10
P90P90	0
P90P50	-40
P90P10	-80
P90BARE	-90
P50C100	+50
P50P90	+40
P50P50	0
P50P10	-40
P50BARE	-50
P10C100	+90
P10P90	+80
P10P50	+40
P10P10	0
P10BARE	-10
BAREC100	+100
BAREP90	+90
BAREP50	+50
BAREP10	+10
BAREBARE	0

Figure 3: Conversion key for all possible combinations of percentage cover change with corresponding percent change value.

2015 to 2017				2017 to 2019			
% CC per grid cell	Count	% of grid	Area (m²)	% CC per grid cell	Count	% of grid	Area (m²)
-100	352	0.32%	140800	-100	7997	7.31%	3198800
-90	380	0.35%	152000	-90	4185	3.83%	1674000
-80	103	0.09%	41200	-80	990	0.90%	396000
-50	907	0.83%	362800	-50	7258	6.63%	2903200
-40	481	0.44%	192400	-40	2334	2.13%	933600
-10	1151	1.05%	460400	-10	21408	19.57%	8563200
0	104135	95.19%	41654000	0	62502	57.13%	25000800
10	505	0.46%	202000	10	480	0.44%	192000
40	92	0.08%	36800	40	714	0.65%	285600
50	440	0.40%	176000	50	375	0.34%	150000
80	22	0.02%	8800	80	150	0.14%	60000
90	219	0.20%	87600	90	454	0.42%	181600
100	608	0.56%	243200	100	548	0.50%	219200
Total	109395	100.00%	43758000	Total	109395	100.00%	43758000
Total Loss	3374	3.08%	1349600	Total Loss	44172	40.38%	17668800
Total Gain	1886	1.72%	754400	Total Gain	2721	2.49%	1088400
No Change	104135	95.19%	41654000	No Change	62502	57.13%	25000800

Figure 4: Results of cover change analysis for the two most recent studies, displaying the frequency, percent of grid, and area of seagrass that experienced varying degrees of gain or loss.

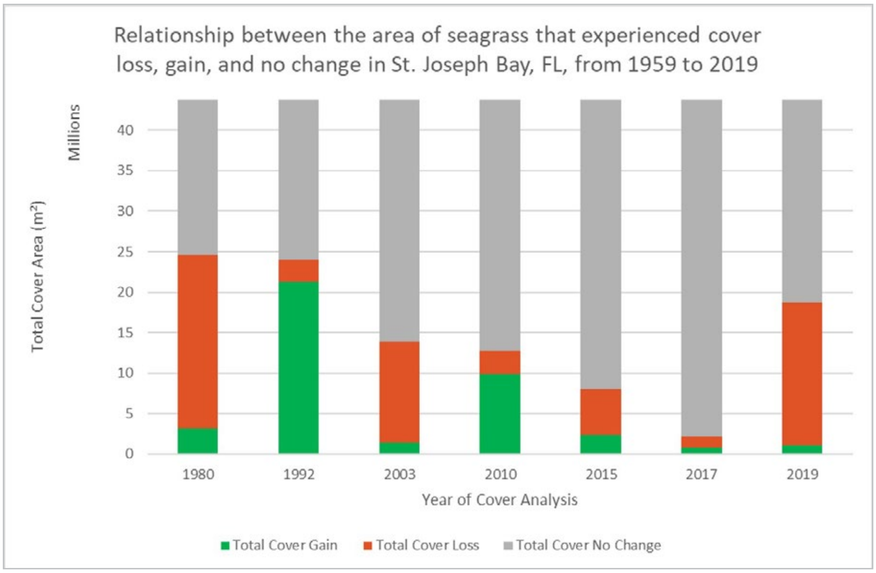


Figure 5: Percent of seagrass that experienced cumulative cover gain, loss, and no change 1959-2019

For this study, I hand digitized all of St. Joseph Bay's seagrass meadows in the aforementioned empty 20 x 20 m grid shapefile's Cover19 attribute field. The grid consists of approximately 109,395 cells, each with an area of 400 m2, and follows the interior perimeter of St. Joseph Bay, including the littoral zone where seagrass meadows are located and distributed. Each cell was objectively assigned one classification label using the classification table in **Figure 2**.

Techniques to achieve this quickly and efficiently are made possible by ArcMap, as it is much too time-consuming and therefore inefficient to classify one cell at a time. These tools include highlighting, de-selecting highlighting, and the field/classification calculator within the attribute table.

After the preliminary manual classification was completed, an additional field was added to the grid's table. The purpose of this is to re-classify the 'Cover19' field, so it has the same classifications as the historical seagrass cover maps in St. Joseph Bay and can then be compared. The real difference is that the reclassification takes away the subclasses of dense versus sparse for eight classes in total. The second layer group contained the historical cover shapefiles from FWRI and was spatially joined with the newly filled and converted shapefile so that the cover data from the years 1959, 1980, 1992, 2003, 2010, 2015, 2017, and now 2019 exist all in the same shapefile under the same data point classification key. From there, the calculations of cover change were made within the attribute table for this map document on ArcMap by combining two years of cover data at a time (example: 17_Cover and 19_Cover).

There are 25 resulting classifications or values of this calculation, which correspond to the 25 possible combinations of cover change codes that represent the approximate total cover lost or gained within every grid cell in the shapefile for two consecutive cover studies. These 25 possible combinations are then treated like subtractive equations, with 25 differences and numerical values to represent the difference in the percent cover change between studies. **Figure 3** depicts this relationship. These values are then added to the attribute table of the grid so they can be displayed to map the change between two studies. The field calculator was used to fill each attribute with the numerical value, as it had been used to populate the preliminary 2019 cover data.

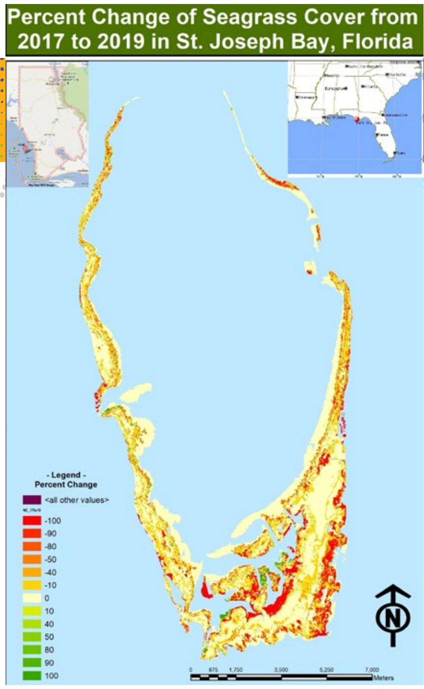


Figure 6: Map of percent cover change per grid cell 2017-2019.

Finally, the frequency, area of cover, and subsequent percent of total cover for each of the 25 class/value combinations of cover change can be calculated for any study year. The frequency of grid cells that experienced any percent of cover change was determined using the 'Select by Attribute' feature for each numerical value of percent change. Then each frequency was multiplied by the area of one grid cell (400 m^2) to calculate the total area of seagrass that experienced any of the possible percent changes per grid cell. These calculations were then divided by the total area of the grid that contained bare sand or seagrass (109,395 grid cells = 43,758,000 m^2 or 43.758 km2), which excludes classifications of land, deep water, and missing imagery, to find the percent of the total study area that experienced each possible percent change. **Figure 4** compares the percent cover categories of the 2017-2019 results with that of 2015-2017.

By using an interpretation-based mapping and calculation process, this study found that, between 2017 and 2019, approximately 17.6688 km^2 of seagrass cover experienced a decline while only 1.0884 km^2 experienced cover gain. This recorded cover loss is greater than that of previous cover studies except for that between 1959 and 1980. As displayed in Figures 5 and 6, this study found that 40.38% of all seagrass meadows in St. Joseph Bay experienced decline from 2017-2019, 2.49% experienced cover gain and 57.13% did not experience cover change. 7.31% of all seagrass meadows experienced a total loss in 2017-2019.

Thus seagrass in St. Joseph Bay experienced a significant decline between 2017 and 2019, likely caused by a combination of multiple stressors present in the area, including but not limited to Hurricane Michael, recreational boat propeller scarring, sea urchin grazing, nutrient runoff, water clarity, and phytoplankton. Earlier FWRI seagrass mapping efforts determined that all but one of these stressors are either episodic or increasing, with propeller scarring determined to be extensive (Yarbro and Carlson, 2016). The maps created from this study, using imagery from 2019, indicate continued evidence and extent of thinning.

Future work

This study is subject to human error during manual classification and photo-interpretation, related to the limitation of the grid's resolution. Each grid cell or pixel is 20 x 20 m, so all calculations are approximations. Without historical data before 1959-1980, it is impossible to determine longer-term trends. There remains a need for restoration and/or conservation, since seagrass beds are so valuable ecologically and economically on both global and local scales. Using the data, statistics and maps, areas of highest concern and vulnerability can be identified as part of the third *Seagrass Integrated Mapping and Monitoring Program Mapping and Monitoring Report* produced by FWRI. Seagrass mapping and monitoring is crucial for the effective ecosystem management of St. Joseph Bay.

Allison Senne is an undergraduate at University of South Florida St. Petersburg, majoring in environmental science and policy. She has a minor in geospatial sciences and is completing the honors designation in the Judy Genshaft Honors College at USF. She will graduate in May 2021. She works part-time at the Florida Fish and Wildlife Conservation Commission's Fish and Wildlife Research Institute in the Seagrass Habitat lab (led by Drs. Laura Yarbro and Paul Carlson) using ArcMap and aerial imagery to map and digitize seagrass meadows in coastal areas of the Florida panhandle.

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Overview of colorized point cloud used in RCI project.

Mobile lidar for Roadway Characteristics Inventory

MOBILE LIDAR FOR ROADWAY CHARACTERISTICS INVENTORY

Using mobile lidar for Roadway Characteristics Inventory (RCI) projects seems ill-advised. On deeper examination, however, it's a viable solution. Based on the name alone, some may think that RCI is just Building Information Modeling (BIM) for roadways, and that is exactly what it is. Traditionally, RCI projects have been linear-based referencing systems using starting and ending points, such as mileposts or intersection-to-intersection, to identify features and their positions relative to the start and end points.

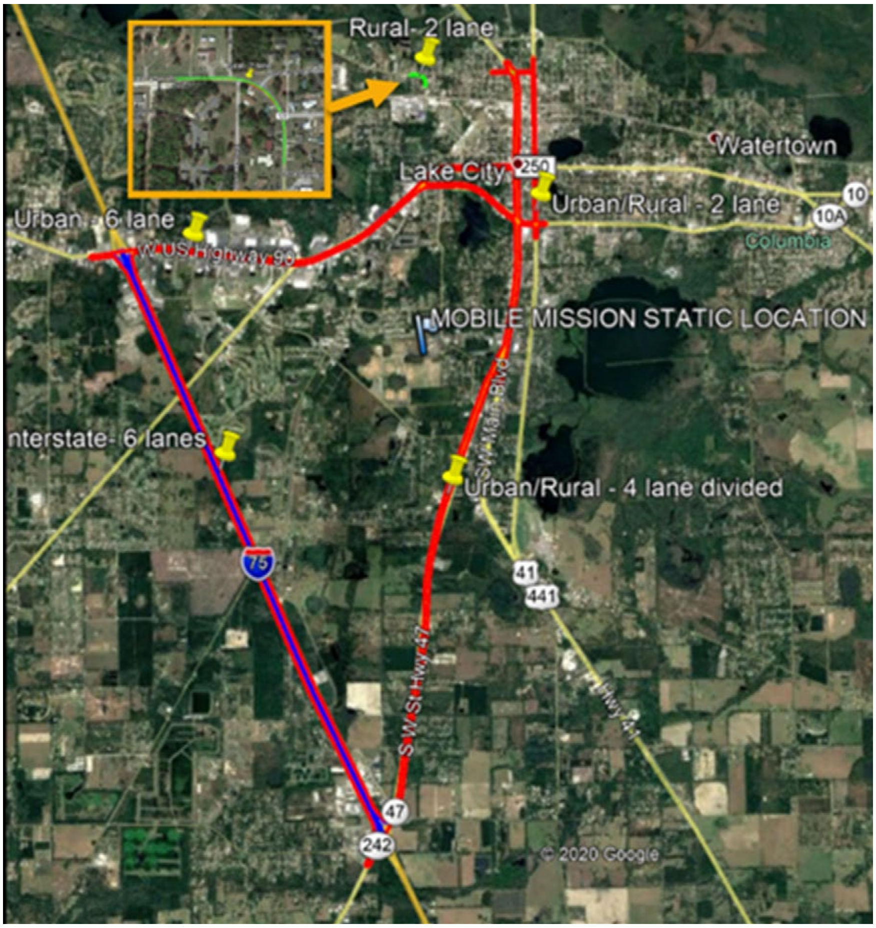
Several different tools are used to capture the required information to create and properly attribute features. These can range from a video log to "boots on the ground" assessments. Since we are already mobilizing to the project site driving video, why not use mobile lidar that has GNSS, lidar, imagery, IMU, and georeferencing video capacities? Being able to convert from a linear system to a GIS management system justifies looking into the possibilities of what can be achieved with a geographically-based RCI system.

BY TREVOR **TYSON**

GPI's mobile van, used for data collection on the pilot. The *RIEGL* VMS-450 lidar system can be seen mounted on the roof.

Florida Department of Transportation (FDOT) and many other clients have been asking similar questions. FDOT recently contracted GPI Geospatial, Inc. (GPI) to perform an RCI pilot project. Before describing the specifics of the pilot, however, we discuss some of GPI's capabilities that gave the confidence to take on an RCI pilot project. GPI owns and operates two *RIEGL* VMX-450 dual-channel lidar sensors. Some may wonder why we don't use the VMX-2HA, but we consider the VMX-450 to be the most hardened of the VMX systems. It is relatively low noise and very dependable. Although the VMX-450 suffers transfer speeds that limit still imagery capture rates, GPI has added a georeferenced video component, which raises the bar.

GPI has performed a wide variety of projects for FDOT, other municipalities, and private developers that helped to



Location of FDOT RCI pilot project.

qualify us for this opportunity. For many years, GPI has performed survey-grade mapping using mobile lidar for engineering design all over the eastern seaboard and across to Minnesota. GPI has not only used mobile lidar on these projects but has developed streamlined workflows to acquire and merge aerial lidar, static lidar, and traditional surveying to make a single seamless survey-grade base map for the use of engineering and design projects. We also provide uncontrolled GIS work.

One of GPI's largest markets was sign inventory: we collected data and built GIS databases for the Massachusetts Department of Transportation and the New York City Department of Transportation. More recently, GPI provided lidar and imagery of several remote roadways to the Maine Department of Transportation for roadway conditions assessments. GPI is also integrating a georeferenced video system into our mobile lidar—this is still in the early stages of development but functional. We are expecting our video capabilities to grow substantially over the next year.

The FDOT pilot consisted of approximately 28 centerline miles of mobile lidar data acquisition and processing to determine whether mobile lidar could be used to replace traditional RCI collection methodologies for a statewide program. There were many unknowns for both the contractor and the client, of which the biggest was relative and positional accuracy. Once the accuracy component was proven, the rest of the project was simply data delivery and data extraction. The RCI's linear referencing model had adopted an acceptable relative accuracy requirement, so to justify a complete overhaul of the RCI system, GPI had to push the limits of both relative and positional accuracy.

FDOT and GPI decided to set both accuracy thresholds at ±0.25 feet (±0.076 m). Most lidar system suppliers claim the absolute accuracy of untargeted mobile data is about ±3.28 feet (±1 m). For GPI to achieve the accuracies required we relied on our extensive experience in surveying, geomatics, and extensive mission planning. We had a consistent outlook on the project as a scalable statewide mapping project instead of just focusing on the 28 centerline miles of the pilot project.

One of our biggest concerns was the method of applying the corrections to the mobile GNSS observations. We briefly discussed the use of RTK via modem to receive corrections, but that idea was discarded owing to the unreliability of statewide cell coverage. Instead, we decided to post-process our GNSS/IMU data using POSPac. Another concern was baseline and mission drift. GPI requested that FDOT allow us to test out the Florida Permanent Reference Network (FPRN) according to several different plans. The first was to use a physical FPRN base station. This was a "tried-and-true" processing method but, like RTK

> "This data successfully demonstrated that sub-foot accuracy can be achieved over a large area using a multi-sensor mapping vehicle with precise onboard timing synchronization with vehicle trajectories processed solely from the FPRN."
>
> *—Brett Wood, PSM, FDOT State Surveyor*

correction, lacked coverage. The second plan was to use the virtual base station derived from the FPRN. This solved the coverage issue affecting the first plan, but did the virtual base points have the repeatability and reliability that a physical base station could provide? The third plan was to use a network of virtual base points surrounding the mission area, so as we moved away from the pilot area, we could use at least one common virtual base station between missions. This plan provided coverage reliability and scalability.

The first plan was chosen to perform the downstream task of the pilot. The first and second plans had remarkably equivalent results, which reassured us when using the virtual base points derived from FPRN. The first plan had a slightly better fix/float ratio to the mobile GNSS/IMU observations but we would feel comfortable using either approach. Unfortunately, the third plan gave inconclusive results. POSPac's smart network tool did not accept the virtual base data. We are continuing to pursue this issue with Applanix with a view to future projects.

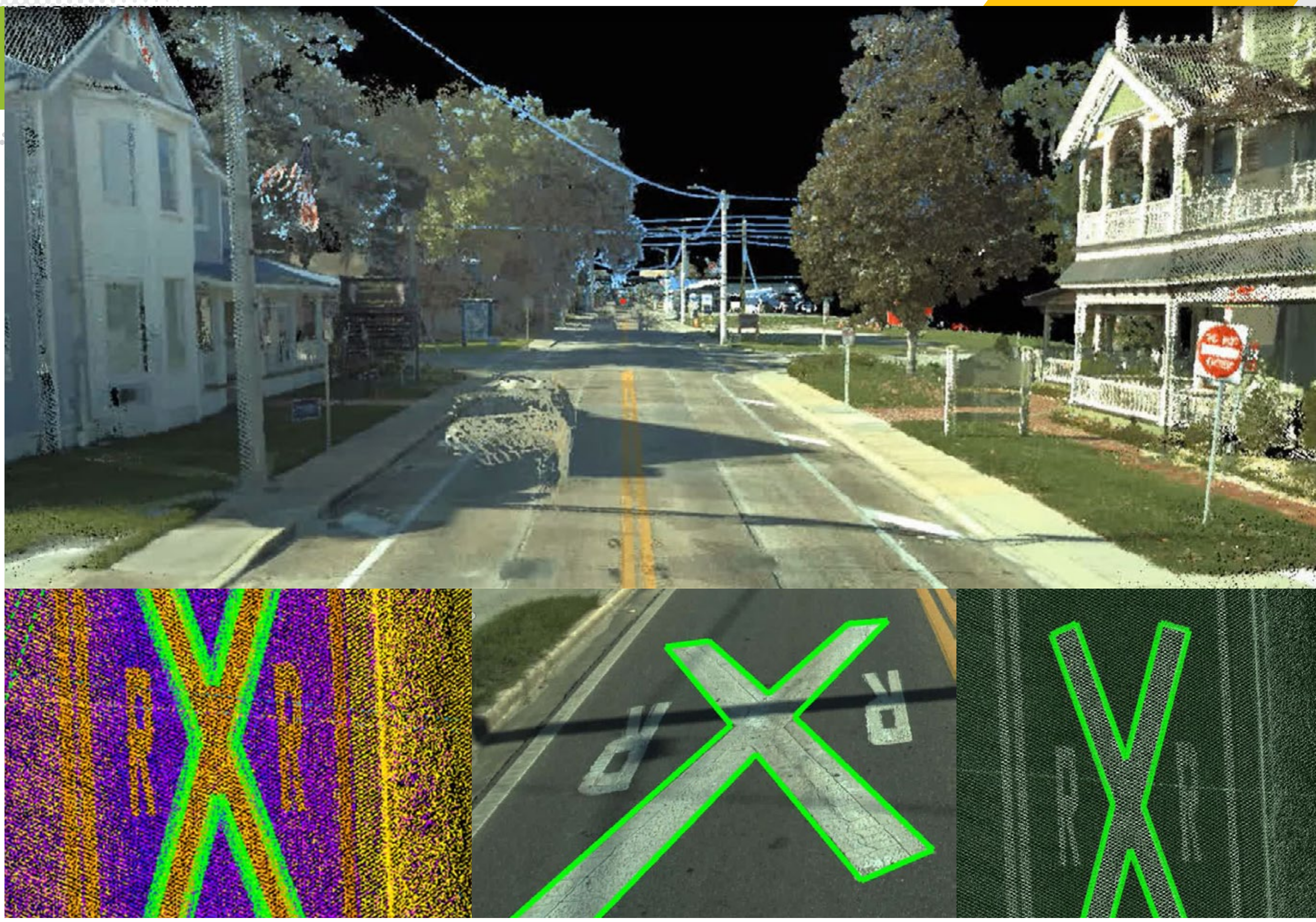
Using our best GNSS approach we processed the lidar and imagery. FDOT placed ground control but we did not receive the locations or values, so the pilot was a blind accuracy test. We began analyzing the data by comparing adjacent passes, like comparing traditional GNSS RTK observations to identify the error between passes. In general, the average of multiple observations is most likely the true value. With that in mind, we moved forward to QC/QA checks. As expected in areas with few GNSS obstructions, the error was low with discrepancies of about 0.15 feet or less between passes. In areas with GNSS obstructions, such as building canyons and tree lines, the error jumped up to 0.3 feet between passes. When the discrepancies between adjacent scans were around half of the agreed error of ±0.25 feet, GPI had confidence that we met blind test expectations of the pilot. We decided to move forward and delivered the raw, uncalibrated lidar, imagery, and video.

Since GPI always tries to push limits and increase expectations, another component we asked to incorporate in the pilot was a limited relative calibration of the raw data. We have developed a unique approach for calibration using the *RIEGL* software. It allows us to focus on areas that are out of tolerance around route corridor crossings, so we can provide limited calibration using a weighted average instead of the typical options of full calibration or raw data delivery. We explored this option with the intent of reducing the cost of full calibration when scaled statewide. GPI wanted to provide an additional level of quality at acceptable cost.

This took our data from the raw 0.15 feet of error to an average of 0.05 feet between passes in most areas with

- Through Lanes
- Auxiliary Lanes/Turn Lanes
- HOT/HOV/Toll Lanes
- Bike Lanes
- Sidewalks/Shared Paths
- Sidewalk Barriers
- Inside/Outside Shoulders
- Medians
- Median Barriers
- Intersections/Driveways (ingress/egress points)
- ADA pedestrian push buttons and detectable warning ramps
- Limited Access
- Crosswalks
- Signage
- Traffic Signals
- One-Way Roads
- Two-Way Roads
- Roundabouts
- Curve data
- Ramps
- Structures (culverts/bridges)
- Light poles
- Utility pole
- Utility features
- Drainage and Sewer structures
- Relative Clearance
  - Bridges
  - Traffic Signals

Asset and RCI features from lidar.



Samples of data processed by GPI. From top, left to right: colorized point cloud with street-level perspective; rail road crossing feature fitted to colorized point cloud, imagery captured by van, and intensity point cloud.

limited GNSS obstructions. Even the 0.3 feet discrepancies were reduced to 0.05 feet of error between passes. Although this adds cost upfront, the improved quality should allow a technician to load multiple passes to decrease voiding from moving traffic and increase point density when looking for features, which will increase efficiency.

With the data acquired, it is essential to understand what can be done with mobile lidar and associated imagery. In general, lidar allows more experienced people the opportunity "to be a rodman again". This simply means it is possible to extract exactly what is required for the project. This process eliminates the need for work to be repeated, which increases the cost. On top of increased productivity, the level of data mining is almost limitless. In addition to the obvious features, such as signs, striping, and other pavement markings, it is possible assess features such as Americans with Disabilities Act compliance, roadway condition, drainage flow, etc., from the lidar point cloud. In addition to what can be identified, extracted and assessed with just lidar, the georeferenced imagery, colorized point cloud, and video are available to assist further in the data mining process.

Like everything else in our industry, processes are rapidly changing and improving. If its methods do not change, a firm can quickly become obslolete. Converting RCI from a linear reference system to a graphical system allows the client to know not only what assets are there but also where they are. Adding mobile lidar allows for precise location and assessment of features without "boots on the ground", while allowing planning and development studies with the data. Additionally, GPI has been developing its tools to include high-resolution georeferenced video, oblique stereoscopic imagery, and artificial intellegence capabilities. Thus the answer to the question, "Is it possible to use mobile lidar for RCI projects?" is emphatically positive. Firms and their clients who have not begun to use mobile lidar for RCI are missing a major opportunity.

Trevor Tyson has 15 years of experience in surveying and lidar services. His duties have ranged from rodman to leading all aspects of the mobile lidar department at GPI Geospatial, Inc. In addition to his traditional survey expertise, his lidar experience includes mission planning, acquisition, GNSS/IMU processing, calibration, extraction, and creation of final deliverables utilizing aerial, mobile, and static platforms. Trevor is passionate about geospatial services and all the unexplored possibilities in this industry.

‘Virtual’ ASPRS President Jeff Lovin Shares Industry Reflections, Forecast

Woolpert Senior Vice President Jeff Lovin has served as president of the American Society for Photogrammetry and Remote Sensing (ASPRS) since March 2020. In this Q&A, the industry veteran shares what it was like leading the organization virtually, what technologies are shaping the industry and what geospatial trends to watch as 2021 moves forward.

Jeff Lovin, Woolpert senior vice president, was sworn in as president of ASPRS on March 25, 2020. Lovin likely will serve out his entire term virtually due to the worldwide COVID-19 pandemic.

To set the stage for 2020 and beyond, what were some of the more notable advances in lidar, photogrammetry and remote sensing in recent years?

The biggest advancement in the last few years has been the huge leap forward in linear-mode lidar capability. The emergence of Geiger-mode (GM) and single-photon lidar (SPL) a couple of years ago created a huge buzz, generating excitement but also sparking some panic about what the introduction of these new lidar methods meant for the industry. In the end, GM and SPL didn’t change the market as projected, but they did spur manufacturers to further develop traditional linear-mode lidar systems.

As a result, we now have the best, most advanced and efficient lidar systems. We are seeing sensors that are about three times as efficient as the former models, collecting lidar at higher altitudes and gaining a wider swath of data per flight. We would not be where we are today if it weren’t for the commercialization of GM and SPL, which seem to be finding their niche in markets like energy.

The other notable advancement would have to be the industry’s integration of deep learning and cloud solutions, which I didn’t anticipate coming so fast into our world. The emergence of artificial intelligence, machine learning and deep learning into the photogrammetry and remote sensing marketplace has quickly become integral to our operations, effectively replacing traditional processes.

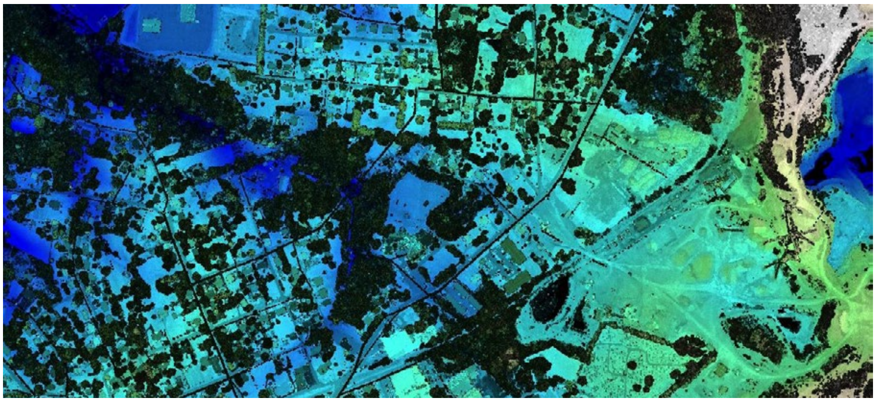
2020 was a difficult year for just about everyone. What challenges did 2020 present specific to the industry?

Working remotely, like so many around the world, was a challenge for the industry. We produce, process and manage big data and huge datasets daily. The industry has a technical workforce that had never worked from home—never even tried it. We dealt with the challenges of local broadband issues and developed protocols to keep projects running.

The second far-reaching challenge was the impact the pandemic had on our clients, government budgets and the market itself… and we haven't felt the full effect of that yet.

Third would be its impact on conferences and tradeshows. We have gone nearly nine months now since the last in-person conference and most of us have attended several virtual conferences. We learned how to stay relevant and how to get in front of clients, but it's been a huge challenge as a vendor and as president of ASPRS. It's been tough on all organizations trying to adapt to hosting a virtual conference and on participants trying to get value and ROI from that conference. Another downside is not having that in-person contact with clients. That kind of facetime can't be replicated on video conferencing platforms.

The big upside to virtual conferences is that we've learned the value of online learning. At ASPRS, we saw an uptick in our technical session attendance due to the ease of logging in from anywhere around the world, and the format enabled us to be more flexible with what we could do. We will likely retain those online sessions moving forward.



Lovin said one of the biggest advances in the last few years has been the huge leap forward in linear-mode lidar capability.

Image courtesy of USGS

How has the industry changed as a result of the pandemic?

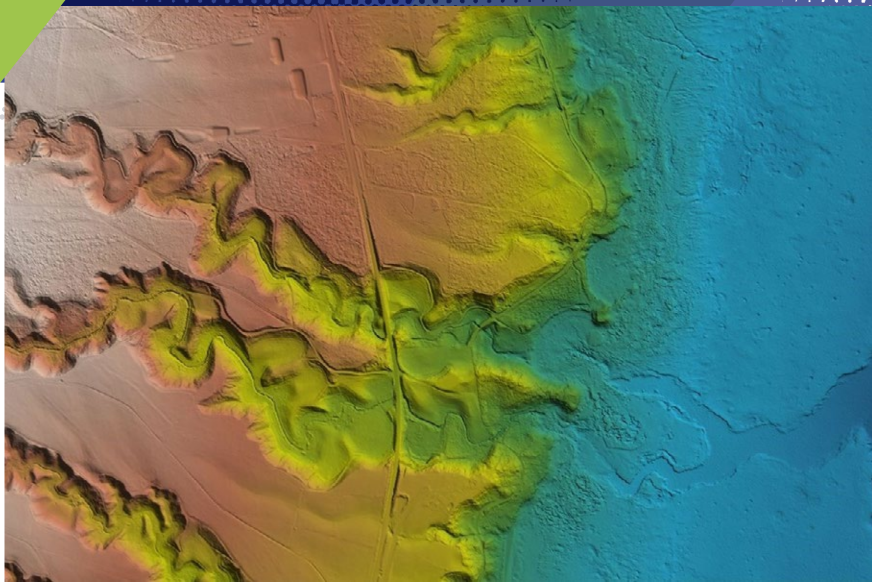
The use of video conference technology has changed the way we run our industry, as well as many others, forever. Companies already have begun to evaluate whether people will continue to work remotely or go back to a more office-centric setting. It was more of a cultural thing before; we had a lot of these tools, but people worked from home as a luxury. This has forced us to rely on those tools. That's just been unique to watch.

What advances were made in 2020 in general that will impact the industry moving forward?

The move to the delivery, hosting and managing of data in the cloud made great strides. Throughout 2020, many people did not have access to the office and the data that was stored there. For some clients, they were not at their offices to receive data deliveries. Remote access to that data has been the key. This was a big push for us at Woolpert in 2019 and it has proved crucial to operating successfully in our remote environment. By being able to deliver data quickly and easily in 2020 and in this setting, it also helped accelerate clients' acceptance of this practice. This remote environment also has helped the industry as a whole embrace this movement to the cloud.

Looking ahead to 2021, what hot topics or trends do you expect to advance or emerge?

Budgets will be a lot tighter after a whole year of COVID-19. Shortfalls in revenue can be supported by multiyear remote sensing data packages that bundle hosting services to greatly discount the price of the data. Software-as-a-service solutions also will help clients save money. You don't have to spend a million dollars that you don't have on your server this year because that data can be hosted via subscription software systems like Woolpert's STREAM:RASTER, for example, that will cover your needs on a limited budget. The best companies out there will help you find creative and innovative solutions that will bring you value now, when you need it the most.



The bathymetric lidar market came into its own in 2020, with many initiatives underway in 2021 to map the near-coastal environment. "Vessel-based sonar has been mapping the ocean depths for some time, but that in-between tidal zone and wave action zone is the challenge," Lovin said. "It's of enormous importance due to a host of coastal management, navigational charting and disaster management needs."
Image courtesy of USGS

What technologies and solutions are you excited about in 2021?
Bathymetric lidar. The bathy lidar market came into its own in 2020, and there are huge initiatives underway for 2021 with multiple agencies like the U.S. Army Corps of Engineers, the National Oceanic and Atmospheric Administration and the U.S. Geological Survey. The technology for bathymetric lidar has matured, and there are exciting new sensors available. Woolpert was ahead of this curve when it created its maritime market in 2019. Our industry is unique in that we can create or shape our markets to fit our technology.

Now the maritime market is taking off with several years of bathy lidar work ahead. As many of us know, the near-coastal environment is the least-mapped place on earth. Vessel-based sonar has been mapping the ocean depths for some time, but that in-between tidal zone and wave action zone is the challenge. It's of enormous importance due to a host of coastal management, navigational charting and disaster management needs.

You have been president of ASPRS since March—right around the time the pandemic hit the U.S. How did this shape your presidency and/or affect the trajectory of the organization?
Yes, it looks like I will be the virtual president—serving virtually my whole term. But I am super proud of ASPRS in how the organization reacted and what it accomplished in 2020. When we heard Geo Week wasn't happening, we decided to host a virtual conference, and it ended up being hugely successful. We conducted workshops in conjunction with the Association for Unmanned Vehicle Systems International (AUVSI) and were active in the Coalition of Geospatial Organizations (COGO), which is like the UN for geospatial organizations.

ASPRS also was approached by a geospatial group in Saudi Arabia that wants to stand up a certification program like ours, so we are working with them. Another group, the Surveying & Spatial Sciences Institute out of Australia, approached us about a knowledge swap after seeing our online materials.

Some of the ASPRS Regions have gotten stronger as well and have had successful virtual meetings. Meeting attendance is up and, due to being virtual, many regions have hosted both attendees and speakers from around the nation.

Personally, my one disappointment from my tenure is that I won't be able to give out awards in person. That's the most fun part of being president—when you get to hand out all the awards and recognize the year of great work during the last meeting in March. But for now, I just hope that we get through COVID. Despite the economic uncertainty caused by all this, I hope we all stay healthy physically and that our businesses all survive.

What do think the next five years hold?
There is tremendous opportunity for our industry to integrate deep learning capabilities not only to improve current processes, but to support the next step—which includes autonomous vehicles and systems. Whether aircraft, land-based or waterborne, these vehicles are going to need precise geospatial location information, and that is creating huge opportunities for our industry.

Our whole geospatial world has become mainstream. Everything on your phone is location-based. Who would have thought 30 years ago that our little industry would be so important? The opportunities abound.

Woolpert Senior Vice President Jeff Lovin is a Certified Photogrammetrist and photogrammetric surveyor who has been with Woolpert for 34 years. He has served on the AUVSI board, chaired COGO, been president of MAPPS and was appointed to the National Geospatial Advisory Committee. He will finish his tenure as president of ASPRS in March 2021.

Graham, *continued from page 64*
drone laser scanners are repurposed automotive or industrial scanners.

Laser-scanner pulse repetition rate

In this article, we will examine the pulse repetition rate (PRR) of the scanner. PRR is the number of pulses *emitted* by the scanner per second.

> ***Example:*** the PRR of the Quanergy M8 Ultra (the scanner used in the True View 410) is 430,000 outbound pulses per second (so 430 kHz).

However, the M8 belongs to the 360° class of rotating scanner (as do most of the *RIEGL* systems). We use 90° to 120° of this in our field of view (FOV), since the remainder of the rotation is scanning the bottom of the drone! Let's be conservative and say we limit our swath cross-track to ±45°. This means we use 90° of the total FOV which embraces one quarter of the available pulses. Thus, we have an effective PRR of 107,500 pulses per second.

Now, consider the *RIEGL* miniVUX-2UAV used on GeoCue's True View 615/620 3DIS. This scanner is also a 360° configuration with a PRR of 200,000 pulses per second. If we again consider our ±45° cross-track FOV, we see we have an effective PRR of 50,000 pulses per second, less than half that of the True View 410!

So how can it be that the miniVUX-2UAV is a more capable scanner? The key is the number of ***returns*** seen by the scanner, not the number of outbound pulses.

Many factors in addition to the number of outbound pulses contribute to the number of returns, for example:

- the energy in the outbound pulse
- the divergence of the beam
- the size and quality of collector optics
- the reflectivity of the object that is reflecting the pulse
- the sensitivity of the detector

No sensor manufacturer (of which I am aware) even attempts to quantify the number of expected return pulses. The closest we can come is the range of the sensor, expressed as a function of the reflectivity of the surface. But we find this to be dubious in all the automotive-grade laser scanners.

What are you to do when evaluating the system you need?

I think the best approach is to request data from the sensor flown over the type terrain that will be your "sweet spot" for business.

> ***Example:*** If coal inventory is something that you must be able to do with your scanner, then ask for data from coal stockpiles. If you are trying to decide between several scanners, try to have them flown under the same operating parameters (altitude, drone velocity, etc.).

At GeoCue we are very careful about the information that we supply. We will provide you with information that is accurate to the best of our understanding. If our understanding is not sufficient to accurately answer your questions, we will tell you that! If you have specific questions that are not being addressed, please feel free to email us at *info@geocue.com.*

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.

LEWIS GRAHAM

What to Consider When Investing in a Laser Scanner For Your Projects

As a provider in lidar and drone mapping solutions we constantly monitor the lidar scanner market, searching for the perfect laser sensors to integrate into our True View product line. A True View 3D Imaging Sensor (3DIS®) contains a number of integrated components such as the laser scanner, cameras, time synchronization systems and so forth. In this article, I am referring only to the laser scanning component. For example, in **Figure 1** the laser scanner is the *RIEGL* miniVUX-2UAV. How do we select the right scanner for the data products we are trying to extract?

Survey-grade laser scanners

At the survey-grade end of the business (such as GeoCue's True View 615), this is easy.

These scanners were purpose built for collecting high-accuracy topographic data with high sensitively and network accuracy. The only manufacturers of survey-grade laser scanners for drones are Teledyne Optech and *RIEGL*. GeoCue currently offers *RIEGL*-based products and is constantly monitoring new solutions from Teledyne Optech.

Utility-grade laser scanners

On the "utility-grade" side of things, the performance of a particular lidar scanner cannot solely be predicted from its manufacture-supplied specification sheet.

Outside of the *RIEGL* and Teledyne Optech purpose-built scanners, all other

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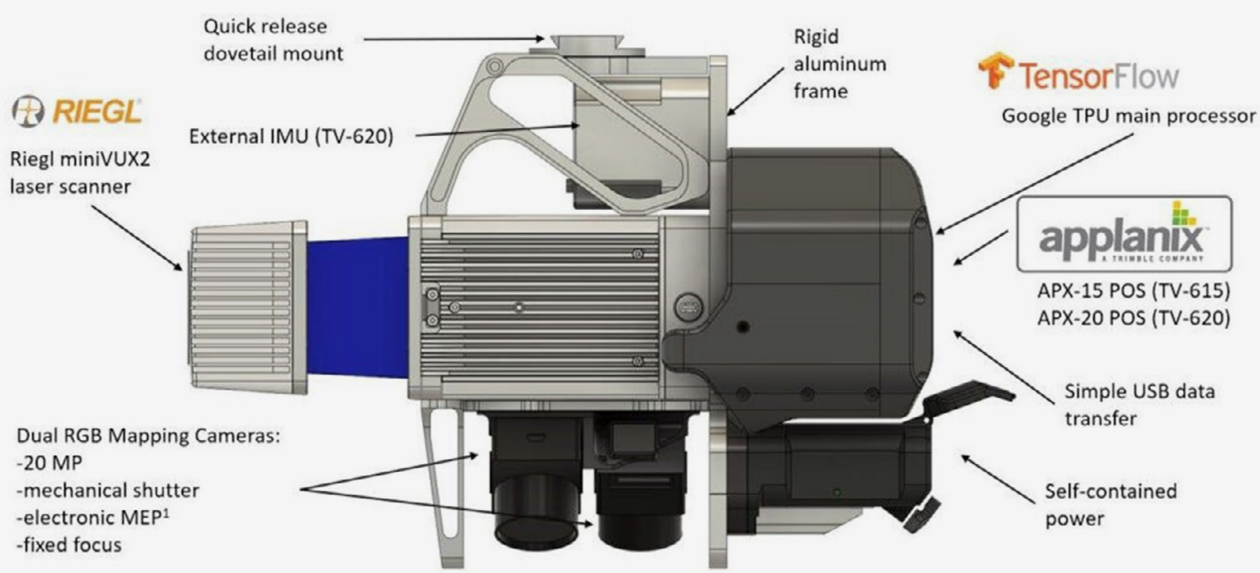

Figure 1: True View 615 3DIS