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LIDAR MAGAZINE

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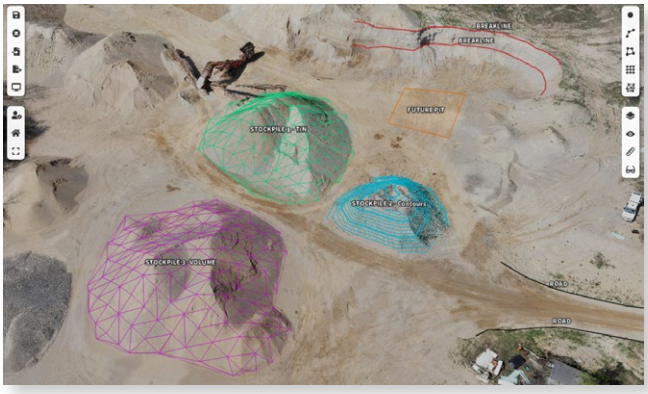

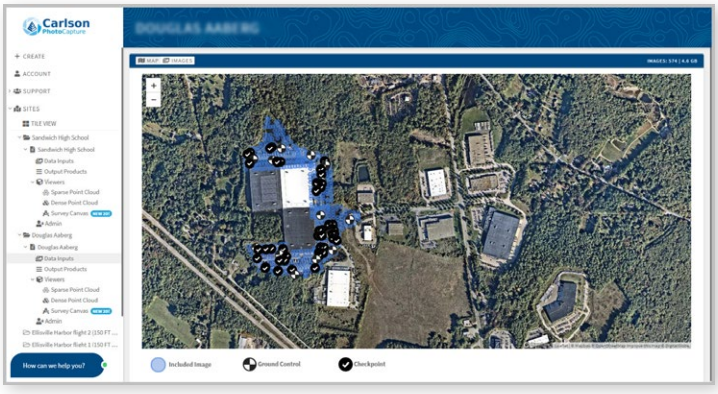

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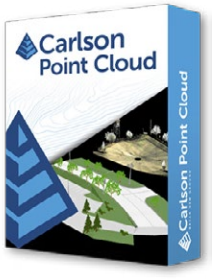

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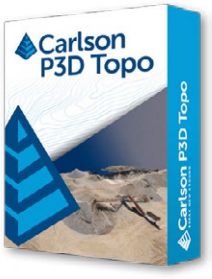

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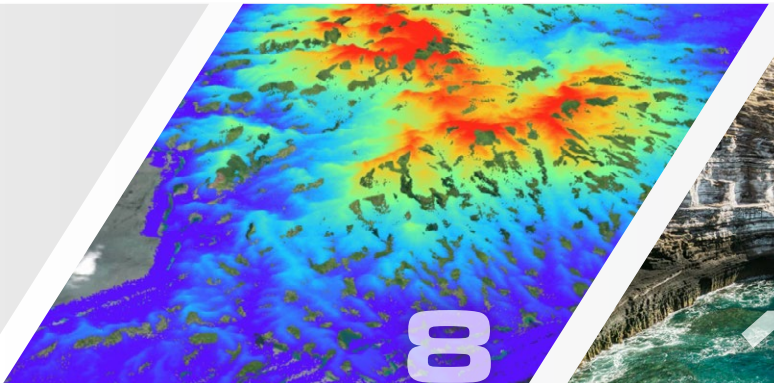

IN THIS ISSUE

COLUMNS

◀ ON THE COVER

The DJI Matrice 300 and YellowScan Mapper on a recent training session in Hawaii, courtesy of Frontier Precision (see interview on page 14). Representatives had the opportunity to educate environmental and engineering groups on UAS and lidar technology.

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DR. A. STEWART WALKER

The nature of work—are we happy to be going back?

There are now female bosses in 41 of the Fortune 500 companies[1]. The ceiling has been shattered, seemingly, but there is a long way to rise, through the cables, ducts, pipes and floors, to the level above. Indeed, in terms of percentage of women in board seats, the US is very much in the peloton of OECD countries, well behind progressive Scandinavian countries and New Zealand. Nevertheless, progress is apparent. The ASPRS group on Diversity, Equity, and Inclusion committee (DEI; Oxford comma—ouch!), formed quite recently, is active and strong.

Covid has had its effect. Despite the opportunities inherent in working from home, female participation in the US labor force has fallen during the pandemic. Maybe this will be reversed. The return to work, usually for less than five days per week, has spurred endless articles on the nature of work now and in the future. Employers are grappling with the mix of employees, some desperate to return to the office, others aspiring to work from home forever more. Which way will it go? I remember the late Augusts of my youth, the famous couplet from *As You Like It* reminding me that the new term was approaching all too fast: "And then the whining schoolboy, with his satchel, And shining morning face, creeping like snail, Unwillingly to school." But not my son, texting excitedly from his Googlebus! A recent report from Stanford suggests that employees regard working partly from home as equivalent to an 8% pay increase[2]. We are grateful that analog stereoplotters are no longer the bedrock of geospatial endeavor.

This issue brings an intriguing blend of articles. Let's start with the short piece in which our new contributing writer, Amar Nayegandhi, introduces himself. He's well known in the geospatial lidar world and we look forward to his explorations of the interplay between industry and technology.

We are pleased to bring four articles from last year's SAR workshop run by the ASPRS Florida Region and the University of Florida. Another of our contributing writers, Al Karlin, provides a summary, then a third, David Maune, gives grades to organizations based on their approach to subsidence—light-hearted, yet it brings home the immediacy and severity of the problem and underlines that it is much easier to measure than manage. Well known geospatial writer Mary Jo Wagner describes SAR work by the Italian firm TRE ALTAMiRA, which has developed

1 Anon, 2022a. Women in the workplace: no-ceiling fans, *The Economist*, 442(9287): 55, 12 March.
2 Anon, 2022b. The value of clarity: clear expectations are the secret to making hybrid work a success, *The Economist,* 443(9291): 53, 9 April.

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PUBLISHER Allen E. Cheves
publisher@spatialmedia.us

MANAGING EDITOR Dr. A. Stewart Walker
stewart.walker@lidarmag.com

ASSOCIATE PUBLISHER Daniel Mann
daniel.mann@lidarmag.com

EDITOR EMERITUS Marc S. Cheves, LS
marc.cheves@spatialmedia.us

CONTRIBUTING WRITERS
Dr. Qassim Abdullah
Dr. Srini Dharmapuri
Jeff Fagerman
Dr. Juan Fernandez-Diaz
Dr. Al Karlin
Aaron Lawrence
Raymond Mandli
Dr. David Maune
Amar Nayegandhi
Mike Shillenn
Evon Silvia
Ken Smerz
Dr. Jason Stoker
Larry Trojak
James Wilder Young
Dr. Michael Zanettii

The staff and contributing writers may be reached via the online message center at our website.

GRAPHIC DESIGN LTD Creative, LLC
WEBMASTER Joel Cheves
AUDIENCE DEVELOPMENT Edward Duff

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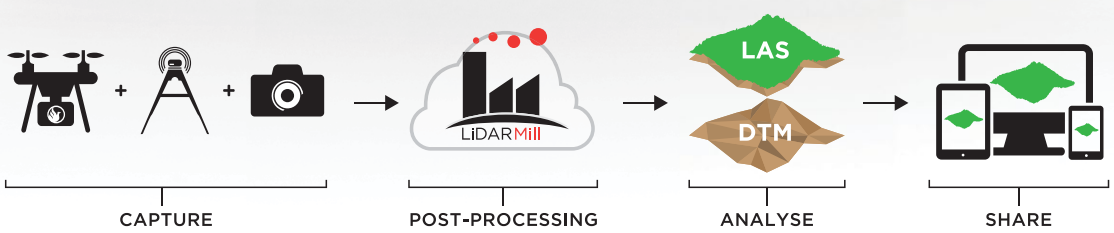

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a software technology called SqueeSAR to analyze time series of SAR data. And the airborne side is not forgotten as Ian Wosiski highlights the successes and products of Intermap Technologies. These articles, plus other contributions to the workshop summarized in the Karlin piece, confirm the complementarity of lidar and SAR—end-users are indeed blessed with accessible technologies to address major issues, not only subsidence, but also landslides, and their changes through time.

We continue our series of articles from Esri authors with one from Linda Peters. Imagery and lidar of the whole island of Grenada were acquired by Fugro, then Esri applied its deep-learning technology for rapid extraction of information from the point cloud, an exemplar of modern software providing useful deliverables from massive data sets rapidly and effectively. The goal is a nationwide digital twin.

Our story about Frontier Precision is heartwarming. We interviewed co-founder and CEO Dennis Kemmesat and learned how this Trimble dealership, which spans 11 states, has expanded over the decades into a vigorous business built on a broad portfolio, including UAV systems. Frontier Precision has a novel approach to introducing prospective customers to complex, expensive systems: it provides its own equipment and experts to work through a project with the client, who is much more likely to make a purchase once it's clear that the technology is efficacious and profitable. Dennis meticulously restricts this service to evangelism and carefully avoids situations that could be construed as competition with surveying and engineering firms. As Frontier Precision expands its territory and the products it represents, we hope to report case studies in future articles.

Geospatial professionals are obliged to stay up-to-date on rules and regulations governing their activities. Often this means entering the world of certification and licensure. In the US we have the additional challenge that the regulatory landscape undulates from state to state. Mike Zoltek's article is an update of one that originally appeared in *Photogrammetric Engineering and Remote Sensing*: we are indebted to ASPRS for permission.

I've written on the website about the meetings we hope to cover this year. We don't have the bandwidth to cover every event, for example we've had to forego an invitation to AEC-ST in Anaheim in June 2022, because we'll be in France covering the XXIV ISPRS Congress in Nice and YellowScan's LiDAR for Drone 2022 conference in Montpellier. Other European commitments will preclude attending HxGN LIVE Global 2022 in Las Vegas, but publisher Allen Cheves will be there. And we'll be back stateside for the Esri International User Conference in San Diego. We're shaping up for a hectic fall, with Commercial UAV Expo in Las Vegas and the Photogrammetric Week in Stuttgart in adjacent weeks. Intergeo is in Essen this year, in October, then there's Trimble Dimensions+ in Las Vegas in November. We'll be grateful for a few relaxing days in the holiday season, but we'll know a lot about lidar!

While waxing lyrical on the return of face-to-face events, we should remember the ongoing program of remote ones. The magazine recently attended two well prepared webinars: one was a combined effort from Applanix and the precision ag system supplier GRYFN; the other, by photonics supplier Excelitas, which supplies lidar components. Also on the calendar are another lidar workshop from ASPRS Florida Region and the University of Florida, and a technical meeting run by ASPRS Pacific Southwest Region and its student chapter at San Diego State University. You will have your own favorite events—the point is that there are endless opportunities for education about the technologies that fascinate us and their applications.

Our next issue will have a focus on automotive lidar—the people and the products in this huge, dynamic market. A useful article in *Photonics Spectra* provides context[3]. The consensus is that it is lucrative for suppliers to concentrate on advanced driver-assistance systems (ADAS) for the time being, because autonomous vehicles (AVs) are not with us yet, for both technical and regulatory reasons. It's heartening to know, however, that small robots are operational, for example for warehouse tasks[4] or local deliveries[5].

These technologies help Steve Bezos speed parcels on their way or pizzerias deliver to homes and offices, but let's end by looking upwards and forwards. Lidar is amongst the tools deployed to battle space debris[6].

Thank you for reading the magazine.

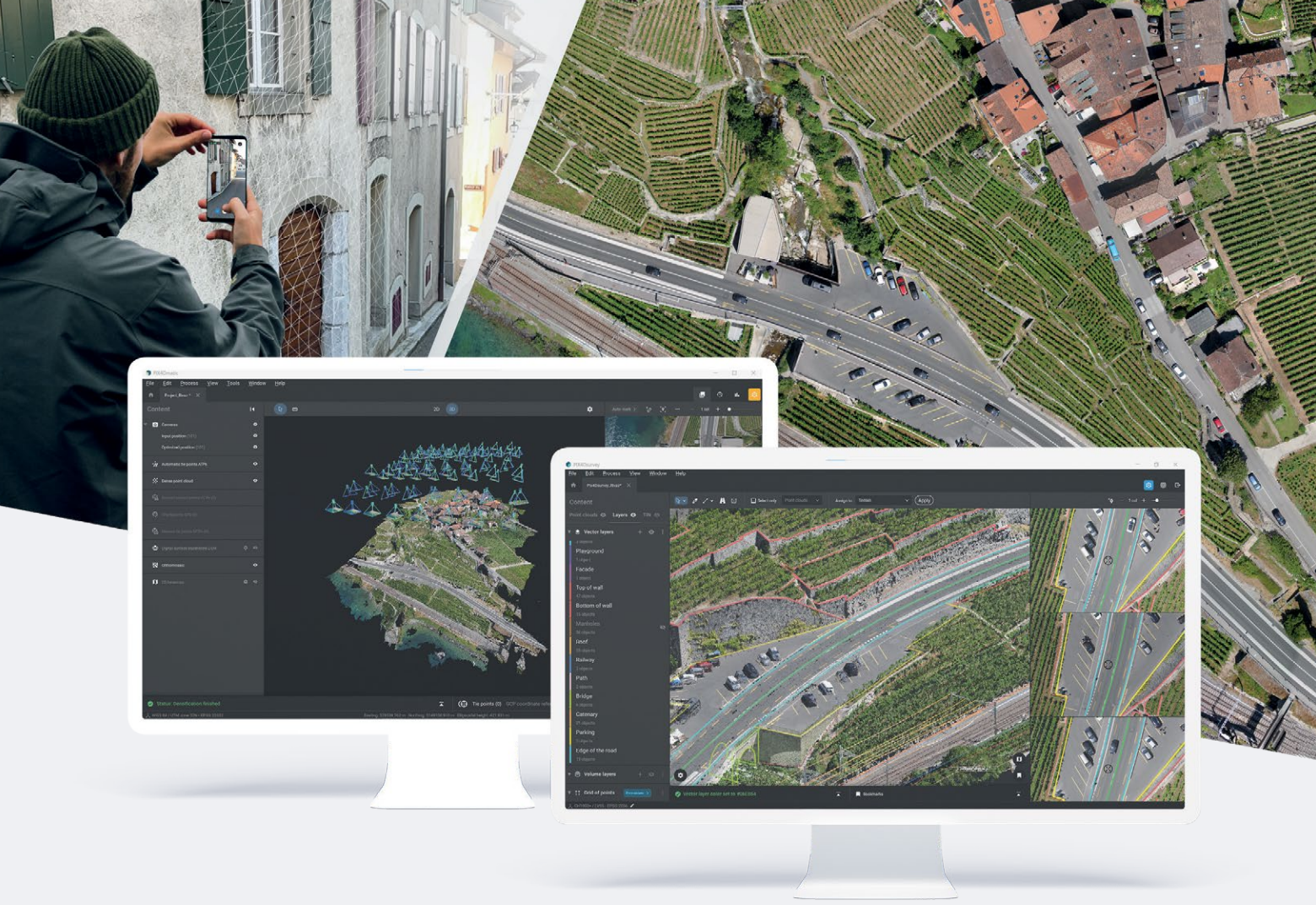
A. Stewart Walker // Managing Editor

3 Li, L., 2022 Advancements in diode lasers fuel automotive lidar, *Photonics Spectra*, 56(3): 44-49, March 2022.

4 Anon, 2022c. The bots taking over the warehouse, *The Economist*, 442(9283): 68, 12 February.

5 Anon, 2022d. Autonomous vehicles: sidewalk robots are already busy delivering groceries, *The Economist*, 442(9283): 69, 12 February.

6 Beaulieu, E., 2022. Advanced imaging rises to the task of detecting space debris, *Photonics Spectra*, 56(3): 56-61, March 2022.



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Amar Nayegandhi, CP, CMS, GISP

Introducing LIDAR Magazine's new contributing writer

LIDAR Magazine is pleased to announce that Amar Nayegandhi has agreed to join our team of contributing writers. Amar is a senior vice president at Dewberry and is based in the firm's Tampa, Florida office. This article introduces Amar's accomplishments in the geospatial industry, though of course many of our readers already know him well through personal contact or his numerous publications and conference presentations. Amar will continue to co-author articles about projects executed by Dewberry, but we are excited that he is also planning a series of short pieces giving his own thoughts on the important trends in geospatial business and technology. Welcome, Amar.

Dewberry Senior Vice President Amar Nayegandhi leads the firm's geospatial and technology services team and technology solutions market segment. He provides program oversight for the execution of all remote sensing projects for Dewberry's federal, state, and local clients. Amar has a bachelor's degree in electrical engineering from University of Mumbai and a master's degree in computer science from University of South Florida. He has more than 23 years of experience in the geospatial industry and is a former director of the American Society for Photogrammetry and Remote Sensing (ASPRS) Lidar Division. He is an ASPRS Certified Photogrammetrist and Certified Mapping Scientist – Remote Sensing, and a GIS Professional.

Contributing subject matter expert to the geospatial community

Amar has authored 16 refereed manuscripts in various international journals and more than 65 published reports to support the U.S. Geological Survey (USGS) and other federal agencies. He co-edited the *ASPRS DEM Users Manual, 3rd Edition*[1] and authored the chapters on Airborne Topographic Lidar and Airborne Lidar Bathymetry. He also wrote the *USACE EM 1110-1-1000 Manual on Photogrammetric and Lidar Mapping*[2].

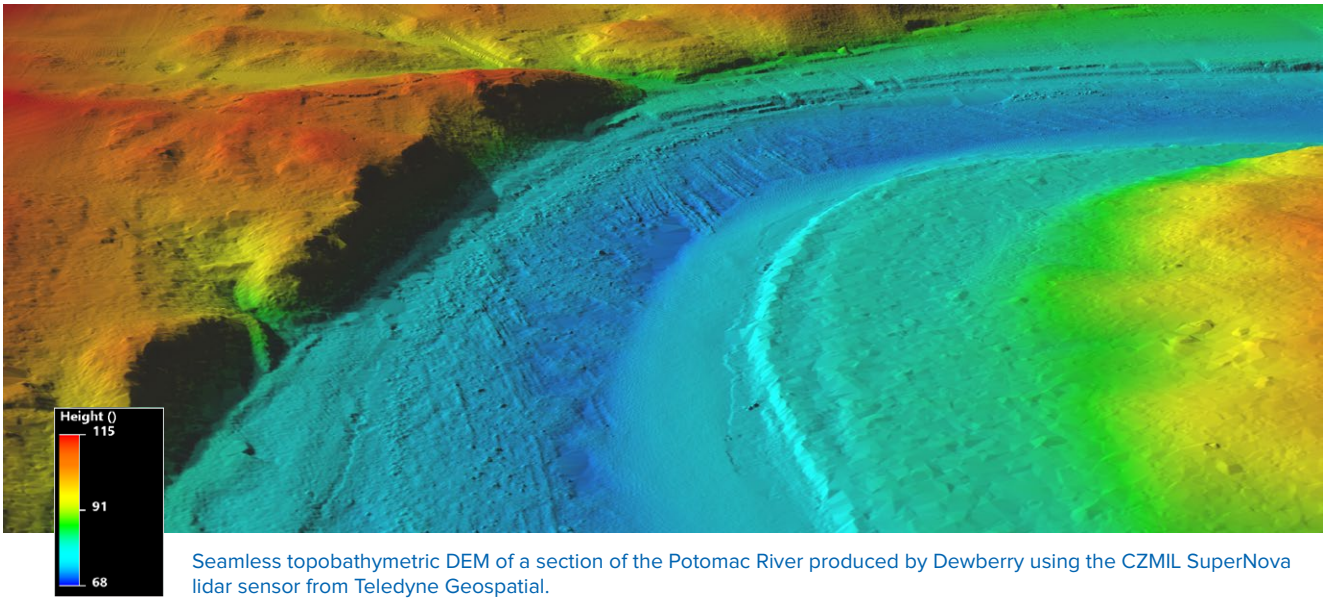
1 Maune, D.F. and A. Nayegandhi (eds.), 2018. *Digital Elevation Model Technologies and Applications: The DEM Users Manual*, 3rd edition, American Society for Photogrammetry and Remote Sensing, Bethesda, Maryland, 652 pp.

2 https://www.publications.usace.army.mil/Portals/76/Publications/EngineerManuals/EM_1110-1-1000.pdf.

Amar has led scores of complex topobathymetric lidar projects for federal clients, including serving as the project manager for the National Oceanic and Atmospheric Administration's (NOAA) Supplemental Sandy Topobathy Lidar and Imagery project to map the national shoreline following Hurricane Sandy, which received the 2015 LCDR Peter Johnson Best Practices Award from the Joint Airborne Lidar Bathymetric Technical Center of Expertise (JALBTCX).

From 2001 to 2011, he managed operations and was involved in the research and development of the NASA/USGS Experimental Advanced Airborne Research Lidar (EAARL) sensor for the USGS Coastal Program. From 2011-2012, he developed Dewberry's Lidar Processor (DLP) to process airborne bathymetry data acquired with the Riegl VQ-820-G, which included correcting for refraction of the green lidar signal as it traversed through the water column, using water surface returns from the near-infrared (NIR) lidar.

Additionally, Amar led the review of Geiger-mode and single-photon lidar data for the USGS 3D Elevation Program (3DEP). He has presented his research and technological findings at more than 100 international conferences and technical workshops, including an invitation from USGS to present the industry perspective for the USGS 3DEP at the 2018 United Nations World Geospatial Information Congress (UNWGIC) in Deqing, China.



Seamless topobathymetric DEM of a section of the Potomac River produced by Dewberry using the CZMIL SuperNova lidar sensor from Teledyne Geospatial.

Championing the latest airborne bathymetric lidar technology

Throughout his career, Amar has advanced the use of airborne topobathymetric lidar for coastal and riverine applications. Based on three decades of research and operations, airborne lidar bathymetry has proven to be an accurate, cost-effective, rapid, safe, and flexible method for surveying coastlines where sonar systems are less efficient and can even be dangerous to operate. In the early 2000s and prior, green-wavelength lidar sensors were limited to mapping bathymetry using a large laser footprint on the seafloor, thereby limiting the accuracy and density of data in shallow water environments. With the advent of small-footprint green-wavelength lidar sensors, such as the EAARL, the application of this technology enabled coastal and riverine mapping at data densities and accuracies that were comparable to airborne topographic lidar systems over land. A seamless topobathymetric digital elevation model (DEM) became a reality thanks to advances in sensor technology and data processing. During the first ten years of his career, Amar focused on improving the technology by writing software to process waveform data from the EAARL sensor to produce high-resolution seamless topobathymetric DEMs. For the next ten or more years, Amar helped build a business case for this technology and promoted the application of this technology in the public and private sectors. Today, the technology has evolved to enable topobathymetric mapping in shallow- and deep-water environments. Amar was instrumental in securing Dewberry's position as the first private company in North America to own the Teledyne Geospatial CZMIL SuperNova topobathymetric lidar sensor. The addition of this sensor to Dewberry's service offerings provides clients with innovative technology to deliver high-caliber data and the ability to produce seamless topography and bathymetry in coastal, lacustrine, and riverine environments with significant cost savings. The deep channel CZMIL SuperNova uses high-energy green and NIR wavelengths (532 and 1064 nanometers) to map the topographic surface and penetrate the water's surface to map the bathymetric bottom. It can seamlessly map both topographic and bathymetric surfaces, is typically operated at lower altitudes (400 meters or 1300 feet) and collects data to exceed USGS Quality Level 1 (QL1) specifications, leading to high-density data and resolving above-ground and underwater features in greater detail.

The future of topobathymetric lidar is bright, and the ability to produce inland and coastal seamless topobathymetric data will enable the use of this technology in a myriad of applications, including nautical charting, storm inundation modeling, monitoring engineering structures and the movement of sand, environmental protection, and resource management and exploitation.

Climate Change Prompts Grenada to Create the First National Digital Twin

Lidar data is key component of modern approach to sustainable growth

BY LINDA PETERS

Grenada, a nation small in both size and population, recently recorded a monumental achievement. In 2021, the country became the first to make a digital copy of itself, a 3D model government officials can use for sustainability plans. Like many island nations, Grenada is confronting an uncertain future in the face of climate change. Increasing heat, intense rainfall, and saltwater intrusion into the water supply and soil have begun to threaten[1] the country's two primary economies—agriculture and tourism. One key challenge was how to continue to grow in a sustainable way and adapt to the changing environment. This would require a geographic approach—understanding what was happening, where.

1 https://news.sky.com/story/climate-change-cop26-is-make-or-break-moment-for-dozens-of-island-nations-grenada-minister-says-12432981

Airborne lidar over St. George, Grenada, colorized using aerial imagery

The island of Grenada divided into enumeration areas based on population distribution

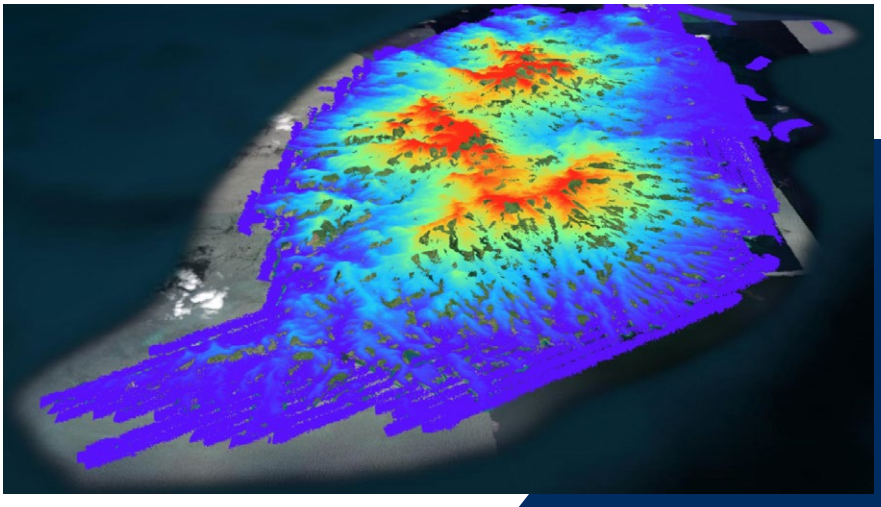
The power of two

The digital twin[3]—a virtual representation of the objects and processes of a real-world system—has rapidly evolved in recent years. The earliest digital twins were built to monitor the functioning of industrial factories, down to the level of individual valves and gaskets. Digital twins are now complex enough to model entire municipalities. City managers use them to monitor urban functions.

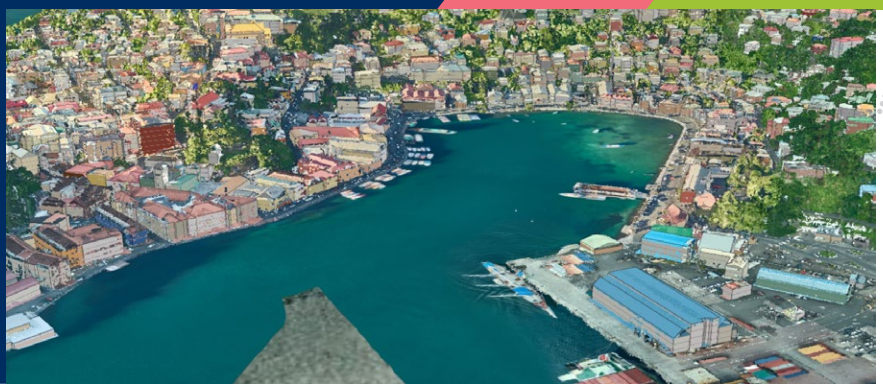
3 https://www.esri.com/en-us/digital-twin/overview

Grenada's government had stores of raw geospatial data in the office of the Ministry of Agriculture and Lands. In 2019, the office had received World Bank funds through the Regional Disaster Vulnerability Reduction Project[2] and hired Fugro, a company that specializes in geographic and geological data-gathering and analysis, to do extensive aerial reconnaissance of Grenada. Fugro surveyed the Caribbean nation's three major islands, as well as six smaller ones. The result was a treasure trove of information, including a lidar point cloud and extensive orthophoto mosaics. But for practical purposes, it was more like treasure without the trove. In short, there appeared to be no way to organize all this valuable information, until Esri spoke with the ministry about creating a "digital twin."

2 https://www.nowgrenada.com/2018/06/topographical-data-unprecedented-insight-into-grenadas-terrestrial-and-coastal-landscapes/



Airborne lidar over Grenada, colored by point-cloud elevation



St. George Harbor, Grenada without sea level rise projection

Projection of 2 m sea level rise in St. George Harbor, Grenada

Planners use them to visualize and analyze the likely effects of proposed changes.

Today's citywide digital twins can be intricately detailed. Singapore's digital twin, for instance, extends to underground infrastructure and even some indoor features. IT experts within Grenada's government ambitiously decided to extend the country's twin nationwide, built on a geographic information system (GIS)[4]. Necessary for making digital twins truly operational, a GIS stores and displays disparate datasets that share locational components. These interactive and collaborative 3D models can then be used to drive better decision-making and policies at a larger scale than previous systems allowed.

A GIS enabled officials in Grenada to stack the imagery and point-cloud data. These could be consumed as separate map layers but could also be combined to create something functionally larger than the sum of its parts. With its 20 cm resolution, the resulting orthomosaic produced a data-rich, detailed representation of the island. Linking the 3D lidar data brings the imagery into full relief.

The digital twin goes deep

Government officials ultimately sought to use the country's digital twin to improve the lives of Grenadians, who are at the mercy of a swiftly changing ecosystem. For members of the ministry, this started with extracting streets and buildings from the visual data so these could be sorted and quantified. The data could then be manually coded, a process that even for Grenada—a nation with a population smaller than Provo, Utah—could require up to six months of work. So Grenadian officials worked with analysts from Esri[5] to deploy artificial intelligence capabilities within a GIS. A deep learning model in the ArcGIS Living Atlas of the World[6], able to identify buildings, could easily be adapted to Grenada's data. Within a day, analysts were able to use the program to identify and label 55,000 built structures. They then used GeoAI[7] capabilities to sort and classify other parts of the digital twin's visual data, such as roads, powerlines, streams, and other inland bodies of water, along with vegetation and land cover.

Endless combinations

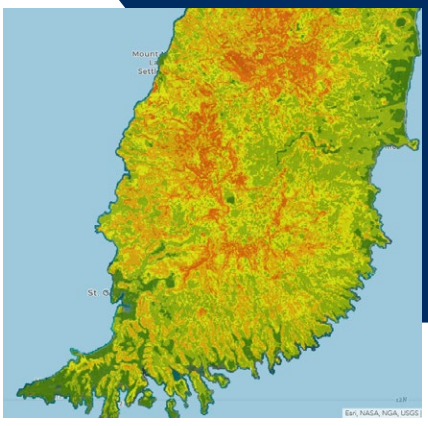
These classifications are valuable by themselves. For instance, staff from Grenada's Central Statistics Office, which were partners in the digital twin efforts, realized that the building data could greatly simplify the process of planning the national census and recognized the value of having for the first time ever a complete building inventory of the country.

But the categories were also powerful when combined. The Grenadian government and Esri used the stream data, vegetation classifications, and digital terrain model (another segment of Fugro's aerial collections) to highlight spots in the country most in danger from landslides. This was mainly an automated process: with the classifications in place, the GIS could generate the results. Other formulas and calculations produced flood susceptibility models, revealing where island residents were most vulnerable to the effects of weather related to climate change.

4 https://www.esri.com/en-us/what-is-gis/overview

5 https://www.esri.com/en-us/home
6 https://livingatlas.arcgis.com/en/home/
7 https://landing-geoai.hub.arcgis.com/

Airborne lidar over St. George, Grenada, colored by point-cloud classification



Landslide susceptibility for the island, as calculated from soils, elevation, and land cover data

The 3D nature of the lidar data further contributed to the power and utility of Grenada's new model. Seeing how far a building or road is from a landslide-prone area is helpful. Having the ability to zoom in and examine how a building is perched on a steep hillside, or how a vulnerable road's angle of descent would appear from the perspective of a motorist, pedestrian, or cyclist, adds further context.

An Esri ArcGIS Dashboard for tracking enumerator progress as they conduct a population and housing census

Seeing the future

Grenada's digital twin has a foundational quality. The data it comprises is now the basis for what the United Nations calls an Integrated Geospatial Information Framework (IGIF). It provides a complete view—both realistic and holistic—of the country, which serves the needs of decision-makers today. This digital twin also has a predictive component that enables officials to visualize future challenges posed by climate change, along with possible solutions.

The government has used the twin, along with the bathymetry information included with Fugro's data, to model sea-level-rise scenarios. This allows it to illustrate storm surge and flooding damage—to see what will be impacted and where. The visual context of the map transcends numeric projections, facilitating policy decision-making for prevention and mitigation.

The digital twin can also serve as an ongoing historical record. For example, the lidar data identified 4.5 million trees, and, if more aerial data is gathered at points in the future, the twin's GIS can analyze tree growth and note any significant deforestation. As important as the AI capabilities are for this kind of calculation, they wouldn't have been possible without the lidar-enhanced imagery. Grenadian planners, interested in growing the country sustainably, can now look at a section of the map and imagine how further development will impact—and be impacted by—future changes in vegetation.

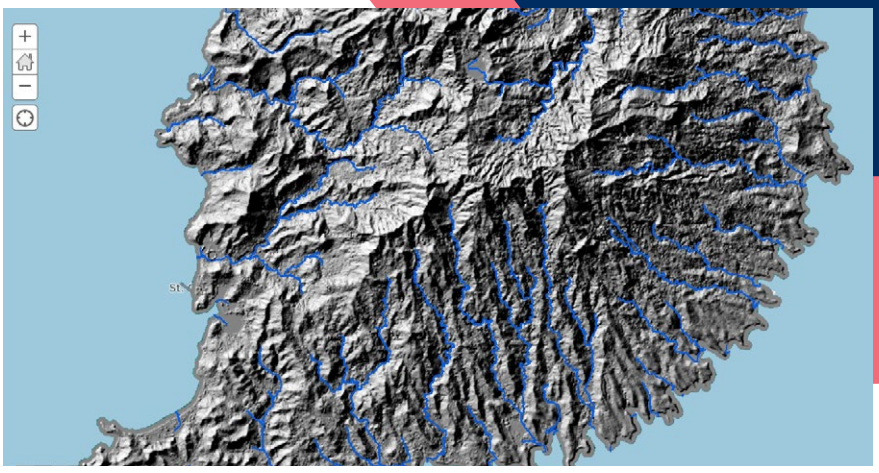
The power of a GIS-powered digital twin is that it enhances human

observation. While a digital twin can't literally see into the future, it is a window into several potential futures. However, none of this would be possible without highly accurate imagery data and geospatial technology that ties geographic information together. These collaborative technologies are turning data into something meaningful, viewable, measurable, and, ultimately, actionable.

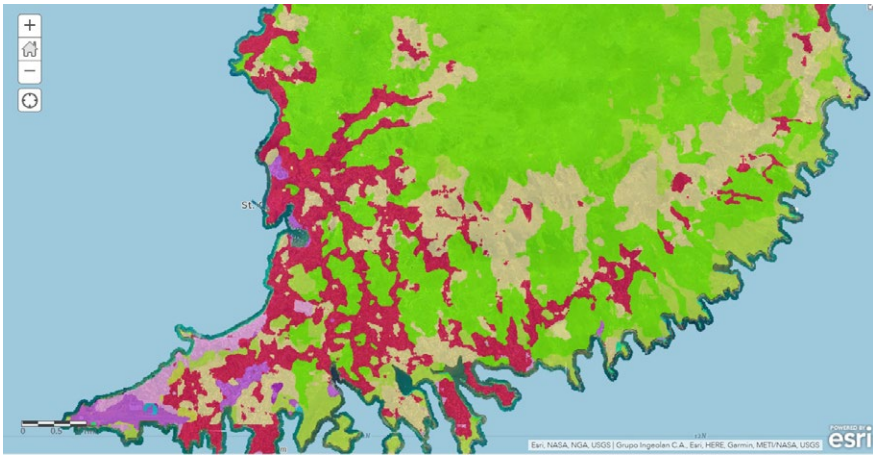
Working toward sustainability goals of their own, other countries will likely follow Grenada's lead, building location-intelligent digital twins of their own.

GIS and sustainability

To learn more about how GIS and imagery can be used to help create a sustainable, prosperous future, visit esri.com/en-us/geospatial-thinking/overview.



Drainage flow lines show the path precipitation would take across the island, based on the elevation



Land cover classified from the aerial imagery

Digital twin for part of the island of Grenada, including 3D buildings extracted from lidar

Linda Peters is the Director of Official Statistics Solutions at Esri. She has over 25 years of experience working in the geospatial industry. Working for Esri for 17 years, Linda has consulted with companies across industries, helping them achieve greater efficiencies by leveraging GIS technology and spatial analysis. Today she works with national statistical offices across the globe, helping them understand how to apply geographic methods and GIS to census and statistical activities.

Linda is a member of the UN-GGIM Expert Group on the Integration of Statistical and Geospatial Information, as well as Big Data working groups, and has consulted with other expert groups. She is also currently a board member of Applied Geography and past president of the Business Geography Specialty Group. In 2014, Linda authored Esri's massive open online course, "The Location Advantage," designed to teach students how to apply geospatial technology to business. And most recently, she co-authored the book *GIS and the 2020 Census: Modernizing Official Statistics*.

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Dennis Kemmesat, co-founder and CEO, Frontier Precision.

Frontier Precision (Corporate), Bismarck, North Dakota.

Frontier Precision: How You Measure Matters

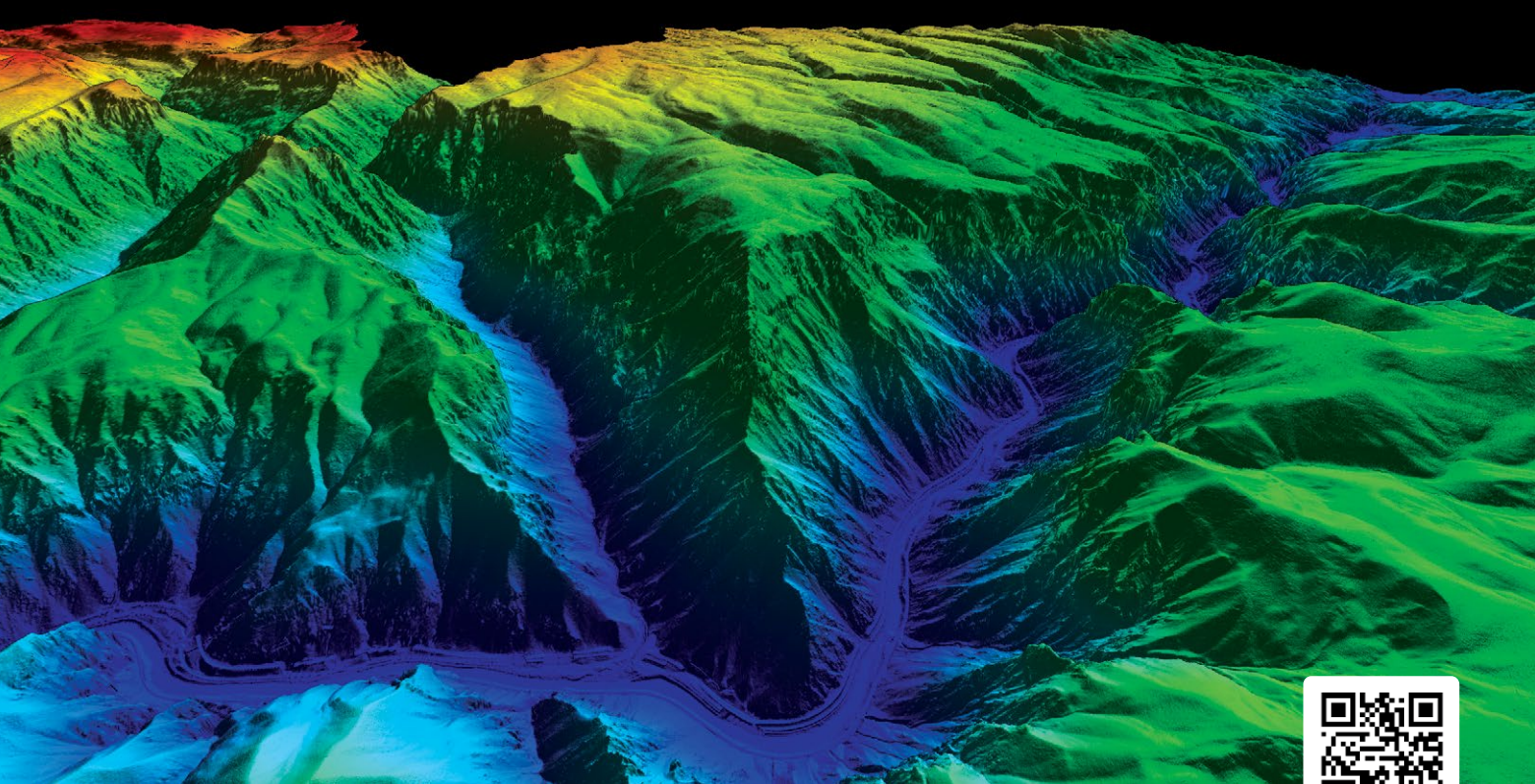
Expanding Trimble representative diversifies portfolio

Frontier Precision, Inc. is a supplier of hardware and software products and related services for customers in geospatial and adjacent markets across large areas of the US. It is best known as a Trimble distributor, but has grown to embrace offerings from multiple suppliers and extend beyond a purely geospatial customer base. *LIDAR Magazine* was given the opportunity to interview co-founder and CEO Dennis Kemmesat, who spoke to us from his headquarters in Bismarck, North Dakota.

LM: Dennis, thank you very much indeed for taking time to answer our questions. Frontier Precision is extremely well known in the land surveying world, but perhaps some of our readers on the purely lidar side don't know you so well—though this is rapidly changing as a result of your relationships with DJI, YellowScan and other big players in the UAV-lidar space. Please tell us something about your company.
DK: I founded Frontier Precision back in 1988 with my former partner Mike Althaus. It has been quite a journey.

BY STEWART WALKER

DERIVING INSIGHTS THAT EMPOWER DECISION MAKING



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Nathan Stephenson, applied geospatial engineer at Frontier Precision, training employees from Sebago Technics, on the DJI Matrice 300 and YellowScan Mapper lidar solution, in Portland, Maine.

We both were working for a competitor here in Bismarck, back in the day when total stations were just becoming a mainstream product in the market. The company we worked for was looking to sell or just close the branch where we were both working. We felt there was a business opportunity and we decided to take the plunge. Buying the inventory and assets, we started Frontier Precision.

It was a two-man operation for a while. All the duties of a start-up business—salesman, service technician, bookkeeper, accountant, shipping and receiving clerk, and delivery guy—we did it all. We built everything around customer service. Over the years we slowly took advantage of opportunities as they presented themselves, first opening an office in Denver in the early 90s, then one in St. Cloud, Minnesota, then acquiring other Trimble dealerships over the past 34 years to give us the footprint today. I bought Mike out in 2000 and he remained with the business as our service manager until his retirement a few years ago.

We jumped into the unmanned/drone space a little over 10 years ago when Trimble purchased Gatewing and brought the Trimble UX-5 to market. We saw a future in UAVs with our customers even though Trimble decided to exit that space in 2016. At that point we decided to go "all in" on UAVs and began to build a bigger portfolio of products that would extend far beyond surveying and mapping.

One thing evident to me is that our "secret sauce" for success has been the people who are part of this company. We have been so blessed to have many long-term employees—some for the whole 34 years—but also the great young talent we continue to add over time, a perfect mix that preserves our culture of a company focused on customer service. In these days of the changing workforce we have been fortunate to continue to find great people committed to serving our customers and the whole company culture.

For our geospatial business we have 12 physical locations covering 11 states across the northern plains, mountain states, and Pacific Northwest including North Dakota, Minnesota, South Dakota, Colorado, Wyoming, Montana, Idaho, Oregon, Washington, Alaska, and Hawaii.

Frontier Precision Unmanned Division has personnel in several of our geospatial locations plus its own physical locations in Bend, Oregon, Fort Worth, Texas, and Jacksonville, Florida.

LM: Are the geospatial locations different from the other locations?
DK: We've evolved into different business areas. We've divisionalized, even though we still operate as a whole under Frontier Precision. We have our Geospatial Division, which is our primary business area for Trimble. We sell all their geospatial products. We're part of their


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BuildingPoint group now, so we have a Buildings and Construction Division, which strictly focuses on vertical construction. We offer all the products in the Trimble buildings portfolio and their MEP[1] portfolio. We have our Unmanned Division, which encompasses all our UAV products—sensors, underwater ROVs, pipe crawlers, and software and services. In that realm, we have two additional offices and plans to add a couple more, because, unlike our Trimble business, it's not territory-restricted. With Trimble, we have our footprint and Trimble has other distributors throughout the country that have their own territories as well. On the UAV side, we represent several product lines across the whole country, so we have responsibilities to have a presence. The two additional offices, which are specifically for Unmanned, are in Fort Worth, Texas, and Jacksonville, Florida. And we're looking at adding one or two more offices to give us a full breadth of coverage for the US.

LM: You've mentioned Bend, Oregon as well.
DK: Bend is part of our Unmanned Division. We acquired Air-Supply Aerial there late last year. They were an e-commerce hardware provider for UAVs. Their owner was originally from South Dakota and he had built a nice little business. E-commerce, specifically on the UAV side, was something where we really didn't have a big presence. It was a good fit and we ended up buying them, so their team came across to our team. They touch into different areas outside the traditional land survey, engineering and construction markets. They were working with high-res cameras like Phase One, and other interesting stuff including extreme sports. It was a cool addition and they brought some fine talent for integration of sensors on UAVs, and things like that with some of our manufacturers. It's been a great addition. They do things all over the country as well, more on the e-commerce side.

LM: I've attended a couple of Trimble Dimensions meetings. One aspect that really impressed me at the last one was the outdoor demos—you go out into the desert and they have construction vehicles with sensors on them. Some of them can operate unmanned, but they always have a driver in the cab, and they do precision earthmoving etc. Do you sell that equipment for opencast mining and for construction?
DK: That's one area of Trimble that we don't get into. They have a dealer network set up under the brand SiTech for that, and most of the SiTechs are affiliated with a Caterpillar dealer. We do work alongside them in some respects. Even being as entrenched with Trimble as we are, there's always fun new stuff to see.

You're seeing a lot of autonomous stuff coming into the ag market. Deere just introduced an autonomous tractor. All the other manufacturers are following suit. I think people are still a little leery about really jumping into it. They want to see the technology mature a little bit more. But I think it's on everybody's radar. Give it another 12-18 months, you're going to see a whole other generation, more mature and more reliable. I think you're going to really start seeing some people adopt it into their workflows.

LM: Do you cover some of the agriculture market then?
DK: Again, Trimble has another distribution channel, called Vantage, so we don't really do anything in ag with Trimble specifically. We are starting to do a fair bit of business, though, in our Unmanned Division. We're starting to see that gain traction. The sprayer drones are becoming a discussion topic. People are taking note of those as hopefully the FAA gets more clear definition of how to get properly licensed to fly them. Right now it's quite a process and should get more streamlined. Beyond the sprayer drones, we're starting to see many different segments of the ag market adopting

1 Mechanical Electrical Plumbing.

UAVs just to scout crops, plant health, plant identification. It goes beyond traditional ag into range land management and forestry management. When I got into the business back in the mid 80s and our relationship with Trimble started, the development of RTK was a complete game-changer. I see this being a little bit beyond that, because it has such a widespread effect on society and every business.

LM: Please also tell us something about yourself. How did you begin your career and reach the decision to found Frontier? Were you brought up in Bismarck? Were you a land surveyor?
DK: I was a native of North Dakota, born here in Bismarck and grew up on a farm west of the town. As a farm kid growing up, I got a two-year business degree at our local college and began school for my computer science degree, but I figured out about a year in that that wasn't going to be my bag, I didn't see myself doing that the rest of my life. I ended up taking time off from school, I went to work for our competitor at that time, or one of our former competitors. That was back in the day when blueprint machines were a big thing, the mechanical transit was the standard survey tool and top-mount EDMs were the latest innovation. I got my start in this industry in '84, when the K&E Ranger and Wild Heerbrugg T1 and T16 were the predominant survey tools. I joined our former competitor, which is no longer around today, and ended up working for them for less than a year, because I got laid off and went to work for their competitor. This was the company we started from. They didn't have a service job—I had transitioned into service work on blueprint machines and transits while I was at the other company—so they said, we have a sales job—you want to try that? Why not? I liked the technology—obviously, it was rudimentary compared to what we have today—but I got involved. I did not have a survey background, but I learned it. I had a lot of great customers who helped me learn. That's how I got started and it grew from there. When the company we were working for wanted to close the branch here or sell it, my former partner and I thought, we need a job, we think we can make a business out of this, let's give it a go. The worst thing we can do is fail. That's how we started.

LM: It's a great story. Success comes to those who take risks, as long as the risks work out, and that's what you've done.
DK: Yeah, 100% It's not that we didn't have some bumps along the way like any business, but you learn from those, you persevere, and I think businesses that do that are the ones that are successful. I haven't done this by myself, we have a lot of great people who have been with me, from the very start. We've continued to add talent and people who buy into our culture and our customer-service values. It's a team effort. I'm fortunate to find excellent people, really smart people, people smarter than I am on the technology by far, who know how to make this stuff just sing and dance, do the right thing by our customers and make sure they're also successful with it.

LM: How many people do you have?
DK: We're just over 100.

LM: Of all the business relationships Frontier has and the products you distribute, the Trimble representation is probably the best known. Would you like to talk more about how your relationship with Trimble began, then prospered?
DK: Our relationship with Trimble has been core to our business growth over the years and we could not ask for a better partner. We have grown together, starting back in 1989 when we first signed up to be a dealer, selling the Trimble 4000SE and 4000SSE GPS receivers. We were fortunate to be part of helping deliver the very first RTK system in the world with Trimble to a mine in Wyoming and then share in all the growth that Trimble has had over the past three decades. It has been quite a ride and, because of the partnership and the great products they continue to give us to sell, we have been fortunate to be one of their top geospatial distributors in the world for several years running.

> "Our relationship with Trimble has been core to our business growth over the years and we could not ask for a better partner."

LM: We consider GNSS and lidar similar in that they're "sea change" technologies (as they relate to the process and procedure of land surveying). One could add UAS/UAV to this list. Having witnessed both "revolutions", which do

The DJI Matrice 300 and YellowScan Mapper on a recent training mission in Hawaii.

you believe made the bigger change? Alternately, speak to the similarities and/or contrasts between the two.

DK: I see many similarities and a differences in the evolutions of both technologies. RTK proved to be a complete game-changer as to how surveyors worked. RTK has evolved and expanded across other industries beyond surveying and construction. I see UAS technology and lidar having a much broader impact across society in general, as we now see lidar in not only scanning and mapping devices but automobiles, phones and many other devices—it is truly impacting everyday life and becoming familiar technology to the average consumer.

LM: Where do you see UAV/UAS technology headed from a surveying perspective? Is this technology essential to compete, moving forward? Whereas five or ten years ago, small sites were always surveyed using traditional methods such as total stations, today UAV-photogrammetry and UAV-lidar can provide fine deliverables, usually much more quickly. What does this mean for the future? Does it mean the emergence of new competitors, or merely the addition of UAV-borne sensors to the toolkits of land surveying firms?

DK: I foresee UAV technology becoming a standard tool for every surveyor, especially when it is coupled with high-res cameras for photogrammetry or with lidar. Of course the sensors are a small part of the equation: the back-end software is equally important—ease of use for photogrammetry processing or point-cloud processing is becoming more common with workflows that are easy to understand and learn. This was a hurdle early on for both photogrammetry and lidar—workflows were complicated and processing was time-consuming and needed a lot of computing power. We now are seeing many cloud-based software platforms that are simplifying the whole process. We offer one ourselves in the form of our FP Vision software, which allows a user an easy-to-understand workflow for photogrammetry processing and also a data depository that can accommodate all types of data including surveying, photogrammetry and lidar—all in the cloud.

LM: Please speak to Frontier's experience with customers during the covid-19 pandemic and the ways (if any) in which you adapted.

DK: We were extremely fortunate during the pandemic to be in an industry that had many of our customers working outdoors and they were considered essential—so even though many traditional offices were shut down our customers were out working and still needing the equipment and services we provide. Our staff also did a great job of pivoting to online for many of the training and support services which our customers have come to expect, such as our annual user group meetings and in-person training classes. We moved to an online user conference called TechXpo in 2021, which offered breakout sessions on everything from GIS-related topics to drones. It was a great success, allowing our team to stay engaged with customers even though we could not be there in person. But it is better to be able to be in-person with our customers.

LM: Are you planning to go back to face-to-face events this year?

DK: A lot are centered around our state land survey trade shows, so we've

Sean Muldoon, UAS sales and support specialist at Frontier Precision, recently had the opportunity to train and educate environmental and engineering groups on UAS technology with the DJI Matrice 300 and YellowScan Mapper in Hawaii.

pivoted back to in-person and we're finding, as we've been attending different shows from the beginning of the year, that people are really happy to be back in-person. There was a little anxiety over online meetings, Zoom calls and online trade shows. People are happy to be back in-person and talking to people face-to-face, being able to shake hands, have a beer or whatever it might be. We've pretty much transitioned back to in-person.

LM: What is Frontier doing with augmented reality?
DK: We are approaching augmented reality as an evolving technology—our involvement is predominantly in the geospatial survey/mapping space and in construction with products from Trimble like SiteVision and XR10. While augmented reality seems to be the buzz in many circles we are seeing a more metered acceptance into the market. This will certainly accelerate as the technology becomes more mature and improves like all advanced technologies do.

LM: If you were operating a land surveying or geomatics business today, what would you emphasize?
DK: Be an early adopter—not bleeding edge but leading edge. The maturity and efficiencies of technology in our industry simply cannot be ignored—companies in the survey/mapping and construction industries are either embracing and adopting it or finding it very tough to compete with companies that are. In the present state of our economy and workforce this also becomes important, as qualified workers are becoming harder to find every day. The efficiencies of today's technology allow more work to be done faster with fewer people, so a company can scale without necessarily adding workforce and other overhead and maintain a healthy bottom line.

LM: Please speak to your current portfolio.
DK: Our portfolio consists of two parts—hardware/software and services.

Our hardware/software portfolio consists of products from many different manufacturers. That is by design, as we have gone through an extensive process of seeking out and partnering with companies we feel are best-in-class in each one of the product categories. Our UAV portfolio includes products from DJI Enterprise, DJI Agriculture, Freefly, Inspired Flight, Parrot, Autel, Quantum Systems and Delair, covering all variations of aircraft from drones for survey/mapping applications to public safety to agriculture and everything in between.

The Frontier Unmanned Team can provide the latest innovations in drones and sensors to deliver the right product for the right UAS application. Shown here are the DJI Matrice 300 and YellowScan Mapper.

With sensors we really sought out the best of the best—lidar sensors from YellowScan, DJI, Green Valley and others; cameras for photogrammetry and inspection from Phase One, DJI, and FLIR; sensors for agriculture, forestry, and other plant management applications from MicaSense; and then all the necessary components to go with them.

We've moved into the water—pipes and tanks—offering underwater ROVs from Deep Trekker for inspection, maintenance, and search and rescue applications, as well as pipe and utility crawlers for pipe and tank maintenance and inspection.

Our goal in developing the portfolio was to be able to provide a solution to our customers for any application they have—in the air, in the water, in a tank, in a pipe—and the software, training, and support to give our customers a complete workflow and solution, all from one source.

We developed our services portfolio after seeing a big need from our customers for a "try before you buy" scenario—without the huge capital outlay. Our customers had real jobs on which they wanted to give the technology a test run before investing—and they did not have an in-house resource who knew the technology, how to process and interpret data, and most importantly how to develop a deliverable product for their clients. Our services division allows our customers to partner with us and have access to expensive technology like mobile scanning, UAV-lidar, UAV-photogrammetry and terrestrial scanning without any capital outlay, plus experts from the Frontier Precision team guiding them through the whole process, so they have the competitive advantage of the technology but also the peace of mind knowing they have an expert running the equipment and helping them process the data.

LM: The hardware/software part of the portfolio includes training and maintenance—do you do a lot of work in those areas?

DK: We do. It's a big part. We've been doing geospatial training for many, many years, since we started. We have a whole team that predominantly works in what we call our services area, and that falls in a number of different buckets, but we do designate our training as services. We do in-person training, online training, and on-demand training. There are different aspects of it, and it's in all aspects of our business. We put a lot of stock in making sure that we have the highest qualified people to go out and assist the customer and get them properly trained, once they buy a product from us, whether it's a GNSS system, a mobile scanner, a UAS, or UAS with lidar. We make sure that we have the right people in place who can promptly direct them down the right path and make sure they're getting the proper training to use the equipment right way.

LM: I was interested in what you've described as your services portfolio. You're assisting, or you're working with, a customer to use a new technology through to results, then the customer will be enthusiastic and will buy the product you're offering?

DK: That became important when we started getting into mobile scanners and UAV-lidar. A mobile scanner, for example Trimble MX9 or MX50, is an investment of hundreds of thousands of dollars. Most customers weren't ready to spend that kind of money and not know, how am I going to put this piece of equipment to work and how am I going to make money with it? We started looking at that. We have the equipment, the hardware, the scanners, we have the expertise to run them, we have the expertise to help them on the back-end processing of the data—why don't we offer that as a service to our customers? It gives them a chance to test-drive it, on a real project, where they're very able to make real money. Then they can figure out the LOI, or we can help show them how it's going to work, how much time they're saving,

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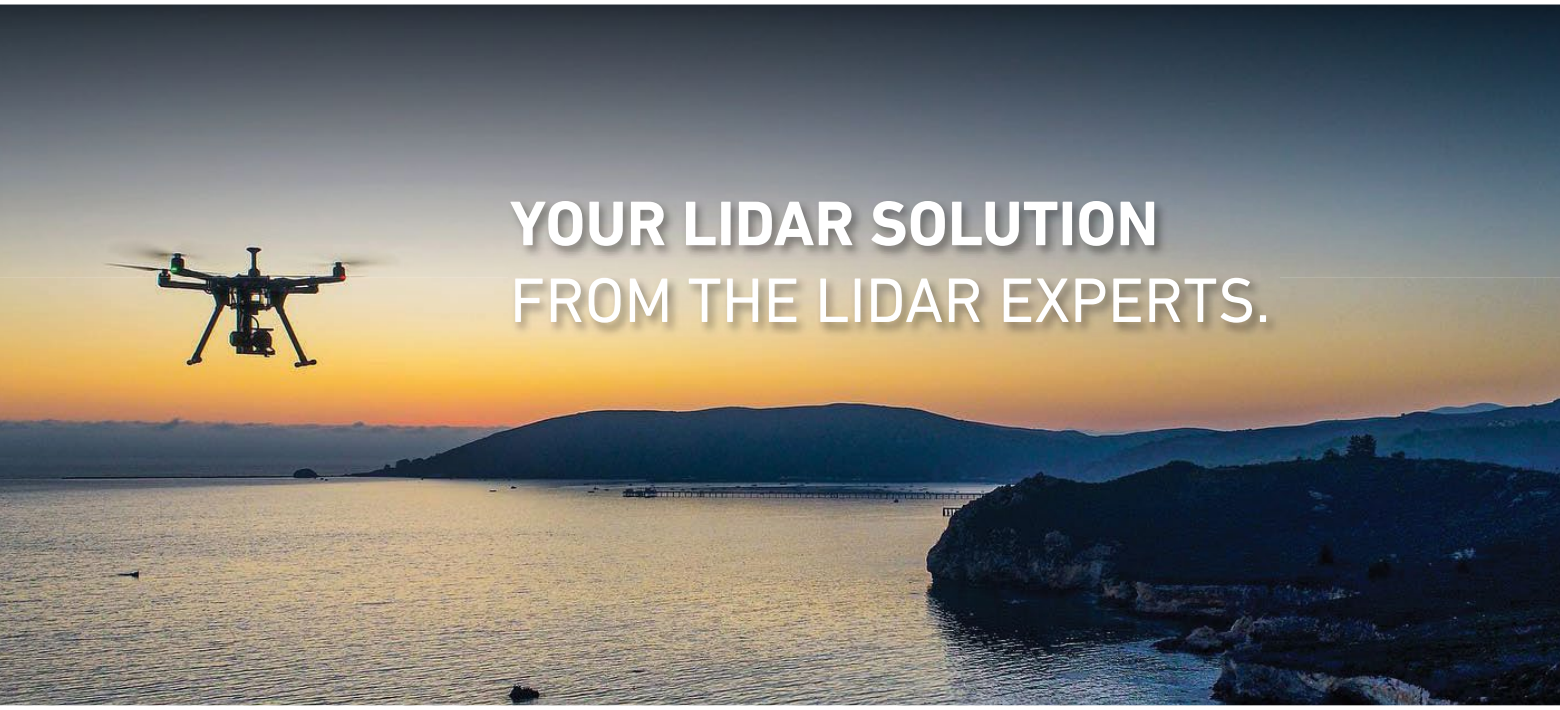

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how fast they can get a job done, how efficient it is. We did approach it with caution: we only do it where we are working for one of our customers, we don't go out and directly pursue jobs on our own, it's always in conjunction with a customer. We want to make sure that we stay in our lane and we're not competing with engineering or other firms or agencies. We want to be our customer's technology consultant and do everything we can to make them profitable with the technology we can sell. It's always going to be under the umbrella of an engineering, survey, construction or related agency or firm looking to implement and eventually acquire the technology. We were very careful about that, because we take our relationships with our customers very seriously. The last thing we ever want to do is compete in that marketplace with them.

LM: We see that Frontier is employee-owned. How did that come about?
DK: In 2009, Frontier Precision became an employee-owned company. I divested my stock into an ESOP[2], allowing our employees to become shareholders in the company. That was important to me, from the standpoint that the company wasn't built by myself. It was built by a lot of outstanding people who have been part of this company over the years—that just speaks to how our employees really become family. I wanted them to have some tangible interest in our success beyond just getting a paycheck as an employee. It has worked out tremendously. Our employees have embraced it and I think it's been huge part of making us the company we are today. People feel they have a vested interest in the overall success of the company, and they great pride in the brand and our place in the industry.

> "We've done a good job of screening and working with different vendors. Our long history and success with Trimble carry a lot of weight."

LM: The last question partly reflects my own experience back when I was with the UK distributor for Kern: you're representing many different companies selling their products—do they ever give you any hassle, because they feel you're not giving enough attention to their product compared to somebody else's product?
DK: Oh, of course, all the time! Early on, when you're taking on new product lines, in many cases you're taking on products that are similar, it's just the nature of the beast, where you're trying to offer the best of everything to your customers. It's gotten less and less of an issue over the years as we've developed our portfolios and, I think, done a good job of screening and working with different vendors and knowing what we're looking for, understanding their business model and having them understand ours. Our long history and success with Trimble carry a lot of weight. That helps considerably and we can be a little more picky about the people we represent and the companies we affiliate ourselves with. We have a fabulous relationship with Trimble and have for years, but some other relationships are great too—we have fantastic relationships with YellowScan and Freefly. DJI, being a Chinese company, with superb products, is a little tougher to deal with logistically, because it's a different culture, we have to deal with the importing of the products, and many times we are dealing with reps in a different part of the world. They approach things a little differently, which is fine moving forward, we learn to navigate that. We have found companies that we deal with on a regular basis and we feel we have strong partnerships with them. We're on the same page as to how we want to approach bringing their products to market. They know they're going to get properly represented. And we try not to have too much overlap in our portfolios.

LM: Dennis, once again, many thanks for finding time for *LIDAR Magazine* in your schedule. Our readers will be fascinated by what you have told us. We look forward to publishing this interview—and to further articles about your company and its successes in the future.

2 Employee stock ownership plan.

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.

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Introduction to SAR

ASPRS Florida Region and University of Florida run successful workshop

Since 2016, the Florida Region of the American Society for Photogrammetry and Remote Sensing (FL-ASPRS), in conjunction with the Geomatics Department of the University of Florida, has been conducting bi-annual "Lidar Workshops". While these have focused on emerging lidar technologies and applications, other remote sensing technologies have been explored—in true ASPRS fashion—including unmanned aerial sensors and electromagnetic remote sensing. After the Fall Lidar Workshop in 2020, it became apparent that there was growing interest around the state in synthetic aperture radar (SAR) for applications ranging from sea-level rise measurements and subsidence to structure maintenance.

Recognizing this, FL-ASPRS and the Geomatics Department at the University of Florida partnered with Dewberry, as a financial sponsor, to provide a "Special Summer SAR Workshop", held virtually on August 19, 2021. As the goal of the workshop paralleled the goals of the lidar workshops, to highlight emerging technologies and applications, seven agencies and/or providers were solicited to make presentations. The overall focus was to highlight space-based platforms, aerial platforms and recent applications.

To accomplish these goals, following a high-level introduction by Dr. Al Karlin, representing Dewberry, 20-minute presentations were made by: Dr. Athanassious Ganas, European Space Agency; Dr. Batuhan Osmanoglu, NASA/Jet Propulsion Laboratory (JPL); Chad Baker, Capella Space; Ms. Natalie Findlay, Intermap Technologies; Dr. Giacomo Falorni, TRE ALTAMiRA; Drs. Michael Tischler and Jonathan Stock, US Geological Survey (USGS); and Dr. David Maune, Dewberry. Three of these presentations are provided as full-length articles following this synopsis. The presentations were recorded and are available for review through the Online Learning Catalog at https://www.ASPRS.org.

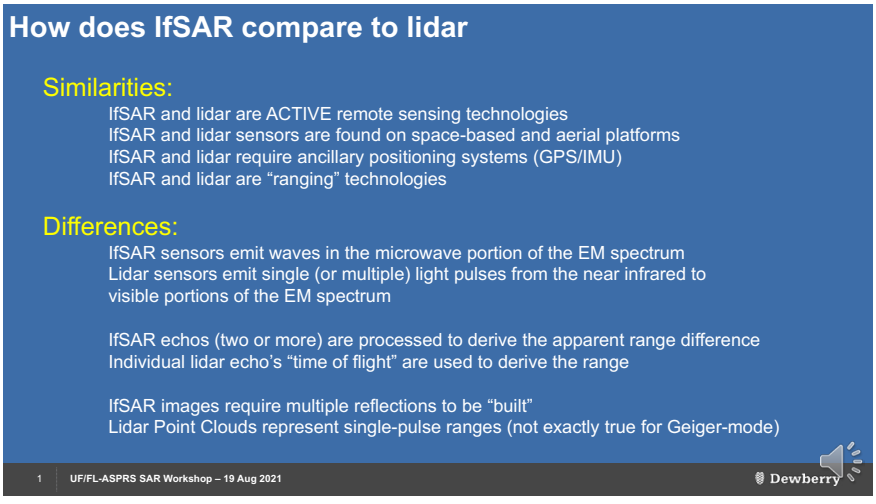


Figure 1: Introductory comparison of IfSAR and lidar.

Introduction

Dr. Karlin opened the workshop with introductions to FL-ASPRS Board members and a high-level overview of SAR. As the workshop participants were very familiar with lidar and this was the first workshop focusing on SAR, he emphasized some similarities and differences between the technologies and provided a few graphic examples (**Figure 1**).

The presentation concluded with an overview of the agenda, thanking the participants and recognizing Dewberry as the sponsor.

The Sentinel program

Dr. Athanassious Ganas of the National Observatory of Athens Institute of Geodynamics opened the technical presentations with an overview of the

COMPILED BY AL KARLIN

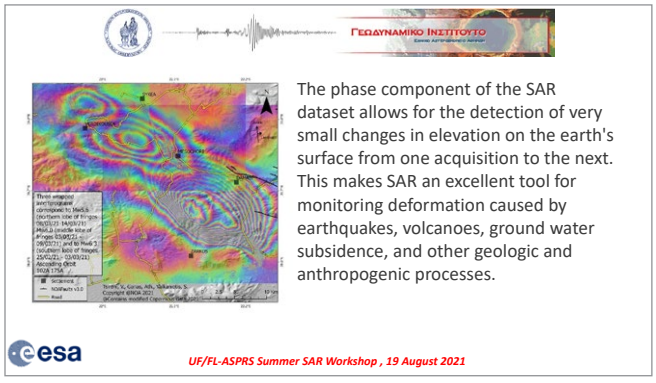


Figure 2: Introduction to the use of IfSAR to measure deformations.

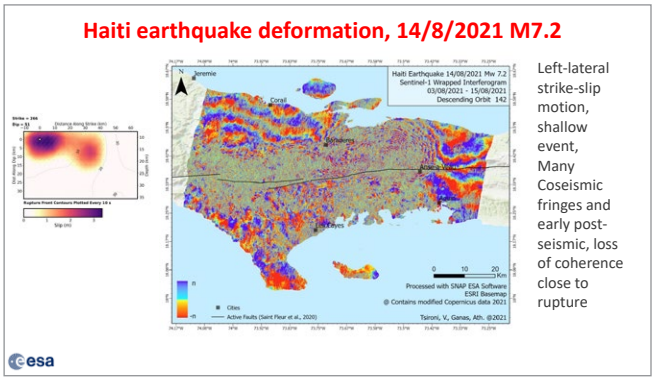


Figure 3: Deformations resulting from the Haiti earthquake of 14 August 2021, measured with IfSAR.

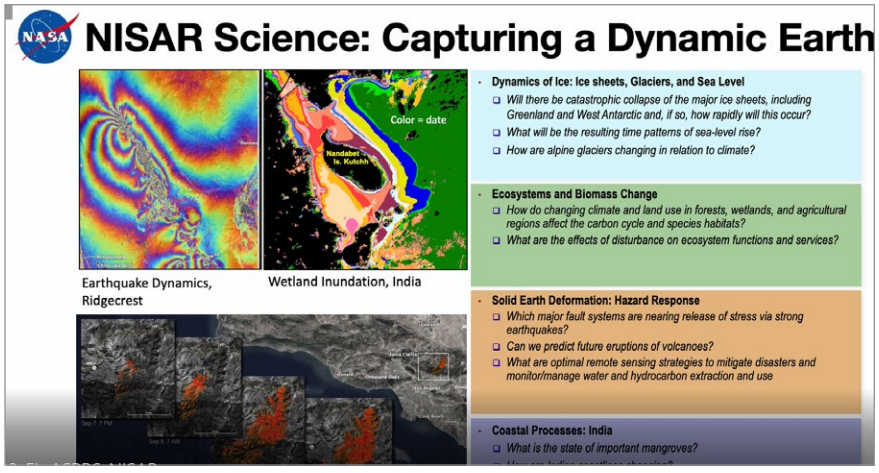


Figure 4: Goals of the ISRO-NASA NiSAR mission.

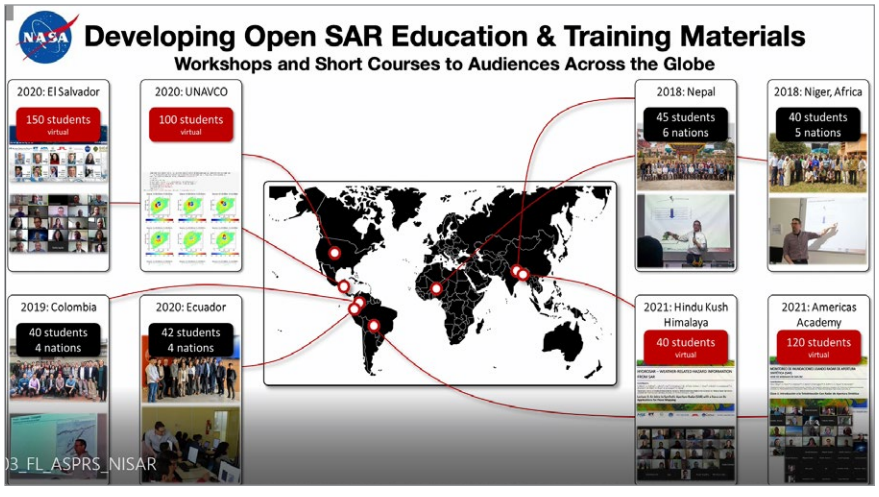


Figure 5: Open SAR educational opportunities.

Sentinel-1A and Sentinel-1B constellation and mission. He described how the C-band operates to provide resolution down to 5 m with a swath width of up to 400 km. Dr. Ganas went on to explain how interferometric synthetic aperture radar (IfSAR[1]) can detect small changes in elevation, which are particularly useful to measure deformations resulting from several natural processes (**Figure 2**).

Dr. Ganas concluded his presentation with several recent examples and applications of IfSAR (**Figure 3**).

The NiSAR program

Dr. Batuhan Osmanoglu started his presentation by introducing the collaboration between NASA/JPL and the Indian Space Research Organization to construct the NiSAR satellite (**Figure 4**). He continued to elaborate on the multi-faceted mission of the satellite for the dynamics of ice, ecosystems and biomass change, and solid earth deformation. He went on to discuss the characteristics of the NiSAR sensor and the probable launch date.

1 The initialisms IfSAR and InSAR are both used for interferometric synthetic aperture radar. In this issue of *LIDAR Magazine*, we have followed the usage of the authors of the articles.

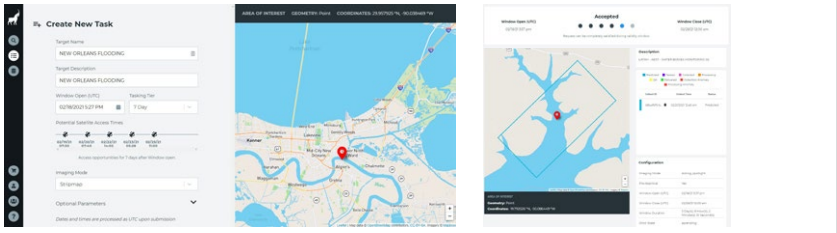


Figure 6: Capella Console.

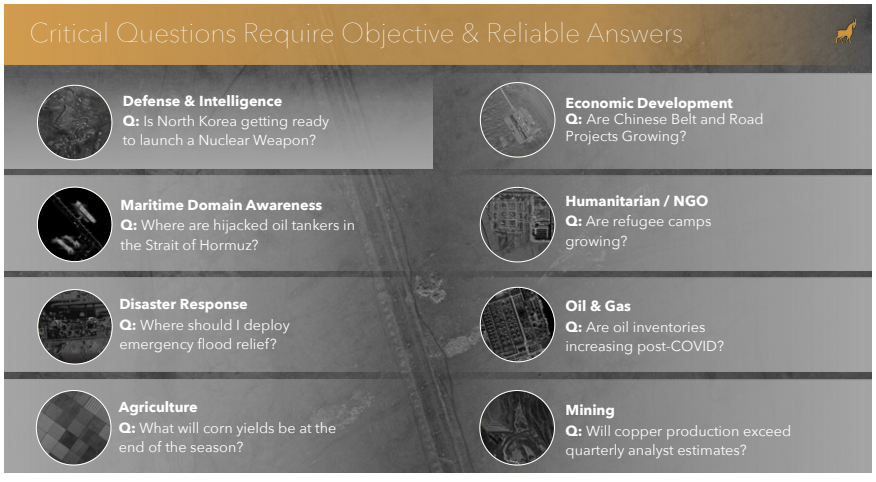


Figure 7: Intelligence questions that can be answered by SAR data from Capella Space constellation.

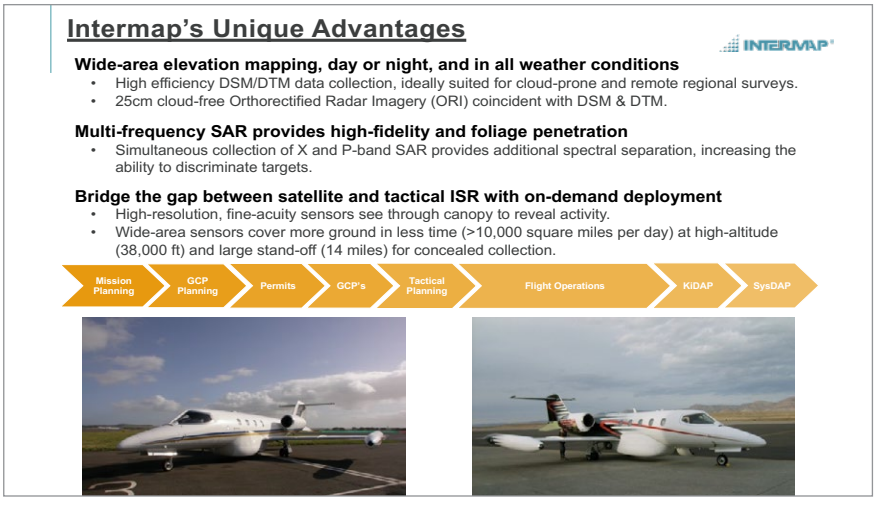


Figure 8: Advantages of airborne SAR deployed by Intermap Technologies.

Dr. Osmanoglu concluded his presentation with an overview of Open SAR educational opportunities, workshops and short courses around the world through NASA/JPL (**Figure 5**).

Capella Space constellation

Chad Baker introduced Capella Space and explained how SAR can image objects that light-based technologies cannot. SAR is not affected by smoke or clouds, and can be used day or night. Mr. Baker discussed the Capella constellation, its current status and how a user could task the satellites from their desktop computer. He proceeded to a "live" demonstration of the Capella Console, the desktop satellite-tasking tool (**Figure 6**).

Mr. Baker followed up by discussing multiple use-cases for multi-temporal SAR and provided several examples (**Figure 7**).

Intermap Technologies—airborne SAR

Ms. Natalie Findlay introduced Intermap Technologies as a provider of remote sensing products, starting with aerial imagery more than 100 years ago. She described the unique advantages of the SAR systems installed in two aircraft that can be deployed around the world (**Figure 8**). She discussed the construction of IfSAR products and deliverables.

Ms. Findley described the successful use of aerial IfSAR for the USGS 3D-Elevation Program and the 10-year mapping effort with Dewberry in Alaska (**Figure 9**).

TRE ALTAMiRA—Sentinel applications and case studies

Dr. Giacomo Falorno recapped the basic principles of IfSAR and focused on data analysis and applications, paying

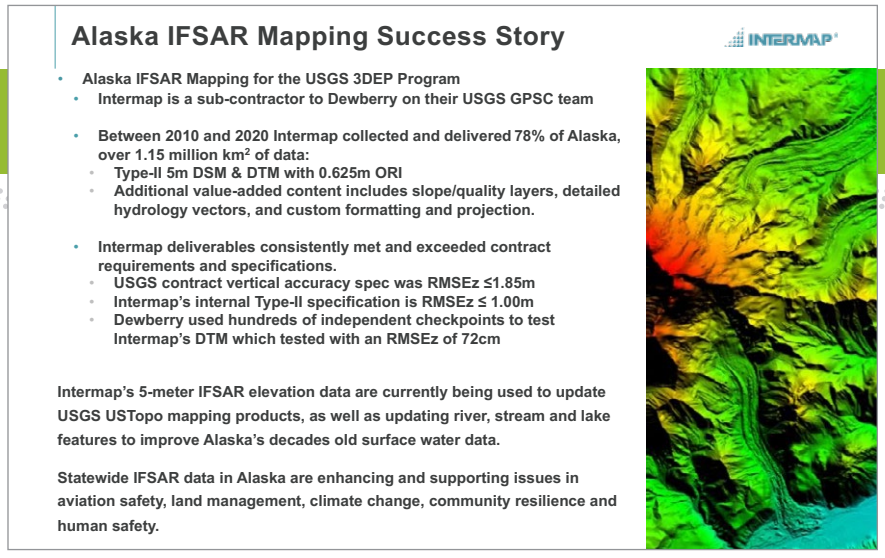


Figure 9: Intermap Technologies' successful use of airborne IfSAR for the USGS 3D Elevation Program and the 10-year mapping effort with Dewberry in Alaska.

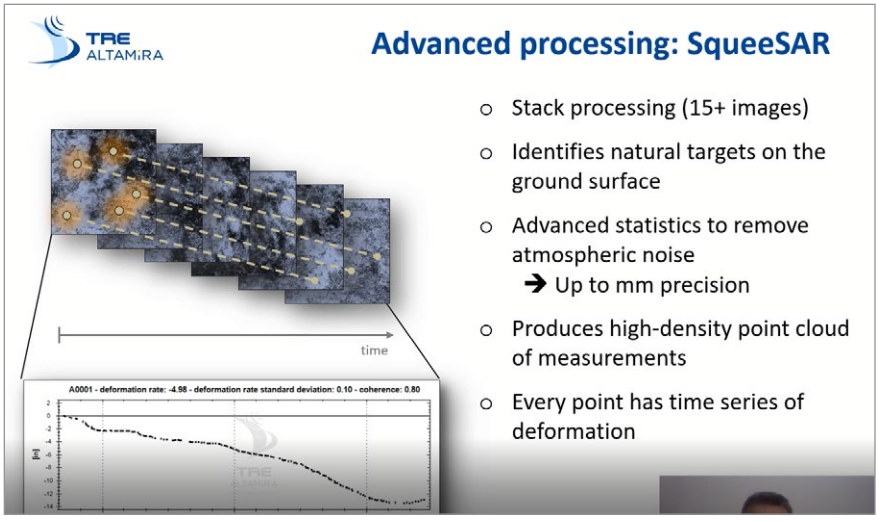


Figure 10: TRE ALTAMiRA's SqueeSAR advanced technique, by which images are stacked and a time-series created and analyzed.

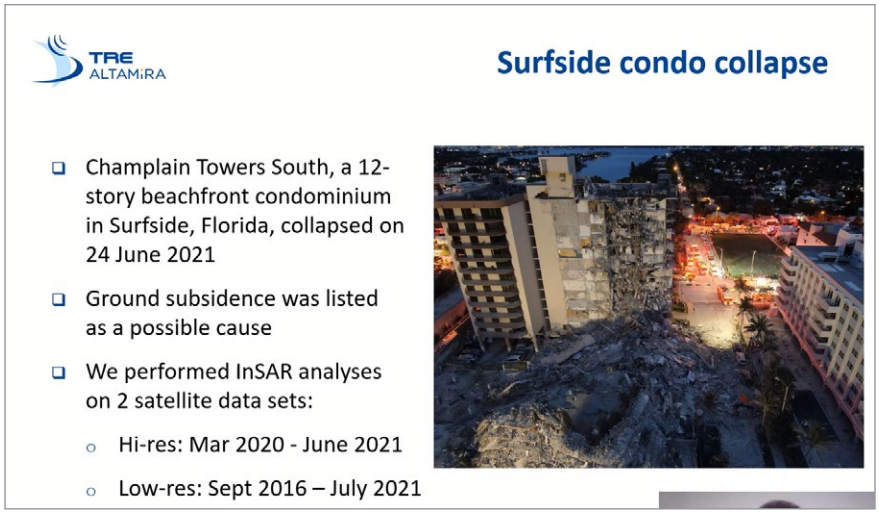


Figure 11: SqueeSAR used to investigate collapse of Champlain Towers South, Surfside, Florida.

particular attention to differential InSAR (DInSAR) and how phase differences can be processed into deformation maps. He then introduced a more advanced analytical technique called "SqueeSAR", where images are stacked and a time-series created and analyzed (**Figure 10**).

Dr. Falorno gave several examples of recent SAR analyses. Most appropriate, at least for the workshop participants, was a time-series/SqueeSAR analysis of the recent collapse of Champlain Towers South in Surfside, Florida (**Figure 11**).

USGS land-level change program

Dr. Michael Tischler introduced the USGS program to construct a "National Land-Level Change Map" and turned the presentation over to Dr. Jonathan Stock, who provided the details and discussed how a partnership between USGS, NASA, JPL and NOAA to construct the map will benefit multiple sectors of the economy. He highlighted multiple use-cases and then drew attention to the large portion of the U.S. that has not been mapped (**Figure 12**). Dr. Stock continued by explaining the importance of the NiSAR program to this effort and outlined the total return on investment for the program to several industries (**Figure 13**).

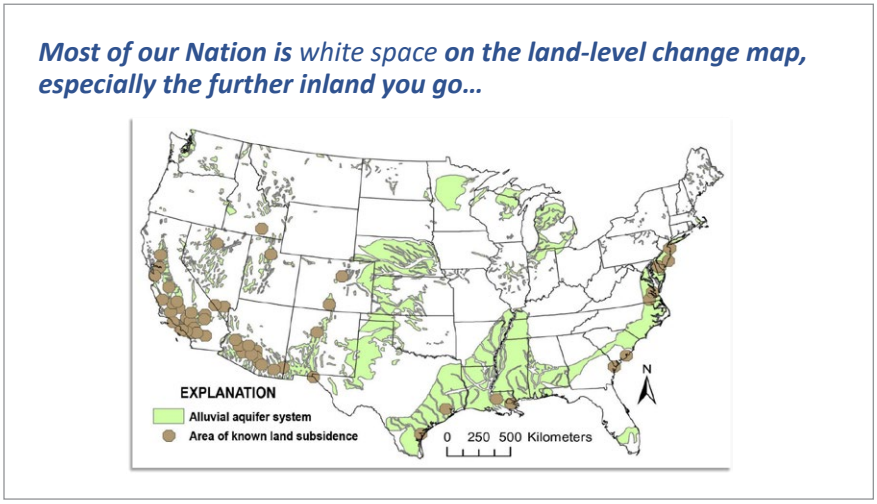


Figure 12: Land-level change has not been mapped across most of the US.

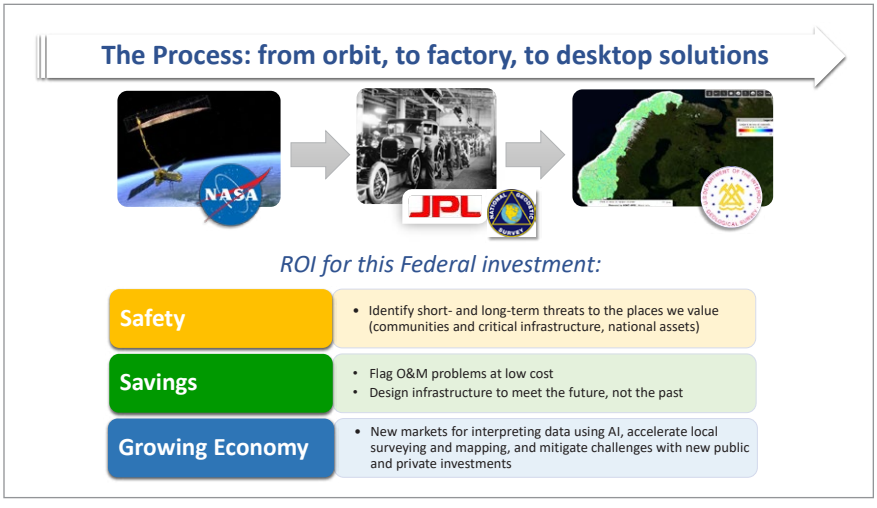


Figure 13: Process behind the NiSAR program.

Dewberry—wrap-up and gradesheet

Dr. David Maune concluded the workshop with an assessment of how multiple programs are addressing and managing subsidence through SAR, IfSAR, DInSAR, and SqueeSAR measurements (**Figure 14**). He emphasized how sea level rise combines with subsidence to exacerbate a bad situation, then gave eight specific examples and awarded each a "grade".

Dr. Maune concluded his presentation with a discussion of the Sustainable Water Initiative for Tomorrow (SWIFT) Research Center in Virginia, which focuses on water treatment, replenishing of ground water and reducing land subsidence (**Figure 15**).

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

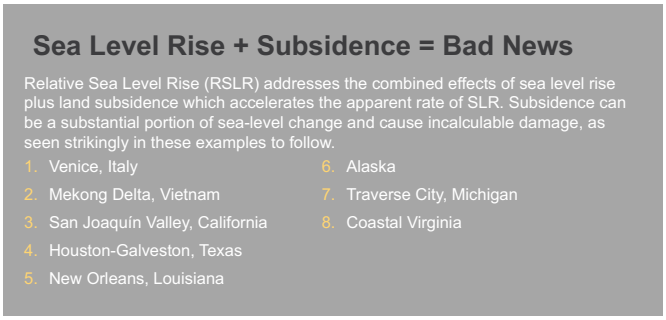


Figure 14: Case studies of sea-level rise and subsidence.

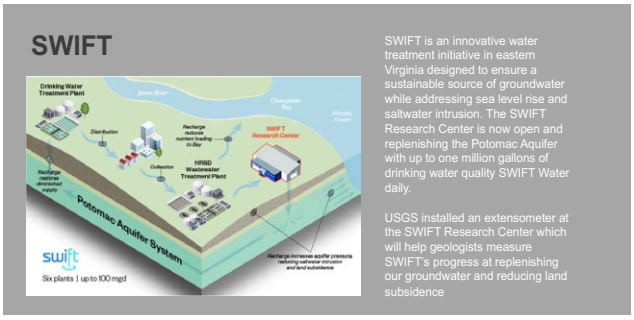


Figure 15: Sustainable Water Initiative for Tomorrow (SWIFT) water treatment project in eastern Virginia.

DInSAR in Proactive Management of Subsidence

New technology plays a lead role in the measurement of subsidence, but managers must go further and reduce its causes

Subsidence is a gradual settling or sudden sinking of the land surface from changes that take place underground, most commonly from the extraction of water, but also by the extraction of oil and gas, or natural processes. In many locations worldwide, annual rates of subsidence are worse than annual rates of sea level rise (SLR), essentially doubling the "relative SLR" and accelerating the need for leadership.

Dewberry analyzed eight subsidence case studies, six of which used differential interferometric synthetic aperture radar (DInSAR) as a key step in the proactive management of subsidence. For each case study, Dewberry provided a report card, assigning a grade of F if communities only react to subsidence; D if they predict subsidence; C if they map annual subsidence rates and "hot spots" using DInSAR; B if they mitigate the effects of subsidence; and A if they reduce the cause of subsidence. Rather than generating controversy about whether the author's grading system is fair or unfair, the objective of this article is to cause people to think about ways to be proactive and not just react to subsidence as though it is inevitable.

BY DAVID F. MAUNE

Venice, Italy

There is a race to save St. Mark's Basilica, reached by high tides and salty floodwaters about six times per year, eroding the precious marble. During the 20th century, Venice subsided ~12 cm due to natural processes and groundwater extraction, in addition to SLR of ~11 cm. Officials put a stop to the pumping of ground water, but the city is still subsiding at a rate of 1-2 mm/year. Studies indicate that the area is also tilting ~1-2 mm/year eastward because of plate tectonics.

> "In many locations, annual rates of subsidence are worse than annual rates of sea level rise (SLR), essentially doubling "relative SLR" and accelerating the need for leadership."

The $7 billion MOSE project, authorized in 2003, is an underwater fortress of steel designed to rise from the depths during high tides to protect the lagoon city of Venice[1]. There are 78 gates, divided into four barriers. The MOSE walls can be raised to block incoming tides. The project is expected to be completed in 2022, but may never work, because it was designed in the 1980s based on erroneously low projections for SLR and subsidence. The gates cannot be raised permanently, because the Venice lagoon uses the Adriatic as a flushing valve, and its ecosystem would be jeopardized if sealed off from the high seas. Based on current projections, the floodgates would soon need to be raised so often that they would function like a near-permanent wall, turning the lagoon into a stagnant pool for algae and waste.

The author gave a grade of B+, because scientists are considering pumping sea water deep underground to raise the city back up, including the MOSE gates. If such a project were implemented successfully, Venice could then earn an A for reducing the cause of subsidence.

Mekong Delta, Vietnam

This fertile and economically important area (Vietnam's "rice bowl") is subsiding

1 en.wikipedia.org/wiki/MOSE

at a rate of 1-4 cm/year—10 times worse than Venice—and the Vietnamese are increasingly feeling the impact: more flooding and increased salinization of groundwater and surface water. The rapidly increasing population and economic development are driving a swift increase in water consumption. The extraction of groundwater for drinking water, agriculture and fisheries is the primary cause of the dramatic land subsidence in this low-lying area.

Deltares has initiated a large-scale study of the causes and consequences of land subsidence in the Mekong Delta[2]. The aim is to identify the various forces driving land subsidence, establish a 3D model of the subsurface and develop a tool for predicting land subsidence. Hydrological processes and the interaction between land subsidence and the salinization of groundwater and surface water will also be covered. Maps are produced predicting the results of extraction-induced subsidence and SLR by 2030, 2050, 2080 and 2100.

The author gave a report card grade of C to the Vietnamese because they are mapping the rates of subsidence but have not yet initiated steps to mitigate the effects of subsidence/SLR.

San Joaquin Valley, California

The California Aqueduct Subsidence Program documented subsidence of over 30 feet prior to construction of the aqueduct in the 1960s[3]. While rates of subsidence stabilized for a few years after construction, the aqueduct has sustained an alarming and unprecedented increase in subsidence rates, e.g., ~6 inches per year since 2013, as aquifers are not replenished by rainfall or snow melt.

Deep groundwater pumping is the primary cause of this alarming trend and typically ramps up during extended droughts. The recent conversion of row crops (often fallowed in dry years) to orchards and vineyards (cannot be fallowed in dry years) has resulted in more subsidence when surface water is unavailable during dry periods. Subsidence has reduced the flow capacity of the aqueduct, and the system is becoming less reliable for the 27 million people it serves and the myriad of agricultural users that rely on its water.

> "The California aqueduct has sustained an alarming and unprecedented increase in subsidence rates since 2013, as aquifers are not replenished by rainfall or snow melt."

The author gave a grade of C, as authorities clearly use DInSAR to map subsidence rates and "hot spots," but nothing significant, to the author's knowledge, is being done to mitigate the effects of subsidence other than continuing to raise the aqueduct lining and embankments and repairing structures—steps that are more reactive than proactive.

Houston-Galveston region, Texas

The Harris-Galveston Subsidence District has been tracking the effects of land subsidence for many years[4]; and USGS collects, processes, and interprets data on groundwater-level and aquifer-sediment-compaction to understand the effects of groundwater withdrawal on land subsidence in the region. Land subsidence is caused by compaction of fine-grained aquifer sediments (silts and clays) below the land surface due to groundwater withdrawals. This compresses the aquifer, leaving less pore space available to store water, resulting in the lowering of the land surface. Most of this compaction is irreversible: even if groundwater levels rise, compacted sediments and the associated land-surface lowering would remain as is.

Land subsidence reduces the ability to store water in aquifers; partially or completely submerges land; collapses water well casings; disrupts collector drains and irrigation ditches; alters the flow of creeks and bayous; increases the frequency and severity of flooding; and damages roadways, bridges, building foundations and other infrastructure. This is largely the reason why the Houston-Galveston area has flooded more frequently and severely in recent years.

Groundwater withdrawn from aquifers has been the primary source of water for municipal supply, commercial and industrial use and irrigation in the region since the early 1990s. Since 1975, subsidence

2 deltares.nl/en/projects/land-subsidence-research-project-in-the-mekong-delta-vietnam

3 mavensnotebook.com/2020/11/24/water-commission-addressing-california-aqueduct-subsidence-state-water-project-operations-and-maintenance/

4 txpub.usgs.gov/houston_subsidence/

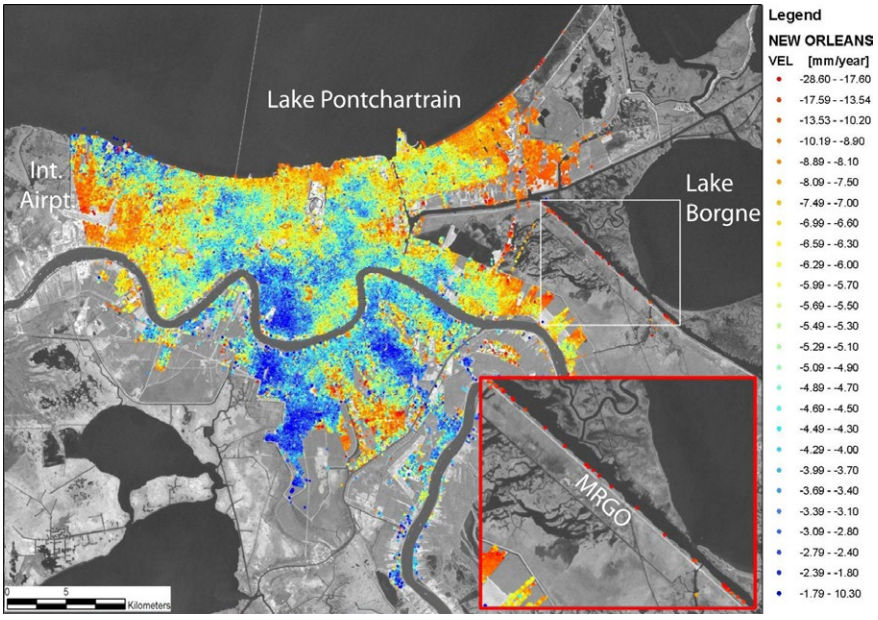


Figure 1: NASA uses DInSAR to map land subsidence rates in New Orleans.

districts have routinely regulated and reduced groundwater withdrawals, but they have increased as urban growth has spread throughout the area and subsidence of over 2 cm/year is still occurring, roughly comparable to subsidence rates in the Mekong Delta.

The author gave a grade of B- to the district. Authorities have used DInSAR to map subsidence rates; Subsidence Districts have regulated groundwater withdrawals; and Galveston is building expensive levees and floodwalls to combat the long-term effects of climate change, SLR and subsidence.

New Orleans, Louisiana

It has long been known that New Orleans is sinking, and human causes of subsidence are routinely reported. NASA and JPL regularly use DInSAR to map subsidence rates and "hot spots" in New Orleans (**Figure 1**). The city has built numerous structural solutions and has extensive hazard mitigation plans for dealing with subsidence: projects include prevention, natural resource protection, public education and awareness, and property protection with voluntary incentives.

The author gave a grade of B to New Orleans as authorities clearly use DInSAR to map subsidence rates and "hot spots," and have been proactive with mitigation strategies.

Alaska

The state has significant subsidence in some areas, especially where permafrost is melting, and significant uplift in other areas from post-glacial rebound caused by the lessening weight of glaciers as they melt. Alaskans have used GNSS at specific locations to map subsidence and uplift, but only recently has DInSAR been considered to map subsidence/uplift rates. The author gave Alaska a grade of C-, because it is not systematically mapping subsidence and uplift, relying only on repeat GNSS observations at specific locations throughout the state.

Traverse City, Michigan

Traverse City has experienced three feet of classic scour beneath its river wall, leading to subsidence on the landward side. The city established criteria for evaluation of alternatives and its Unified Plan shows environmental priorities, including shifting the balance towards habitat and nature over human recreation and economic development. Because the Unified Plan's priorities include mitigation to restore the natural river corridor, but because the city has not yet decided to adopt the plan, a grade of B- was awarded.

Hampton Roads, Virginia

Under contract to the National Geodetic Survey in 2017, Dewberry and TRE ALTAMiRA used DInSAR, working with a six-year data stack of Cosmo-SkyMed SAR imagery, to map subsidence for the Hampton Roads area of Virginia. Subsidence averaged ~1 mm/year, but subsidence "hot spots" were as much as -2.76 inches (70 mm) on a taxiway at the Norfolk Naval Air Station over the six-year period. For mitigation purposes, Dewberry provided the framework for Virginia Coastal Resilience Master Planning and developed the Sea Level Wise adaptation strategy for Virginia Beach to enable the city to adapt to changing environmental conditions, but those steps could only warrant a grade of B.

Earning a grade of A, the Hampton Roads Sanitation District (HRSD) Sustainable Water Initiative for

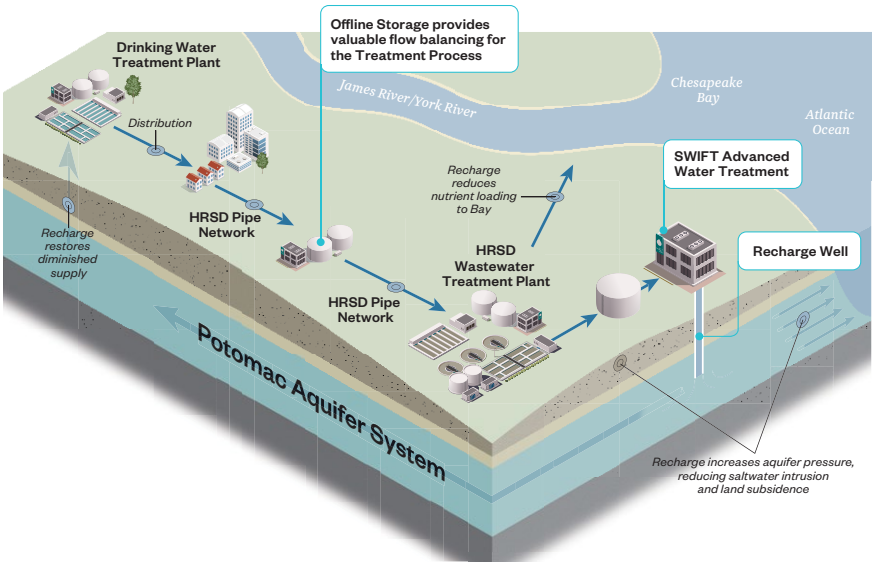


Figure 2: SWIFT is an innovative water treatment initiative in eastern Virginia to ensure a sustainable source of groundwater while addressing sea level rise, subsidence and saltwater intrusion.

Tomorrow (SWIFT)[5] is slowing the rate of land subsidence in the Hampton Roads area in addition to stabilizing and restoring the water supply in the Potomac aquifer. USGS estimated that groundwater withdrawals are responsible for more than half of the land subsidence in Hampton Roads, and land subsidence contributes more than half of the net effect of SLR. A reduction or complete halt of subsidence would provide years of added use of highly valuable developed land impacted by subsidence and SLR and protect thousands of acres of environmentally valuable wetlands from complete inundation.

SWIFT takes highly treated water that would otherwise be discharged into the Elizabeth, James or York rivers and puts it through additional rounds of advanced water treatment to meet drinking water quality standards (**Figure 2**). SWIFT water is then added to the Potomac Aquifer, the primary source of groundwater throughout the area. When HRSD's five main plants are operational, SWIFT will replenish the Potomac Aquifer with 100 million gallons of purified drinking water daily. USGS has installed an extensometer at the SWIFT Research Center to help geologists measure SWIFT's progress at replenishing the groundwater and reducing land subsidence.

When all five major plants are operational, a grade of A+ is possible if a new DInSAR analysis is performed to prove SWIFT's reversal of historical subsidence trends in the area.

The lessons learned from SWIFT technology could potentially benefit Venice, the Mekong Delta, the Central Valley of California, Houston-Galveston, New Orleans, the state of Florida and many other areas with similar challenges from subsidence, SLR and saltwater intrusion.

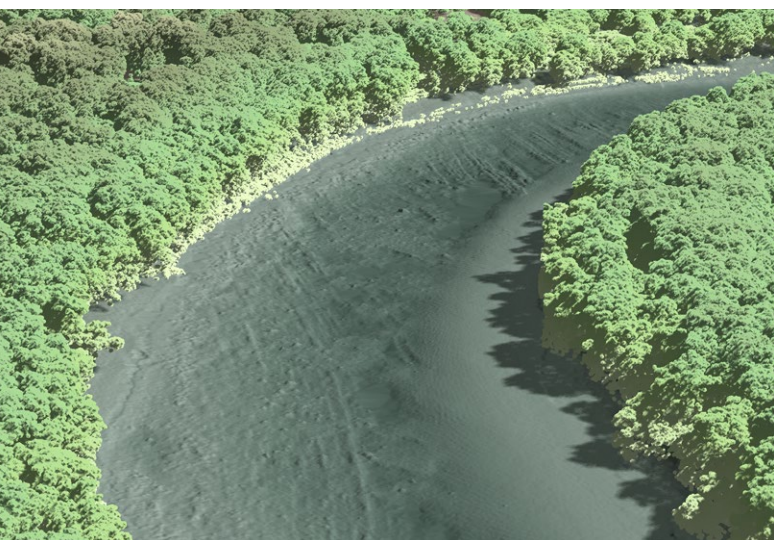
5 swiftva.com

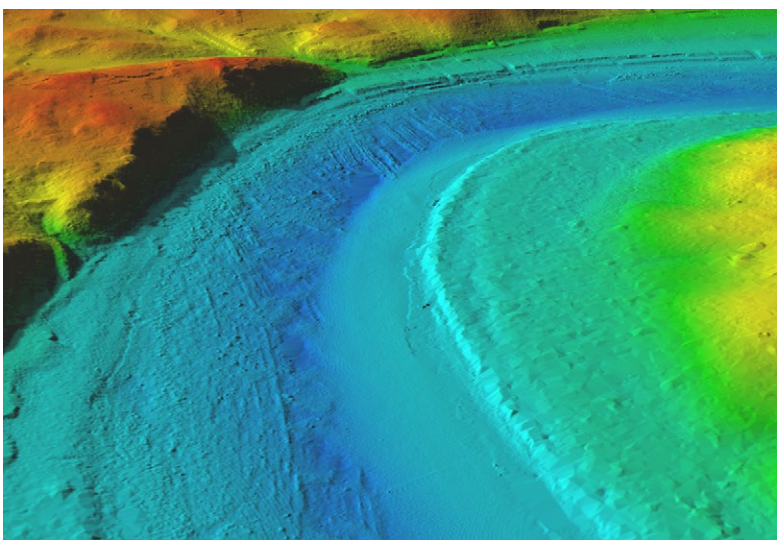
Endnote

Rather than debating whether the report card grades discussed here are fair, the author hopes this paper will cause managers to think about whether they are doing everything they can to be truly proactive in addressing the combined threats of SLR, subsidence, and saltwater intrusion. DInSAR can provide metrics for defining an area's subsidence problem, but it takes leadership to mitigate the effects of subsidence and reduce its cause by proactively managing subsidence.

David F. Maune, PhD, CP, CFM, PSM, PS, GS, SP is is an associate vice president and serves as a senior project manager with Dewberry's geospatial group. With nearly 60 years of experience, Maune is recognized as the industry's leading authority on digital elevation models (DEMs) and lidar. He is the editor and principal author of *Digital Elevation Model Technologies and Applications: The DEM Users Manual*, the 3rd edition of which was published in 2018. He has managed major mapping programs for NOAA, USGS, U.S. Army Corps of Engineers, Federal Emergency Management Agency, and state, county, city, and private clients. Maune serves as the project manager for the firm's independent quality assurance/quality control contracts with various states and counties. Using IfSAR, Maune is managing the mapping of the entire state of Alaska, which has never before been mapped in accordance with National Map Accuracy Standards.

He is a member of the American Society for Photogrammetry and Remote Sensing (ASPRS), Management Association for Private Photogrammetric Surveyors (MAPPS), and Association of State Floodplain Managers (ASFPM). Maune received the Outstanding Personal Achievement Award in Lidar at the International Lidar Mapping Forum (ILMF) in February 2018.





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Lidar and InSAR: Not All Remote Sensing is the Same

TRE ALTAMiRA SqueeSAR® technology pinpoints subsidence

Figure 1: As InSAR can use natural features such as buildings as measurement targets, it is well-suited for detecting subsidence in urban environments. Here is one result of ground displacement data in an urban area: a 3D view of movement over the River Thames in London, with the O2 stadium upper right; the red dots signify abnormal or rapid movement.

Search Google with the words "are lidar and InSAR the same thing" and you'll get about 375,000 results. That doesn't mean that there are 375,000 documents or articles that support or address that exact question, but the matches are indicative of one thing: lidar and interferometric synthetic aperture radar (InSAR) are intriguing professionals in a variety of sectors. And that interest is helping to transition the technologies from their innovative beginnings into commercial commodities.

According to a report published by Fortune Business Insights in January 2020[1], the global lidar market hit $1.3 billion in 2018 and is projected to swell to $6.7 billion by 2026. There is less market analysis of InSAR, but industry insiders estimate the global market value is currently about $60 million—and growing steadily. Market leader TRE ALTAMiRA (TREA), a CLS Group company and 20-year veteran of InSAR services with offices in Milan, Barcelona and Vancouver, has seen its revenues triple in 10 years.

As the popularity and advance of these technologies have grown, however, so have the misconceptions about their capabilities, how they can be used, and what information they can provide.

"A common misunderstanding about lidar and InSAR is that they are

1 fortunebusinessinsights.com/light-detection-and-ranging-lidar-market-101969

BY MARY JO WAGNER

directly competing technologies," says Giacomo Falorni, technical director of TREA's Vancouver office. "While it is true that they are both remote sensing technologies that can be used to measure topography and 3D structures, they are different in what they measure. Lidar is great for modelling surface topography or urban infrastructures. InSAR measures the *displacement* of topography or buildings over time. So they are complementary. You can create a base DEM or DSM with lidar and then use InSAR to see how the topography in areas with subsidence is changing over time with millimeter precision."

However, recognition of that key differentiator—surface topography versus ground-surface movement—is on the rise, says Falorni. And that awareness is enabling more users to understand the strengths of each, the limitations of each, and the advantages of using lidar and InSAR together.

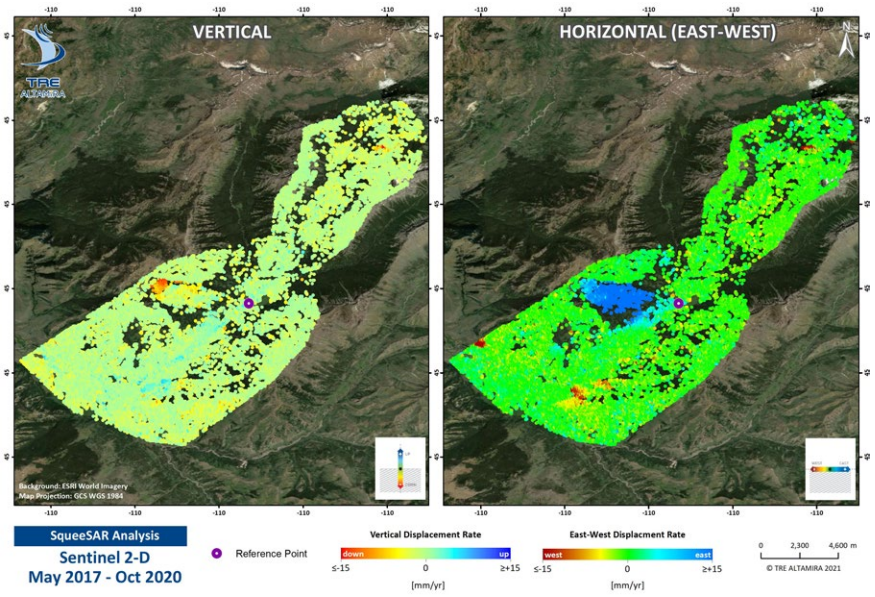

Figure 2: TREA's InSAR color-coded results show a four-year deformation history of a landslide in Yellowstone National Park. The image on the right indicates that the landslide has been subsiding 25 mm per year for the past several years.

Key differentiators

Users familiar with lidar understand its aptitude for delivering dense 3D data of land cover. Its ability to acquire precise 3D X, Y and Z coordinates allows users to map and model features for a range of applications, such as forestry, urban planning, geomorphology, mining, landslides and utilities.

InSAR is a 1D or 2D technique that provides planimetric and height measurements. The vertical component can cause confusion, leading people to think that InSAR, like lidar, is measuring elevation. The difference is that InSAR's vertical measurement correlates with change in elevation over time for a point on the ground rather than a true Z coordinate.

"InSAR won't tell you the height of something," says Falorni, "but it will tell you the movement of something. InSAR captures hundreds of thousands of points and, for any measurement point, it can tell you with millimetric precision if it's moving, the direction it's moving—up or down or horizontally—and if the movement is accelerating. It can also provide that displacement detail over weeks, months, years or decades."

> "You can use InSAR to see how the topography in areas with subsidence is changing over time with millimeter precision."

In addition to measuring movement rather than pure height, InSAR is based on satellite imagery, enabling substantial areas of interest (AOIs) like the city of London to be covered in a single scene and as often as every week (**Figure 1**). Measuring change with lidar is too costly and impractical over large areas or frequent repetitions and it yields accuracies around ten centimeters rather than millimeters. Large-area coverage, frequency and precision make InSAR the technology for deformation mapping.

InSAR, however, cannot achieve the same spatial coverage as lidar because it is more affected by vegetation. That makes lidar the better mapping tool for many deliverables, for example DEMs, vegetation surveys, building heights, utility line surveys and modeling and volumetrics of materials such as waste piles at a mine.

InSAR involves examining SAR backscatter signal phases from satellites over the same geographic area at regular intervals. The differences in the phases are a direct result of changes in the

distance between the target and satellite, due to the slightly different position of the point on the ground at each pass. Combining two SAR images taken from a similar vantage point in space produces an interferogram, which illustrates phase differences between the images through a colorful pattern of fringes that represent changes in ground movement.

InSAR's unique ability to go back in time—nearly three decades—is a benefit that can not only provide historical context for lidar-based DEMs, but has also helped shift perspectives on land management and what is assumed to be stable ground.

"Because of InSAR's point density and substantial spatial coverage over AOIs, we can often show millimetric movement that clients were not aware of," says Falorni. "Those revelations enable them to take proactive steps to avert a potential failure."

Indeed, with the possibility for small movements to lead to major events and potentially sizable damage, understanding surface instability is crucial for geohazard management, urban subsidence, mining, civil engineering, oil and gas, or water utilities.

Figure 3: In mining, InSAR's consistent check on ground movement provides an early-warning system for potential ground-movement hazards of which site engineers may not be aware. Image by István Mihály, Pixabay.

Remote complements

Analyzing, mapping and monitoring geohazards, such as landslides has been a mainstay application of InSAR since the technique was first developed in 1993, and it still is. Although InSAR isn't a tool for sudden, swift landslides, it is very effective in detecting and monitoring "creeping landslides," or deep-seated, slow-moving slides that are a continuous threat. The velocity detail from InSAR also enables users to analyze land movement over time and potentially forecast how landslides might continue to move based on historical movement. Coupled with lidar, which isn't vulnerable to ground-surface disruptions and can penetrate vegetation, users can create comprehensive landslide maps and flag unstable areas.

The combined technologies helped authorities at Yellowstone National Park design a better course for a road that was planned to be re-routed near the toe of an active landslide. Unsure of the risk to the road, they sought an InSAR historical analysis to validate whether the landslide was moving and how quickly. TREA acquired an existing lidar DEM and 115 scenes from the European Sentinel-1 satellite from 2016 to 2020. Using its advanced SqueeSAR algorithm, it processed the entire image stack to develop a timeline of displacement over an area of 130 km^2. In March 2021, TREA delivered a color-coded point cloud of the AOI in which each point has a four-year deformation history (**Figure 2**). The results showed that that particular landslide had been rapidly subsiding by 25 mm/year for the past several years—a surprising discovery that allowed them to rethink the road design.

In addition to mapping pre-collapse shifts from sudden slides, such as California's massive Big Sur landslide in 2017, TREA has been monitoring landslides in Alaska's Denali Park, Dawson Creek in Canada's Yukon Province, and others around the world. Its office in Italy has been providing on-going landslide monitoring to Italy's Tuscany region since 2016. Using imagery from the European Sentinel-1 constellation, TREA processes millions of measurement points across the whole region every 12 days and provides an InSAR bulletin that highlights areas of sudden movement or acceleration in movement.

"This precise, simplified view allows local authorities to take a proactive

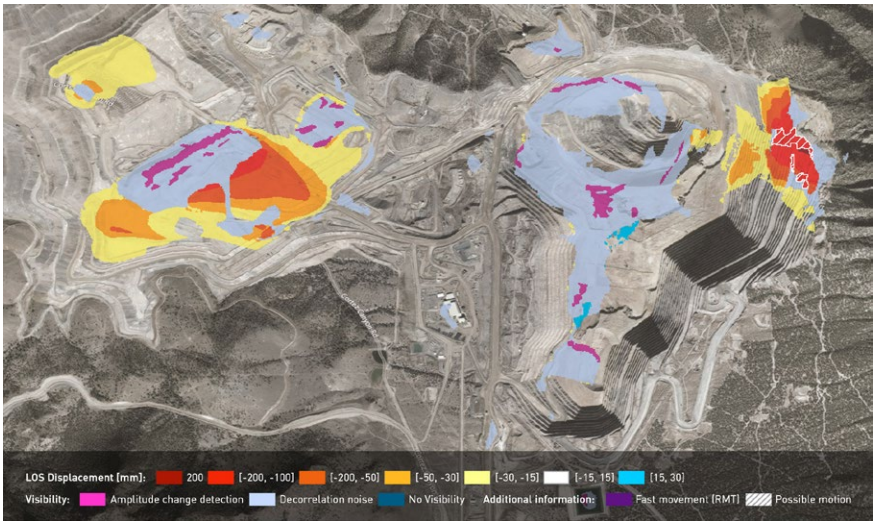

Figure 4: An InSAR map of ground deformation over an active mine. InSAR's synoptic view of entire mine sites can help manage risk and focus efforts for higher-frequency ground-based monitoring systems where required.

approach to geohazards and dispatch people into the field to examine at-risk areas," says Falorni.

Mining for the truth

Adopting a more comprehensive preventative approach for monitoring structural assets has been particularly widespread in the mining sector. Since the catastrophic failure of the Brumadinho tailings dam in Brazil in 2019, the mining industry has collectively moved towards implementing more effective asset-monitoring tools. Lidar and InSAR have been a significant part of that pattern.

Many companies use lidar to model entire mines or specific sections of a site for planning and managing resources (**Figures 3 and 4**). It is particularly suitable for determining the amount of rubble in waste piles.

InSAR is becoming the first choice for monitoring deformations of pit slopes and waste rock dumps, tailings, natural landslides, and subsidence induced from underground mining, particularly where historic information is limited or unavailable (**Figure 5**).

"InSAR's frequency, accuracy, large area coverage, relatively low cost and historical datasets have made it highly attractive over the last decade," says Neil Bar, a geotechnical engineer with international geotechnical engineering services company Gecko Geotechnics. "Ground-based monitoring systems, such as prism monitoring and inclinometers, whilst incredibly useful, require significant installation time and maintenance and it's practically impossible to cover an entire mine site where human resources are scarce. InSAR's consistent check on ground movement provides an early-warning system for potential ground-movement hazards we weren't aware of, usually well before there are any visual signs of ground disturbance. This helps manage risk and focus efforts for higher frequency ground-based monitoring systems where required."

In one recent case, TREA acquired and processed high-resolution TerraSAR-X imagery of a tailings dam. The results showed clear signs of horizontal movement, a significant indicator that bulging may be occurring

Figure 5: As subsidence can often happen outside localized measurements of GNSS or inclinometers, InSAR provides an early-warning system for potential ground-movement hazards at mine sites. This InSAR view shows an unstable slope in a mine pit in South America.

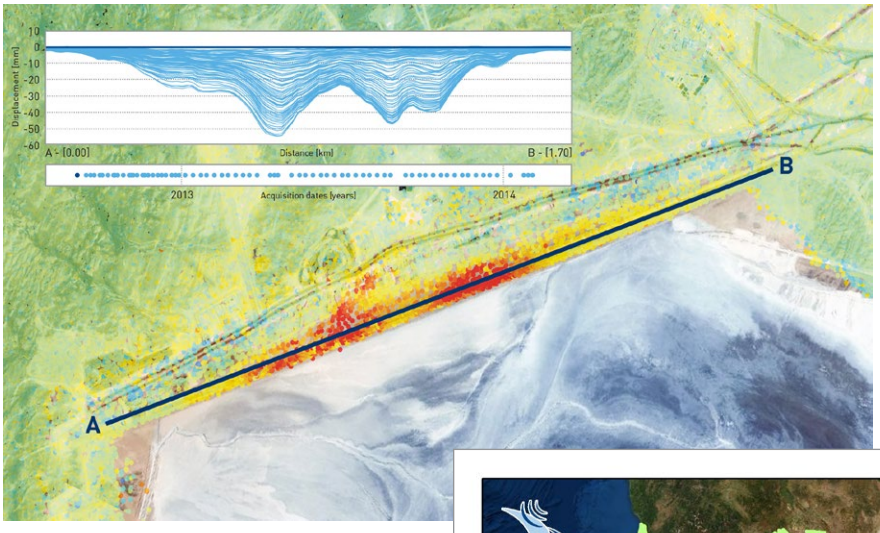

Figure 6: An annotated InSAR view showing uneven settlement in a tailings dam in South America. Since some recent catastrophic failures of tailings dams, the mining industry has collectively moved towards implementing more effective asset-monitoring tools.

in the dam (**Figure 6**). That precise detail enabled the company quickly to alter operations and implement preventative measures.

"Often subsidence happens outside the localized measurements of GNSS or inclinometers," says Falorni. "And although there might not be significant movement initially, the history of motion provided by InSAR allows non-linear movement to be monitored and, in a worst-case scenario, inverse velocity methods can be applied to predict if and when a collapse may occur."

In addition to active mines, companies also use InSAR as a remote tool to help monitor subsidence and other changes at decommissioned sites.

At present, TREA provides ground-movement monitoring for about 100 mining sites and is adding more than 110 to its portfolio through a recent agreement with natural resources company Glencore—the largest industry agreement to date for monitoring of tailings storage using satellite data.

Monitoring the flow

There are other applications, such as dam monitoring, tunneling and management of water resources, where lidar is not needed as a complement to InSAR.

A California state government (CSG) department has been using InSAR since 2018 for statewide subsidence

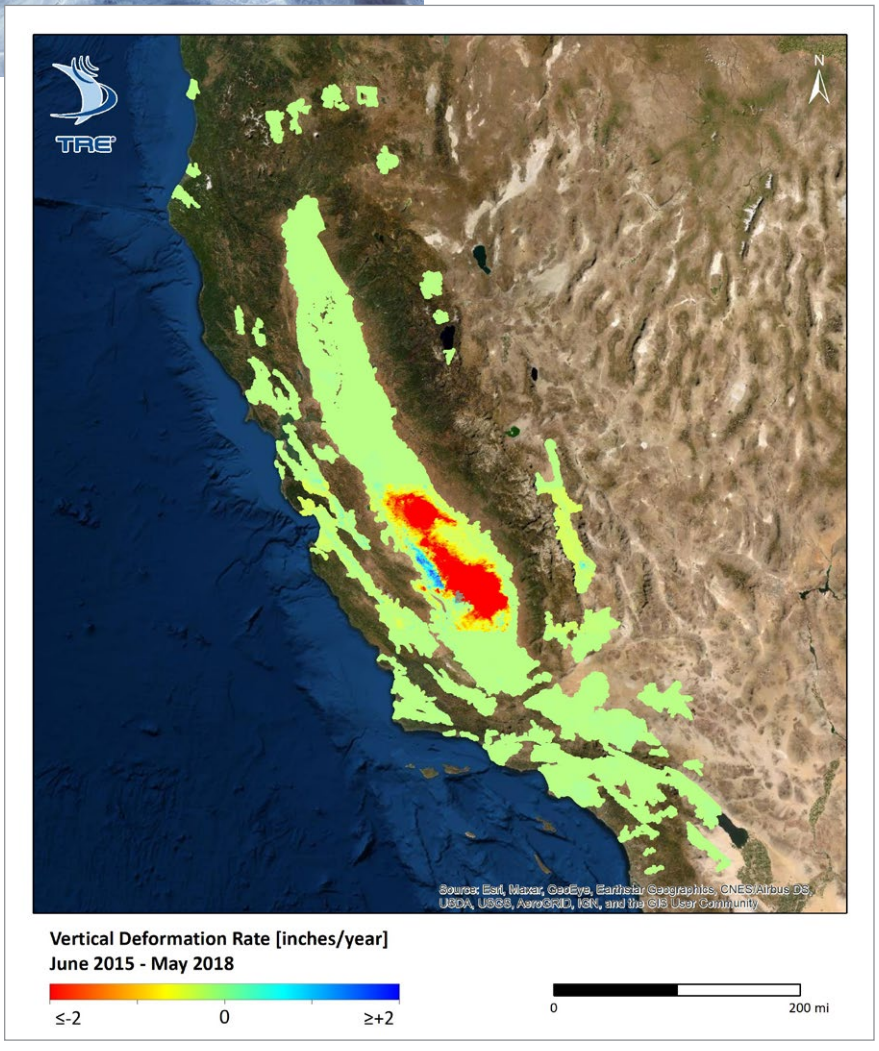

Figure 7: View of ground subsidence over high-risk water basins in California. The Central Valley is subsiding at rates of up to 30 cm per year.

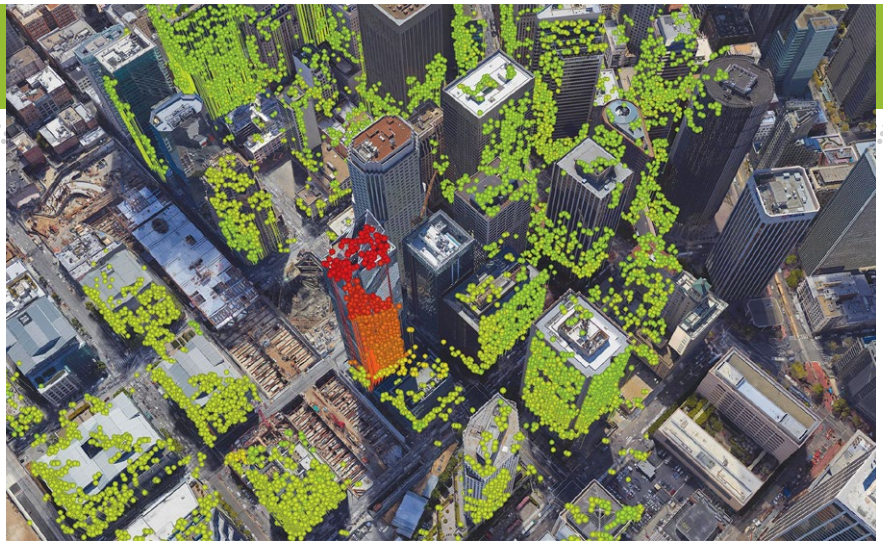

Figure 8: InSAR is quite effective for measuring ground subsidence in urban areas. This image shows significant movement of the Millennium Tower in downtown San Francisco, a luxury high-rise that became known as the "Leaning Millennium Tower". Despite a $100-million construction project to fix it, it is still sinking and tilting.

monitoring of 127 high- and medium-priority groundwater basins.

CSG first tasked TREA with a historical analysis to establish a baseline. TREA processed 6424 Sentinel-1 scenes over a three-year period from 2015-2018. In accordance with the department's request, they used 231 existing GNSS station measurements to calibrate the InSAR measurements and a survey company used an additional 600 GNSS measurements to validate the InSAR results. Within three months TREA delivered a 2D, fully calibrated point cloud of ground displacement over 100,000 square miles (259,000 km^2) that revealed widespread subsidence—agricultural areas in the Central Valley showed more than 30 cm of deformation over three years (**Figure 7**).

After that initial report and subsequent annual updates, CSG solidified the value of InSAR by increasing the monitoring with a detailed point cloud every three months.

"InSAR is so consistent and precise that it's like giving the CSG 90 million GNSS points instead of the existing 900," says Adrian Bohane, CEO of TREA's Vancouver office. "They can track and monitor precise areas of movement and amount of movement from their desktop, giving them quantifiable information to proactively manage their critical water resources."

InSAR is also a valuable tool for extractive operations such as tunnelling. Because it can use natural features (buildings, metallic objects, pylons, and exposed rocks) as measurement targets, it can identify subsidence during tunnelling operations as well as after. TREA, for example, has been providing regular InSAR details to the Société du Grand Paris during the construction of the Grand Paris Express, a 200-km network of underground metro lines, to monitor the impact of tunnelling operations on existing buildings and surface structures along the track and adjacent areas. Once construction is done, they'll continue to use InSAR to detect any residual subsidence (**Figure 8**).

Synergistic tools for the future

Whether an application is suited to lidar, or InSAR, or would benefit from both, the two technologies bring their own valuable perspectives to an increasing number of industries. As more professionals become familiar with these tools, those Google search strings may lead to more business for each. And that kind of movement would no doubt be welcome.

Mary Jo Wagner is a writer, based in Vancouver, Canada, with more than 25 years of experience in covering geospatial technology. She can be reached by phone at +1 604 221 4583; or e-mail mj_wagner@shaw.ca.

WHICH TOOL?

Lidar	InSAR
Topography: creating DEMs/DSMs	Topography: wide-area subsidence mapping/monitoring
Land cover: mapping tree canopies/ vegetation	Mining: mapping/monitoring deformation
Urban development: mapping buildings/determining heights	Tunnelling: monitoring displacement
Mining: surveying for volumetric calculations	Geohazards: monitoring landslides
Utilities: surveying power lines and poles	Urban infrastructure: mapping/ monitoring structural subsidence
Land management: erosion control	Dams: measuring/monitoring reservoir slope stability
Geohazards: mapping landslides	Water management: monitoring groundwater basin integrity

Intermap Technologies' Airborne IfSAR and SAR

High-altitude SAR collection serves clients worldwide

Intermap Technologies is a world leader in remote sensing and geospatial solutions, with a long history of commercial and government contract success. Leveraging high-speed, high-altitude Learjets equipped with proprietary X-band IfSAR and P-band SAR sensors, Intermap has helped more than 50 governments on every populated continent to meet their national mapping needs. Headquartered in Colorado, with offices in Prague, Jakarta, and Calgary, Intermap provides solutions to enable its partners and clients to make critical decisions affecting resource allocation, land management, environmental monitoring, public safety, and defense.

Intermap's story began in 1919 when its predecessor, Pennsylvania Aero Service Corporation, was founded as North America's very first aerial survey company. Organic growth and evolution with technology led to the establishment of Intermap in its current form in 1996, when the company acquired the world's most advanced radar terrain-data collection system from DARPA. Today, Intermap operates two modified Learjet 36A aircraft equipped with advanced X-band IfSAR and P-band SAR sensors that allow for collection of wide-area elevation data and high-resolution cloud-free imagery, day or night, in any weather conditions (**Figure 1**).

Airborne IfSAR

Figure 2 is a conceptual diagram of Intermap's X-band IfSAR system and processing workflow. Intermap's X-band IfSAR systems transmit radar pulses toward the terrain, then record the reflected energy with two antennas that are precisely separated by an interferometric baseline. The two antennas simultaneously record two SAR images containing amplitude and phase of the same point on the ground—varying only by the phase difference created by the baseline between the two antennas. In addition, as the aircraft passes over the terrain, global navigation satellite system (GNSS) data and navigation data from an inertial measurement unit on board the aircraft are also collected.

Figure 1: Intermap's Learjets are modified for long endurance and equipped with X-band IfSAR and P-band SAR sensors.

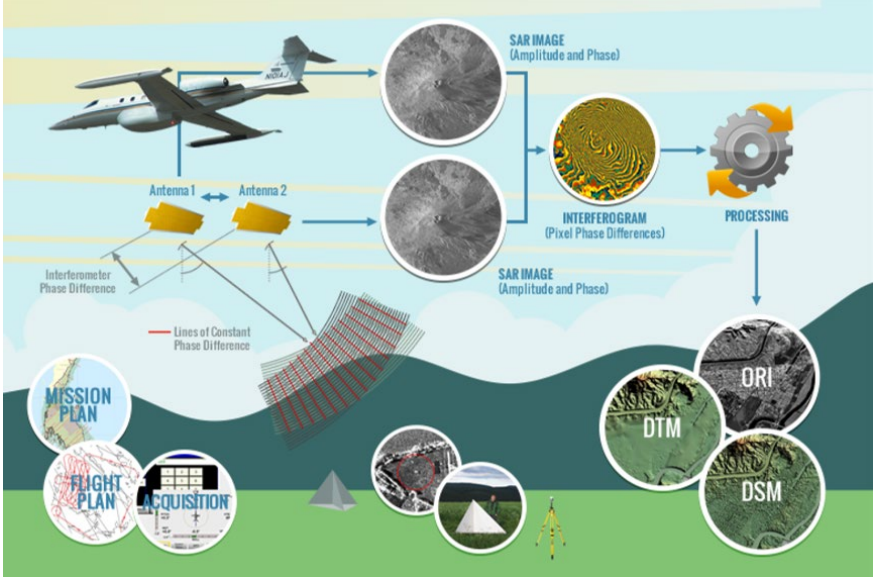

Figure 2: Conceptual diagram of IfSAR system and workflow.

BY IAN WOSISKI

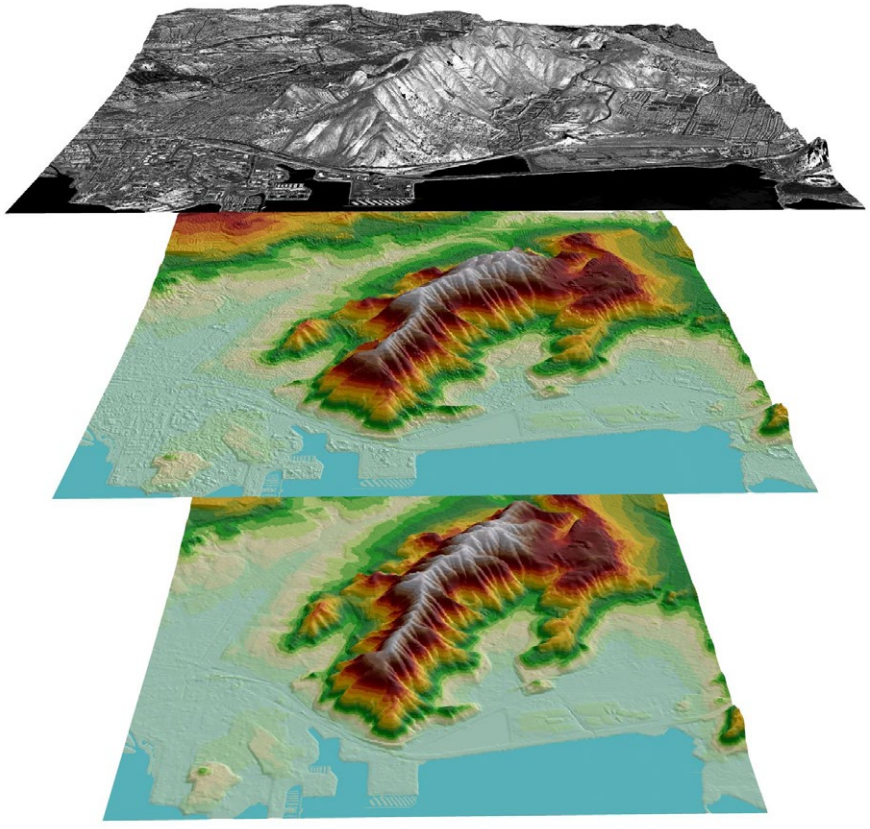

Figure 3: Intermap core products, ORI, DSM, and DTM.

Airborne IFSAR Standard Deliverables

2m DSM / DTM	Accuracy Specifications		Post Spacing / Pixel Size	Acquisition Altitude
Product Type	RMSE	LE95/CE95		
Type I - 2m	0.5 m	1.0 m	2.0 m	18,000 ft
Type II - 2m	1.0 m	2.0 m	2.0 m	18,000 ft
Type III - 2m	3.0 m	6.0 m	2.0 m	18,000 ft
5m IFSAR DSM, DTM, and ORI				
Type II - 5m DSM & DTM	1.0 m	2.0 m	5.0 m	28,000 ft
ORI	2.0 m	4.0 m	0.625 m	28,000 ft

Intermap has recently developed an acquisition and processing workflow that enables delivery of 2m post X-band DSM & DTM by flying at the lower altitude of 18,000ft. and modifying filters and bin size in processing.

- Product Types I-III are based on Vertical Accuracy, which is governed by flight planning and number of ground control corner reflectors deployed
- X-band ORI Resolution: up to 25cm (HH Polarization)
- P-band ORI Resolution: 85cm (Tri-polarization (HH, VH, VV))

Table 1: Summary of Intermap's standard products and their specifications.

The phase difference between the antennas for each image point (along with range, baseline, GNSS, and navigation data) is used to infer the precise topographic height of the terrain being imaged. This enables the creation of an interferogram (depicting the phase difference) from which Intermap's Digital Surface Model (DSM) and Orthorectified Radar Imagery (ORI) products are derived. Through additional processing, seamless hydro-enforced bare-earth DTMs and other derived products are generated.

Airborne IfSAR core products

Intermap generates three core products from its X-band IfSAR system: Orthorectified Radar Imagery (ORI) with up to 25 cm GSD, Digital Surface Models (DSM), and Digital Terrain Models (DTM) which is created by digitally removing all structures, objects, and vegetation from the DSM (**Figure 3** and **Table 1**).

Intermap's standard Type-II DSMs and DTMs have a post resolution of 5 m with better than 1.0 m $RMSE_z$ vertical accuracy in unobstructed slopes of 0-10 degrees. Recent innovations in IfSAR processing, combined with acquisition at lower altitude (18,000 feet AGL), enable Intermap to generate native 2 m IfSAR elevation datasets with vertical accuracy of 0.5 m $RMSE_z$ or better.

From these core products, additional thematic layers can be derived to create full-featured topographic line maps including contours, hydrology, hill-shades, land-cover, building footprints, and roads. Wide-area IfSAR elevation data is complementary to higher resolution lidar data, which is often collected in smaller high-priority areas then fused with the wide-area IfSAR. Intermap's

3D foundation data layers provide the framework necessary for governments and businesses to make informed decisions and find intelligent solutions to their planning and operational challenges.

In addition to X-band IfSAR, Intermap's side-looking P-band SAR sensors allow for foliage-penetrating (FOPEN) imagery collection at altitudes up to 38,000 feet and with a stand-off distance of up to 14 nautical miles. The P-band imagery is tri-polarized (HH, VH, VV) with a pixel resolution of 85 cm, facilitating identification of a variety of phenomena including roads, trails, and objects

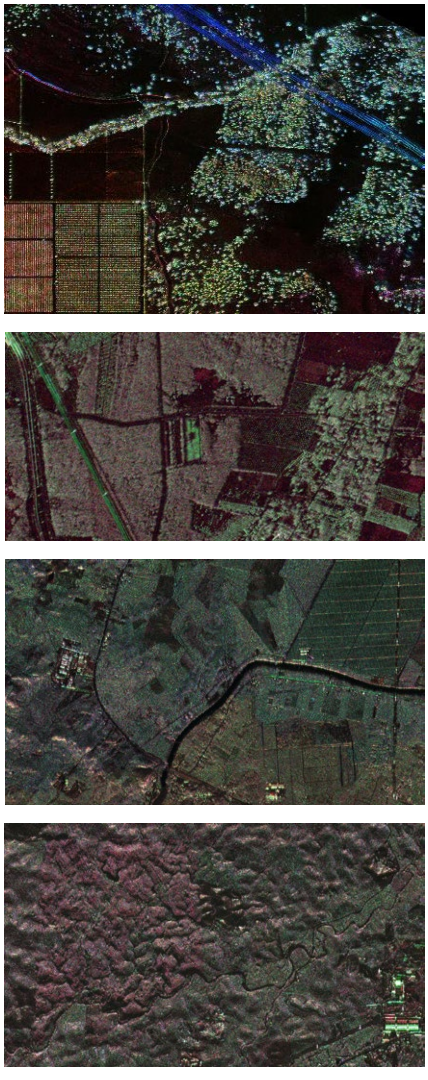

Figure 4: Multi-polarized P-band image showing high-definition detail such as sub-canopy structures and transmission line corridor.

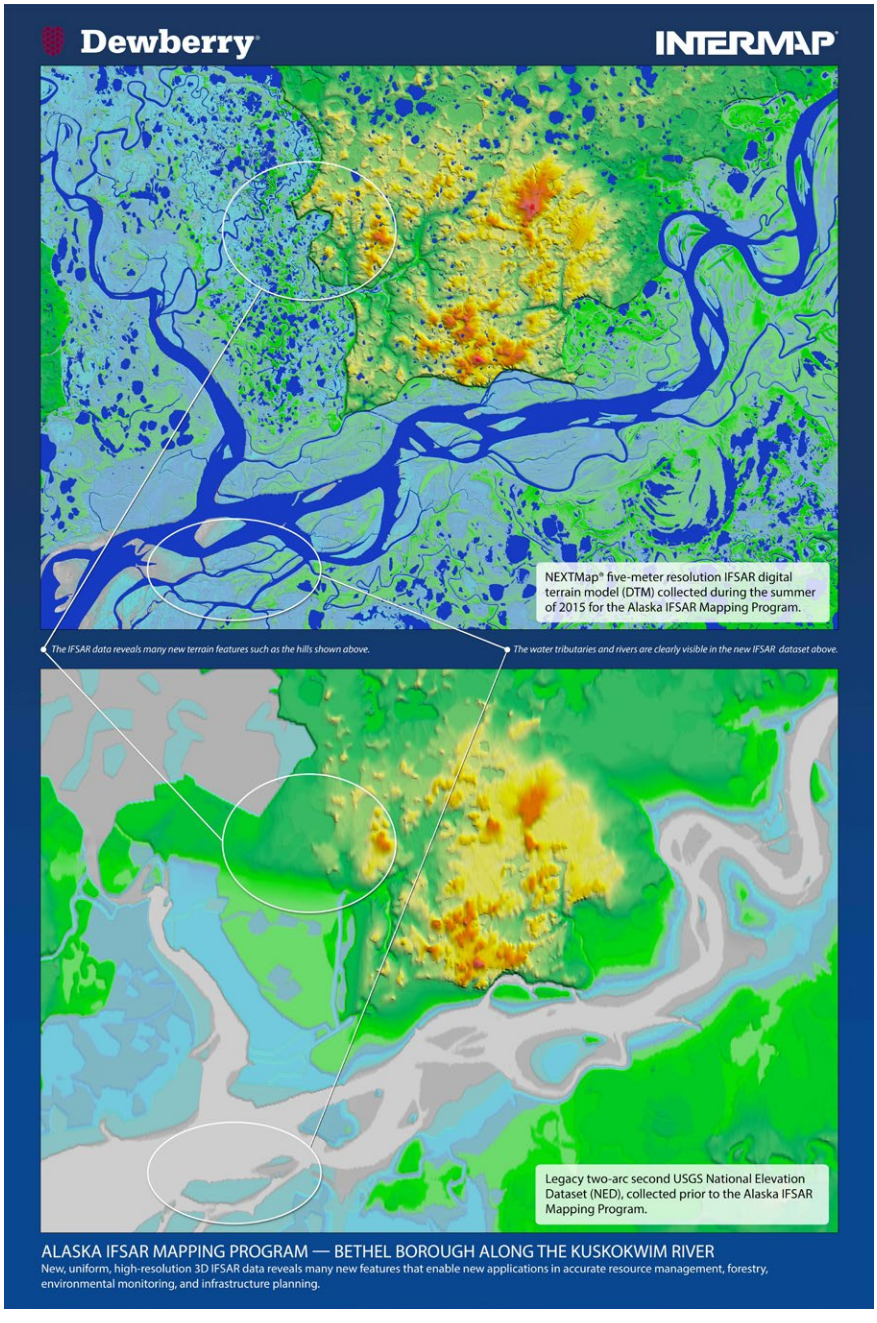

Figure 5: Intermap's 5 m IfSAR DTM (top) shows the improvement in resolution and spatial detail compared to the 2 arc-second legacy USGS NED (bottom).

or infrastructure otherwise obscured under dense canopy. With optimal flight planning parameters, data collection rates can exceed 10,000 square miles per sortie. Intermap's P-band SAR imagery is delivered as 24-bit tri-colorized RGB GeoTIFF, with each polarization mapped to a single color-channel (**Figure 4**).

Global experience

Intermap has collected more than 16 million square kilometers of IfSAR data for government projects on six continents. Clients include defense departments and national mapping agencies, as well as airport authorities and large regulated industries such as oil and gas, utilities, transportation, environmental protection, and insurance. Some major recent government projects include the U.S. Geological Survey (USGS) Alaska Mapping Initiative, Philippines national mapping program, Peninsular Malaysia mapping project for JUPEM[1], and lidar fusion in Dominica.

Figure 5 demonstrates the vast improvement governments can realize when they leverage airborne IfSAR, especially in cloud-prone regions. When USGS and the state of Alaska required updated statewide elevation data, Intermap provided partner agencies with an IfSAR solution to meet their stringent accuracy requirements across the rugged, remote, and often cloud-covered state. Over the course of 10 summer-flying seasons, Intermap was tasked with collecting and delivering seamless DSMs and DTMs at 5 m post spacing, along with detailed hydrology vectors and cloud-free 62.5 cm orthorectified radar imagery. The total area collected and delivered exceeded 1,150,000 square kilometers, covering 78% of Alaskan territory, including the North Slope, the Brooks Range and the entire Aleutian island chain (**Figure 6**). Intermap's deliverables consistently exceeded all contract specifications, on time and under budget, bringing Alaska's outdated state maps up to national mapping standards. The data is now being used to improve the economy, quality of life and safety of all Alaskans, while satisfying needs for flood modeling, flight safety, environmental monitoring, and climate change adaptation in America's last frontier.

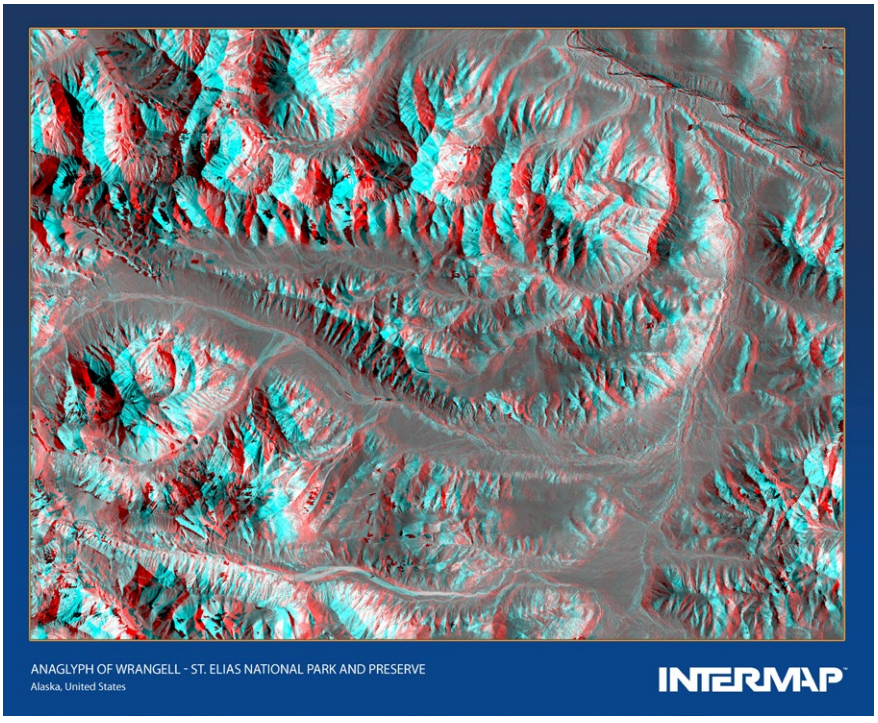

Figure 6: This IfSAR anaglyph of Wrangell–St. Elias Park and Reserve can be enjoyed by using 3D glasses.

The future

Intermap continues to invest in research and development, building new solutions, and growing its library of AI-driven algorithms, making each new solution faster, more affordable and richer in information. Intermap deploys globally, delivering products and solutions with simple and lightweight architectures, through the cloud or behind a firewall. Whether the requirements are for a national mapping program, better terrain awareness, change detection, feature extraction or predictive analytics, clients around the world can leverage Intermap to optimize their geospatial investments.

1 Jabatan Ukur dan Pemetaan Malaysia, the Department of Survey and Mapping Malaysia.

Ian Wosiski is Intermap's managing director of national sales and strategic accounts. Based in San Diego, California, Mr. Wosiski has over 25 years of experience in business development, program management, remote sensing, computer graphics, visualization, and feature-film visual effects. Please send technical questions, sample data requests, and business inquiries to iWosiski@intermap.com.

Thought Leader, *continued from page 48*

potentially regulated product or service should be aware of and understand how specific state regulations impact their practice, because each state regulates geospatial products and services differently. Products or services that are regulated in one state may not be regulated the same way (or at all) in another state. For the practicing geospatial professional (whether an engineer, surveyor, photogrammetrist, GISP or UAS pilot), knowledge of an individual area of practice is essential. Knowledge of state, local and possibly even federal regulations is required to properly perform services, provide products, and fulfill contractual requirements for clients.

As mentioned earlier, the geospatial industry is going through rapid changes as advances are made in measurement technologies and capture platforms. The miniaturization of measurement technologies (e.g., imagery and lidar systems), combined with the new and readily available low-cost UASs, has created an unprecedented opportunity for both individuals and firms to get into the business of collecting data to support an ever-expanding variety of geospatial products and services. The field-to-finish (e.g., black box) software solutions supporting these developments enable anyone to provide products that appear to be the same as those that have historically been created utilizing validated photogrammetric methods.

At almost every major geospatial conference in the last few years, the "big" giveaway is a UAS. Does this mean that anyone can use this technology to create and provide services to the public? Various states have proposed or enacted legislation that clearly states otherwise. Over the last few years, regulations have been enacted by over twenty (20) states regarding UAS use[3]. FAA enacted its Section 333 exemption policies through the FAA Modernization and Reform Act of 2012[4] and in November 2015 published its report[5], in which it recommended that all UASs flying within U.S. airspace that have a mass of more than 250 grams (0.55 pounds) be registered with FAA.

The new legislation and rules are examples of how the landscape of certification and licensure is being affected by new technologies. These rapid changes beg the questions as to which geospatial products and services should require certification and which should require licensure. How will the current and future practice of certified and/or licensed professional practice be affected by these changes? The answers to these questions will define the future of all practicing geospatial professionals, whether they are engineers, surveyors, photogrammetrists, GISPs or UAS pilots.

To help facilitate appropriate regulations regarding certification and licensure, the ASPRS Professional Practice Division (PPD)[6] proactively engages states to discuss potential legislative changes and assists states by reviewing current and proposed state licensure laws related to geospatial products and services. ASPRS PPD works with individual states to ensure that there is an available licensure path for appropriately educated and experienced professionals. ASPRS PPD also actively engages other national geospatial organizations (URISA, NSPS, MAPPS, etc.) to coordinate efforts of regulation review and interpretation, with the goal of appropriately advising legislative bodies on legislation relating to existing and future geospatial products and services. Additionally, ASPRS has formed its Unmanned Autonomous Systems Division[7], the objectives of which include outreach and education, liaising with UAS-interested parties outside the Society, development and promotion of standards and best practices, establishment of calibration and validation sites, and credentialing and certification activities.

While it is in the best interest of every practicing professional to be active in his or her individual national organizations, it is incumbent upon every practicing geospatial professional to stay up to date on the specific rules affecting his or her practice. This combination is the only way to ensure the appropriate implementation of certification and licensing requirements, while also safeguarding the health, safety and welfare of the public in our fast-paced geospatial world.

3 ncsl.org/research/transportation/current-unmanned-aircraft-state-law-landscape.aspx
4 faa.gov/uas/resources/policy_library/media/Sec_331_336_UAS.pdf; faa.gov/uas/resources/policy_library/media/section333_public_guidance.pdf
5 faa.gov/uas/resources/policy_library/media/Micro-UAS-ARC-FINAL-Report.pdf
6 asprs.org/divisions-committees/professional-practice-division
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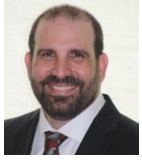

Mike Zoltek is a land surveyor, photogrammetrist, and GIS professional with over 30 years of geospatial experience. As the National Geospatial Program Director at GPI Geospatial, Inc. (GPI), Mike is responsible for the coordination, execution, and supervision of projects for local, state, federal, DOT, and private clients. Mike currently serves as chair of the ASPRS Evaluation for Certification Committee, overseeing the Society's certification program. Mike has presented numerous technical seminars at universities and community colleges, as well as at industry conferences, and as has served as expert witness in boundary litigation cases in the state of Florida.

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BY MIKE ZOLTEK

Licensing, Certification and New Technologies[1]

Education and professional development in the geospatial community

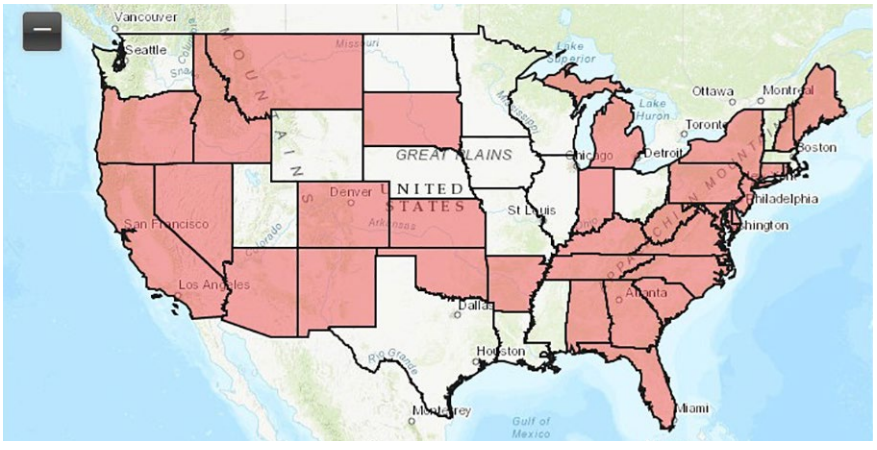

Figure 1: State licensure map—authoritative imagery; from the ASPRS "Licensure Maps and Regulations" website.

It is a challenge in the current environment of fast-paced technological advancement to ensure that those providing products and services are both capable and qualified to fulfill the needs of clients and customers. How do users of current and future technologies choose providers? How do they know that the product or service they are receiving will have a reasonable level of correctness and completeness? Licensure and certification have provided traditional paths for demonstrating knowledge and technical proficiency. "Certification" has historically been utilized to evaluate and ensure technical competence, while "licensure" has traditionally been the mandate of legislation (at both the state and federal levels) premised by the need to "*protect the public health, safety and welfare*." Traditional requirements to become licensed include a combination of a defined level of formal education, experience (e.g., time), demonstrated competency in practice (e.g., examples of past work), references from other licensed persons and validation by testing.

Licensing has long been a requirement for doctors, lawyers, engineers and land surveyors. As technologies have advanced, many states have realized the need to license photogrammetrists, providers of a variety of geospatial information (e.g., geographic information systems professionals, or GISPs) and, more recently, those providing lidar data collection and processing services by operating unmanned aerial systems (UASs), such as pilots and/or flight planners. As more states enact legislation relating to existing and new geospatial products and services, it is difficult for practicing professionals, state and national organizations, and the public to keep up with changes to existing rules and regulations and the addition of new rules and regulations. The American Society for Photogrammetry and Remote Sensing (ASPRS), as the leading scientific organization representing the photogrammetry and remote sensing profession, provides a resource to readily access this new and changing information. **Figure 1** is part of the "Licensure Maps and Regulations" website[2], which gives metadata on state surveying regulations, board website, individual state regulations and composite state regulation document; and state licensure maps for GIS services, lidar and topographic products, georeferenced imagery, and authoritative imagery.

As of this writing, twenty-one (21) states have existing regulations relating to georeferenced imagery products and services; thirty-three (33), relating to authoritative imagery products and services; forty-seven (47), relating to topographic mapping-related products and services (which includes lidar services); and fifteen (15), relating to GIS-related products and services.

A list of the current regulations is just the first step. Every provider of a

1 This article is an updated version of a previously published paper: Zoltek, M., 2019. Licensing, certification and new technologies, Photogrammetric Engineering & Remote Sensing, 85(9): 621-622. doi: 10.14358/PERS.85.9.621. Published here with permission from the American Society for Photogrammetry and Remote Sensing, Baton Rouge, Louisiana, www.asprs.org.

2 asprs.org/news-resources/licensure-maps-and-regulations

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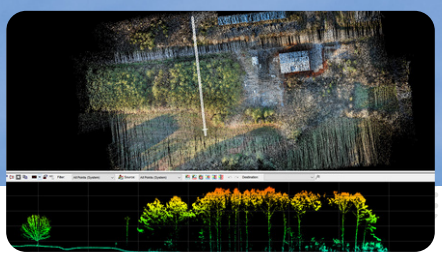

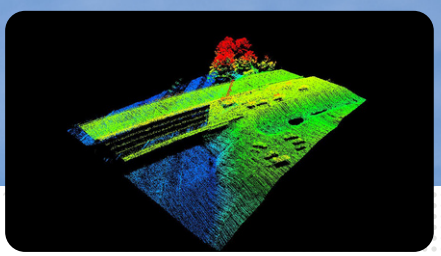

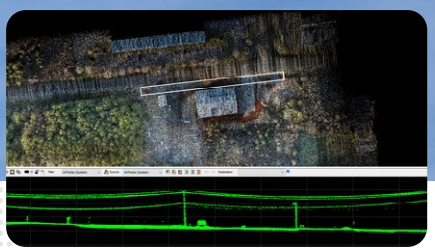

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