APOGEO SPATIAL

ELEVATING GLOBAL AWARENESS

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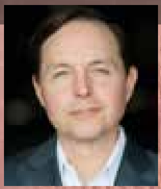

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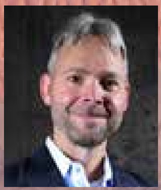

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"QKD is the ultimate in security. It's guaranteed by the laws of physics."
-David Mitlyng, CEO of Speqtral Quantum Technologies, Inc.

PanaMapping:

Mapping the Mamoní Valley Preserve in Panama

"A line drawn through the Mamoní Valley Preserve in Panama from the Pacific north to the Atlantic would be only 60 km long (37 miles) and so conserving it widens the Mesoamerican Biological Corridor, a thread of land connecting North and South America."
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FORMERLY Imaging NOTES

This image of the Sahara Desert in Algeria is pictured from the International Space Station. See page 4 for more info.

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COVER IMAGE

Sahara Desert in Algeria

This image of a portion of the Sahara Desert in Algeria was taken by Italian astronaut Luca Parmitano from 260 miles above north Africa, from the International Space Station on July 26, 2019.

Luca is an Italian engineer and astronaut in the European Astronaut Corps for the European Space Agency. He was selected as an astronaut in May 2009.

The image is published as part of a partnership between *Apogeo Spatial* and NASA. More photos appear on pages 32-34.

APOGEO SPATIAL

Formerly Imaging NOTES

MISSION

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News: Quantum and Blockchain in Space

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Dear Readers,

As a quarterly magazine, it is rare that we get to announce actual news for our space and satellite industry. In this issue, we get to do just that! I interviewed David Mitlyng, CEO of Speqtral Quantum Technologies and COO of Singapore-based parent company SpeQtral, about SpeQtral's satellite that is currently on orbit testing Quantum Key Distribution (QKD) in space (and doing quite well)! They are the first commercial company doing so in the world, though the government of China has been using quantum technologies in space for several years. Read our interview with David on page 16 and listen to the podcast at www.ApogeoSpatial.com.

Breaking news also came from blockchain company ConsenSys during the 70th International Astronautical Congress in October. The reason that they acquired asteroid mining company Planetary Resources a year ago is now clear: The company has launched a new branch called ConsenSys Space, as well as its first platform-led initiative – TruSat, an app-based system that makes use of crowdsourcing and Ethereum blockchain technology to monitor and provide a trusted record of satellite orbital positions.

Blockchain technology (best known as a software-based foundation for cryptocurrencies) will provide transparency about the source of orbital data. It's an open source answer to space debris, working ultimately toward space sustainability. Given that, it's no surprise that Secure World Foundation, a long-time partner of *Apogeo Spatial,* is involved. Watch for coverage of ConsenSys Space and their innovations in upcoming issues.

The Mamoní Valley Preserve (MVP) in Panama is a land conservancy nonprofit dedicated to conservation and education. It's featured on page 22, with its sophisticated maps of land cover, watersheds and carbon sequestration, each created in partnership with University of Redlands Center for Spatial Studies. The article is an excerpt from the book, *GIS for Science: Applying Mapping and A Spatial Analytics*, originally published by Esri Press.

MVP is part of the umbrella organization of Geoversity, which is an ecosystem of leaders and organizations collaborating in the pursuit of breakthroughs in human design, enterprise, and creative expression, inspired by nature. Geoversity's main campus is Centro Mamoní, a rainforest science, research, retreat and training center in the Preserve that was established by Fundación Geoversity. This center is strategically located in forested land on the continental divide, which is also the southern border of Gunayala, an autonomous territory of the indigenous Guna people. Geoversity works closely with the Guna, and leads expeditions across the continental divide, immersing people in nature for life-changing experiences.

Dylan Taylor's column, ***Spatial Capital***, is about investing in space companies. He shares the importance of companies that are manipulating satellites in orbit, such as Tesseract, Accion Systems and Momentus, on page 12.

In our ongoing partnership with NASA and the International Space Station, we continue to publish photos from the ISS on page 32. In our next issue, we'll share how instruments on the ISS are used to monitor plastics in the ocean.

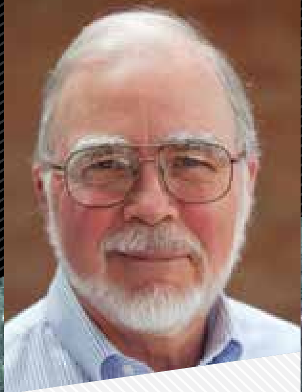
I attended two events that expanded beyond our usual geospatial world this summer: Earth's Call in Aspen in May, and The NOVUS Summit in NYC in July. Both included people and sessions committed to making sure that Earth is inhabitable in the future. For example, at the NOVUS Summit, Marc Collins Chen, CEO of Oceanix, shared their planned communities that will float in the sea; as the sea rises and takes over more land, these will be needed in the future.

I'm grateful that Ray Williamson is still our editor, being mostly retired in beautiful Cortez, Colorado these days, and for his commitment to our industry. His missive about climate change is on page 8.

I will be moderating panels about NewSpace companies at next year's GeoBuiz Summit in Monterey, California, in January as well as at Geospatial World Forum in Amsterdam in April. See pages 6 and 21 for more info. I hope you'll join us!

Warmly,

Myrna



Ray A. Williamson
Editor, *Apogeo Spatial*

CLIMATE CHANGE:

1

Figure 1.
Paradise Pines, California pictured on Sept. 10, 2018, prior to the fires. Satellite image ©2019 Maxar Technologies.

Figure 2.
The Camp Fire in Paradise, California on Nov. 9, 2018, showing the town in flames via WorldView-3's short-wave infrared sensor. Satellite image ©2019 Maxar Technologies.

Climate change, climate change, climate change…After years of being a niggling background issue for many, the effects of climate change are now front page news, whether it's the incredible destructive power of 2019 Hurricane Dorian over the Bahamas, the intense Camp Fire that took out nearly the entire town of Paradise, California in 2018, or the slow but relentless loss of ice in the Arctic and Antarctic and of glaciers around the world. I never thought I would see a front page treatment of climate change in *USA Today*, but recently this ubiquitous newspaper led with an article entitled, "Climate Change is Coming for Your Wine." [1]

If there was still doubt about the destructive character of climate change, the recent United Nations report, *Climate Change and Land: An IPCC Special Report on Climate Change, Desertification, Land Degradation, Sustainable Land Management, Food Security, and Greenhouse Gas Fluxes in Terrestrial Ecosystems*[2] makes clear that living beings around the globe will be in a world of hurt if we don't respond with verve and ingenuity to the imminent crisis.

The UN report emphasizes that no part of the world will be unaffected by the continuing effects of climate change. Although the three examples cited above are among some of the most dramatic warnings, highlighting human anguish and loss in vivid headlines and disturbing photos, the myriad less dramatic, slow-developing effects can be just as worrying and destructive over the long run.

The Looming Threat That Can't Be Wished Away

Editor's Note: See also Maxar SDG Special Section to read more about how EO data is important for achieving the UN SDGs, on page 28.

Where I live in Southwestern Colorado, we see increasing periods of drought and the slow migration of species moving north. My wife and I recently experienced vivid evidence of species migration when a Roadrunner, a non-migratory bird endemic to the deserts of southern New Mexico and Arizona several hundred miles south, became caught in one of our fences. Fortunately, we were able to help it escape without damage and it quickly ran away. This was the second appearance of a Roadrunner on our property in two years, indicating a steady movement of the species northward.

Birds, mammals, reptiles, and fish can often move with changing conditions, but the trees cannot, so they tend to weaken and die out when the climate becomes too hot and dry, leading to loss of biodiversity. In our area of short piñon-juniper forests, the piñon trees are succumbing to the depredations of the bark beetle, which move in right along with the drought, and don't freeze out with warmer temperatures.

We are now losing our own piñon trees at an alarming rate, primarily as a result of the continuing drought conditions. In the higher elevations to the north and east of our area, millions of Ponderosa trees have fallen victim to the combined assaults of bark beetle infestation and drought. These losses leave the area increasingly prone to damaging forest fires.

Elsewhere in the world, climate change is producing many disturbing alterations in the environment. As recently reported in *The Guardian*, the Hindu Kush-Himalayan ice sheet has lost 25 percent of its ice since 1970. The reason that such a loss is especially concerning is because this ice sheet is the third largest ice sheet, encompassing about 15 percent of the world's total ice. *The Guardian* article calls this "the water tower of Asia," supplying the water for 10 of the world's largest rivers, including the Ganges and the Mekong. What will happen to those rivers, the lifeblood of millions of people of SE Asia, when this enormous ice sheet melts completely? Sadly, crucial data about the changes occurring in this enormous ice sheet and the downstream effects are very hard to come by, the result of secrecy and other restrictions on access to the glacier and country-specific hydrological data. [3,4]

Although the United States and most of the rest of the world have been slow to respond to the looming crisis, there is still much that can and must be done to: 1) limit the average rise in global temperature; and 2) mitigate damage to our economic and personal well-being as the effects of climate change become increasingly apparent.

Fortunately, Earth observations (EO) data collected from satellites, aircraft, and drones provide crucial information needed for tracking and combatting the effects of climate change. Beyond climate change, EO data can also alert scientists to environmental degradation caused by industrial farming, over-development, and other damaging environmental practices.

Although most of the advantages of EO are common knowledge to most of our readers, it is worth reviewing the key elements of these advantages:

1. ***Synoptic view:*** Satellite images allow researchers to capture a large area at one time, permitting comparisons.

Figure 3.
On overview of the fire, with the town shown in upper left corner (image is rotated), Nov. 9, 2018. Satellite image ©2019 Maxar Technologies.

2. ***Repeatability:*** The ability to capture imagery under similar observing conditions allows for the retrieval of long series of observations over time. Series of observations over weeks, months, and even many years are possible, allowing researchers to follow temporal changes closely. Landsat satellites, for example, have been operating since 1972, making possible long-term comparisons.

3. ***Wide range of geographic scales available:*** From satellites to aircraft and drones, a wide variety of image coverage and resolution are available, allowing a range of scales from 10s of meters to sub-meter resolution.

4. ***Wide range of temporal scales available:*** Using the multitude of both government and private sector satellites at different repeat cycles, as well as numerous EO aircraft now available, both slow and fast-changing conditions can be monitored with ease.

5. ***Increased transparency compared to in-situ observations:*** For parts of the world that are closed to aircraft or drone operations, satellite systems offer an important way to gather environmental information.

The bottom line is that the information revolution, coupled with a wide-ranging mix of public and private data sources and specialized analytics software, enable detailed analysis of climate change and the effects it causes to the world's varied environments.

We aren't talking just about imagery, either. Numerous operational sensors are looking for harmful methane and other gases, and for broad-scale changes in land and ocean surface temperatures.

Information derived from Earth observations data has another, underappreciated advantage over many other data collection methods. It often provides clear visual evidence of changes to Earth's ecosystems over time, countering the stubborn resistance of so-called climate change deniers. Perhaps more important, such information counters the claims of what Nathaniel Stinnett at BuzzFeed term "climate liars," – people who understand and accept the science of climate change but nevertheless deny it for political or narrow commercial motives.[5]

I don't expect to convince climate deniers; they'll always find a way to twist the facts to suit their closely held preconceptions. Even less do I expect to convince the climate liars, who have a political and/or financial stake in not publicly admitting the truth about climate change and its serious effects on the environment. On the contrary, the goal is to demonstrate to as many people as possible in the middle that we face a climate change crisis. Earth observations can go a long way to do that, especially those who will be most affected by the environmental alterations wrought by climate change.

Finally, and perhaps most important in this political moment, Earth observation technologies allow us all to document the effects of climate change in detail and use that information to tell better, more accurate stories about how climate change will impact all our lives now and in the future.

As we go forward, *Apogeo Spatial* will focus more and more of its attention on how Earth observations can assist in documenting and combatting the worst effects of climate change.

Figure 4.
Image of the Bahamas underwater after Hurricane Dorian, Sept. 2, 2019. Synthetic Aperture Radar image courtesy of ICEYE.

Endnotes:

1. Climate change is coming for your wine. What the world's wineries are doing to save grapes. https://www.usatoday.com/story/news/nation/2019/09/08/climate-change-threatens-worlds-wineries-which-grapes-saved/2136457001/.

2. Intergovernmental Panel on Climate Change Report: Climate Change and Land, Summary for Policymakers: https://www.ipcc.ch/site/assets/uploads/2019/08/Edited-SPM_Approved_Microsite_FINAL.pdf.

3. The world has a third pole – and it's melting quickly: https://www.theguardian.com/environment/2019/sep/15/tibetan-plateau-glacier-melt-ipcc-report-third-pole.

4. Changing climate imperils global food and water supplies, new U.N. study finds: https://www.washingtonpost.com/climate-environment/2019/08/08/solving-climate-change-requires-fixing-forests-food-landmark-un-report-finds/.

5. Climate deniers and climate liars: https://www.buzzfeednews.com/article/nathanielstinnett/climate-deniers-and-climate-liars.

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Next Bet: Manipulating Satellites in Orbit

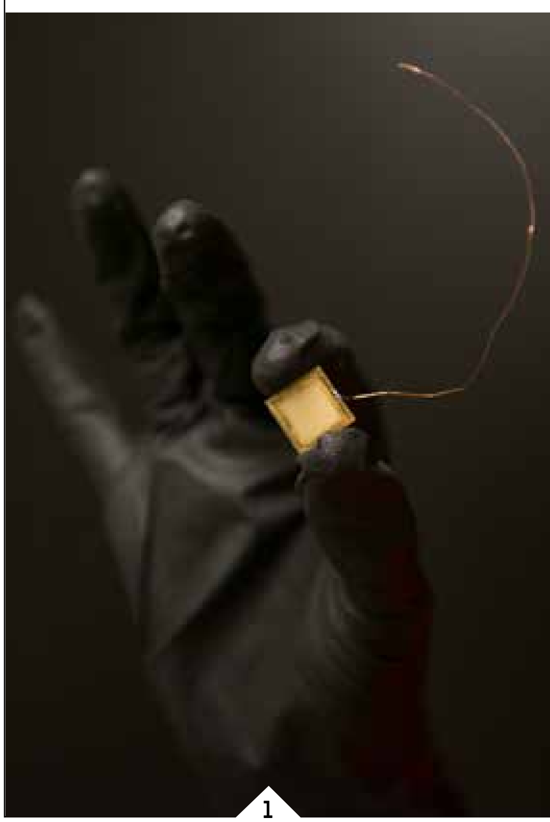
The Importance of On-Orbit Servicing & In-Space Propulsion

Voyager Space Holdings is a privately held global holding company acquiring and operating companies in the space exploration industry. Voyager seeks to increase vertical integration and mission capability to enable humanity's most ambitious projects.

By all accounts, the past ten years have been the golden age of NewSpace start-ups. From SpaceX to the smallest NewSpace companies formed just for Phase 1 SBIRs, the industry has seen an explosion of investment since 2010. According to Space Angels, a leading investor group that tracks space investment, that amount of investment has now exceeded $23B since 2010, growing exponentially in the past 24 months. A large portion of this capital in recent years has been focused on launch and the capability to get mass (actual satellites and payloads) to orbit. I believe the next phase of the industry's growth will now be the ability to manipulate mass while in orbit.

The Little Tug That Could

The most straightforward aspect of in-space servicing is the so-called "tugs" or technologies that allow for hardware in space to be inserted into different orbits (moved from one orbit to another), and in some cases, de-orbited. The two main technologies associated with this capability are the in-space thruster capability (in-space propulsion), and the ability to grapple the hardware to secure it while it is being manipulated. Both of these technologies have seen huge inroads in the past few years. Ion-based propulsion seems to be the most popular technology for in-space propulsion,



1

2

> *"As LEO becomes more and more crowded, collisions in space will become increasingly likely. Given some of the national defense implications of this occurring, it is highly likely that regulations will become much tighter as the industry rolls forward."*

3

Accion Systems (see Figures 1-2) and others being leaders in this regard. There are other propulsion technologies such as water-based (Momentus in Figure 3) and even chemical solids (Tesseract, see Figures 4-5) and nuclear power (Atomos Nuclear and Space) that have their use cases as well. Grappling technologies vary from permanent magnets to electro-magnetic technology that can be turned on and off like a switch to grapple and release.

With this new on-orbit capability, hardware design will undoubtedly change and we are already seeing early evidence of this fact. Now it isn't impractical to refuel satellites or raise their inclination (including the ability to de-inclinate or de-orbit) and even "upgrade satellites" via a sort of USB port capability. In addition, the ability to assemble larger structures while in orbit also becomes possible, if not completely practical. This will be a key technology with NASA's Gateway structure that will be put in place to enable its Artemis Moon landing program, which is targeted for 2024.

Regulatory Impact

Another element driving the on-orbit servicing capability is regulation. As LEO becomes more and more crowded (the classic tragedy of the commons), collisions in space will become increasingly likely. Given some of the national defense implications of this occurring, it is highly likely that regulations will become much tighter as the industry rolls forward. I would expect a requirement to de-orbit or move satellites within the next few years. If this happens, all hardware will need to design a grappling technology into their hardware or to design the ability to de-orbit, or in some cases both.

Figure 1.
Accion Systems' technology is built around a thruster "chip" architecture. Each chip houses hundreds of microscopic emitters that produce beams of ions generated from a novel propellant source: ionic liquid.

Figure 2.
Accion's TILE product is modular and scalable and is made up of three parts: thruster chip, power electronics, and propellant tanks. Seen here is the TILE 500.

Figure 3.
Momentus satellite shuttles are powered by water plasma engines.

4

Impact of Deep Space Missions

Another driver of on-orbit servicing are the several deep space missions planned for the next five years. As of this writing, at least five cis-lunar missions are planned as well as other missions associated with NASA's Gateway project to enable its Artemis Moon landing program. All of these deep space missions will rely on in-space capabilities and infrastructure – all of which are additive to the on-orbit servicing focus and capital pool. I would expect other infrastructure items to be driven by these deep space missions as well, including space-based power generation and in-space communication and the addition of higher bandwidth for data transmission.

What is Next?

As the industry evolves, on-orbit servicing is likely to be the largest area of innovation and investment over the next several years. Here is what to expect:

• Standardization of capture technology

Given the number of large constellations contemplated, it is likely that elements of in-orbit technology will become more standardized. I would expect two to three key grappling capabilities emerging that the industry focuses on.

• Winner and losers in in-space propulsion

Similarly, for in-space propulsion, I would expect the industry to coalesce around one to two ion-based propulsion technologies and perhaps one solid-based propellant propulsion technology. Nuclear propulsion, a technology nearly everyone agrees is the best long-term solution, seems to be impractical at this time due to regulatory concerns.

• In-space refueling

In-Space refueling will also emerge as a necessary capability and I would expect this to likely be close to a winner-take-all market, meaning I would expect one key standard to emerge similar to what we have seen for energy solutions here on Earth. The reason is that in-space infrastructure is expensive and in order for re-fueling to be built upon scale, the size of the market will need to be aggregated.

• Space-based manufacturing and assembly

Longer term, I believe on-orbit servicing will enable more space-based manufacturing and the assembly of larger hardware structures. This will likely occur once the other standardization happens and once the in-space capabilities mature. I would think this should happen in five years or less.

Conclusion

In-space serving is the new golden child of space investment. This new flow of capital will further enable the ability to maneuver in space, capture hardware, manipulate its orbit and/or refuel and upgrade its capability. As the infrastructure continues to evolve, we can expect higher levels of standardization and capability. This in turn should lead to higher level capabilities such as in-space manufacturing and assembly. In-space serving is a classic enabling technology and could be the lynch pin that helps the industry reach its full potential.

Figure 4.
Tesseract Polaris orbital servicing vehicle maneuvering to refuel a satellite.

Figure 5.
On the left is a small satellite in gold-colored multi-layer insulation with Tesseract Adhara propulsion shown at the bottom. The small satellite is refuelable by including reusable fueling ports, and with separate data and power ports, the satellite computing and sensors are upgradable by the Tesseract Polaris orbital servicing vehicle shown on the right. Polaris is shown with a stack of 12 small satellite deployers attached. This system can deploy each of 12 satellites to their own unique orbit, and after deployment refuel and upgrade additional satellites.

David Mitlyng
COO of SpeQtral
CEO of Speqtral Quantum Technologies, Inc.

Myrna James Yoo
Publisher and Managing Editor
Apogeo Spatial

Quantum Key Distribution – in Space!

SpeQtral Launches First Commercial Satellites for QKD

EDITOR'S NOTE:
In a rare opportunity, Apogeo Spatial is publishing this exclusive news, announcing the first commercial company in the world that is testing quantum communications in space.

"LET'S SAY I'M ON A SATELLITE AND YOU'RE A GROUND STATION. IF I'M SENDING YOU THOSE PHOTONS, AND A BAD GUY, AN 'EAVESDROPPER,' INTERCEPTS THOSE PHOTONS INSTEAD OF YOU, THE QUANTUM PROPERTIES ARE BROKEN AND WE BOTH KNOW IT. SO IT'S A LOW DATA RATE, BUT A VERY SECURE APPLICATION. IT'S THE ONLY TYPE OF COMMUNICATION WHERE WE WOULD BOTH KNOW IF SOMEBODY TRIES TO EAVESDROP OR INTERCEPT THE LINK, THE MESSAGE."

Myrna James Yoo: Thank you for joining us, David.

David Mitlyng: Well thank you, Myrna. It is my pleasure to be here. I'm happy to talk to you today about our company SpeQtral and tell you all about the world of quantum communications.

Myrna James Yoo: Very exciting. First let's share a little bit about your background.

David Mitlyng: My background is with the space industry. I've spent over 20 years working at major satellite manufacturers, including big corporate giants like Hughes (now Boeing), Orbital Sciences (now Northrop) and SSL (now part of Maxar), before transitioning about six years ago to a startup called BridgeSat – now renamed BridgeComm, by the way.

There's this explosion in the space industry in what we call 'NewSpace' where there's venture capital coming into new and innovative ideas around space. So it was a good opportunity to come in and work at a startup that was commercializing optical communications, also known as laser communications. So I was the first employee of BridgeComm back a number of years ago. Now the company's grown and done very well around commercializing optical communications for satellites. They closed their Series B, a year or so ago. They're growing, getting very good business.

Myrna James Yoo: That's great. Now you've switched over to this mindblowing new field of quantum communications and how that's going to be needed and addressed – even in space. So your new company is called SpeQtral – with a Q of course for the quantum aspect.

David Mitlyng: Yes, has to have a Q!

Myrna James Yoo: Share with us a little bit about how this came about.

David Mitlyng: Well, so it turns out that optical and quantum communications are very similar technologies. At the time when I was working at BridgeComm, we would go to these conferences where they were focused on free-space optical communications, and they'd always have these sessions where they talked about quantum communications. At the time it was very fascinating, but it was a bit early – a lot more focused on research and scientific papers. It definitely seemed like a very new and interesting field that provides a very important capability for future satellites. So that was how I originally started getting knowledgeable about this new field.

Myrna James Yoo: Before we talk more specifically about SpeQtral, I understand that computing is going to be switching over to quantum computing in general, eventually. But you're not a quantum computing company, right? It's actually about quantum communications and the applications here, and the important thing is that it will be keeping quantum computers safe. It's really about security, right?

David Mitlyng: That is absolutely correct. You know your stuff. Quantum computing and quantum communications both fall under this broad umbrella of what they call quantum technologies. We get a lot of confusion with people thinking we are a quantum computing company. We are not. Quantum computing very basically is taking particles that are entangled and they are trapping them. There are a number of ways they do that and they manipulate them to get what they call qubits. These qubits are a new way of processing information to do very complex problems. That's a whole different field. A lot of major companies and major investments are working on this.

We're in a different field where we use entangled photons. Photons are particles of light and because they're particles of light, they move at the speed of light. My colleagues like to call them "flying qubits." They both rely on manipulating the quantum properties of small particles. So that's why they both got that label of quantum: quantum computing, quantum communications.

Myrna James Yoo: Now let's talk a little bit more specifically about SpeQtral. You've launched out of a university in Singapore.

David Mitlyng: Quantum communications was invented roughly 30 years ago, with some groundbreaking papers written in the 80s and 90s. There were a number of research labs, research groups, and universities that started with these papers. One of the leaders was the National University of Singapore. Around the year 2000, they set up a quantum research group that eventually became the Centre for Quantum Technologies (CQT). It got very well-funded by the government of Singapore. They brought in Artur Ekert to run it. He's one of the original inventors of the quantum communications QKD protocols. They put together a very advanced lab and research group around doing some groundbreaking work with this new technology.

Myrna James Yoo: So is your company a tech transfer company from that university?

David Mitlyng: Yeah, we like to think we're a spin-out. I look at it similar to how Google was a spin-out of Stanford. All these great startups start with researchers that see a commercial application for their research and form a start-up around it.

Myrna James Yoo: Right. So you're commercializing this technology. QKD is quantum key distribution. How does that fit?

David Mitlyng: So quantum key distribution is an application for quantum communications. The way quantum communications works is similar to optical communications where you start with a laser. Optical communications modulates a laser to send a high data rate, 10 gigabits per second across great distances. With quantum communications, we essentially turn down the power of the laser. So you're getting streams of individual photons and then you manipulate the quantum properties of those photons.

Let's say I'm on a satellite and you're at a ground station. If I'm sending you those photons, and a bad guy, an "eavesdropper," intercepts those photons instead of you, the quantum properties are broken and we both know it. So it's a low data rate, but a very secure application. It's the only type of communication where we would both know if somebody tries to eavesdrop or intercept the link, the message.

Myrna James Yoo: It's very difficult for the communication to be intercepted in the first place, right? It's not like RF where the receiving area is a very broad one.

David Mitlyng: Yes – well, absolutely. For people who are very worried about security, this is the ultimate in security. It's guaranteed and backed by the law of physics.

Myrna James Yoo: You're guaranteed by the laws of physics!

David Mitlyng: Yep. The protocols that were written have undergone nearly 30 years of scrutiny within the security and scientific community and no way to overcome this has been found yet. It's considered very secure.

Myrna James Yoo: What is the problem that QKD solves?

David Mitlyng: Quantum key distribution is a way to securely distribute encryption keys. Now, the way keys are distributed today is through public key encryption. The vast majority of encryption keys are submitted through this algorithmic cryptographic method. And then those keys are used to encrypt your messages, your very valuable and sensitive data. So far, public key encryption has not been cracked. It's computationally intensive and it's very difficult. But quantum

Quantum Technologies

developed by harnessing the quantum property of Entanglement

Quantum Computing
Uses stationary entangled particles to create qubits

Quantum Communications
Uses entangled photons, or particles of light, to create "flying qubits"

Quantum Metrology
Uses quantum properties for advanced sensors

Quantum Teleportation

Quantum Clock Synchronization

Quantum Key Distribution (QKD)
The secure distribution of encryption keys

Quantum Radar

Quantum Networking

How QKD Works

Inside the satellite is an Entangled Photon Source that converts blue photons from a weak laser into pairs of red photons that are entangled.

Once entangled, these photons share a "spooky" connection One set is measured on the satellite, one set is sent to the ground.

An eavesdropper will attempt to intercept or "spoof" the signal by intercepting and retransmitting these photons.

But the quantum properties are broken and the Ground Station will know they are not from the Satellite.

QKD Solves a Major Upcoming Problem

Encryption keys are created with each satellite pass, which are then used to encrypt normal communications. Today keys are distributed through Public Key Encryption (PKE), which in the future will be cracked by quantum computers. It is only a matter of time before this happens, which has been deemed the Quantum Apocalypse! Then, QKD will be needed to keep communications secure.

computers, once they reach a certain capability, will be able to crack existing public key encryption protocols within seconds. And this is a known issue. A number of groups are aware of it. It's just a matter of when quantum computers are going to get to that point. Is it five years away? Is it 10 years away?

QKD is a method of replacing public key encryption, which will be much more secure.

Myrna James Yoo: You're talking about what's going to happen after computing switches to quantum computing, which is really inevitable, so you're really thinking ahead about security.

David Mitlyng: Yes. We want to get this up as an infrastructure to offer to anybody who needs secure communications well ahead of what is being called the "Quantum Apocalypse." However, before we reach that point, there's a point called "Quantum Supremacy," where quantum computers have advanced up to the point where they are more capable than the most advanced supercomputer available today. You may have seen this in the news. Google announced on Oct. 23 that they reached that level.

Myrna James Yoo: They were working with NASA on that project, right?

David Mitlyng: That is correct. NASA inadvertently released the paper announcing this a few weeks prior, and it was retracted, but the news is out. It spread like wildfire. Quantum Supremacy has been reached. Now that quantum computer, according to the paper, is roughly around 50 qubit capability and you roughly need around 4,000 qubits before you hit Quantum Apocalypse, before public key encryption could be easily cracked. So, it's just a matter of time before Google, Alibaba, IBM, Intel – all these groups that are working in quantum computing in their race to reach that level – achieve that point.

Myrna James Yoo: This is all happening a lot more quickly than we realize, I have a feeling.

David Mitlyng: Yes. I think that is another reason why there's a lot of interest in the system we're developing because there's a concern that quantum computing is racing forward much quicker than Moore's Law predicts. And then we may be reaching Quantum Apocalypse before people expect.

Myrna James Yoo: So your satellite went up to the International Space Station in April?

David Mitlyng: That's correct.

Myrna James Yoo: Then in June the astronaut Nick Hague, who is featured in this magazine with his photos of the earth, coincidentally was the one who actually launched your satellite from the space station. So it's been on orbit since June, is that right?

David Mitlyng: Yes. The satellite name is SpooQy-1, again with the Q. It is named from the famous Einstein quote where he called quantum entanglement "spooky action at a distance." SpooQy-1 was built and developed as a research project at CQT. A lot of the engineers at my company worked on it when they were researchers at CQT to do some demonstration of this quantum payload, what we call an entangled photon source. The professor Alex Ling is the lead researcher at CQT. They run through the payload. They've done a number of tests on it, so keep an eye out because they'll release a scientific paper on this with the results probably next year sometime. I'll give you a little spoiler: the payload performed well.

Myrna James Yoo: That's really great! So it's actually on orbit. It's actually testing and things are looking great.

> "THIS IS THE ULTIMATE IN SECURITY. IT'S GUARANTEED BY THE LAW OF PHYSICS."

David Mitlyng: Yes.

Myrna James Yoo: My understanding is that you're the only commercial company currently testing QKD on orbit in the world?

David Mitlyng: Yes. Now, I'd like to point out here too, that there is one other group that has on orbit demonstration of QKD. That's the Chinese government. They launched a satellite called Micius a few years ago that made a lot of headlines. When people search QKD, that's the first hit that comes up because that satellite did three groundbreaking experiments, including various flavors of QKD. Because of the success of that satellite, the Chinese government has now committed many more billions of dollars into launching more satellites as part of what they call a "QKD Internet" or the "Quantum Internet." So they've definitely got a very advanced design and a very advanced system.

Now our strength really is, number one, we are more commercial, as you said. We've got a commercial focus on what we're offering. The other thing we have is our team, the CQT team, who has spent a lot of time and effort taking a very large and complex set of quantum optics and miniaturizing it to fit on a cubesat, roughly the size of a loaf of bread.

The Chinese launched a very large satellite that was 630 kilograms. So their system is bigger, heavier, but more capable.

So we went a different direction where we're getting the technology to fit in a small size compact package and something that is inexpensive because we feel that for a commercial solution, that's the key. You have to offer something that can be launched very rapidly at a good price point.

Myrna James Yoo: Who are your potential customers?

David Mitlyng: Honestly, we have two groups that we're talking to. The long-term plan is to offer this as a capability for banks and financial institutions, telecommunication companies, other groups like that who need very secure links with their communications.

Then on the other side of that is – who else needs secure communications – but the government. Military organizations, state department, organizations like that. So we're getting good traction with both groups. Though to be honest the government agencies are the most near-term because again, they've been working on this and they understand the need for security.

Myrna James Yoo: You know what's really impressive about our government is that they really are pushing the envelope, testing things. They're aware of what's coming. I've been doing this for 16 years now and before attending conferences like GeoInt (The Geospatial Intelligence Symposium), I was not aware of that.

David Mitlyng: Yeah. One of the things we did is that we were formed and funded (we got seed investment from Space Angels and six other investors), and with that we stood up a U.S. office specifically to address the U.S. government market and business. That company is called Speqtral Quantum Technologies (SQT) and was selected for an Air Force sponsored accelerator called Catalyst Accelerator. That accelerator was there specifically to connect interesting technology with the Air Force and the DOD community. That's really been a great opportunity for us to go and show off this system and design to the U.S. government. Now that being said, there's a lot of interest in quantum with different organizations within the government, but I think they were all very surprised at the capabilities of the Chinese when they launched that satellite.

There was a bill that was passed at the end of December 2018 called the Quantum Initiative Act that allocated $1.2 billion, as a response to that Chinese mission. That's there to help bring up the U.S. capabilities and to benefit a number of agencies and also private companies like ours. So we're now very actively talking to a number of different groups about supporting their missions and planning and getting a quantum communication system on their satellites very rapidly.

Myrna James Yoo: That's great for you. I do think sometimes we get in our silos and we forget to watch what these other countries are doing. China's really one of those that in technology is really pushing the envelope.

David Mitlyng: Yeah. Give credit where credit's due because they invested in a good design, in a good team, and they're putting a lot more investment into it. So I like to tell people that they are the leaders and they plan to be the leaders in this. My colleague was at a conference about a month ago where they announced they're putting out four more LEO satellites and a GEO satellite, as well as terrestrial fiber optic QKD links as part of a broader vision for this quantum internet. So they're committed.

Myrna James Yoo: So that's fascinating, when at this very moment, One Web and SpaceX with Starlink and other companies are working towards global internet with satellites – but not quantum. Correct?

David Mitlyng: Yes.

Myrna James Yoo: This is the first time I've ever heard that the Chinese are thinking of doing that with quantum technology. That is fascinating.

David Mitlyng: Yeah, this is fresh news. This was at a conference just a few weeks ago that they made these announcements. I think that's the other thing that's surprising people too, is that they are very open about their ambitions around quantum.

Myrna James Yoo: Well, I think that what you're doing is really, really cutting edge with the entangled photon source on small satellites, addressing the future need for security once Quantum Supremacy is reached. Is there anything else that you would like to share?

David Mitlyng: Like I said, quantum key distribution is one application for this technology, what we call broader quantum communications, which is also a part of broader quantum technologies. When you do research on this topic, you'll see QKD, or quantum cryptography described a lot.

Just to be clear, that is an application where you use quantum communications to distribute securely encryption keys and then these encryption keys will be used for encrypting normal communications. That being said, we're also excited because under quantum communications with these entangled photons, there are some pretty incredible additional future applications besides just delivery of encryption keys. This is maybe the first time your readers are hearing about this, but it won't be the last. This will be more and more in the news in the next decade as more of these breakthroughs are made – so very fascinating stuff.

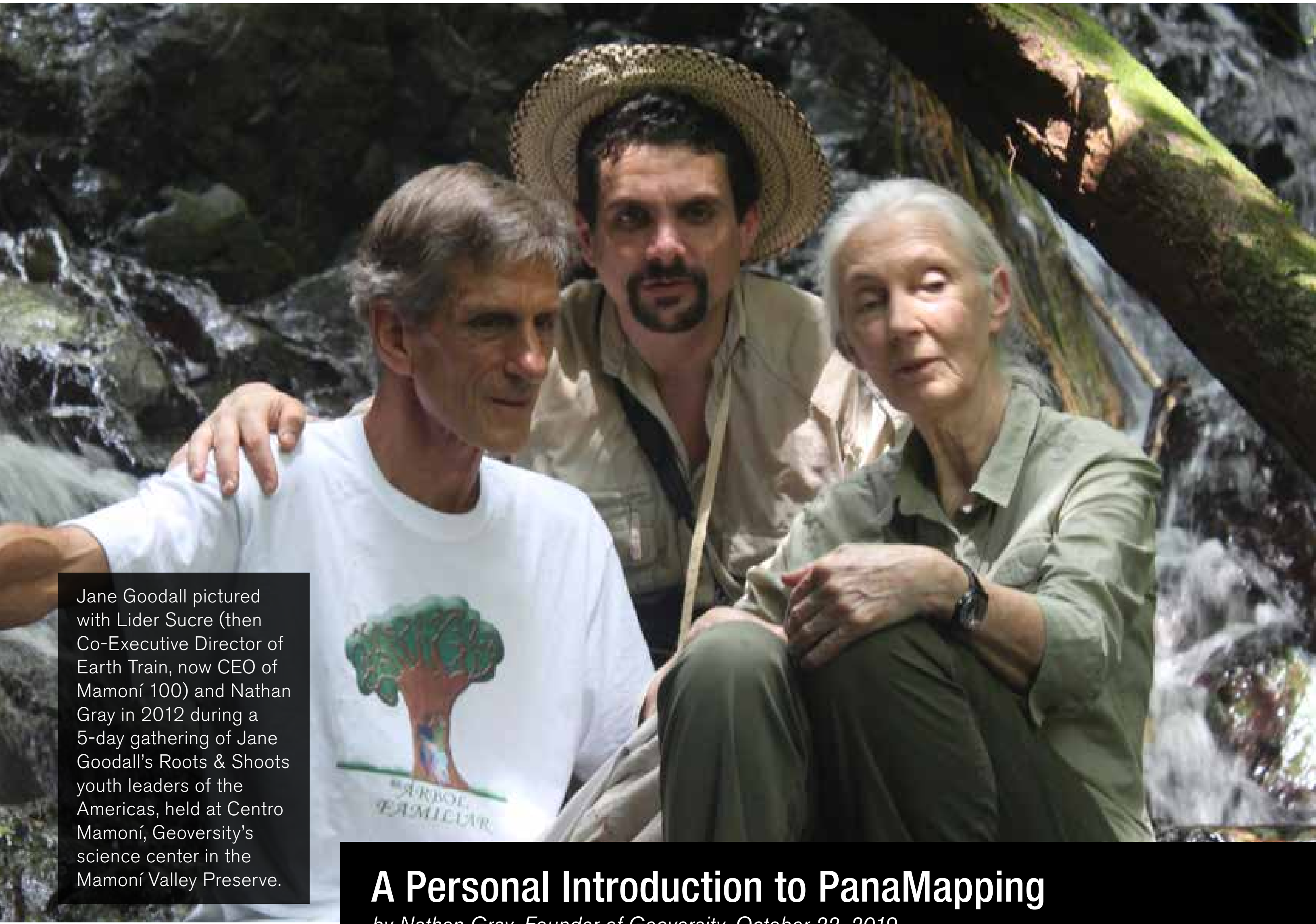
Myrna James Yoo: Thank you so much, David.

David Mitlyng: My pleasure.

PanaMapping: GIS for Conservation Science

The Mamoní Valley Preserve

By Dan Klooster, David Smith, Nathan Strout, University of Redlands; and Fundación Geoversity



Jane Goodall pictured with Lider Sucre (then Co-Executive Director of Earth Train, now CEO of Mamoní 100) and Nathan Gray in 2012 during a 5-day gathering of Jane Goodall's Roots & Shoots youth leaders of the Americas, held at Centro Mamoní, Geoversity's science center in the Mamoní Valley Preserve.

Editor's Notes: This article is an excerpt from the book *GIS for Science: Applying Mapping & Spatial Analytics* originally published by Esri Press, Redlands, CA. Copyright 2019. The companion website is [www.GISforScience.com.](http://www.GISforScience.com)

A Personal Introduction to PanaMapping

by Nathan Gray, Founder of Geoversity, October 22, 2019

I'm in the rustic dining room of our science center at jungle's edge in the 12,000-acre Mamoní Valley Preserve in Panama fussing with my laptop so that our special guest, Dr. Jane Goodall, can open the plenary session for the 2,000 educators and scientists participating in the First Annual Conference of the Association for Environmental Studies and Sciences (AESS) taking place in Madison, Wisconsin. I'm explaining to my counterpart 4,000 miles away, University of Redlands professor and first AESS president Monty Hempel, that the limited bandwidth of our satellite service will permit voice only. This was my first conversation, in October 2009, with someone who would soon become a dear friend and, years later, play a key role in creating the Geoversity ecosystem.

"Nathan, what the hell is all of that racket I'm hearing in the background?" Monty asked. I replied with a laugh, "That pepper grinder sound is a pair of keel-billed toucans cackling in a tree right next to us. And that barking sound you're hearing is a tribe of howler monkeys that just started marauding among the fruit trees on the nearby hillside." Jane, with a big grin on her face, sits down in front of the computer, leans toward the microphone and, with Mother Nature's inimitable soundtrack in the background, begins to speak. Later, Monty would tell me that a hush came over the giant auditorium where they were gathered before a giant screen with pictures of Jane exploring the Mamoní forest. "You could hear a pin drop," he said. "The excitement was palpable."

With Monty come many stories of unusual conversation and adventure, such as hiking and paddling with indigenous leaders from our preserve on the Pacific side of Panama's continental divide across the autonomous territory of the Guna people to their Atlantic coast. But here, I'll keep it to just a word of thanks to Monty for bringing in his colleagues at the University of Redlands in California, and their groundbreaking Center for Spatial Studies to help start the Geoversity ecosystem in 2016, and for launching the PanaMapping project introduced in this special issue of *Apogeo Spatial*. Quoting him is my way of introducing the topic while acknowledging his contributions of clarity and insight. You'll see why we so value his role in Geoversity with our odd mission of "creating contexts for miracles and, ultimately, bringing about a global biocultural renaissance."

"Mapping a watershed or rainforest ecosystem is like drawing a floorplan for one's home. It seems rather prosaic, when in fact it is how we visualize complex information needed to develop a systems understanding of our environment. The PanaMapping project, with its reliance on advanced geospatial and drone technology, makes it possible to integrate the human perspective of ground-level fieldwork with the avian perspective of interlocking ecosystems. Together they help transform our understanding of the system of systems that is Nature and the interdependence that characterizes all life on Earth."
–Monty Hempel

Figure 1. The isthmus of Panama is the narrow bridge of land that connects North and South America, and includes more than 1,600 islands off its Atlantic and Pacific coasts. Panama is most known for the Panama Canal, which cuts through its midsection.

PanaMapping is about how geographic information system (GIS) technology supports conservation goals in Panama by revealing how physical features of the landscape interact with human uses of the land. The Mamoní River defines the watershed in which the Mamoní Valley Preserve (MVP) works to conserve forests, streams, and the biodiversity and human communities that depend on them.

Forests of the humid tropics shelter biological and cultural diversity, protect watersheds, and sequester carbon from the atmosphere. However, they are threatened by deforestation and climate change, and so conserving them often requires strategies to protect critical areas while promoting resident human communities that are invested in conservation and sustainable uses.

In an ongoing series of field courses starting in May 2017, undergraduate students, faculty, and GIS professionals from the University of Redlands have been working in Panama with the Mamoní Valley Preserve, using GIS to support the reserve's goal of conserving biodiversity while promoting local culture and a sustainable local economy. Working in micro-watersheds defined by tributaries of the Mamoní River, each field course conducts parallel and overlapping research projects. These include: global positioning system (GPS) mapping of trails and watercourses and micro-watershed boundaries, collecting original high-resolution 3D land cover data with unmanned aerial vehicles (UAVs), land cover mapping, carbon mapping, and watershed analysis. Over time, the idea is to build a thorough geographic database of increasing value for reserve management.

The Conservation Problem in the Mamoní Valley Preserve

Field courses at the University of Redlands examine a valley that is both a conservation priority and also representative of people-forest dynamics elsewhere in the humid tropics. The upper Mamoní Valley watershed covers approximately 121 square kilometers (29,900 acres) at the narrowest part of the Americas. A line drawn through the preserve from the Pacific north to the Atlantic would be only 60 km long (37 miles) and so conserving it widens the Mesoamerican Biological Corridor, a thread of land connecting North and South America. The valley acts as a buffer to the Chagres National Park and the pristine Guna Yala Comarca; it buttresses the Tumbes-Chocó-Magdalena eco-region—one of the top 20 ecological hot spots on Earth.

The valley shelters the full complement of tropical forest mammals, including jaguars and four other species of wildcats, two species of sloths, several kinds of monkeys, and abundant snakes, lizards, and amphibians. Scientists from Harvard University and elsewhere have observed 290 species of birds here. The valley also appears to be a refuge for species of frogs decimated by disease elsewhere in Panama, and the Smithsonian Tropical Research Institute's Amphibian Recovery Unit studies remnant frog populations and restoration techniques.

Recent history has turned the valley into a mosaic of pasture, 15- to 30-year-old secondary forests, and stands of old-growth forest. Starting in the 1960s, small-scale farmers and cattle ranchers began clearing forest in the valley. A rough road entered in the 1980s, and deforestation pressures began to leak out of the Mamoní Valley as settlers and the hired hands of absentee landlords crossed the continental divide into indigenous Guna territory to clear fresh lands for food crops and pastures.

In a well-known example of indigenous resistance, the Guna people demarcated their lands and spent many years firmly evicting settlers from homesteads in Guna territory and turning back settlers at their border with the Mamoní Valley. In the last several decades, subsistence agriculture and small-scale cattle ranching became less economically viable, and some families began to abandon the valley. This created the threat that large-scale cattle ranchers would consolidate smaller properties and convert much more of the valley to pasture.

In 2000, in coordination with the Guna people who were looking for allies to stabilize their frontier, Nathan Gray, a social entrepreneur and sustainable development activist, established a Mamoní Valley campus of Earth Train, an environmental youth leadership training organization he had founded in 1990. Earth Train recruited allies to buy strategic parcels of forest and pasture to prevent the consolidation of pasture lands into large-scale cattle operations.

These actors established the Mamoní Valley Preserve, a 501(c)(3) nonprofit organization using the tools of landownership, conservation easements, and landowner pledges to conserve the extent and quality of the valley's forests and waters, to strengthen biodiversity, to improve the health of the forest's inhabitants, and to promote a sustainable local economy. Currently, the reserve has the explicit support of the landowners in possession of about half the valley. The goal, however, is to extend forest conservation and sustainable development to the entire upper Mamoní River watershed.

GPS: From Footprint to Map

Using GPS, students turned walking into a mapping activity. They quickly realized the need for more detailed location data on the trails, watercourses, ridgelines, and watershed boundaries of the area. They became aware of the limitations of the GPS units, especially under heavy tree canopy. A discussion of GPS accuracy and precision ensued with a decision to smooth out

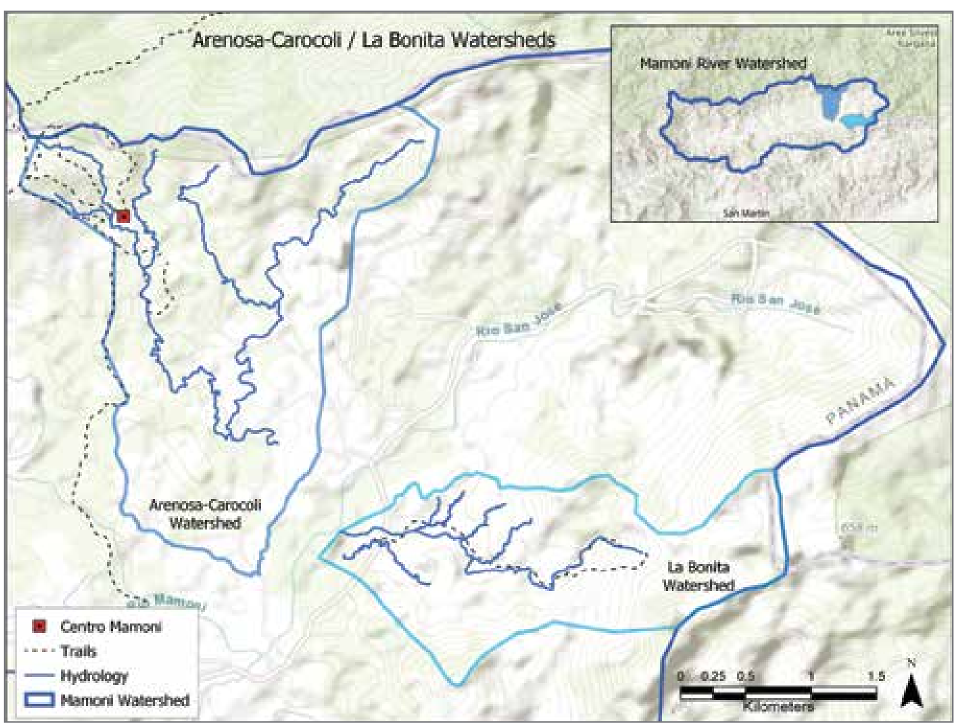


Figure 2. In addition to the trails and watercourses noted, two micro-watersheds, the Arenosa-Caracoli and the La Bonita, have been delineated, forming the basis for the research in the valley.

the trails and watercourses to account for the lack of accuracy in areas of dense forest. See Figure 2.

UAVs: A High-Resolution View from Above

To truly appreciate the complexity and diversity of the rain forest, you must immerse yourself in it and experience it—but to understand the structure and health of the rain forest, you need to get above the tree canopy and see it on a much broader scale.

Two DJI Phantom 4 Professional UAVs were used to acquire roughly 4,500 photos above the study area. The Phantom 4 Professionals have a 1-inch 20-megapixel sensor for a high-resolution product and also a mechanical shutter to eliminate the distortion often introduced flying at higher speeds with a rolling shutter.

Flight planning was done using Pix4Dcapture on an iPad at the headquarters in Centro Mamoní with internet connectivity, but changes were regularly made in the field due to changing conditions. Consumer flight planning apps such as Pix4Dcapture require that missions fly at a constant altitude above the takeoff point, set by the operator.

The image resolution and overlap calculations are made based on this altitude and assumed constant because the UAV isn't aware of the changing ground elevation underneath it. This presents a challenge when mapping a large area with varying terrain because the elevation of the ground under the UAV is changing and therefore the image overlap and resolution is difficult to plan for. To resolve this issue, missions were planned in "terraces" following topo contour intervals.

Pix4Dmapper was used for processing – a photogrammetry software for generating and analyzing orthomosaics and other mapping products from images collected via UAV. Students ultimately used a combination of Pix4D-generated orthomosaics and the photo points layer with linked photos to complete tasks such as land cover classifications. These were imported into an ArcGIS mosaic dataset with time stamps. This dataset now covers roughly 9.25 square kilometers of high-resolution aerial imagery and can be used for further research and land management.

Land Cover Maps

To produce a land cover map, researchers worked with a professional forester familiar with the area.

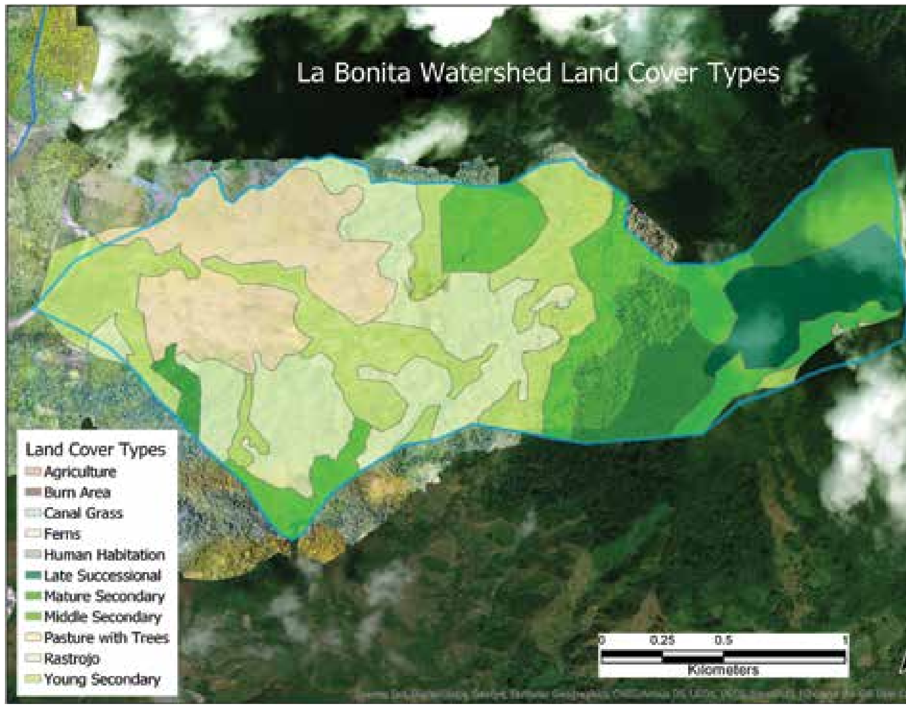


Figure 3. Land cover maps showing a sequence of land cover types found in La Bonita, ranging from pasture through different ages of forest regrowth, including areas of very old, late successional forest, revealing a landscape shaped by a history of deforestation for pasture in valley bottoms and forest conservation in the more remote headwaters of streams.

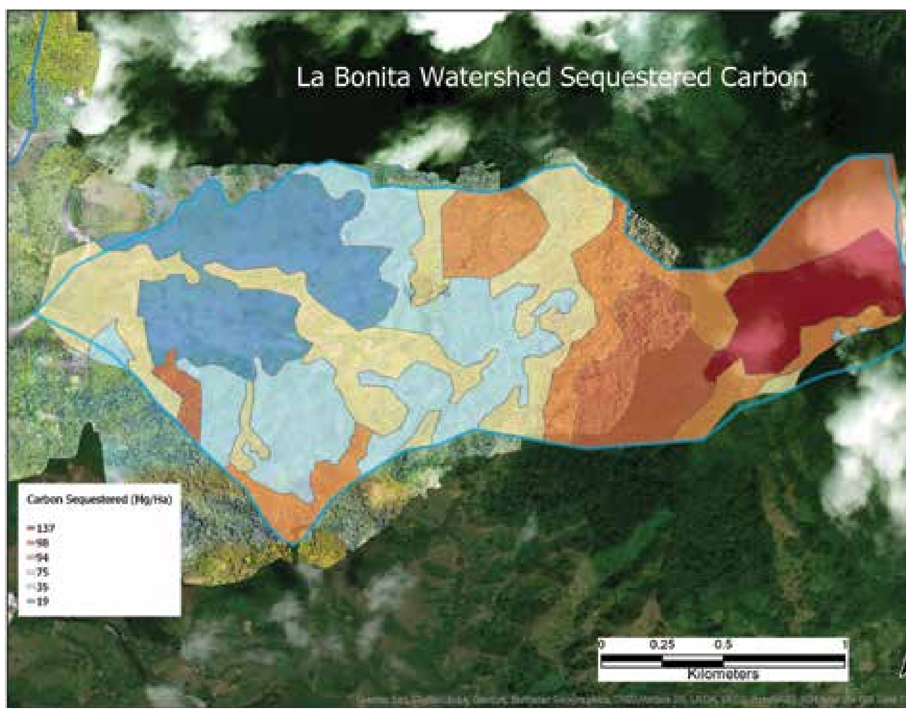


Figure 4. The carbon maps indicate the highest carbon density is found in the oldest forests in the headwaters of micro-watersheds, and the least carbon is in the pastures.

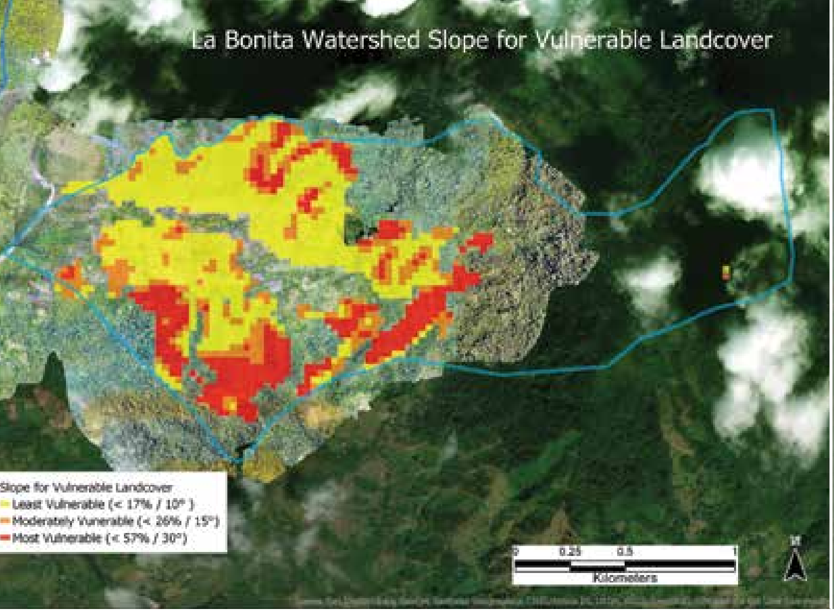


Figure 5. This map shows where pastures are found on very steep slopes – the areas that are most vulnerable to erosion. These areas could be the focus of reforestation efforts.

Figure 6. UAVs were used to document illegal deforestation and road building in Majé Emberá lands. On the left is 2016 imagery from ArcGIS Online, with polygons showing the forest cover lost by May 2018. The right image is UAV images from May 2018 verifying the deforestation and roadbuilding.

They learned to understand and recognize forest stands and chronosequences. A forest stand is a community of trees generally similar in composition and age, while a chronosequence is the series of successional phases a forest stand goes through as it recovers from a disturbance such as being cleared for agriculture. See Figure 3.

Carbon Sequestration and Forestry: How to Measure Carbon

Carbon emissions from deforestation are a major contributor to global greenhouse gas emissions, while growing forests sequester carbon, and so conserving forests provides an important environmental service. Mamoní Valley Preserve managers wish to visualize and communicate how much carbon they are managing and where it is located. Carbon maps could also tell them where to concentrate conservation efforts to avoid carbon emissions from deforestation, and where they might best invest in reforestation projects that could sequester carbon from the atmosphere.

Students gathered data from sample plots, including the height and diameter of all trees within the plot. They entered the data into a spreadsheet and calculated the volume and carbon content of the trees in each fixed area plot. The forester selected plots to represent the various land covers.

Students used GPS data to confirm the correspondence of sample plots with their land cover map and then took the average of the results from the plots in each land cover type. They then assigned the average carbon content value to each land cover. Finally, they joined the carbon value data with the land cover data to produce a new map representing the distribution of carbon within each watershed studied. See Figure 4.

Watershed Analysis

Efforts to conserve and improve the forests and waters in the upper Mamoní Valley watershed require an understanding of the watershed dynamics at the micro-watershed level. As such, students analyzed the erosion vulnerability of each micro-watershed by answering six questions for each one, including locating boundaries, the main stream and tributaries, the riparian forest buffers, forests and pastures, and slopes and flat areas.

The first step is delineating the micro-watershed by analyzing a digital elevation model (DEM) to identify initial watershed boundaries. Second, students mapped riparian barriers by performing visual analysis of the UAV orthomosaic. The third major component was to visualize and represent the topographic shape of the watershed. Using the DEM, students created vertical profiles showing the descent of the major stream and the shape of cross sections at various points along the valley. Fourth, students combined the slope map with the land cover map. Students were able to locate areas of special concern, such as steep slopes under pasture or early forest regeneration. See Figure 5.

Results

Each of these projects helps MVP managers meet their goal to conserve the extent and quality of the valley's forests and waters. The land cover map helps them more easily visualize the locations of target land cover types such as old growth forest, to correlate land covers with other data such as elevation and slope, and—by repeating the process with land cover data from different time periods—to quantify and visualize change over time. Carbon mapping reveals that the micro-watersheds so far studied store significant amounts of carbon; that most of this carbon is in relatively remote, higher elevation areas spared deforestation during the twentieth century; that there are many areas where young growing forests are capturing carbon; and that many pasture areas are potentially available for carbon-capturing reforestation projects.

Micro-watershed mapping locates essential management units in which managers can now develop, compare, and monitor useful new indices such as the percentage of a micro-watershed covered by pasture or forest.

GIS for Conservation Education Conclusion

Students are building an enterprise GIS for the Mamoní Valley Preserve, including land cover, watershed analysis, landownership, carbon storage, hydrology, and trails. Their use of GIS tools contributes to conserving the rain forest, but at the same time it also advances students' education in conservation science.

GPS mapping gets students into the forest, walking along trails, tracing ridgelines, and wading in creeks. It teaches an important data entry skill for GIS and promotes concrete appreciation for accuracy and precision—students become savvier, appropriately critical users of spatial information. Flying UAVs also gives students additional experience integrating original data into a GIS while introducing optical remote sensing and a compelling new geospatial technology.

Using GIS to analyze watersheds, students think about the connections in a landscape. They visualize links between land cover, slope, and erosion. They consider the role of riparian barriers in buffering streams from the runoff from cattle pastures. Using GIS to map forest carbon provides additional learning opportunities for them. Tasked with answering the question "Where is the carbon?" students work backward, first developing an understanding of the science of forest succession in a temporal, nonspatial sense, then developing basic skills in the science of forest mensuration. As they create and interpret land cover maps, they learn about the social process of deforestation, conservation, and forest recovery. In Panamapping, GIS becomes a powerful vehicle of scientific education.

With the direction of indigenous leaders, the students and faculty of University of Redlands are using GIS and UAVs to document processes of deforestation that threaten both conservation and the indigenous rights to land and livelihood.

GIS in the Struggle for Conservation: Supporting the Majé Emberá Indigenous People

It is dark and there is no electricity. Students crowd around a makeshift table under a palm-thatched roof. Only our headlamps illuminate the map we are using to plan tomorrow's UAV flight. Dressed in his traditional garb, Cacique (Chief) Lorenzo points out the village site to University of Redlands UAV pilots. He shows us where ancestral lands were flooded out in 1976 to provide hydroelectric power to Panama City. "We had to give up our lands so the rest of the country could have electricity, but we don't have electricity, or water, or even rights to the remnant of our territory that we live on," Lorenzo tells his visitors. With his finger, he traces the watershed boundary on a map.

Lorenzo points out areas where his people used to collect medicinal plants to support pregnant women and to cure the sick. Many of those areas are deforested now. The problem, he explains, is that his people's remaining lands have been declared a conservation area, and this means they cannot officially own them, protect them, or manage them. But conservation authorities don't protect the lands from ranchers and loggers. Settlers have cleared large areas of pasture near the village, and a fire set to clear forests for pasture spread into the valley of the creek that the Majé Emberá use for drinking water, destroying their aqueduct.

Cacique Lorenzo's map was produced by the Danish NGO Forests of the World, and it shows areas of land cover change calculated using radar remote sensing from a European Space Agency satellite. Visitors from the University of Redlands are there to support the Majé Emberá by gathering data to help verify and illustrate the larger image. Lorenzo asks them to use their UAV to document a recently deforested area and gather UAV data showing a forest he knows will soon disappear. The Majé Emberá will use the UAV imagery to support their ongoing campaign to defend their territory from encroachment and to help them lobby the Panamanian government for land rights to defend what is left of their ancestral territory. University of Redlands students, meanwhile, are seeing the role GIS can play helping indigenous people engaged in conservation struggles. See Figure 6.

THE ROLE OF SATELLITE-DERIVED GEOSPATIAL DATA *for* SDGs

Accelerating Achievement of the United Nations' Sustainable Development Goals

by Maxar Technologies

For half a century, Earth observation (EO) satellites have provided consistent and accessible information about the state of our natural environment. Today, EO satellite imagery and the geospatial data it generates are helping us better understand the effects of climate change, monitor economic and social development, and protect human rights on a global scale. This data and its providers are quickly becoming a vital source for success in achieving the United Nations' Sustainable Development Goals (SDGs).

Figure 1. Maxar satellite image of al-Hol refugee camp in Syria, taken on March 31, 2019.

Advanced EO capabilities provide essential data for accurately mapping remote areas, updating incomplete or outdated maps, especially in regions of rapid change. Not only does this assist in analyzing change, but it helps government and non-governmental organizations ensure they account for all those in need or at risk.

Innovations in EO satellite and geospatial data technology directly or indirectly support every single SDG. While in some cases, such as monitoring deforestation, it has been an established method for decades, the role of geospatial data has recently expanded into new use cases, such as providing valuable insights into gender inequality and disrupting human trafficking networks, thanks to advanced tradecraft and machine learning.

In 2017, the UN General Assembly adopted an indicator framework and assigned more defined targets to make the goals more concrete and measurable.

While a few countries are on track to meet SDG targets, many more are not and may or may not know it. How do these organizations measure and document success?

Traditional survey methods could cost as much as a quarter of a trillion dollars over the lifetime of the SDG, take too long to be effective, and lead to incomplete or inconclusive results. Moreover, it is hard to gather consistent data across countries and regions.

Among satellite imagery and geospatial data providers, Maxar Technologies stands out for its innovative geospatial solutions and partnerships across all 17 SDGs. Maxar owns and operates the most sophisticated commercial satellite imagery constellation in orbit, continuing to feed its 100+ petabyte archive with more than 3 million sq km of high-resolution satellite imagery every day.

As the source of critical geospatial data—both current and historical—Maxar collaborates closely with partners in developing valuable analytics and derived datasets to help analysts detect, understand, and address change.

A key objective of Maxar's purpose is making advanced geospatial data and insights more accessible—especially for those who need it but might not necessarily know how to use it. Its SDG partnerships are centered around empowering both analysts and volunteers to collaborate and collectively scrutinize imagery to tag important objects, features, or locations. The input of this human network is then validated and refined using advanced geospatial consensus algorithms that enable unprecedented accuracy at scale.

GOAL 1. END POVERTY IN ALL ITS FORMS EVERYWHERE

Target 1.1 By 2030, eradicate extreme poverty for all people everywhere, currently measured as people living on less than $1.25 (USD) a day	**Indicator 1.1.1** Proportion of population below the international poverty line, by sex, age, employment status and geographical location (urban/rural)
Target 1.5 By 2030, build the resilience of the poor and those in vulnerable situations and reduce their exposure to climate-related extreme events and other economic, social and environmental shocks and disasters	**Indicator 1.5.1** Number of deaths, missing persons and directly affected persons attributed to disasters per 100,000 population **Indicator 1.5.2** Direct economic loss attributed to disasters in relation to global gross domestic product


2


3

IMAGERY PLUS ANALYSIS

EO satellites can detect changes in land cover, monitor water quality and identify pollutants, evaluate the health of a coral reef, or help assess how coastal zones are influenced by sea-level rise. Satellite images can be used to identify features of interest, such as agricultural land, forests, urban areas, roads, and water, and pixels can be classified into different crop types, or in a binary classification of forest or bare ground.

The rapid growth in the number of EO satellites has dramatically increased their coverage and refresh rate. Additionally, advancement in sensor technology has increased resolution and includes more bands, making them uniquely able to assist with SDG monitoring and implementation. For example, sensors in the infrared (IR) bands make it possible to understand such things as soil moisture and crop health, and radar satellites can capture imagery through clouds and haze.

Unlike the U.S. Landsat and the European Sentinel satellites, which steadily image the globe on a regular cadence, commercial satellites are dynamic and agile. For example, Maxar can task and point its constellation to collect images of areas where it thinks there will be more change, such as coastal areas and urban areas. It can also task its satellites quickly, to investigate suspicious areas or monitor a natural disaster.

Maxar's constellation also features multispectral and radar capacity. Radar can "see" through clouds, haze, and smoke. Together, the constellation can use radar imagery to identify forest areas that are burning, then cue optical satellites to follow up once the air is clear. This allows for efficient post-event analysis or monitoring for ongoing events.

The advent of cloud computing and artificial intelligence (AI) has shifted the field of remote sensing from a data-scarce environment to a data-rich one. Satellite imagery is now also routinely analyzed in conjunction with "big data" from such sources as social media posts and call detail records.

AI is particularly important in disasters, where first responders and relief organizations are unable to analyze large streams of raw data. By comparing archival imagery with new imagery, AI can rapidly identify damaged structures, impassable roads, and priority needs. Crowdsourcing and machine learning can quickly validate and enrich the data to inform critical decisions.

GEOSPATIAL DATA AND TECHNOLOGY AT WORK WITH THE SDGS

In some cases, such as measuring the extent of deforestation, the role of satellite imagery and geospatial technology has been established for decades and is intuitive. In other cases, such as providing insights into gender inequality, its use is novel and surprising. At a minimum, it is essential to map areas that have never been mapped before, because you cannot get a vaccine or a fly net to a household if you don't know it's there.

SDG partners are leveraging Maxar capabilities to:

- Measure the amount of agricultural land, the length of shadows (which are a proxy for building height), and the density of buildings, roads, and cars so governments and stakeholders can estimate economic well-being and better understand the spatial distribution of poverty. (See Figure 2 of buildings in Tanzania.)
- Tag permanent dwellings, temporary ones (such as tents), and herds of livestock in images to help researchers assess the level of food insecurity in a region and humanitarian organizations optimize their responses. (See refugee camp in Figure 1, page 28.)
- Map areas at high risk for malaria, based on population density and nearby water sources, so health workers can determine the required number of life-saving mosquito nets and where to apply insecticides.
- Map schools to address the infrastructure gaps that hinder educational opportunities, whether they be transportation, safety, Internet access, or other barriers.
- Map residential areas, roads, streams, floodplains, and other relevant features, and combine this data with software inputs to run realistic natural disaster scenarios, which improve disaster preparedness planning and response plans.

- Track the rapid growth in solar farms and solar panels on homes so decision makers can integrate this energy source into the grid and expose what motivates individuals to install solar arrays.
- Identify brick kilns and illegal fishing boats, both routinely manned by forced labor, so law enforcement authorities can target them and free slaves.

MAXAR OPEN DATA PROGRAM

In the wake of major natural disasters, Maxar provides support for relief efforts by releasing free and open imagery of affected areas, including recently in the aftermath of Hurricane Dorian. (See Figures 3-4.) Through the Open Data Program, the company releases open imagery for select sudden onset major crisis events, including pre-event imagery, post-event imagery, and a crowdsourced damage assessment.

Maxar partners with dozens of national and international governmental agencies and NGOs to address specific crises.

- In South Sudan, it partners with the Famine Early Warning System Network to study the causes and geographic distribution of hunger and malnutrition due to massive food and water shortages and to help plan optimal responses.
- In Colombia, it uses real-time data from UNICEF to map schools, including those in the most remote regions.
- In Tanzania, it uses street data from OpenStreetMap (OSM) to support flood resiliency and clean water.

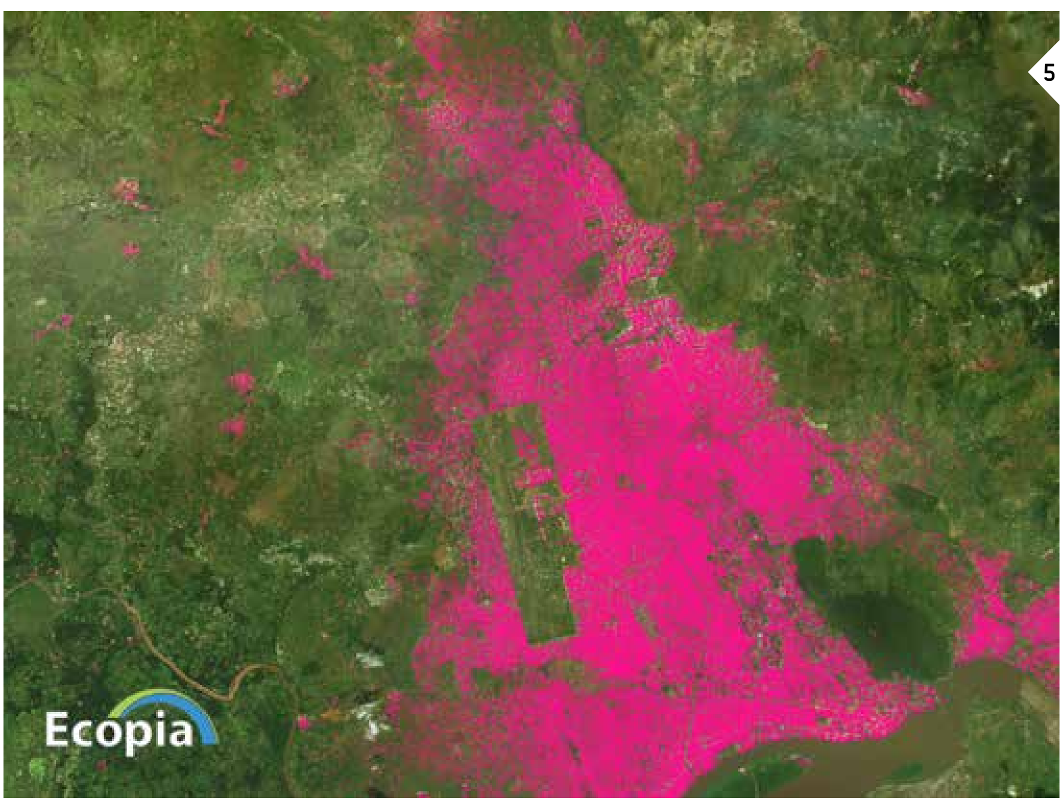
These partnerships, taking advantage of the wealth of insights derived from satellite imagery data, assist governments and NGOs in measuring progress toward the SDG and in achieving them, by better targeting limited resources.

Figure 2. Building footprints in Tanzania, relevant to SDG 6, Sustainable Development.

Figure 3. Damage assessment of Abaco and Green Turtle Cay in the Bahamas after Hurricane Dorian. More than 3,000 buildings were assessed, with more than 1,100 visibly destroyed and 1,400 visibly damaged in Maxar satellite imagery. Building footprints provided by OpenStreetMap.

Figure 4. Maxar satellite image of Green Turtle Cay in the Bahamas after Hurricane Dorian. Image taken September 5, 2019.

Figure 5. Ecopia Building Footprints over the Central African Republic, extracted from Maxar satellite imagery by Maxar partner Ecopia.ai.



The Earth from Space

NASA Partnership Brings Photos from the ISS

This oblique nighttime view of Western Europe and the well-lit coasts of Spain, France and Italy (left to right) was taken by Canadian astronaut David Saint-Jacques on May 13, 2019, as it orbited 256 miles above the Mediterranean Sea. Traveling at 5 miles per second, astronauts on the ISS experience 16 sunrises and sunsets each day.

The SpaceX Dragon resupply ship was captured by NASA astronaut Nick Hague on Aug. 13, 2019, attached to the International Space Station's Harmony module as the orbital complex flew above the Nile River Delta in Egypt. Nick noted, "The curve of the Earth highlighted in vibrant colors provides a picturesque backdrop for the SpaceX Dragon cargo craft docked to the space station. Cargo vehicles, like Dragon, have provided much needed supplies and critical science experiments keeping the ISS mission going for two decades."

The Murghab River flows into the oasis city of Mary in the Karakum Desert in Turkmenistan. At left is the Hanhowuz Reservoir which plays an important role in agriculture in southeastern Turkmenistan. The International Space Station was orbiting above the Central Asian nation when this photograph was taken by NASA astronaut Christina Koch on June 26, 2019.

Boston, Massachusetts, Logan International Airport and Massachusetts Bay are featured in this photograph taken by NASA astronaut Nick Hague on June 17, 2019 from 256 miles above the Atlantic Ocean. Nick noted, "As I flew overhead, I couldn't help but feel the strong connection to the city of Boston and institution of MIT that set me on my way."

The ISS was orbiting above South Australia on Oct. 7, 2018, when German astronaut Alex Gerst captured this celestial view of Earth's atmospheric glow and the Milky Way.

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