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ELEVATING GLOBAL AWARENESS

Ursa Uses Radar to Monitor the Oil Market
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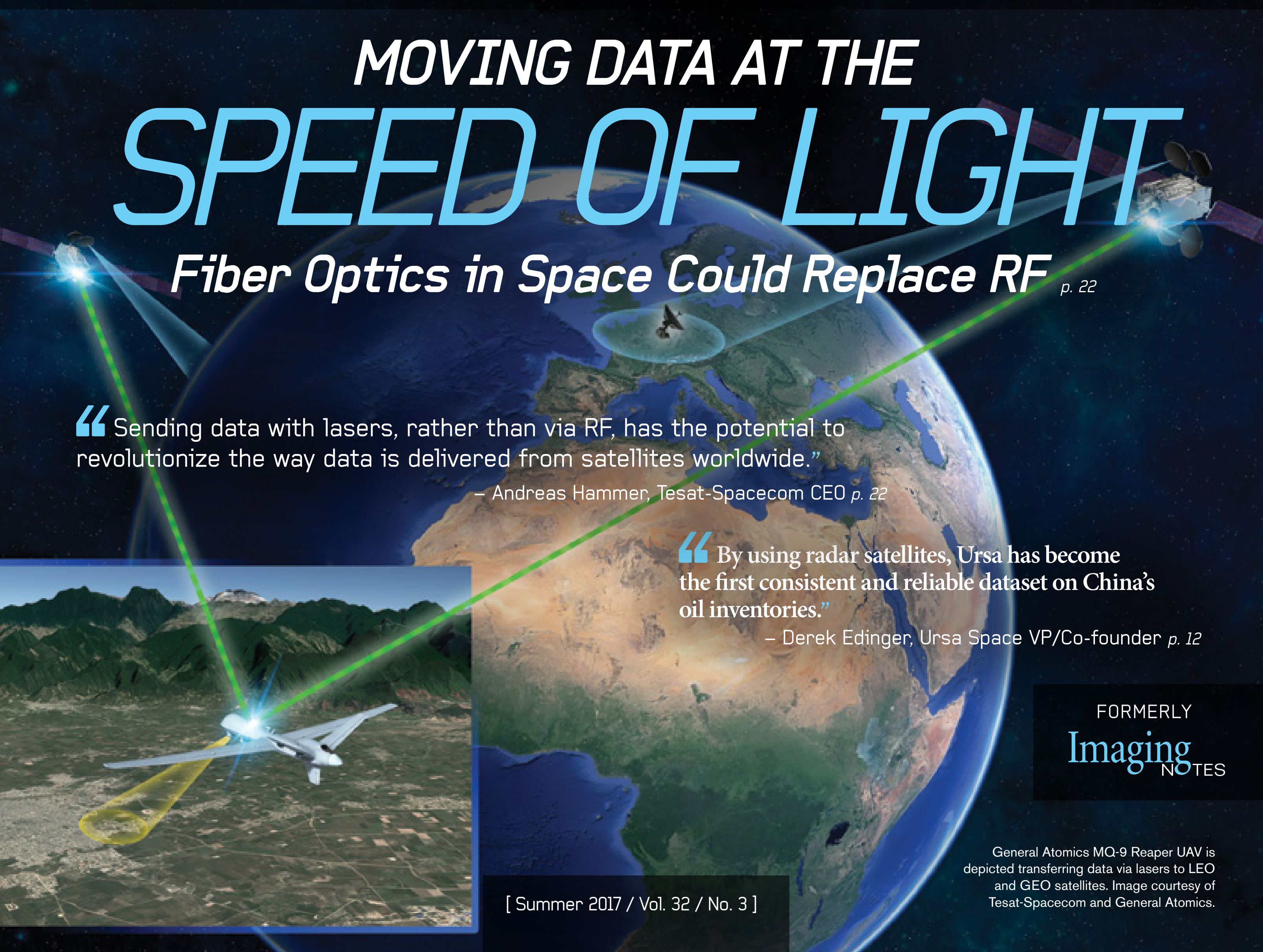

MOVING DATA AT THE SPEED OF LIGHT

Fiber Optics in Space Could Replace RF *p. 22*

"Sending data with lasers, rather than via RF, has the potential to revolutionize the way data is delivered from satellites worldwide."
– Andreas Hammer, Tesat-Spacecom CEO *p. 22*

"By using radar satellites, Ursa has become the first consistent and reliable dataset on China's oil inventories."
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FORMERLY Imaging NOTES

General Atomics MQ-9 Reaper UAV is depicted transferring data via lasers to LEO and GEO satellites. Image courtesy of Tesat-Spacecom and General Atomics.

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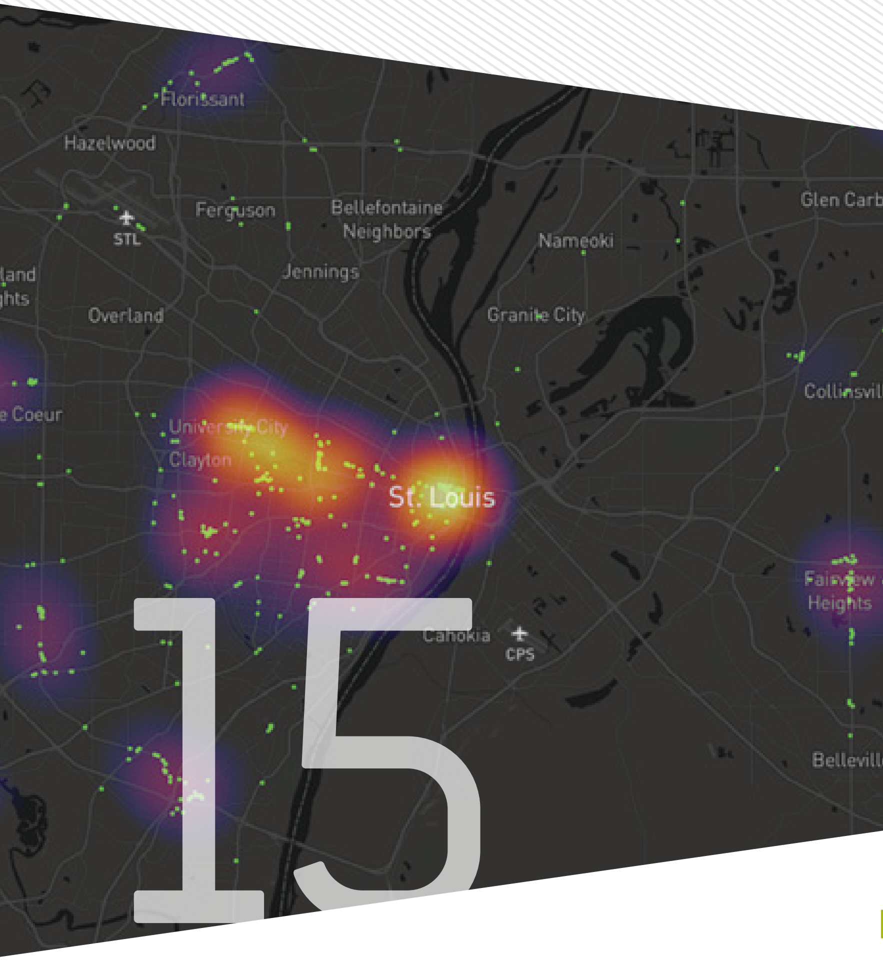

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Columns

Features

COVER IMAGE

Laser Beams of Data

THE MQ-9 REAPER UAV (also referred to as Predator B) is shown here in a depiction of transferring data (in green) via optical laser beams to a GEO satellite (on the right) and a LEO satellite (on the left), both of which also are shown transferring data to the ground (blue beams). UAVs primarily shoot full motion video, and their downlink demands are high. The planet below shows the desert of Northern Africa, with parts of Europe visible above it.

General Atomics Aeronautical Systems, Inc., an affiliate of General Atomics, is the manufacturer of the UAV. The company provides unmanned aerial vehicles and radar solutions for the U.S. military and commercial applications worldwide.

The article about using lasers for transferring data down to Earth from satellites and UAVs begins on page 22. ΛO

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MISSION

Apogeo Spatial communicates the power of geospatial tools and technologies in managing the world's environment and scarce resources, so that the global population has the security of water, food, and energy.

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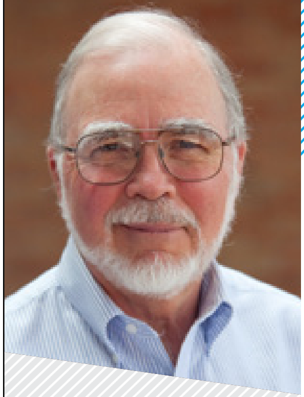


Ray Williamson, PhD
Editor, *Apogeo Spatial*

AS I LOOK BACK on the first half of this year, I am struck with the increasing speed of exciting changes in the Earth observation community. I see new systems, new analytic software and new ways of approaching the distinct opportunities and challenges of understanding Earth and its complex components. How we use them to address our environmental concerns will be key to our quality of life and to Earth's long-term sustainability. The articles in this summer issue exemplify several of these developments.

For example, we could all probably use more accurate, reliable GPS. In "Project Sextant," Matteo Luccio on page 28 examines the efforts by the Aerospace Corporation to develop new means to strengthen GPS, to avoid or mitigate loss of signal from intentional jamming or obscuring natural conditions around the receiver.

In the world of global commodities, traders always need more accurate information about the global marketplace. This is what Ursa Space Systems Inc., a young company that focuses on providing global economic intelligence, is doing (see page 12). The company uses satellite radar data and proprietary algorithms to deliver economic information about the global oil and gas supply chain. Their business model is a powerful reminder that satellite radar data are finding important new business niches.

As noted on page 22, Tesat-Spacecom is responding to the challenge of getting terabytes of data down from the satellites in space using developments in laser (optical) data transfer, including space data relay, at 1.8 Gpbs – significantly faster than legacy systems.

The interest in space entrepreneurship was highly evident in this year's International Space University Summer Space Studies Program (ISU SSP17) in which I led the Policy, Economics and Law Department. SSP is an intensive nine-week international, interdisciplinary, and intercultural program designed to educate the space leaders of tomorrow. This year the SSP was held in partnership with the Cork, Ireland, Institute of Technology (CIT).

While in Cork, I spoke with several lecturers and participants who were starting companies using data from space systems. One intriguing example is a recent start-up begun by our department's Teaching Associate, Ana Cristina Galhego Rosa. She is a Brazilian lawyer and SSP alumna who became concerned about the spread of the zika virus in her country by the *aedes aegypti* mosquito, which also carries a number of other dangerous vector-borne diseases. Consulting remote sensing experts, Ana Cristina developed a way to identify areas of high risk for the mosquito using a proprietary combination of ground and space-borne sensors. This is highly valuable information for the tourist industry and for business people who travel to potentially infected areas. Her new company, Dipteron, is registered in Germany.

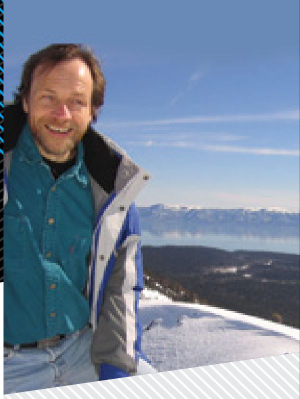
An important part of the SSP is the research, writing and publishing of a Team Project, resulting in a 100-page report. Participants may be space professionals, graduate students, or persons looking to change their profession to a space-related one.

This year, three projects with relevance to Earth observations stand out: The Internet of Things for Space and Energy; Roadmaps and Strategies for National Space Sector Capacity Building; and A Handbook on How to Start Your Own Space Company. In each of these projects, Earth observation data and technologies can play a significant role.

In all of them, the use of open source data and software, as described in Matteo Luccio's piece on open geospatial software (on page 15), could be an important element of achieving success.

This Fall, *Apogeo Spatial* is sponsoring two excellent conferences that bring together stakeholders from around the world, including Geography2050, which will take place in New York City Nov. 16-17 with the theme of "The Future of Mobility," and the Summit on Earth Observation Business, a gathering in Paris organized by Euroconsult, Sept. 14-15, as part of World Satellite Business Week. Join us!

Sincerely, Ray Williamson



ON THE EDGE°

Extreme Weather's Tie to Climate

LANGUAGE MATTERS

Prof. Hans-Peter Plag, PhD
Mitigation and Adaptation Research Institute
Old Dominion University
Norfolk, Va.
www.mari-odu.org

FLOWS IN THE EARTH'S LIFE-SUPPORT SYSTEM (ELSS) were the subject of my last column. This column is about language and how flows and systems are represented in our language. We often use metaphors that are almost right, but then they are also slightly wrong – and by being slightly wrong, they tend to provide a reflection of the real world that is significantly biased and misleading. We use words that misrepresent the system and disguise the causes and consequences. The mix of metaphors, words and underlying paradigms creates a reflection of the world that blurs the threats and hides obvious solutions from our view.

The "Greenhouse Effect" is a poor metaphor for what humanity's effect is on the coupled ocean-atmosphere system and the global warming resulting from the massive changes in flows of energy and matter humans caused in the ELSS during the last few hundred years. Others have pointed out that the metaphor is weak because the heat-trapping mechanism in the climate system is different from that in a Greenhouse.[1] But the systems are different; for the coupled ocean-atmosphere system, the "Pool Effect" or the "Sauna Effect" would be better metaphors.

The glass roof of a greenhouse lets most of the radiation from the sun pass through, and it reduces the transport of heat back through the glass roof and the glass walls. It changes the balance of the energy flow in terms of what goes in and what comes out, and the difference results in a warming of the air inside the greenhouse. Without the glass roof and walls, the warmer air would expand and rise in a convective motion. In contrast, the walls and roof of the greenhouse prevent the warming air from escaping, and this effect leads to much warmer air inside of the greenhouse.

For Earth, the imbalance of incoming and outgoing radiation is caused by heat-trapping gases (HTGs) in the atmosphere reducing at some frequencies the amount of infrared radiation emitted back into space. As detailed in the last column, humanity's interference with the chemistry of the atmosphere and the planet's surface cover has increased this imbalance by a very large factor. But most of the additionally absorbed heat is stored in the ocean, not in the atmosphere, and that makes the system very different from a greenhouse.

Think of a deep swimming pool housed in a glass room. Most of the heat in this system will be stored in the pool water, not in the air above it. Warming the water to a temperature that is in equilibrium with the incoming radiation takes time, and the air temperature in the pool house will lag behind the equilibrium temperature for a long time until both water and air have reached a temperature that has incoming and outgoing radiation in a balance. With the large water body in the pool, the pool house can store far more additional heat than a greenhouse of comparable size. When night temperatures decrease, the water will radiate back some of the stored heat and keep the air above the pool warm throughout the night.

Moreover, evaporation will also lead to higher humidity, which allows more heat to be stored in the wet air than in dry air. And the warmer the air in the pool house, the more water it can hold: in fact, the amount of water that can be stored in air as water vapor before condensation happens depends on the air temperature to the power of three. Thus, if the air in the pool house was 10° C at the start, it could hold 9.4 g of water per m^3. At 20° C, this amount increases to 17.3 g/m^3, and at 30° C it is already at 30.4 g/m^3. If we go all the way to 40° C, we can have 51.1 g/m^3 of water vapor in the air.

A similar consideration applies to the coupled ocean-atmosphere system: As a result of the increased atmospheric contents of HTGs such as CO_2 and methane, the incoming solar radiation not only warms the air, it also warms the ocean. In fact, the heat that can be stored in the ocean is much larger than what can be stored in the atmosphere. Estimates are that currently more than 90% of the additional heat absorbed by the ocean-atmosphere-land system goes into the ocean.[2]

Similar to the pool house, the air temperature rises much slower than it would if there was no ocean. As a result, the warming of the atmosphere lags considerably behind the equilibrium temperature the system eventually will reach for the current level of atmospheric CO_2 and other HTGs. This time lag will continue to exist as long as emissions continue to change the atmospheric contents of HTGs. As a consequence, future global warming will be much larger than the global warming we experience and can measure today.

The impact of ocean warming on evaporation is also comparable to what happens in the pool house. The warmer ocean evaporates more water, and the warmer air can store much more water before condensation and precipitation happen. The water vapor holds latent heat – that is, energy that becomes available again when the water vapor condensates. This energy is available for dynamics and can drive storms. The warmer the air, the more latent heat it can hold and the more can be made available for storms once condensation is triggered.

Thus global warming is all about flows. These include the flow of solar energy into the atmosphere-oceans system and storage of heat mainly in the ocean, the flow of water in the ocean currents that distributes energy throughout the ocean, the flow of energy in the form of latent heat carried by water vapor from the oceans to the atmosphere, the transformation of latent heat into kinetic energy when the water vapor condenses, and the flow of air in storms. These heat-filled storms can bring devastation to human communities.

This full picture of flows is poorly captured by the term “Greenhouse Effect.” The fact that we have oceans that can store more energy by far than the atmosphere should change global warming from a “Greenhouse Effect” to a “Pool Effect” with respect to energy storage and the exchange of energy between water and air. The large amount of additional energy stored in the ocean can be exchanged with the atmosphere and this changes the dynamics of the weather and climate systems profoundly, similar to a sauna, where heat is transported in the form of water vapor. The combination of the “Pool Effect” and “Sauna Effect” produces high-energy flows with many unpleasant side effects for the ELSS and humanity.

Words can change behavior and impact ethics. Our growth-based, addicted economy requires a constant flow of products from producers to consumers – consumers of everything. By nature, we don’t seem to be consumers, but rather users. In past societies of scarcity, people were “consumers” of food but “users” of almost everything else. Tools, cloth, housing all were cherished, carefully maintained and often passed on from generations to generations. Flows of

“The water vapor holds latent heat – that is, energy that becomes available again when the water vapor condensates. This energy is available for dynamics and can drive storms. The warmer the air, the more latent heat it can hold and the more can be made available for storms once condensation is triggered.”

1

▲ FIGURE 1
A large flow of humans and material for the built environment into the coastal zone has created a threat for the ELSS that will create large-scale pollution when the flow of water inundates the urban coasts as a result of sea-level rise.

products were kept at a very low level. But our modern economy is focused on the creation of human wealth by accelerating flows as much as possible, and for that, people had to be transformed from users into consumers of everything: cloth, cars, furniture, houses, etc.

In all areas, products are made today in a way that it is easier to consume them in a short interval instead of using them for a long time. Maintenance is often ineffective and repairing them is not possible. The rapid advance of technology also requires products to change long before the end of their lifetime and those still fully useable have to be replaced to accommodate new technologies. Even getting our food often forces us to consume large amounts of packaging, including a lot of plastic.

Again, everything is about flow: the flow of resources to the producers, the products to the consumers, the waste back to the environment, and the money from the consumers to the producers. By accepting to be denoted as "consumers" we are supporting a system that is accelerating the flows in the ELSS, changing it, and putting it under enormous stress.

Humans operate with the paradigm that we can live wherever we decide to live and do not need to adapt to potentially changing environmental conditions. The human species builds its dens (towns and cities) with great effort but without considerations of reasonable conditions and potential future environmental trajectories. Cities are built in high-temperature deserts, in areas with little access to food and water, and in hazardous places.

In particular, cities are rapidly sprawling in coastal areas with extremely flat topography directly exposed to the rising seas. A growing fraction of the global population is moving into these cities, ignoring the threats of rising seas for short-term benefits. The hazard for the ELSS is not the rising sea; the hazard is a species that ignores all available knowledge and foresight about possible future sea levels and continues business-as-usual.

The rapid flow of people and materials for the built environment into the coastal zone created a growing threat to the ELSS, and when water flows into these areas as a result of the rising seas, it will reverse the flow of people and change the character of the cities inland. However, most of the built environment will be left behind and cause large-scale chemical, biological and material pollution. The large amount of plastics used in modern buildings add to an already urgent problem: plastic pollution of the ELSS and particularly the ocean.

Humans have a tendency to adopt solutions for a specific problem without fully analyzing the consequences these solutions might have now or in the future for the ELSS. An important example is plastic. Plastic has provided apparent solutions for many problems, and today plastic is almost everywhere and in every product produced by humans. The consumption versus usage rate is very high and increasing. Less than 10% of the plastic produced is used more than once, and this high flow of plastic through the human system and into the ELSS has created a mountain of plastic distributed throughout the ELSS.

If current trends continue, by 2050 the ocean will contain more plastic than fish by weight.[3]

And plastic has an enormous lifetime. It virtually never decays. It breaks down in small particles and these micro-particles are now in almost all flows in the ELSS.[4] They are dangerous because they absorb and concentrate chemical pollutants and increasingly contaminate many food chains. More and more animals, particularly in the marine environment, have contaminated micro-particles in their digestive systems.

Our plastic-based solutions create flows of plastic that are degrading the ELSS and may prove disastrous for many animals and ecosystems. If we'd apply our normative ethics to an analysis of the impacts of plastic on the ELSS, the result would be that the current consumption of plastic is highly unethical. Instead of acknowledging our responsibility, we construct chains of arguments to reason that economic growth depends on us consuming more and more plastic.

Finally, let's look at the language we use in our dialog about major threats. The threat of climate change is a good example. Those who use imagination to explore possible futures under climate change often are accused of describing "Doomsday Scenarios." By choosing this word, an open-minded dialog about the spectrum of possible futures is no longer possible. Recently, David Wallace-Wells in the article "The Uninhabitable Earth" painted a dire picture of a possible future as a result of the most pessimistic climate scenarios,[5] and instead of engaging in a serious dialog of this and other possible futures, a number of scientists immediately attacked him for describing a "Doomsday Scenario" not based on scientific evidence. They claimed he was scaring people away from doing something to address the challenge.[6]

The list of events and processes that could lead to global catastrophes in the near future is long and indicates a rather precarious situation for humanity and our civilization. For example, there is increasing evidence that we are in the middle of the 6th mass extinction,[7] which in the end might eliminate humans, too. But instead of developing language and a dialog that allow us to realize the full extent of the challenges, we increasingly listen to fake language that creates a virtual reality disconnected from the real world.

2

◀ FIGURE 2
Since 1950, humanity has produced more than 9 billion tons of plastic and about 80% of this has been ejected into the ELSS. Much of this accumulates in the ocean in the form of contaminated micro-particles.

While scientific evidence is crucial for this dialog, there is also need for imagination in developing a broad spectrum of possible futures. Investigations should include scenarios that are not, or not yet, underpinned by current scientific evidence but cannot be excluded based on the knowledge we have. We should not inhibit the flow of thoughts about the dire futures we might encounter if we don't make a global and unparalleled effort to reduce the human-caused flows in the ELSS.

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A Killer App for Sats

Global Commodity Trading

DEREK EDINGER / CO-FOUNDER / VP STRATEGIC PARTNERSHIPS
ZACKARY DOWNEY / DATA SCIENTIST

Ursa Space Systems Inc. (Ursa) is a satellite imagery analytics company whose focus is on commodities and the financial markets. Ursa aggregates and analyzes satellite-based radar to build proprietary data layers resulting in unbiased, consistent, all-weather location-based services and measurements. Ursa's unique access to most of the world's current and future radar satellites and our unique understanding of how to apply machine vision and machine learning to radar, gives the reliability that has hindered optical systems and allows Ursa to extract asymmetric value from a single image. (Radar is a unique form of satellite imaging that forms images independent of lighting conditions and weather.)

The company currently accesses 12 different commercial or open-source radar satellites which they refer to as their "virtual constellation" to provide data for their analytics products. Ursa generally builds algorithms, analytics, and tools that are "sensor agnostic" to give them the most flexibility and capacity in utilizing these different satellites. This differs from other analytics firms which leverage radar capabilities of "coherent change detection" which are quite powerful, but limit use to a single sensor with further limited imaging parameters on that sensor.

In addition, many of Ursa's algorithms can create useful products from low resolution imagery. This is a significant advantage over optical imagery sources since lower resolution radar images can cover 50-200+ km areas which can be the size of a whole city or industrial area in a single scene. That said, Ursa also recognizes the different traits of each radar satellite and will leverage them for different applications.

For coarse-level ship and vehicle detection, Ursa utilizes ESA's Sentinel-1A and 1B satellites. Data from these satellites is essentially free, has broad-area global coverage, and has a moderate revisit rate, but generally cannot be tasked by a user. Ursa also accesses 10 commercial satellites. Of these, they have special commercial agreements in place with Airbus for access to TerraSAR-X and TanDEM-X satellites and with e-GEOS for access to COSMO-SkyMed 1/2/3/4 satellites. Ursa is also in negotiation with other parties for similar agreements. These include existing radar satellite operators as well as emerging traditional and SmallSat manufacturers and operators.

Ursa has found their radar supplier relationships to be win-win in many respects. Existing suppliers are all public/private partnerships which generally focus on defense, security, and civil missions. By partnering with Ursa, these suppliers can access new commercial and "big data" markets which bring incremental revenue and often for areas of the world where their satellite is underutilized. Further, Ursa is a U.S.-based company and can help access U.S. customers and markets that can be challenging to access by foreign-based suppliers. Finally, Ursa is working with emerging SmallSat suppliers who need a knowledgeable and agile data customer and where Ursa can be first to leverage their revolutionary capabilities.

GLOBAL OIL STORAGE MONITORING

At this point, Ursa is largely focusing their analytics on global commodity trading. Ursa delivers information products to provide economic insights about the Oil and Gas Industry. One of the products Ursa is offering is Global Oil Storage monitoring.

Ursa is developing the Global Oil Storage product region by region, and began with China. China is an

incredibly important global leader in the Oil and Gas market. It is the number one importer of crude oil, and number two consumer of crude oil, behind the United States. However, there is very little information about China's storage and usage of its crude oil. China is also subject to an incredible amount of cloud cover, causing issues when relying solely on optical satellites. By using radar satellites, Ursa has become the first consistent and reliable dataset on China's oil inventories. See ***Figure 1***.

Beyond China, Ursa has products in Beta for the Caribbean, Middle East/North Africa (MENA), and Europe. These regions also suffer from a lack of reliable and consistent information. Caribbean crude oil inventory movement can be an indication of future inventories in the U.S. and provides an added edge to users. The MENA is a source of much discussion and media attention in regards to the Oil and Gas markets, due to its key role as a global crude oil producing region. Ursa will be growing to a full global expansion in early 2018. See ***Figure 2***.

Why does information on oil inventories provide a value or "edge" to financial or Oil and Gas institutions? In financial markets, profit and edge come from asymmetric information. For the Oil and Gas industry, there is value in information that provides more knowledge to the recipient. Ursa is able to use satellite-derived data for its customers to provide competitive advantage, increased efficiency, and decrease risk for the user.

China oil storage data is an example use case of solving a customer's problem with satellites and big data analytics. There are numerous other problems that can be solved with this approach as well.

The combination of global supply and global demand of oil determines oil prices – a constantly shifting value. To help customers better determine this balance of supply and demand, there is a "balance sheet" commonly used across the energy industry:

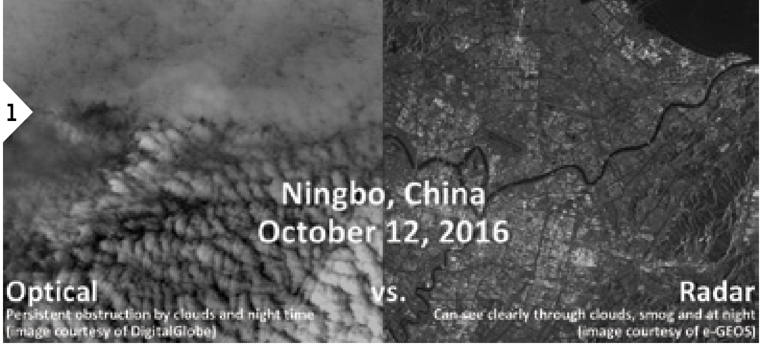
Production + Imports - Exports - Runs = Inventory Change

Production is the amount of oil produced (i.e. pumped out of the ground) in that country, Imports are imported oil, Exports are exported oil, Runs are refinery runs which represent "implied demand," and Inventory Change represents the change in oil inventory which balances the equation.

By having reliable and consistent data on inventory change, users can calibrate the other inputs with more confidence and find discrepancies. Different parts of the Chinese government, including the National Bureau of Statistics and the General Administration of Customs, release estimates on the additional four variables in the balance equation, while the inventory change is calculated based from them. This causes a lack of confidence and risk in the entire balance. If runs information for China matters, then an inventory measurement is needed to give a user more confidence in what that implied demand for oil is.

"By using radar satellites, Ursa has become the first consistent and reliable dataset on China's oil inventories."

Other organizations and businesses use customs and shipping information to estimate crude oil imports and exports from China, which provide some value and estimate of demand, but there is still a level of uncertainty once the oil travels inland into storage. The combination of this import/export data and Ursa's storage data provides a high level of confidence to what



▲ FIGURE 1
Comparing optical and radar images over Ningbo, China, shows the need for multiple types of satellite technology and data to fulfill customer needs.

▼ FIGURE 2
Ursa's technology and capabilities allow for global expansion of its Oil Storage Monitoring product, which will be fully built out by early 2018.

is actually happening with Chinese crude demand.

Ursa has been tracking Chinese crude inventories since November 2016, and has seen large increases in Chinese inventories in late May and early June of 2017. Ursa is able to provide information before any other source, including the government data that comes out of China (which is 1-2 months behind).

An example of how Ursa's data can be used is the balance sheet use case. Consider that China's imports, exports, production, and runs data are not reported until at least 2-4 weeks after the end of the month in question. If the amount of runs drops significantly, it would appear that demand may be slowing (not considering seasonality, general yearly trends, etc.).

Economists, analysts, and traders could alter their short-term or long-term models for crude oil prices based on supply and demand, which may lead to a changed recommendation for buy/sell decisions and therefore could affect the market. There is value to knowing this outcome weeks in advance of everyone else. Since Ursa's data correlates to the general movement of government data, having this information 2-4 weeks ahead of time, especially along with import/export data, allows the user to lock down certain aspects of the balance sheet, and even go so far as to predict the runs number from China.

KEY
Americas
Caribbean
Europe
MENA
Africa
China
APAC

2

Consider a specific example: In July 2017, Chinese imports of crude oil fell from 8.79 mbd (million barrels per day) to 8.18 mbd. Most would see this as a sign of falling refinery activity, and could believe this to be a bad sign for future demand via imports. However, although one variable of the equation is dropping significantly, it is quite possible that other variables (i.e. production, exports, and most importantly for our case, inventory change) could balance this out. If exports and production remain somewhat constant from the previous month, which is relatively common, then the only missing piece to understanding refinery activity/runs ahead of time is inventory change.

If Ursa's storage measurement goes up over the month of July, then it appears that runs will drop accordingly. However, if Ursa's storage measurement goes down enough to balance out the drop in imports coming into China, then it is entirely possible that runs will remain the same, or possibly even rise, all depending upon the storage change in that month. Only Ursa provides a consistent and reliable enough dataset at this point to give an answer to that question, 2-4 weeks before anyone else will have that information.

The China oil storage use case is just one application for this technology and the same model and approach can be applied to many applications in the commercial and government markets including measurement of other commodity storage (coal, iron, copper), ship tracking, oil drilling activity, and many others.

As described in this article, these products for new markets take a different approach where focus is needed on the problem and delivering value to these customers who may be unaccustomed to satellite imagery and big data analytics. However, the upside is considerable.

Satellite big data analytics based on traditional markets was estimated at $3-6B per year by Northern Sky Research (NSR) and Euroconsult in late 2016.[1,2] However, NSR has recently increased this estimate in early 2017 to $15.8B by including some of these new markets.[3] Even this recent update may be too conservative as not all commercial markets may have been considered. As an example, the oil and gas analytics market alone is predicted to grow to $36B by 2024 with a 19% CAGR (Compound Annual Growth Rate).[4]

Ursa believes there is a bright future for analytics for the global commodities and financial markets which, in turn, creates a bright future for satellite imagery suppliers which fuel these analytics. ∧♂

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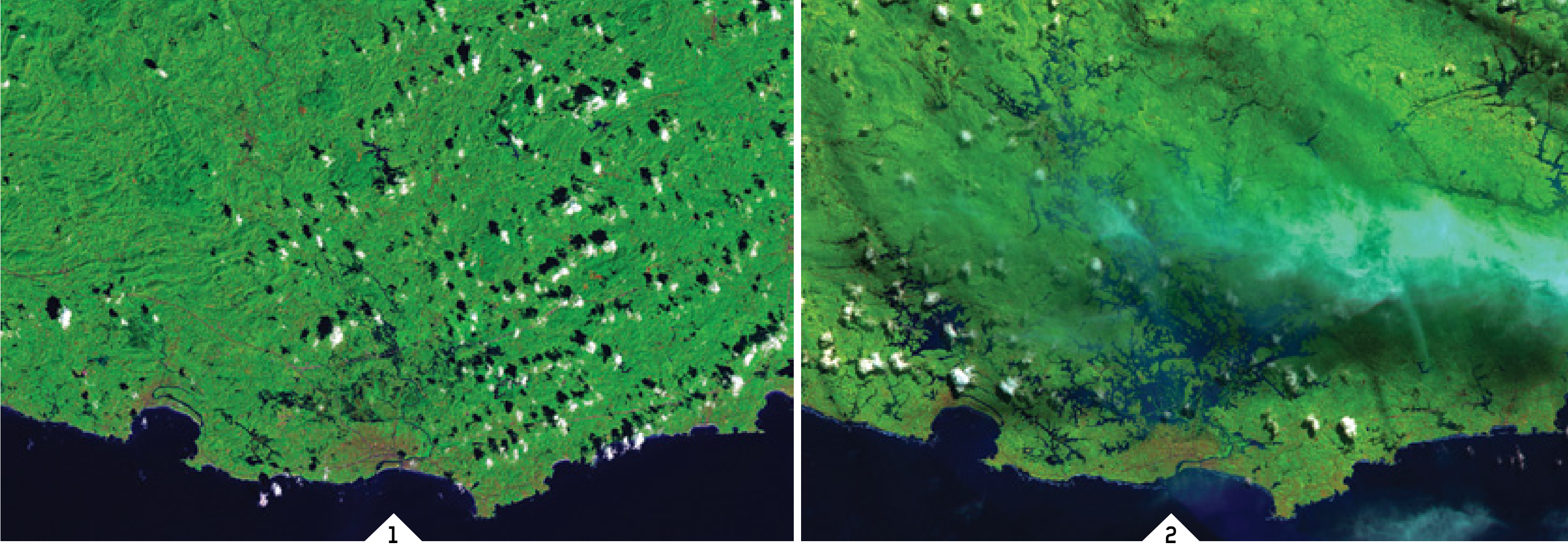


Open Source GEOSPATIAL SOFTWARE

Earning Respect and Commercial Viability

MATTEO LUCCIO / CONTRIBUTOR / PALE BLUE DOT LLC / WWW.PALEBLUEDOTLLC.COM

Open source geospatial software—spatial data management, GIS, and related developer tools and end-user applications delivered with an open source license—has co-existed with proprietary geospatial software for decades. Software developers and users often mix and match the two. The Open Source Initiative developed the definition of open source license, which consists of ten criteria. Two of these criteria are:

↘ THAT THE SOFTWARE MUST BE FREE TO REDISTRIBUTE, AND
↘ THAT EVERY REDISTRIBUTION MUST INCLUDE THE SOURCE CODE.

Unlike proprietary software, which is written by a development team from a single software company, open source software is written by a community of developers from all over the world, some doing this as part of their paid jobs and some as volunteers. Their contributions and bug lists are managed by a steering committee. Local groups can immediately make changes to the code, but it may take a while for those changes to be accepted by the steering committee and placed into the current version. Like proprietary software, open source software is commercial in that companies can profit from it by offering services (such as installation, customization, or training) or related software.

▲ FIGURES 1-2
This Sentinel 2 satellite image taken on May 28, 2017 (Figure 2 on right) captured the extent of the flooding in Sri Lanka after torrential rains poured down non-stop for 48 hours. The Landsat 8 satellite image on the left (Figure 1) was taken months earlier on January 29, 2017.


3

I discussed the interplay between open source and proprietary geospatial software with:

- Anne Hale Miglarese, Founder and CEO, Radiant. Earth
- Andrew Dearing, CEO, Boundless Spatial, Inc.
- Andrew Turner, Director & CTO, Esri DC R&D Center, Esri

RADIANT.EARTH

Radiant.Earth uses open source software and data to enhance and expand the geospatial market for the global development community. Miglarese has been in the geospatial industry for 30 years, working at the federal and state government levels, and with commercial enterprises. Prior to starting Radiant.Earth, she was the CEO of an airborne mapping, remote sensing, and GIS services company called EarthData (now known as Fugro EarthData), as well as the CEO of PlanetIQ, a company that is fielding commercial weather satellites. "What I've never done before," she says, "is work in the not-for-profit sector, which is what Radiant. Earth is."


ANNE HALE MIGLARESE
RADIANT.EARTH

▲ FIGURE 3
The 'new face of humanitarian response' highlights how open data can increase users, encourage innovation, drive grown and spark new solutions to old problems.

ORIGINS

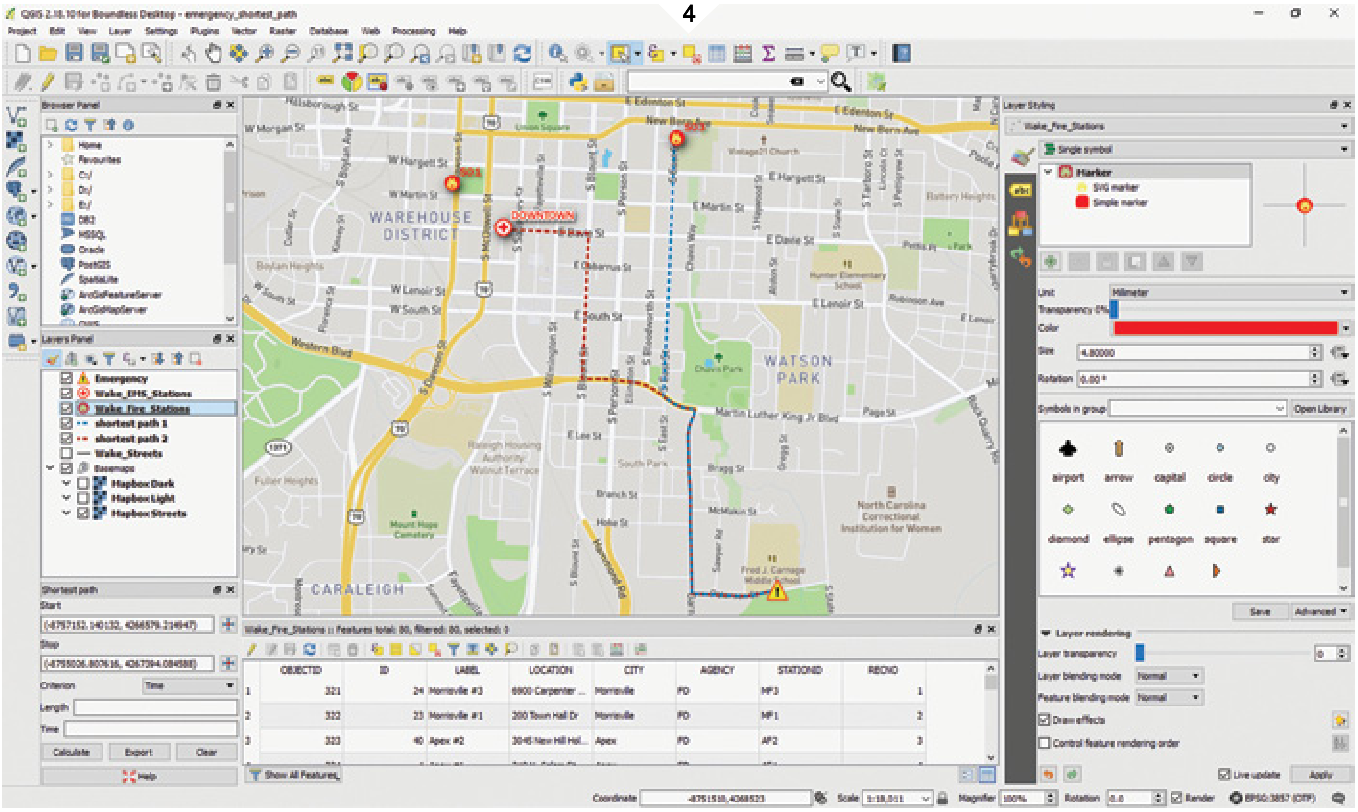
The idea behind Radiant.Earth emerged about two years ago in discussions with Peter Rabley, an investment partner at Omidyar Network. "Peter had an idea about how impactful it would be to organize the world of open data," says Miglarese, "because the data are fragmented and also very costly, difficult, and time-consuming to acquire. Often, satellites are built at great expense, but primarily for principal investigators in the science community, and the data they collect does not find its way outside of that community."

Radiant.Earth was publicly launched at the Thought Leaders Forum, hosted by the Gates Foundation in Seattle in February 2017. Its vision is to aggregate the world's open Earth imagery (collected by satellites, aircraft, and drones), make it easily discoverable and accessible, and allow people to compute on it either within its cloud or by downloading it to their environment. "While our user community may be very broad, our primary focus will be on supporting the global development community, in line with the mission of our primary investors," says Miglarese. While an increasing number of global development specialists use geospatial tools, there are few resources to help that effort grow. For this reason, Radiant is also helping to develop this community.

Radiant.Earth will not house commercial data with a restrictive license because it cannot currently monitor and regulate what happens with it downstream. It does, however, enable its users to discover relevant commercial imagery. "This model is a win-win for everybody because we understand that sometimes the problem is best solved with commercial sources of imagery," Miglarese says. It will be building its platform with open source tools, in partnership with Vizzuality, while Azavea is building its imagery pipeline and analytics tools. "While our platform will be built with open source technology, we anticipate that many of our users will continue to use their commercial software workflows to analyze the data discovered on Radiant.Earth."

USERS

Radiant's primary focus is on the global development community and organizations with a mission to deliver their services and products at the local community levels. Its platform will be open for anyone to register and use and Miglarese anticipates seeing some commercial traffic on it. "We'll certainly see education



▲ FIGURE 4
Boundless Desktop displaying shortest route for a local fire station to an emergency

and academic research institutions, as well as traffic from a broad swath of the conservation, environmental, and global development community," she says. Innovation in satellite imagery and analytics enable faster and more accurate change detection, she points out. "It is going to meet many needs for the international and global development sector."

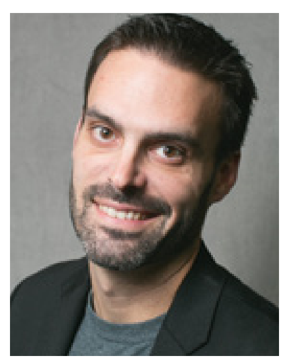
DATA

Radiant has developed a partnership with Amazon Web Services, which already hosts Landsat and Sentinel data, and aims to expose additional open datasets. It has advanced formal relationships with the European Space Agency and the United Nations Institute for Training and Research (UNITAR) through its Operational Satellite Applications Program.

"Clearly, there are valuable commercial archives out there," Miglarese says. "We have selective interest in older satellite archives, which we may be able to add to our platform and expose to users for greater use. I think they'll be particularly interesting for conservation, climate change, and development efforts." Additionally, she hopes that Radiant's effort can make it more cost effective for drone operators to collect data for global development and conservation projects.

"We have a wide portfolio, whether it's for agriculture, property rights, government transparency, global health, financial inclusion, or basic cartography for the developing world," Miglarese explains. "We are also setting up a sandbox for people to be able to experiment and run models with the data. We are developing a very collaborative relationship with the commercial sector, with both software companies and imagery providers."

BOUNDLESS



ANDREW DEARING
BOUNDLESS

Dearing has worked in and around the geospatial industry for almost 15 years. He began at a small startup using GIS to help support the defense industry, then spent almost ten years at Esri, working with a variety of industries. In early 2015, he joined Boundless as the VP of professional services. "We had a variety of customers and initiatives that were looking into deploying open GIS tools," he recalls, "including the traditional OpenGeo stack that Boundless maintained, then transitioning it from an Esri environment to an open source platform." In late 2015, he was promoted to CEO.

ORIGINS

Boundless (known in its early days as OpenGeo) started in 2001 with a New York City nonprofit called OpenPlans. Its goal was to enable the free flow of communication and data between communities and the government, specifically as related to city planning. "The city wanted to provide an easy way of sharing geospatial information, without being tied to proprietary software platforms," Dearing says. Out of these efforts emerged a server technology able to disseminate geospatial data and information in applications and maps. In 2002, the team built a project known as GeoServer. It was donated to OSGeo and a powerful open source geospatial community formed around the project. "We continue to support GeoServer today through a variety of community efforts with OSGeo."

In 2008, to fulfill the need for a complete supported open source geospatial enterprise platform, Boundless created OpenGeo Suite, which bundles PostGIS, GeoServer, GeoWebCache, and OpenLayers. By 2010, there were more than 20,000 downloads of OpenGeo Suite.

OpenGeo Suite's release was followed by a significant uptake in downloads from the federal government, which had realized that open source GIS could help enable its enterprise and reduce dependencies on single vendors of proprietary software. Additionally, the federal government is required to establish commercial support for their open source implementations. "OpenGeo (Boundless) is the only commercial support provider for the open source geospatial platform, but at that time, we were still a non-for-profit," Dearing recalls. In 2012, In-Q-Tel (the federal government's investment arm), Vanedge, and several angel investors invested in OpenGeo to transform it into a for-profit organization known today as Boundless.

MISCONCEPTIONS OF OPEN SOURCE

With open source, Dearing points out, the developer community and the customers, not a single company, shape the software platform's vision and roadmap. Among the misconceptions about open source geospatial software are that it is insecure, buggy, or unmonitored. "That is far from reality," says Dearing. "There are many great gate checks out there and well-established steering committees. Core contributors control the code base to ensure high quality, that there are no malicious code or security holes, and that the technology performs at the level it should. Then you have organizations like OSGeo and LocationTech that help promote, sponsor, and maintain these communities around the open source projects."

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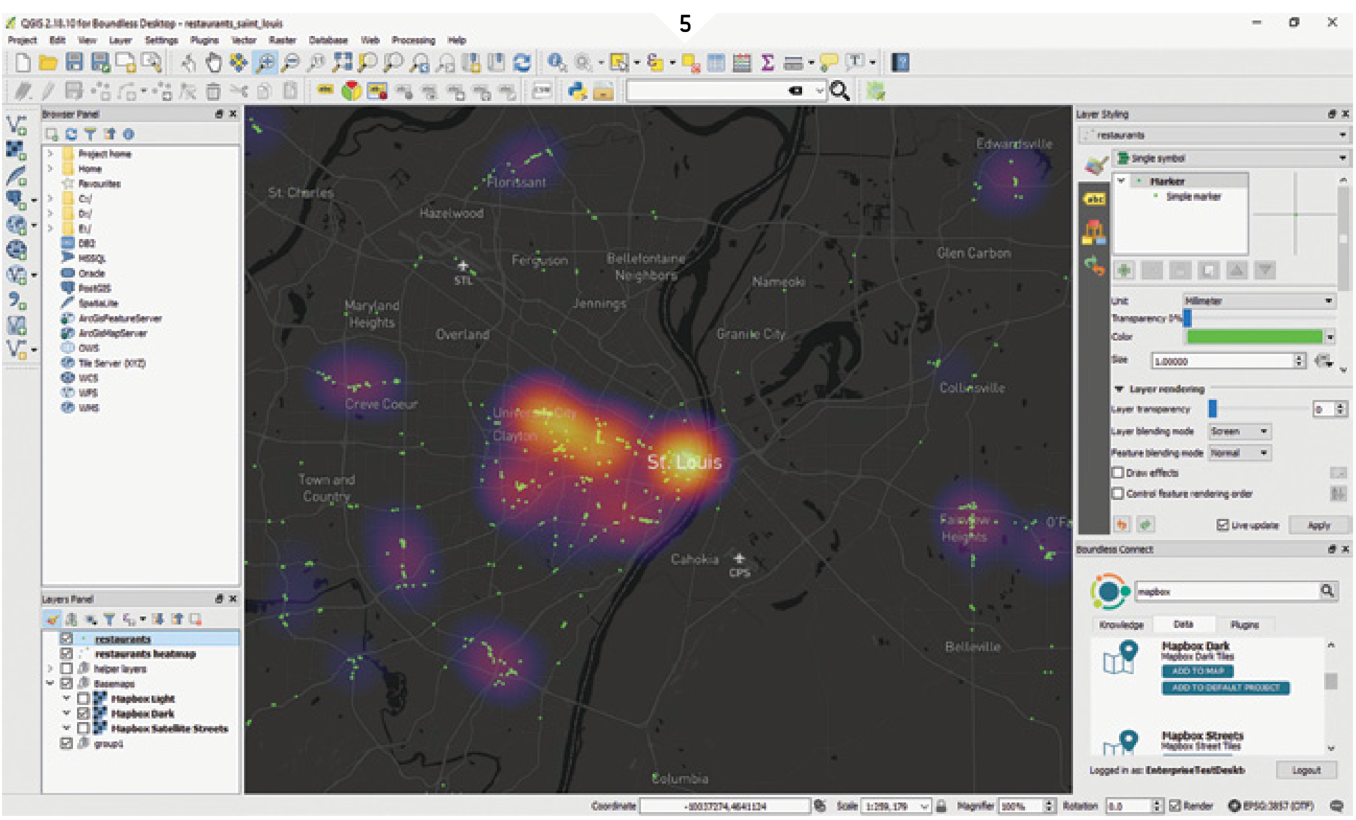
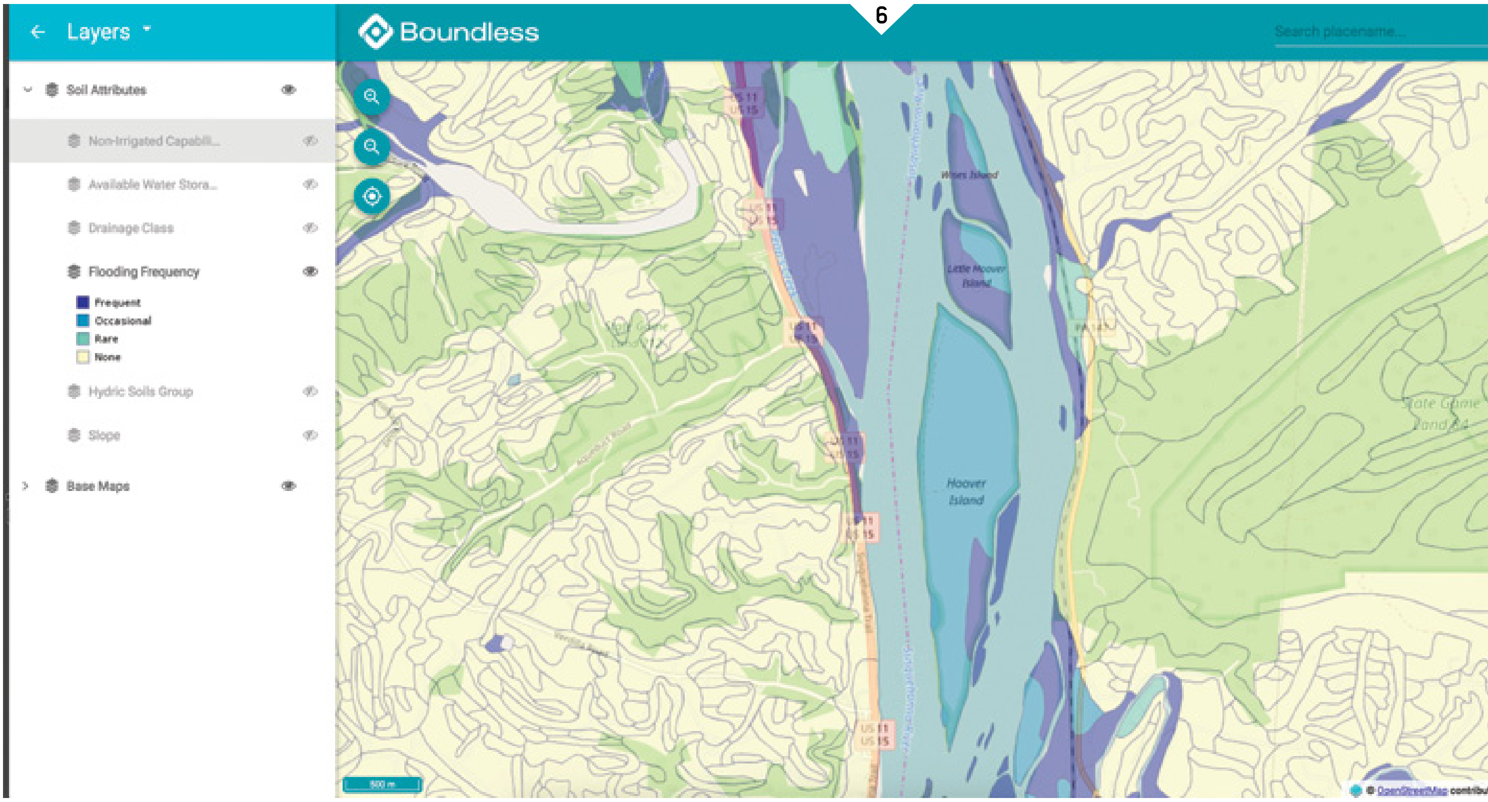


▼ FIGURES 5 Boundless Desktop displaying a heatmap of restaurant clusters in the Saint Louis area over Mapbox dark basemap style



Up until five to ten years ago, open source geospatial web applications and desktop products were not widely adopted, says Dearing. However, he points out, "as many organizations saw the performance, scalability, and the cost advantages of open source platforms, the gap in usability and functionality between them and proprietary solutions narrowed significantly. There are desktop tools, such as QGIS, as well as web mapping technologies, such as Leaflet and OpenLayers, that now are widely adopted to help GIS professionals, and developers create, share, and visualize geospatial information." There is an explosion in the adoption of the open GIS platform in many federal government entities, he adds, and agriculture, insurance, and healthcare are also huge growth sectors.

Often, Dearing points out, Boundless' customers are also Esri's customers. The fact that Esri is now pushing code out on GitHub is "a nice first step," he says, but the core of its business is to provide proprietary software to its customers. By contrast, Boundless offers a hybrid approach: "Many organizations are seeing success in implementing open source in a proprietary way. There is a progression to implementing and realizing the value in open source, as you minimize your dependency on closed source solutions."

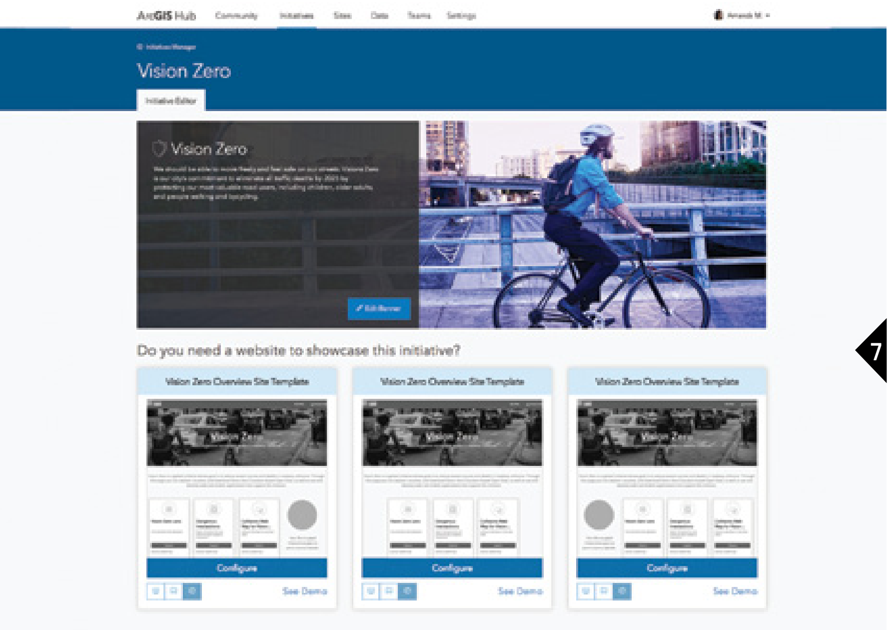
ESRI

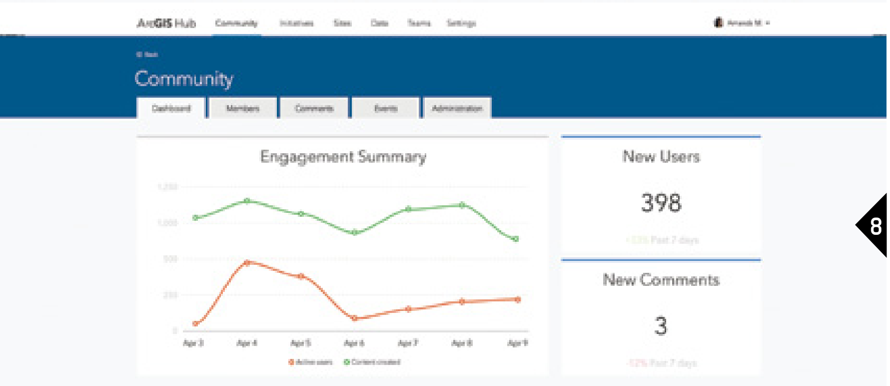
ANDREW TURNER
ESRI

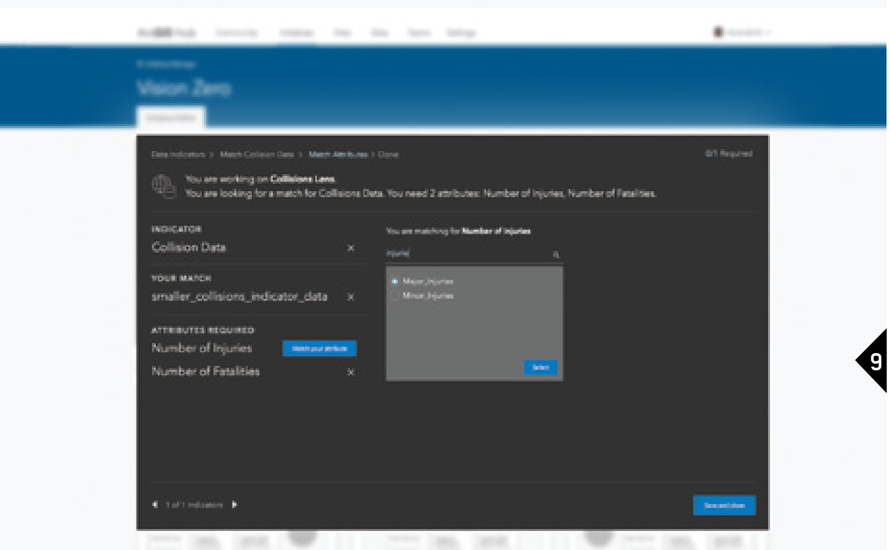
Turner has worked in the technology domain for 20 years, the Web domain for 15, and the geospatial domain for a little over ten years. "I come from the open source community," he says. "I began learning LINUX in 1997." When he started to work at Esri, he was surprised at how much open source was part of its culture. "Internally, all the engineers have access to all the different projects. So, if I see that there is a feature that I want to add to ArcGIS Pro or Enterprise or Online, I could make a pull request against that, much as you can do in the open source world. We might even bring open source projects into our technology, improve them, and release the results back out. We also take things that we built ourselves and open source those. There are currently 400 open source projects on Esri's GitHub repository."

GIS is not an app, says Turner, but a system of many interconnected components. "That's fundamentally the way that ArcGIS has been designed. We've been doing open source, kind of quietly, for the last several

▲ FIGURES 6
Boundless Web SDK displaying flooding frequency in Pennsylvania







▲ FIGURES 7
ArcGIS Hub includes a set of ready-to-use Initiative Templates to make websites for your initiatives, so you can spend less time creating web pages and more time solving problems. They can be easily configured, branded, and customized.

▲ FIGURE 8
Members can create accounts in your Hub using social media logins to collect data, respond to surveys, and join teams.

▲ FIGURE 9
ArcGIS Hub Initiatives each come with a set of content and apps to inform, engage, and demonstrate progress.

decades, while also adopting other open source projects. We've been heavy supporters of GDAL and other libraries." A lot of popular open source geospatial software, he adds, came out of Esri's research.

"One of Esri's crown jewels is the open source code we use to manage and manipulate spatial operations on core geometry. We use the Apache 2 reusable license. You can use it and modify it and may share those modifications but don't have to."

GITHUB

Starting around 2010, Turner points out, GitHub made it very easy to distribute, discover, and access open source code. "We want to make a lot of our technology open source because we want to make it as accessible as possible for any of our 23,000 government customers to find on GitHUB, then download, deploy, and modify."

When he joined Esri in 2012, Turner says, Esri had two or three open source projects that were part of its product line, including Geoportal, a catalog and distribution tool, and one for editing OpenStreetMap data with Esri tools. Then, Esri decided to re-engage with the open source community. "It was a tactical shift in terms of where we were doing it. Geoportal Server is a metadata catalog and search tool. Another one is an extension for ArcMap that allows people to download and analyze the map data or upload it to ArcMap."

"Esri is interested in the broader context of open source," says Turner, "that it is not just available, but also accessible, so that it is easy to discover, use, and integrate into existing workflows." People bring their own ideas and perspectives into open source projects and are able to influence them. "In the end, this will make better technology and better solutions for everyone."

SUPPORTING OPEN SOURCE

Esri supports the larger open source community through collective funding as well as code changes to various open source libraries, says Turner. "We open sourced our geometry engine and are now working with the University of Minnesota to integrate that into different libraries and tools. Now we're working with other communities to adopt their tools and improve them. Esri Leaflet, for example, is a popular Web mapping library. We've improved that core concept code, and we've built extensions to that, that we open source. We adopt existing open source tools, share them back out, and sponsor open source-focused conferences as well." For example, he points out, Esri has been the longest continuous sponsor of the FOSS4G (Free and Open Source for Geospatial) conference.

Esri recently launched ArcGIS Hub, to try to put open source data and software "into the perspective of what communities are actually trying to accomplish to improve lives, safety, health, and happiness," says Turner. "How is Los Angeles going to accomplish its own Vision Zero pedestrian death reduction program? How is New Orleans going to do that? How is Rio going to do that?" ArcGIS Hub enables them to share their plans and methodology as they develop them, as well as their data, he says.

LOCATION

Location, Turner points out, is as fundamental an aspect of all software as time, but implementing geospatial software requires particular expertise. "There are particular complicated mechanisms and algorithms that make geospatial possible," he says. "They include how to code data, handle precision, handle accuracy, make it scalable, make it fast, make it capable to do the different kinds of analytics that we understand today but also that we might implement in the future."

Geography, he points out, is interesting because it's fractal. "You can never measure perfectly. Geospatial has tools, mechanisms, and expertise that we have acquired through centuries of measuring and coding geography. I think that's the unique aspect of geospatial as we see it."

CONCLUSIONS

The roots of open source GIS can be traced back to the Map Overlay and Statistical System (MOSS) developed by the U.S. Department of the Interior in 1978, followed shortly by the Geographic Resources Analysis Support System (GRASS). In a 2005 article introducing open source geospatial tools, Tyler Mitchell wrote, "The development of open source geospatial software is an exciting part of the new geospatial landscape." In 2013, Boundless became the first company to provide commercial support and maintenance for the world's most popular open source GIS applications at the database, server, desktop, web, mobile, and cloud levels. Evidence of Esri's commitment to the open source community is the launching of ArcGIS Hub. As the developer and user communities including Radiant.Earth continue to grow, open source geospatial software holds great potential for increased collaboration, the sharing of valuable data, and access to key resources. ∧♂

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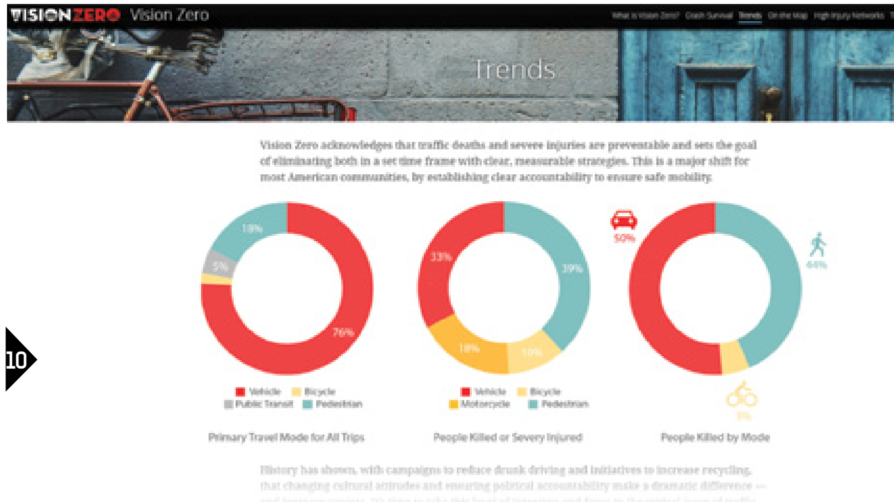

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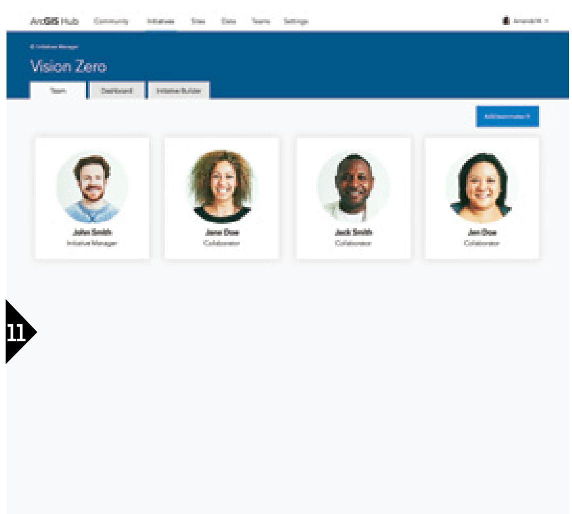

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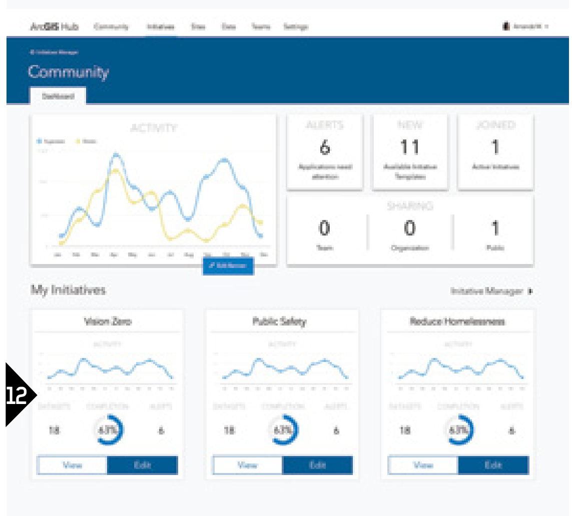
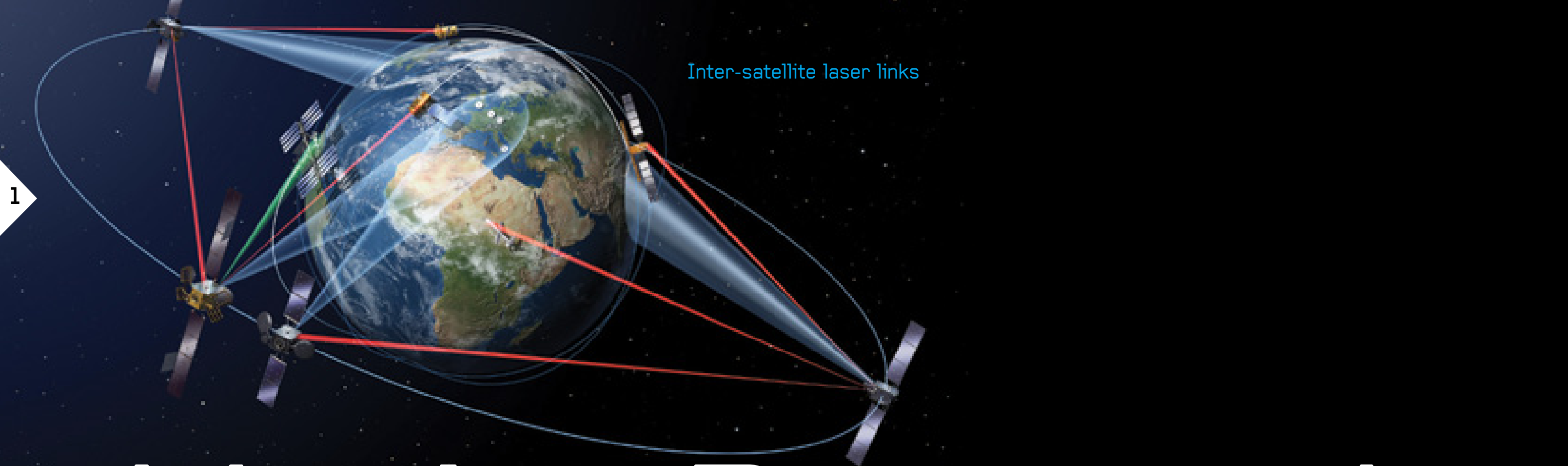


▲ FIGURES 10
Use story maps, dashboards, and infographic reports to share information with your community and to measure progress and accountability.

◀ FIGURE 11
Governments can create a central place to collaborate by inviting trusted members of the community (business people, universities, NGOs) to collaborate on initiative teams.

◀ FIGURE 12
Monitor initiative progress and community engagement with the ArcGIS Hub Community dashboard.



Moving Data at the

Enabling Fiber Optics in Space

KAREN NOZIK / FREELANCE WRITER / WWW.LINKEDIN.COM/IN/KARENNOZIK

The amount of data being collected from satellites is extremely high and continually increasing, putting severe pressure on downlink providers. Satellite operators have been using the Radio Frequency (RF) spectrum for decades, which has a finite amount of spectrum available, and the demand for it is insatiable.

As increasing numbers of companies and countries are sending up their own systems, data demands continue to increase. The number of satellites alone is astounding. According to Euroconsult, about 3,600 SmallSats are predicted to launch in the next 10 years, the majority of them for Earth observations (http://www.euroconsult-ec.com/7_July_2016). With the Earth Observation (EO) and communication satellites all using the RF spectrum for downlink, and now add the unmanned aerial vehicles (UAVs) sending live streaming video to facilities globally, demand has never been higher.

In addition, there is continued pressure for decreased latency (near real-time delivery). In the event of natural and man-made disasters, where rapid humanitarian aid can save lives, or locating pirates at sea who often have hostages who need aid as fast as possible, transmission speed means everything.

The overcrowded RF airwaves are also prone to interference, interception or jamming. RF transmissions have data transfer speeds of approximately only 200 Mbps (megabits per second), and yet the RF spectrum is one of the most valuable commodities on earth. Since July 1994, the FCC has conducted 87 spectrum auctions, which raised over $60 billion for the U.S. Treasury. Information and its timely transport are critical to national security, disaster response, and commercial customers; assured communications is a must.

Fortunately, there is now in place a reliable, efficient, and affordable solution to move data at an order of magnitude faster using Laser Communication Terminals (LCTs), which also resolves the issues with the current RF spectrum.

LCT TECHNOLOGY

Laser communications (optics in space) has been considered for space applications since the invention of the laser. The attraction has always been the fact that wavelengths in the optical regime are shorter by a factor of 10,000 compared to RF wavelengths. The shorter wavelength results in a smaller diffraction spot compared to traditional RF communication options, leading to smaller optics versus larger RF antennas. The narrow optical beam width makes optical communication links the ideal candidate for point-to-point links.

SECURITY OF LASER COMMUNICATIONS VS RADIO FREQUENCIES

Sending data with lasers, rather than via RF, has the potential to revolutionize the way data is delivered from satellites worldwide. Laser communications transmit information through a data stream of narrow beams of energy that is virtually undetectable and very difficult to jam, due to the coded acquisition signal and coherent detection. To disrupt a laser communication transmission, one would have to be able to detect the narrow beam and find a way to put an object in front of it. To actually intercept data, an adversary would have to place a receiver in its path. The vulnerability to link disturbances through a third party adversary is drastically reduced. Jamming an optical inter-satellite link is almost impossible.

In addition, there are no regulations for the use of the optical spectrum, which is not the case with RF communication bands.

Speed of Light

3

Alphasat in orbit

The filing process for RF spectrum-use approval through the International Telecomunication Union (ITU) is long and difficult and success is not guaranteed.

BACKGROUND OF LASERS IN SPACE

Tesat-Spacecom envisioned this capability with lasers decades ago, and with persistent technological advancements, a quantum leap has been made in bandwidth. See ***Figure 1***. As of October 2016, the Tesat LCT 135 is the only functioning commercial laser communication terminal that has been space-tested and rated TRL9 (Technology Readiness Level 9, the highest rating). See ***Figure 2***.

Celebrating 10 years of lasers in space, Tesat's laser communications journey began with the 2007 launch of U.S. Air Force NFIRE and Infoterra's TerraSAR-X. Both LEO (Low Earth Orbit) satellites were equipped with first generation Tesat LCTs on board. These LCTs demonstrated optical communication links at a data rate of 5.6 Gbps at LEO-to-LEO distances.

Since 2008, LEO-to-LEO communication links and LEO-to-Ground communication links were successfully achieved. The first-generation LCTs helped refine the basic functionality of the pointing, acquisition and tracking (PAT) aspects of optical communications. The second-generation LCT currently in operation is designed to be used for large distances such as data relay systems. In this role, bi-directional data rates of 1.8 Gbps have been achieved over LEO to GEO (Geostationary Orbit) distances of up to 45,000 km. The second-generation LCT design is an enhancement of the first generation to enable it to cover the distances between LEO to GEO, GEO to GEO and GEO to Ground.

CURRENT IN-ORBIT STATUS

Currently Tesat has two GEO LCTs and four LEO LCTs from Tesat operating in orbit. Since 2014, LEO to GEO communication links have been demonstrated continuously using the Technology Demonstration Terminal on Alphasat. See ***Figure 3***. In November 2016, after finishing the in-orbit-commissioning phase of the GEO Spacecraft EDRS A, the commercial data relay service known as SpaceDataHighway became operational. In-orbit testing demonstrated a robust design with solid link margins. See ***Figure 4***.

Based on these in-orbit tests, it became apparent that the LCT can cover distances up to 80,000 km and therefore is well suited to also support longer distances as required for GEO-to-GEO links. This is a significant development, and shows that creating a GEO fiber optic "backbone in space" is possible.

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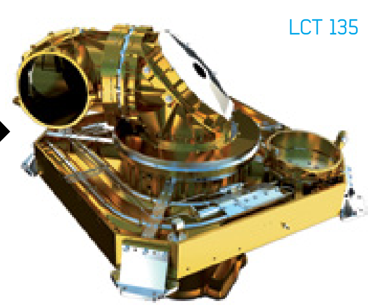
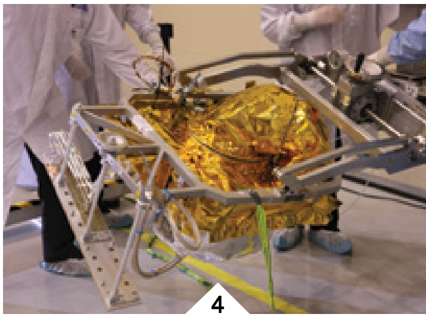


LCT 135



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Integration of laser terminal into EDRS A

The Tesat LCTs are the basis for the European Data Relay System (EDRS), which provides LEO-GEO data relay services of 1.8 Gbps. Sentinel-1 as part of the European Commission's Copernicus program is a SAR (Synthetic Aperture Radar) satellite used primarily for maritime domain awareness. See ***Figure 5***. It was the first satellite in LEO to use the EDRS SpaceDataHighway. The satellite dumps its data down to European ground stations, then once it passes them, it switches over to the EDRS Data Relay System. This doubles the capacity of possible data collection and reduces data latency, just by using different downlinks.

Andreas Hammer, Chief Executive of Tesat, knows well about the aforementioned challenges, and perhaps even more about solutions. He says his biggest challenge is making others understand. He states, "When it comes to space, there is resistance to new technology. But with data constantly growing and an insatiable drive for faster information, the benefits of LCTs become manifest."

Meeting the Needs of NewSpace

NEW DATA TRANSMISSION PRODUCTS DESIGNED FOR SMALLSATS

Clearly, a major disruptor in the Earth observations and satellite communications markets is the proliferation of SmallSats (usually under 180 kg), including CubeSats (using a standard size and form factor). The latter uses a "one unit" or "1U" measurement of 10x10x10 cms and is extendable by multiplying that out, up to "12U." These spacecraft are so small that their payloads need to be smaller and lighter, but full functionality is still expected. Tesat is answering that demand by increasing their product portfolio and offering smaller and more affordable LCTs, planned to be available by 2019.

Some options for SmallSats include using the GEO nodes for data relay, because they have a data latency demand compared to standard RF ground network services. Obviously, SmallSats need smaller payloads. Smaller LCTs such as LEO SMART offer solutions, at 22 kg. This is the option for SmallSat companies that want to use GEO satellites for data relay, transferring data up to 45,000 km at 1.8 Gbps.

Many SmallSats carry high data-rate sensors but they are too small to carry RF subsystems and antennas, so they need new ways to transmit data to the ground. In this case, the TOSIRIS Terminal is the right choice at less than 8 kg, data rate of 10 Gbps, and range of 2,000 km down to Earth.

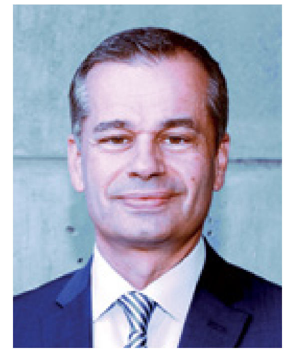
The smallest laser terminal is CubeL, designed specifically for CubeSats. It weighs only 250 grams (.25 kg, or about half a pound!) and it is still able to deliver data at 100 Mbps over 2,000 km DTE.

A new domain is coming with LEO Constellations, which have high numbers of satellites needing SmallSat solutions. For this market, Tesat has created the ConLCT for links among satellites in constellations. ConLCT is very effective and based on high integrated photonic and integrated electronic solutions. ConLCT can transfer data at 5-10 Gbps at ranges around 6,000 km.

In addition to providing the smaller form factor for the SmallSat world, using laser communications for data transfer would be secure, because laser/optical beams cannot be jammed or detected (unlike RF signals).

Even though Tesat has been working on LCT in space for over thirty years, laser communication is still considered new. Those who have been dependent on RF technology – just about everyone – are comfortable with the technology they've been using, and are slow to accept the new capabilities.

"They (commercial industry) have stayed with the current rate and frequency for decades and they've been fine with it," explains Hammer. "So there is a lot of convincing in the very beginning for the market to understand the benefits of laser. But over the past two years, it's changed; operators are interested now because the need for more bandwidth and better frequency management is self-evident." But change is coming fast and a laser relay system is quickly catching on.



ANDREAS HAMMER
TESAT CEO

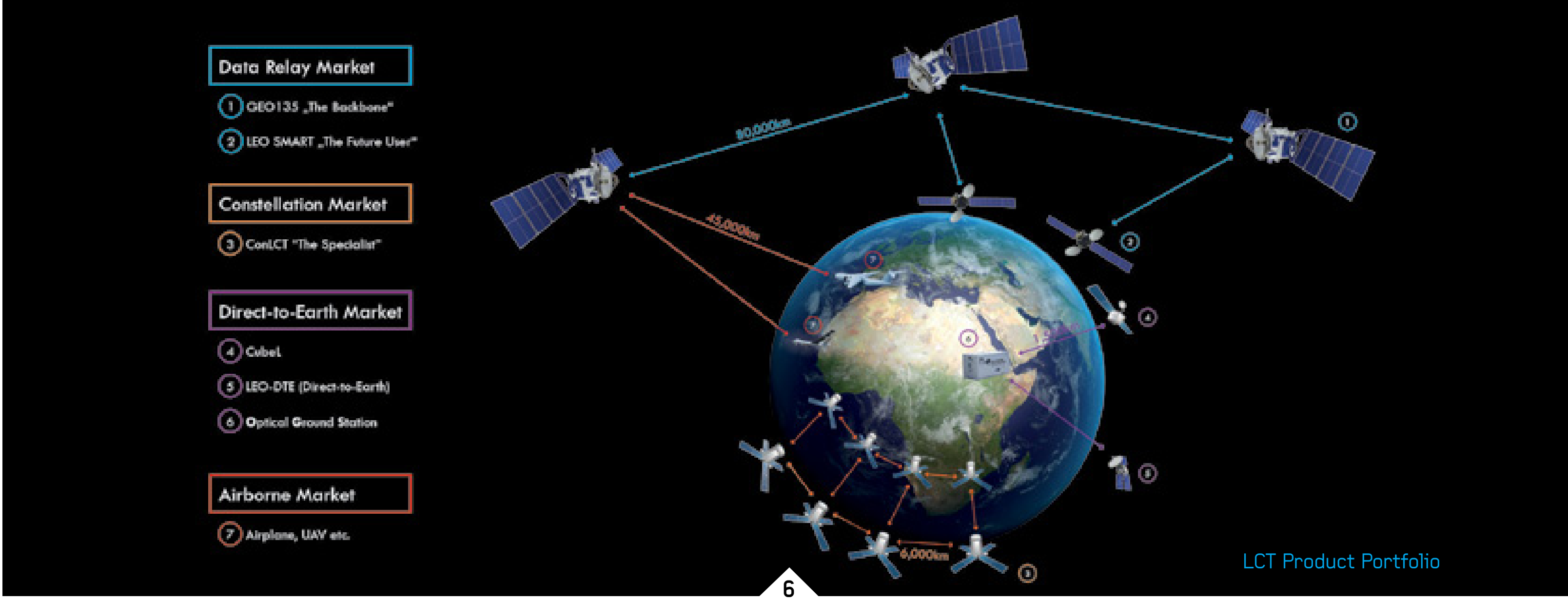
THE BOTTLENECK FOR DATA DOWNLINK

Currently, the RF spectrum is limited. Satellite sensors and instruments are collecting more data than they can transfer off the satellite in a timely manner, using the current legacy RF spectrum. Some operators are filing with the ITU to move to Ku- or Ka-band, but those bands are not secure and at risk of jamming and of data being intercepted. Also, data rates are in the Mbps, while current laser communications offer much higher capacity at 1.8 Gbps, with even higher data rates coming.

DATA RELAY DECREASES DATA LATENCY

Another problem with the current downlinks is data latency; it takes too long for the data to reach the ground and end users. Optical data relays help to reduce this delay. We have all heard this before over the years, so let's look at specifics, and how this is different. Using laser beams to transfer data is a game-changer.

Currently, two GEO LCTs (on Alphasat and EDRS A), and four LEO LCTs (on the original NFIRE and TerraSAR-X, plus two Sentinel satellites) are operating in orbit. Instead of waiting to pass over a fixed-location ground station, satellites in LEO can transfer their data to these GEO satellites via lasers, which in turn transfer



LCT Product Portfolio

6

it to the ground via Ka-band. The transmission time window from GEO to the ground is perpetual while the typical LEO link to a ground station is finite. Also, the data rate through the laser relay is significantly faster at 1.8 Gbps.

The link to the GEO node would be via laser communications, while the link to ground is still via RF (Ka-band). In the near future, these links to the ground will be a combination of laser beams and RF, to take advantage of the most efficient downlink options depending on geographic location, atmospheric distortions, and specific needs of the satellite operators.

Absolute minimum latency is needed for ad-hoc services for monitoring events or disasters. An incredibly low latency of 10-15 minutes is possible with space data relay, in some cases. The EMSA (European Maritime Surveillance Agency) has a requirement to process the data from the sensor of the LEO S/C to the Mission Operation Center in Lisboa/Portugal within 15 Minutes – this can only work with data relay. This is truly "near real-time," the definition of which has changed drastically in the past few years, from days to hours and now to minutes.

THE ONLY CHALLENGE: THE CLOUDS

Just as electro-optical sensors taking Earth imagery from satellites cannot "see through clouds," laser communication links cannot transfer data through clouds due to atmospheric distortions. This is not a problem for the lasers operating from satellites in LEO to those in GEO, or LEO to LEO, as they are all operating above the atmosphere. This is only an issue for getting data down to Earth, which is why RF is still used for this last step.

However, using lasers for getting data to Earth is being demonstrated. Approximately 900 links from NFIRE and TerraSAR-X have been sent to optical ground stations in Hawaii and Mount Wilson. Potential solutions to improve the groundlink performance are adaptive optics, such as the Transportable Adaptive Optical Ground Station (TAOGS, which is in operation in Tenerife Island, Spain. This TAOGS is terminating the bi-directional 1.8 Gbps link from GEO Alphasat. Another measure to improve the availability for optical ground links is site diversity with more locations around the globe.

MATTHIAS MOTZIGEMBA
TESAT VP

CONCLUSION

Hammer drives his points home. "Tesat is the 'one stop shop' for laser communication solutions. We have a wide range of products from 10 Gbps over 2000 km to 1.8 Gbps over 80,000 km. We are working with manufacturers to ensure their future equipment can utilize laser technology. We are a well-known player in the established space market. We are now addressing a low-cost approach in the NewSpace market. Therefore, we now also offer the smallest 100 Mbps Cube Laser Transmitter (CubeL) weighing only 250 g. We are simply an equipment provider, offering a new transmission media – fiber optics in space. As the world moves towards building an 'internet of things,' we can no longer operate without fiber in space."

Matthias Motzigemba, VP at Tesat adds, "With our laser communications products, we are able to support important applications for multimedia services, security, criminal investigations, Earth observation and crisis intervention management." See ***Figure 6***.

The high-speed optical backbone in space is now a reality. Tesat's LCT portfolio enables future Communication Network Architectures, where an optical terabyte service is the key. High data-rate transmission capability, operational security, and immunity to interference sources, as well as ultimate link robustness are decisive factors for security applications, disaster relief or commercial connectivity providers. ∧♂

GA-ASI image of Airborne Laser Communication System

Future LPI/LPD Architecture for Defense and Security

BY DAVID S. GERMROTH, PRINCIPAL, PACE GLOBAL SOLUTIONS, WWW.PACEGS.COM

The United States military and its Allies rely heavily on the use of satellite bandwidth as a part of its overall strategy in winning current and future battles. The existing SATCOM systems are unable to meet current and future DoD bandwidth requirements. They lack capacity, in both aggregate data rate and the number of users they can support.

Intelligence, Surveillance and Reconnaissance (ISR) platforms that include Remotely Piloted Aircraft (RPA), P-8's, Rivet Joint, and others that collect ELINT, MASINT, SIGINT, Full Motion Video and other forms of intelligence require high-capacity, secure and often clandestine links. Additionally, the increased presence of Radio Frequency (RF) interference and jamming are driving the demand for robust, anti-jam communications links. Laser communications can provide the bandwidth, security and robustness to meet warfighter needs today and in the future.

Having the ability to deploy laser communication in support of U.S. and Allied warfighters will also go a long way towards resolving the current Anti-Access/Area Denial (A2/AD) strategies of our adversaries. Targeting RF communications to inhibit the military movement and deny freedom of action to the U.S. and our allies in areas within our adversary's control is very problematic. This threat has profound consequences but can be mitigated with laser communication, which is more difficult to jam, intercept, or detect, while offering high data-rate communication across ground, air and space domains.

The military has been analyzing free-space optical for decades. Laser communication has applications in everything from tracking links between unmanned aerial vehicles and satellites, to communications on the move for ground troops riding in combat or tactical wheeled vehicles. TLR9 laser communication terminal (LCT) technologies are now available at 1.8 Gbps data rate, developed and deployed by Tesat-Spacecom.

The point-to-point nature of laser beams creates a Low Probability of Intercept and Low Probability of Detection (LPI/LPD) communications link. A laser beam from a satellite-to-earth link will have a footprint of approximately 0.01 miles squared in area, versus a 125,000 miles squared footprint produced with today's RF space system links. This extremely small footprint makes existing space-borne LCT virtually jam-proof from the ground, air, and space. There are also no frequency spectrum restrictions as the laser is far removed from the congested and contested RF spectrum.

BANDWIDTH REQUIREMENTS OF ISR SENSORS ARE MET WITH LASER TECHNOLOGY

With these characteristics, laser communication is well suited for high-speed, secure links between space and the Joint Aerial Layer Network. For example, a terminal can reside on an RPA that is collecting ISR data and transmit the data to a Geosynchronous Earth Orbit (GEO) communication satellite. This high-speed secure link provides the reach back required for effective and coordinated operations with extremely low data latency. RPAs are using full motion video. For live video streams, the laser communication terminals support 1.8 Gbps, which enables high-definition video streaming from multiple video packages.

General Atomics (GA-ASI) is developing an Airborne Laser Communication System (ALCOS) and will demonstrate a laser communication link between an MQ-9 Reaper (Predator B) UAV and a GEO satellite. The airborne laser communication terminal is capable of pointing, acquiring and tracking the GEO satellite while compensating for the vibration and changes in headings encountered in flight.

The bi-directional capability of lasercomm is ideal for ISR because reactive surveillance is possible, rather than static or near real-time mapping. Data can come via the uplink that is in response to imagery just obtained from the downlink, so decision makers on the ground can take action more quickly and easily. A system incorporating LCTs such as TESAT 135 LCTs could deliver significant communications bandwidth by incorporating advanced laser and RF terminals and software.

The U.S. and its allies could consider deploying LCTs on a secure, protected constellation with a minimum of three satellites capable of providing worldwide coverage to the warfighter. (Six satellites would be ideal to provide redundancy and to allow links at shorter distances.) The constellation would be the only secure global satellite constellation that is fully laser cross-linked and providing X-band, and Ka-band frequencies supporting airborne intelligence, surveillance, and reconnaissance (AISR) and other next-generation satellite constellations.

CREATING A SECURE GEO RING

Considering the current trajectory of the technology in terms of next-generation development, speed of utilization, and projected deployment, the most likely commercial availability of a global laser communication option is in CY 2026. The TESAT LCT 135 was deployed for the SpaceDataHighway data relay system. This geostationary constellation currently consists of operational nodes EDRS-A, with EDRS-C launching in early 2018, each with one LCT head in orbit over Europe. A third multi-head node, EDRS D is planned for the Pacific region. In addition, Alphasat is an operational demonstration GEO node in orbit 25° East over Europe. The SpaceDataHighway can transfer high-volume data from Earth observation satellites at a data rate of 1.8 Gbps and can transmit up to 40 terabytes per day. By 2025 there will be a fourth node (EDRS E) in a to-be-determined location in operation that would complete the global Civil GEO data relay ring.

General Atomics (GA-ASI) MQ-9 Reaper (also called Predator B) UAV

The ideal military space segment could consist of a constellation of six geostationary satellites with CONUS ground gateway elements (CGGEs). The six geostationary satellites could be connected into a ring forming a closed optical backbone in space. The inter-satellite cross-links would be capable of transmission rates of up to 2 Gbps. The lasercomm backbone would provide wideband connectivity between terrestrial data networks and battlefield networks and existing satellites, thereby removing communications constraints to users who have the proper system capabilities and authorization to access the constellation. Predator, Global Hawk, AWACS, JSTARS, and other manned and unmanned, high-altitude, long-range airborne ISR aircraft missions would benefit immensely from a Tesat 135 LCT-enabled lasercomm constellation.

The GEO ring offers the capability of collecting user data from RPAs, Aircraft or LEO satellites and transferring it along the GEO ring to any desired location around the globe. An optical sonnet ring concept can be realized with each GEO node acting as an Add Drop Multiplexer. This would allow the ability to add or extract data from the backbone traffic at each GEO node. The bidirectional nature of the optical communication link allows for clockwise or counter-clockwise communication flows within the ring. The GEO backbone ring ensures 24 x 7 x 365 x 15-year secure, mission-assured communications.

Using LCTs could transform DoD's next generation GEO communication satellite system into a protected space-based fiber optic network, and enable the DoD's next-generation communication system with a number of the following features:

- High-capacity packet switched services in space
- A multi-gigabits per second rate space backbone
- High-capacity circuit switching in space
- High-rate circuits to airborne, space-borne, and terrestrial terminals
- High degree of automation and ease in network planning, management and access

A cost-effective wideband communications operational demonstration capability can be executed by flying an LCT on a USAF Long Duration Propulsive ESPA (LDPE) platform. It would provide a secure (anti-jam), multi-layer (space, air, and ground), system to support reduced BMC3 (battle management, command, control and communications) timelines and increase communication path diversity.

THE FUTURE OF GPS

Seamless Navigation Anywhere: Project Sextant

MATTEO LUCCIO / CONTRIBUTOR / PALE BLUE DOT LLC / WWW.PALEBLUEDOTLLC.COM

More than half a century after a study by The Aerospace Corporation first laid out the design options for it, the Global Positioning System (GPS) is now used for a vast array of missions, from personal navigation to tracking fleets of vehicles, from landing aircraft to timing the Internet, from location-based services to missile guidance, from surveying to scientific research. This has made GPS – as the essential source of positioning, navigation, and timing (PNT) data – a "critical infrastructure" for the country. For this reason, the U.S. Air Force, through its Space and Missile Systems Center's GPS directorate, has been working for many years to modernize, toughen, and augment the system and to increase its resilience against such threats as jamming, spoofing, and space weather events.

▲ FIGURE 1
Randy Villahermosa, Executive Director of Innovation at The Aerospace Corp. discusses how Sextant creates an alternative for precision positioning, navigation, and timing (PNT) that will enhance the resiliency of PNT while leveraging the global GPS signal.

Additionally, the Department of Defense is now promoting the development of an alternative PNT system to act as a backup to GPS. As part of this effort, two years ago Aerospace launched Project Sextant, to study current and future options to improve the resilience, flexibility, and availability of PNT where and when GPS is not available. A federally funded research and development center chartered in 1960, during the space race, Aerospace Corporation is "unbiased and free from conflict of interest," says Dr. Randy Villahermosa, the Executive Director of the company's Innovation Lab. Its primary mission is to assure the success of U.S. satellite systems and missions.

Project Sextant is studying how to protect PNT services from both natural phenomena and man-made threats, how to increase flexibility and reduce costs, and how to expedite the introduction of new technologies. The study's scope includes inertial sensors, optical sensors, and "beacons of opportunity," such as WiFi routers and cell phone towers. All of this work overlaps in large part with the parallel effort by car manufacturers, car service companies, and geospatial hardware and software vendors to develop self-driving cars. It aims to transition from GPS, which is a vertically integrated system, to a horizontally integrated system in which GPS is augmented by a variety of PNT sources. (Editor's Note: See "Lidar is Key to Autonomous Vehicles" in the Winter 2017 issue of *Apogeo Spatial*.)

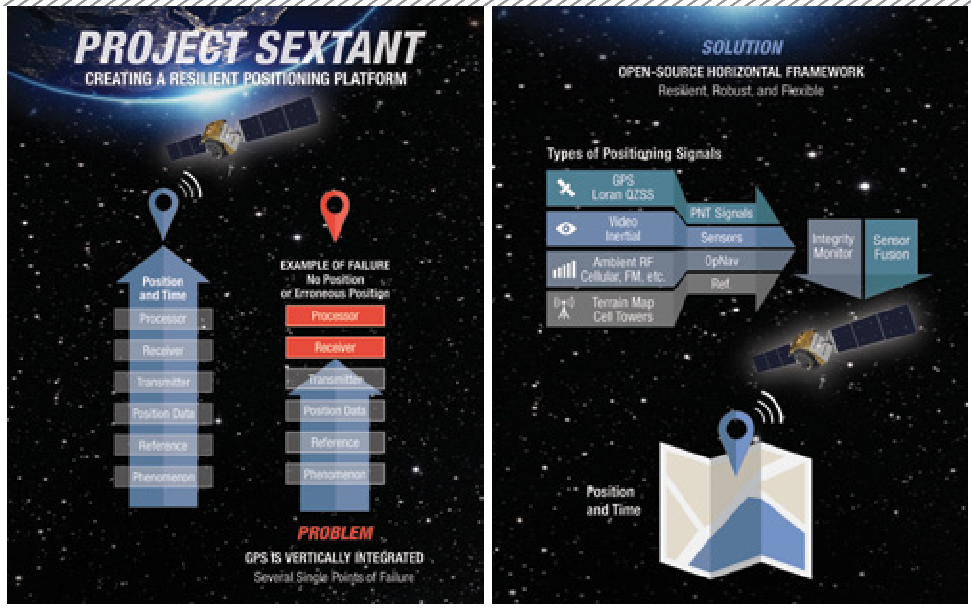
According to Villahermosa, one initial conclusion of the study is that there is currently no replacement for GPS. Another one is that end users should have more flexibility in how they integrate different sources of PNT using a single device.

FROM GPS TO ILAB

A recently declassified study that Aerospace conducted for the Air Force in 1964 was a milestone in the genesis of GPS. It was in response to a request by the Air Force to review existing technologies and help it devise a way to use satellites to provide navigation. "We looked at the available computing power at the time, especially in receivers," says Villahermosa. "We looked at two–dimensional and three-dimensional navigation. We asked very fundamental questions about what the satellites should do and how the system should be architected. The result was analysis of twelve options and recommendation of one option. The Air Force accepted the Aerospace recommendation, and that is still, today, the way that GPS is architected."

Aerospace has worked hand-in-hand with the Air Force on GPS ever since, providing technical advice on architecting, developing, acquiring, and building satellites, setting up ground control stations, designing some of the military receivers, all the way to launch, operation, and system performance monitoring. "We are integral in many ways to the government's space enterprise," says Villahermosa. "We support a variety of customers across the space-faring government agencies. The Air Force is one of our primary focus areas."

About six months ago, Aerospace launched its iLab initiative. "It was borne out of a desire to ask some basic questions," says Villahermosa. "What is the next big idea? What role can Aerospace play in conceiving it and bringing it to reality? GPS was very much in that theme, being a transformative, innovative idea. We innovate on a daily basis. We have a tremendous talent pool of engineers and scientists and we want to leverage it as one team in search of new ideas and bringing them to the forefront." Project Sextant was one of iLab's very first projects.



BEYOND GPS

GPS receivers require a clear view of the sky. Therefore, they work poorly or not at all in urban and natural canyons, indoors, under dense foliage canopy, underwater, and so on. Additionally, GPS signals can be degraded by intentional or unintentional sources of interference. "We understand that there is a lot of activity happening right now in ways to augment GPS, both indoor and outdoor," says Villahermosa. "We wanted to figure out whether there was a different way to think about the problem. That's where the context for Sextant was born."

Sextant envisions a device that is able to pull in many different sources of PNT, including satellites, WiFi or cellular signals, and vision sensors that can recognize landmarks. "Maybe there's a peer-to-peer way to do PNT, in which different users are coordinating with each other and give each other information about their whereabouts," Villahermosa speculates. The project is also looking at the role of inertial sensors and at miniaturizing atomic clocks.

"Once it settled on the all-source approach to PNT and recognized the commercial sector's tremendous role in innovation, Villahermosa recalls, the iLab team wanted to connect the innovation happening in the commercial sector with the needs of government users."

"A couple of decades ago, the federal government may have driven innovation and been the major source of that activity, but certainly now we are seeing many examples where the commercial sector is a significant source of the innovation," says Villahermosa. "Look at cloud computing, for example."

Once it settled on the all-source approach to PNT and recognized the commercial sector's tremendous role in innovation, Villahermosa recalls, the iLab team wanted to connect the innovation happening in the commercial sector with the needs of government users. "We came up with the idea that we should think about this as an open source problem," he says. "How do we create an open source platform for user equipment that allows them to get multiple sources of PNT while maintaining an open source approach to its development?"

The Sextant approach does not require users to install additional hardware. "Our vision for the first generation is a dongle-like device that you can plug into your cell phone," says Villahermosa. "It has a software-defined radio and a GPS receiver and is able to do opportunistic navigation. It could use the cell phone's camera or, if you are talking about autonomous vehicles, the cameras that are mounted in the vehicles would do that. And then, obviously, there's the inertial piece. The idea is that it is self-contained and easy to upgrade."

KEY CONCEPT 1: SENSOR FUSION

iLab designed the Sextant concept around three key concepts. The first one was sensor fusion. "This is where there is a lot of overlap with autonomous vehicles and the Internet of Things," Villahermosa points out. "We are leveraging technologies that would ordinarily be thought of in those realms and bringing them into the more pure PNT world."

KEY CONCEPT 2: OPEN SOURCE

The second one was open source, as the way to spur innovation and technological advances. "Here you have a community of developers who are creating the interfaces, the software, and the application."

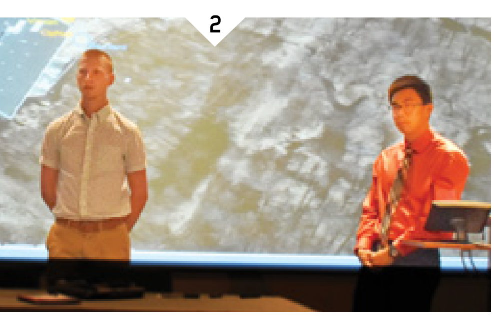
KEY CONCEPT 3: INTEGRITY

The third one was integrity. "That's really where we are leveraging a lot of our unique capabilities and expertise. We are developing algorithms and experimenting with approaches that evaluate all the signals and try to decide which ones should be weighed more heavily and to see how well you can maintain your position relative to truth using these integrity algorithms."

Of course, there is a huge difference between being in the center of a dense urban area, with a multiplicity of signals of opportunity and visual cues, and being in the middle of a desert or an ocean. For this reason, Sextant also aims at developing the capability to show users what the expected performance of PNT would be at any location on the planet, given the sources available. "A vision for this capability is that we can simply enter in a lat/long and estimate the available RF signals. This could also lead to the development of new technologies to augment GPS, such as beacons. The ability to intelligently do the make/buy decisions is key."

CHALLENGES AND OPPORTUNITIES

iLab does not currently have any government clients for its Sextant project. "We create new ideas and incubate them and look to form strategic partnerships," says Villahermosa. "Right now we talk fairly regularly with other elements of the government or the commercial sector who are involved in this way of thinking about augmenting GPS and we are constantly keeping each other apprised on what we are doing and sharing our thoughts on that." This is a traditional technological leadership role for Aerospace, which is prevented by law from competing with the commercial sector in manufacturing. "This is how we are able to remain free of conflicts of interest."



▼ FIGURE 2
Aerospace engineers Alon Krauthammer and Marcus Liou (from left to right) highlight how Sextant can precisely identify their location indoors.

AN OPEN SOURCE COMMUNITY FOR PNT

Villahermosa wants to create an open source community around this project. "I see a lot of folks interested in PNT and the community is quite vibrant. The challenge we are taking on is how to get people who don't think about PNT and get them excited about what is possible when you know your location that well and what location services can do for their businesses and how that can be enabled. Recently, Google released an article on how they keep time among their data centers and a lot of that technology you will recognize from the PNT world. I doubt that most of the people in IT would make that connection."

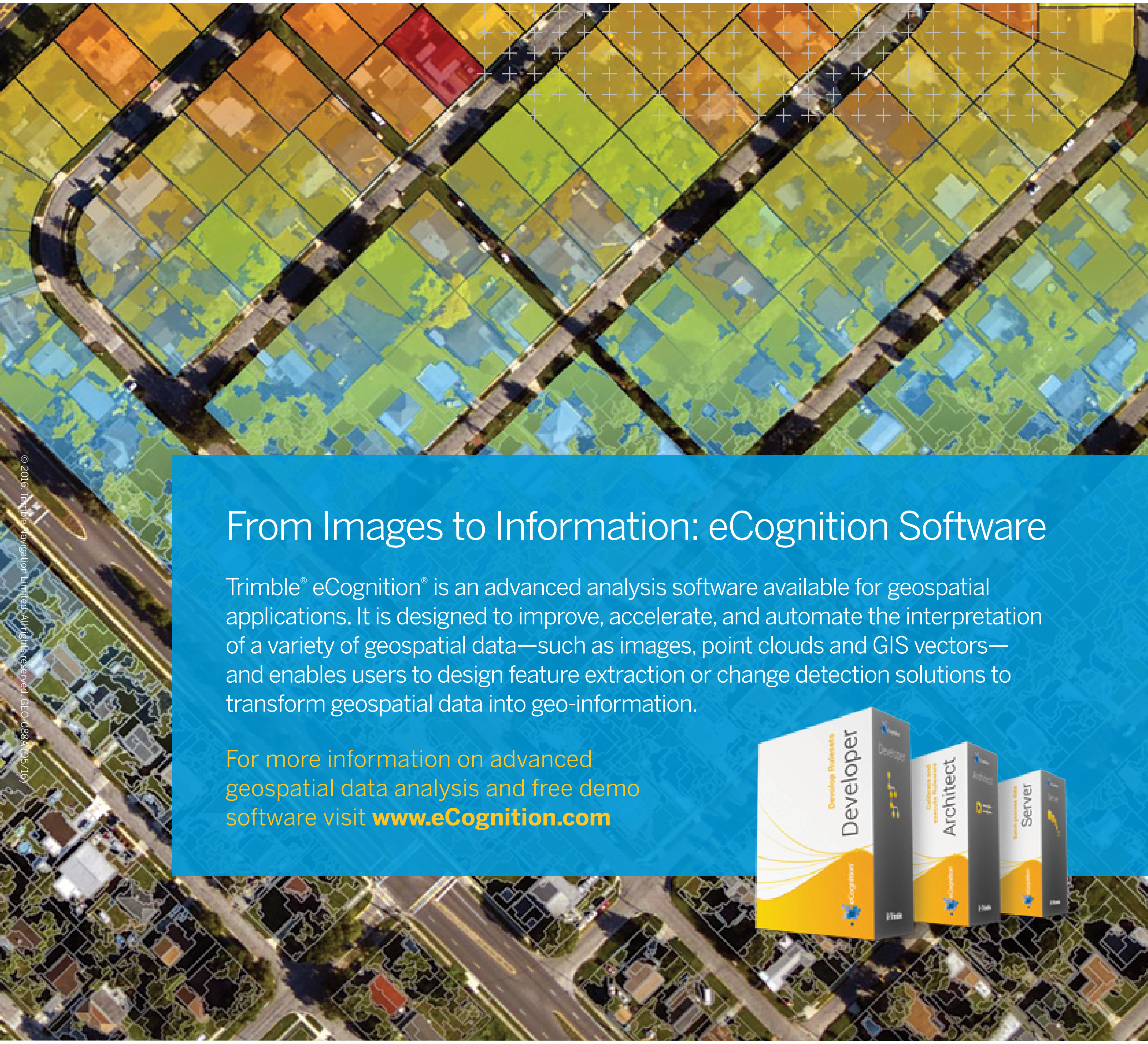
▶ FIGURE 3
Aerospace digital communications engineers, Alon Krauthammer and Sebastian Olsen (from left to right) work on the rapid development of the Sextant prototype and incorporate the latest technology in machine learning.

NO STANDARDS

A key challenge when trying to integrate multiple sources of PNT is that they have different accuracies and spatial references. The disciplines of geodesy and surveying will be essential to the creation of a consistent reference framework. "These signals are inherently different: they operate on different time scales, they have different types of error," Villahermosa points out. "It is really about managing the errors in these sources and they all behave differently. So, the challenge and the smarts of Sextant will really be to make those choices between different sources in order to be able to give an accurate estimate of position and knowledge of that."

CONCLUSIONS

The success of Sextant and similar projects will enhance the spectacular success of GPS, now available to billions of people, by eliminating or ameliorating its current weaknesses. It will enable seamless navigation in and out of buildings, tunnels, canyons, and dense forests and the advent of a new generation of automation, such as driverless cars.



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