APOGEO SPATIAL

ELEVATING GLOBAL AWARENESS

ANALYTICS SERIES:

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The Value of Space Standardization

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THE HISTORY AND FUTURE OF SAR

by Jörg Herrmann, SAR Remote Sensing Expert, HUtAB Consulting

"There has been doubt among the SAR community if such compact designs can deliver any useful imagery… Now the first of its kind has been launched by ICEYE, and it works: 10-m resolution SAR imagery from a prototype, and a plan of reaching 3-m resolution with future satellites." *P. 16*

Loft Orbital MAKES SPACE ACCESSIBLE

Executive Interview with Alex Greenberg, Co-founder & Head of Operations

"Our approach is to make space simple for both current and would-be users of space. Our initial clients include startups with business cases that require space-based data, government agencies with monitoring missions that need a more robust platform than a cubesat, large corporations looking to demonstrate a technology in orbit, and academic institutions that have developed a novel payload and need a ride to space." *p. 20*

FORMERLY Imaging NOTES

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Mato Grosso, Brazil in South America, courtesy of TellusLabs.

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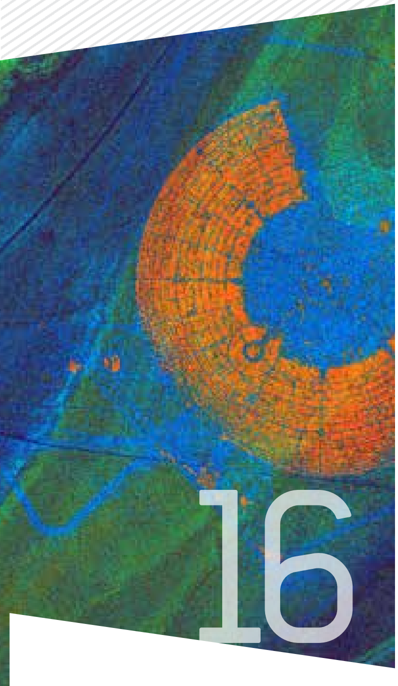
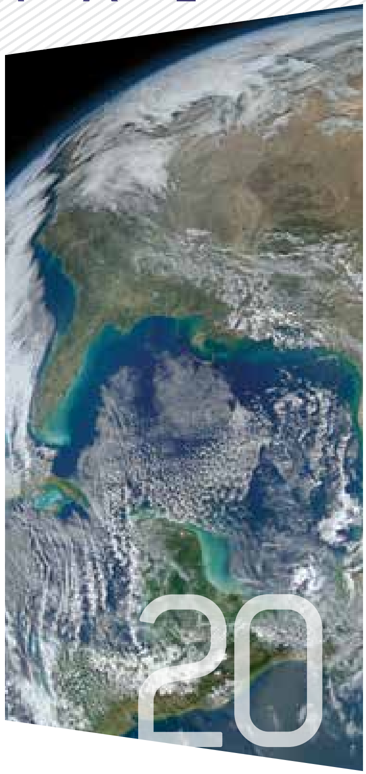
Innovation

Vega’s Small Spacecraft Mission System (SSMS) is a product of the innovative culture that prevails at Arianespace. The SSMS payload dispenser will revolutionize and democratize access to space for countless new satellite companies that would otherwise remain grounded due to lack of launch capacity. With its perfect record and competitive pricing, the Vega is the right vehicle at the right time.





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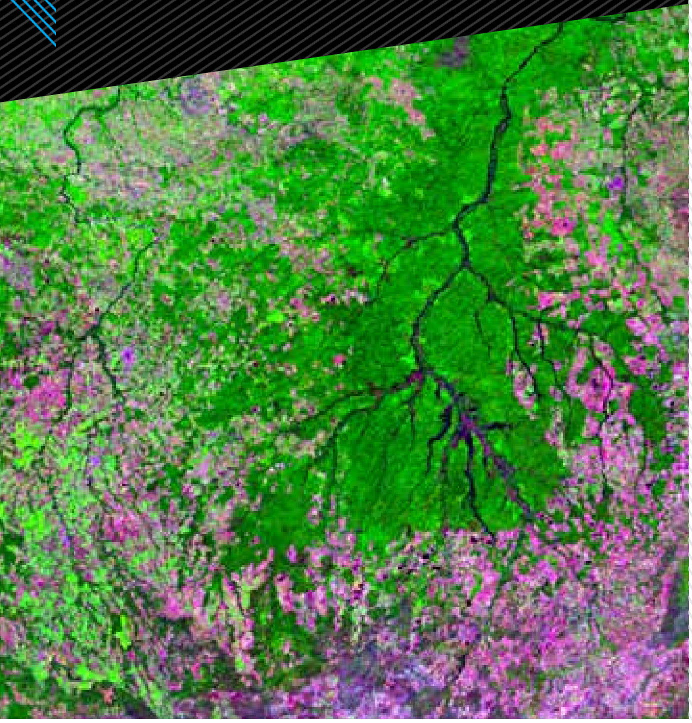

Mato Grosso, Brazil

XINGU RIVER BASIN

The 4th in our Series on Geospatial Analytics-as-a-Service includes examples of how data is used for crop monitoring around the world by TellusLabs. This MODIS false-color composite image shows the Xingu River Basin in Mato Grosso, Brazil, with healthy vegetation and wet areas in green and less wet areas in purple. The image shows different spectral bands, including SWIR (Shortwave Infrared) in Red, NIR (Near Infrared Reflectance) in Green, and Red band is shown in Blue.

The Xingu River is a 1,640-km river in north Brazil. It is a southeast tributary of the Amazon River, and one of the largest clear water rivers in the Amazon basin.

The article on page 24 includes interviews with Nick Malizia, Head of Data Science at TellusLabs regarding their crop monitoring, and also Laura Schewel, CEO and Founder of StreetLight Data, which focuses primarily on urban transportation analytics.

The image was taken May 8, 2016, and is courtesy of TellusLabs.

APOGEO SPATIAL

Formerly Imaging NOTES

[Summer 2018 / Vol. 33 / No. 3]

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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Space-Based Radar: Looking Back and Forward

SPACE GETS MORE ACCESSIBLE

Myrna James Yoo
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Dear Readers,

Innovation in space is not only democratizing access to space, but is creating many exciting opportunities for new players to enter the market. Geospatial tools and technologies ("geospatial intelligence," as coined by the U.S. Geospatial Intelligence Foundation), with deep roots in the federal government and intelligence communities, have incredible potential for the commercial sector.

Making Space Accessible

Trends for several years have included the space industry moving towards easier and less expensive access to space, enabled in part by NewSpace companies, which has allowed university students to launch smallsats and NGOs to access the International Space Station – and now we have Silicon Valley-based Loft Orbital and United Kingdom-based Open Cosmos.

While not exactly the same, these two new companies are providing space infrastructure as a service. They make it possible for companies to get direct access to space-derived data without having to become a space company. They own and operate satellites and lease space onboard to fly sensors and instruments on behalf of the customers. They handle all the "hard stuff" that is needed to get a sensor or instrument into space and operational: finding the right bus; handling launch; and integrating the payload, the on-board processing, and the data downlink. The customers then have direct access to, and control of their mission-critical space-derived data and important information about our planet.

Loft Orbital was founded by satellite industry veteran Antoine de Chassy, who was U.S. President for France-based SPOT Image (now a part of Airbus Defence & Space), and two partners. Alex Greenberg, Co-founder/Operations, was involved with the first contract signing between the U.S. federal government and a commercial company for satellite-based weather data. Pierre-Damien Vaujour, Co-founder/Product has broad and deep technical and business experience including with NASA, and the X-PRIZE Foundation's Google Lunar X PRIZE. My interview with Alex to learn more about their unique business model appears on page 20.

This new way of operating a space company opens the door for many commercial companies that heretofore would not have considered having their own sensor on a satellite. The sectors that will be directly affected include real estate, insurance and financial services, agriculture and commodities, energy, global trade, shipping and supply chain, targeted marketing, autonomous driving, and security and risk management.

There is also buzz about exciting applications for consumers, as the April announcement of EarthNow demonstrates. This company founded by Bill Gates, OneWeb founder Greg Wyler, Airbus and SoftBank will offer real-time video of the entire planet from space, via constellations of small satellites similar to those of OneWeb. Anyone will be able to experience on their smartphone the extraordinary technologies that space enables!

The Value of Manufacturing Standardization

Another reason that costs are decreasing and more people and companies can get to space is the standardization in manufacturing, demonstrated by the increasing popularity of cubesats, and by the use of assembly line production. Dylan Taylor writes about the value this is bringing to the space economy with examples from York Space Systems and Altius Space Machines in his column, *Spatial Capital,* on page 8.

The History and Future of SAR

We are thrilled to have satellite Synthetic Aperture Radar (SAR) industry veteran and leader Jörg Herrmann's historical perspective about the inception of SAR, as well as his thoughts about the exciting future for SAR beginning on page 16. Significant technological advances and the ability to use smallsats for SAR are creating optimism and excitement for this little-understood but high-potential data.

Thanks for reading! Reach out to me at myrna@apogeospatial.com with feedback and ideas for stories. We love hearing from you.

-Myrna James Yoo

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The Value of Industry Standardization

INCREASING VALUE FOR STAKEHOLDERS

Small satellites continue to be amongst the hottest subsectors in the space industry. According to Research and Markets, as many as 6,000 smallsats will be launched in the next decade and the smallsat market should exceed $30B annually over that timeframe. As I described in a previous column in *Apogeo Spatial*, I believe those estimates to be conservative once the true value creation from the data products they enable is widely known.

As the industry matures however, there could be some natural impediments or accelerators that could impact these forecasts. Industry standards in manufacturing and in-space servicing could be possible focal points.

Industry standardization driving collective value has many historical examples. Perhaps the best known is the national railroad system in the U.S. When the railroads first rose to prominence, they were territorial, proprietary and special gauge. This situation created value at the local level due to local monopolies but limited overall industry growth. No one operator could operate at scale, rail cars and the rails themselves couldn't be produced in mass to a single standard and passengers had to interface with different providers in different parts of the country if they wanted to travel or ship at any distance.

Due to the lack of national connectivity and limited regional connectivity, the value of the entire network was diminished. The costs were artificially high and overall demand was inconsistent and oftentimes mismatched with supply. Once a standard gauge was adopted, this all changed. In fact, the value creation was so large that anti-trust legislation needed to be created because the concentration of value was so immense.

Another recent example of industry standards creating enormous value is the

1

▶ **FIGURE 1.** Prototype of BullDog Gripper, courtesy of Altius Space Machines.

IEE802.11 standard more commonly known as "Wi-Fi." Imagine a world where you would have to configure your computer for a different wireless internet protocol in every city, country and perhaps even every building. Imagine the lost productivity and value that lack of interoperability would entail, not to mention the loss in reliability, security and other qualitative factors. Having a global Wi-Fi standard insured that wireless internet became the standard method of moving ones and zeros and led to the explosion of industries such as streaming media.

Do these examples have analogies in space? I believe there are several but the two most likely to drive value are standards in manufacturing and standards in design.

2

▼ FIGURE 2. DogTag Magnetic-Mechanical, courtesy of Altius Space Machines. The flight unit will have a different surface finish in that it will be a clear aluminum surface etched with the optical fiducials and clear anodized.

ALTIUS SPACE MACHINES' ROBOTIC INTERFACE

One example is Altius Space Machines, which is working on a standardized robotic interface known as a "DogTag" that would allow their proprietary grippers to capture and provide on-orbit services to smallsats, be that refueling, de-orbiting or perhaps even upgrading the smallsats functionality. Imagine the possible value creation for the industry if a standardized method was developed and adopted for in-space servicing.

YORK SPACE SYSTEMS' STANDARDIZED BUS

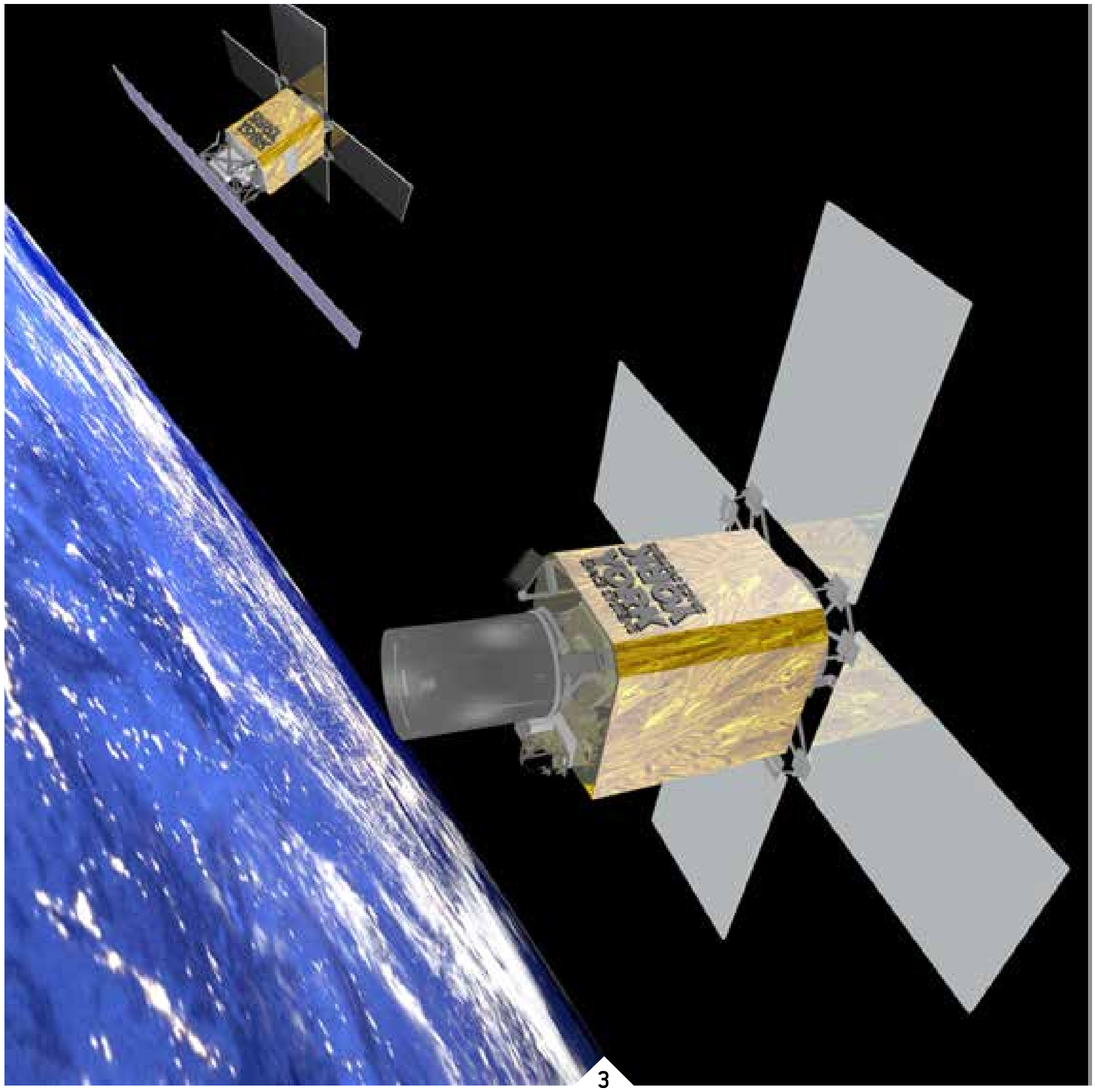
Another example of a company contributing to industry standardization is York Space Systems, which is developing an industrial-grade standardized bus system that they claim will both allow for lower price points and enable new data verticals to arise, due to the reduced barriers to entry. There are early signs, given recent partnership agreements York has signed, that this bus system could become an industry standard.

There is value in manufacturing standardization as well. OneWeb is tooled up for very large volume manufacturing of smallsats with a new factory that is reportedly a prime example of automated manufacturing. If elements of their design were standard, these automated processes could be more readily leveraged by others, decreasing cost and cycle time and potentially benefiting the entire industry long term.

So what is the downside of industry standardization? Typically, the arguments are two-fold. One is that in a winner-take-all market, being proprietary, differentiated and unique is critical. In the case of smallsats, the differentiation mainly comes from the specialized tech and software within the smallsat envelope, helping to mitigate this concern. Furthermore, really none of the smallsat companies are currently operating at scale. By creating more ways to leverage additional scale, the whole industry should benefit both in terms of value and speed to market.

The second argument against industry standardization is that it stifles innovation – that by conforming around a standard, innovation is no longer the focus. This argument has some merit but only for the elements of design that are being standardized. That is to say, it wouldn't keep smallsat manufacturers from innovating around other elements of their design that are non-standardized.

In summary, the smallsat market's massive growth could be accelerated by additional industry standardization. Like in other industries, this standardization would lead to additional value creation in the overall supply chain and enable the industry to achieve additional scale. The additional value created would benefit companies, customers and investors alike.



▲ FIGURE 3.
Artist rendering of an ICEYE SAR (Synthetic Aperture Radar, in the back of the image) and a commercial optical telescope spacecraft, each being developed on a York Space Systems spacecraft bus.

"In fact, one could argue that standardization frees up more resources for companies to innovate around the design parameters that really matter for innovation and differentiation."

ON THE EDGE

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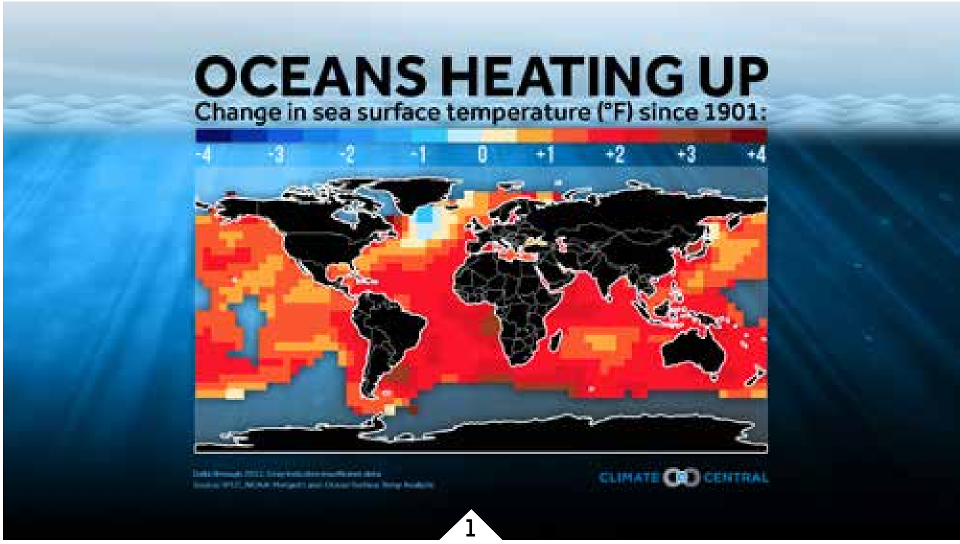
Prioritizing the Ocean: SDG #14, "Life Below Water"

CAN WE CHANGE OUR PRIORITIES TO REDUCE THE MOUNTING THREATS TO THE OCEAN?

A healthy Earth's life-support system is hard to imagine without a healthy ocean. The vastness of the ocean has misled humanity to believe for a long time that the ocean is invincible. However, the rise of humanity to be the dominating species on the planet has changed this. The ocean is assimilating a major share of the carbon emitted by humans in the insatiable hunger for more energy, which drives a flawed growth-addicted economy.

The ocean is absorbing the major share of the excessive heat stored by the planetary system as a result of the anthropogenic changes in the atmospheric chemistry and the land cover. Even in the science community, it is not fully and widely appreciated that most of the excessive heat stored as a result of anthropogenic Greenhouse gas emissions and surface albedo changes – in fact, more than 90% – goes into the ocean. Despite a much larger heat capacity of ocean water compare to air, the increase in ocean surface temperature (***Figure 1)***[1] during the last 100 years was larger than the atmospheric warming, which is to be expected in the global "poolhouse." [2]



▲ FIGURE 1
In many areas, the sea surface temperature has increased more than the air temperature.

Facilitating unlimited growth of the world population required an industrialized agriculture that has accelerated the flows of nitrogen and phosphorous into the ocean overloading the marine biosphere with nutrients. For decades, scientists have warned that the flow of nutrients is creating vast dead zones, and that ocean acidification and ocean warming are further destabilizing marine ecosystems throughout the ocean. Extracting an increasing amount of marine life as food for humans and their lifestock is increasing the stress and the risk of rapid extinction of many marine species.

While scientists increasingly understand the finite nature of the ocean and its resources, media attention has been limited, and the major threats to the ocean – and as a consequence to our civilization – seldom make it into the news.

There are a few exceptions, though. For example, *The Guardian* continually is reporting on the rapid extension of our knowledge of the major threats our civilization is facing as a result of rapid growth and the reengineering of the planetary system. *The New York Times* and *The Washington Post* are also examples of daily newspapers that bring scientific knowledge about the increasing unsustainability of our interaction with the Earth's life-support system to their readers. The BBC makes a huge effort to disseminate the growing knowledge on global risks.

The mounting threat of plastic pollution, particularly in the ocean, only recently has received a lot of attention from the broader media. Although plastic pollution was reported in the 1970s by scientists,[3] it took a long time to raise awareness for the full extent of this threat to the Earth's life-support system. Interestingly, in this case, it seems the science community is lacking technologies for the detection and monitoring of plastics in the ocean environment[4] with scientific assessment only recently appearing.[3]

More and more thought leaders are picking up on the challenge. For example, David Attenborough's recent BBC series on the ocean showed that the wildlife in the ocean is facing its greatest threat in human history as it struggles to survive against warming temperatures and unprecedented quantities of plastic waste.[5] Margaret Atwood, who provided in "The Handmaid's Tale" a scary and dystopian scenario of a possible future under climate change (and male domination), stated, "We need that ocean to remain alive if we're going to have any hope at all."[6] About the growing plastic pollution, she said, "Something has to be done about plastic going into the ocean and it has to be done pretty quickly..." But "something" is just not enough. A fundamental change is needed back to the time when humans valued scarce resources and when one-time use of precious materials was unthinkable.

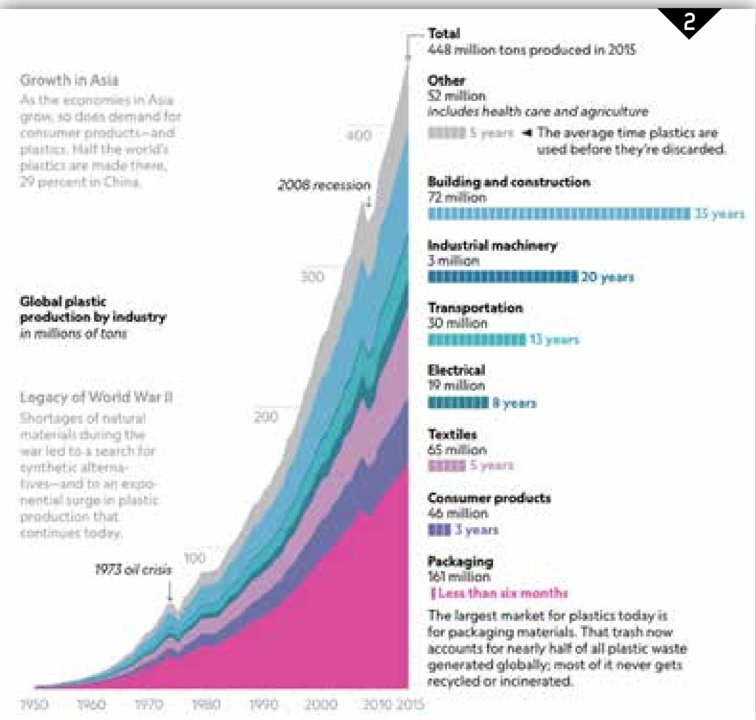
As a child, I was fully integrated in the work that needed to be done at our house and in my family. One job that often was assigned to me was to take bent nails that my father had pulled out somewhere and hammer them straight so that they could be reused. The wasteful and irresponsible one-time uses of materials in today's society would be incomprehensible to my father.

The one-time use of plastics is truly mind-boggling. According to the Annual Review of Marine Science, in 2014, 311 million tons of plastics were produced, but other sources provide larger numbers ***(Figure 2)***.[7] The largest market demand is for packaging,[2] and most of that is used once and then discarded. The average time of use for all plastic before it is discarded is only 5 years.[7] Even in the most advanced countries, only a small fraction of the discarded plastic is recycled.[3] Recycling is always a "down-cycling," and one of the main obstacles for increasing the recycled fraction is the low quality of resulting products and the lack of a market for these products.[3] A large fraction of the discarded plastic reaches the ocean, much of this in the form of microplastics. We are only at the beginning of realizing the devastating impacts of plastic on marine life.

It is good to note that in some countries, the senselessness of one-time use of plastics is acknowledged and actions are taken ranging from cities prohibiting the one-time use of plastic straws in restaurants and bars[8] to regional efforts dramatically reducing all one-time uses of plastics.[9, 10]

▼ FIGURE 2

Production of plastic is rapidly increasing and most of the plastic is in use only a few years before it is discarded. Most of the discarded plastic pollutes the Earth's life support system for thousands of years.



But many of our leaders seem to be disconnected from the existential challenges our current civilization is creating for ourselves.

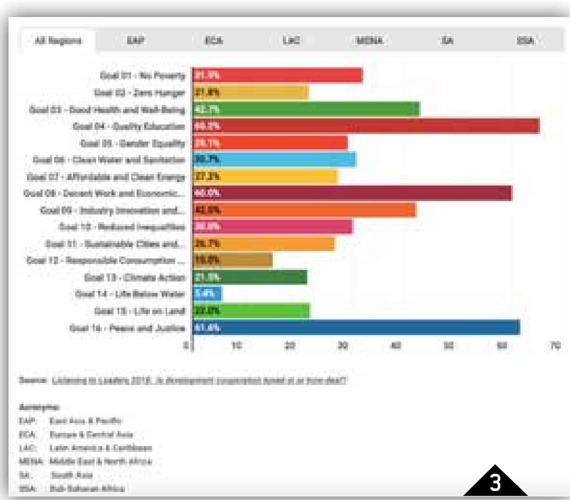
A recent survey of more than 3,000 leaders in developing countries aimed to find out which of the seventeen sustainable development goals have high priority for these leaders.[11] They were asked to list the six goals that have highest priority for them. It was good to see that SDG 5, "Quality Education for All" was the most often listed goal: more than 60% of the leaders included it ***(Figure 3)***. But it is shocking that SDG 14, "Life Below Water," was the extreme outlier in being listed least. Depending on the region, only 3-5% of the leaders included this goal in their list of the six high-priority goals.

The next lowest goal made it into the lists of roughly 15% of the leaders, and it was very worrisome that this second-least represented goal is SDG 12, "Responsible Consumption and Production." There is little hope for the ocean if we don't value responsible production and consumption, which is not based on the unsustainable one-time use of plastic polluting the Earth's life-support system on global scale for millenniums, and don't prioritize the protection of the ocean as a fundamental part of our planetary life-support system. Both SDG 14 and SDG 12 should have very high priority, and the targets associated with these goals should be revised to truly reflect the high priority of maintaining a healthy ocean within the Earth's life-support system, on which the welfare of our global civilization depends.

Unless we change our priorities, we will continue to consider the ocean "the toilet of human civilization," as Director James Cameron recently put it.[12] And, then our destiny might be the one Margaret Atwood sees: "If the ocean dies, so do we."[6]

▼ FIGURE 3

SDG 14, "Life Below Water" is an outlier in that it is least represented in the lists of the six high-priority SDGs provided by 3,500 leaders in developing countries.



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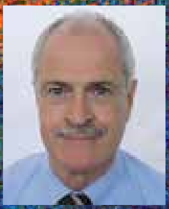
THE 10TH ANNIVERSARY OF SATELLITE-BASED COMMERCIAL SAR (SYNTHETIC APERTURE RADAR) WAS JUST LAST YEAR IN 2017. THIS STILL-YOUNG DISCIPLINE IN THE REMOTE SENSING WORLD IS BRINGING SIGNIFICANT CHANGES BY INTRODUCING NEW CAPABILITY LEVELS WITH UPCOMING CONSTELLATIONS, QUARTER-METER RESOLUTION, MULTI-POLARIZATION, AND COMBINED SAR/AIS COLLECTS. BECAUSE OF ALL THESE SAR DATA VOLUMES AND DIVERSIFYING FEATURES BECOMING ACCESSIBLE TO THE MARKET IN THE COMING YEARS, THERE ARE NEW ANALYTICS CAPABILITIES, CONVENTIONAL OR BASED ON ARTIFICIAL INTELLIGENCE COMING UP THAT WILL CONVERT ALL THESE DATA INTO ECONOMICALLY USEFUL AND ACTIONABLE INFORMATION.

PERSPECTIVES ON SATELLITE SAR REMOTE SENSING

Winds of Change



BY JÖRG HERRMANN, SAR REMOTE SENSING MARKET EXPERT

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1

In this article, I will outline some of the changes that are to be expected in the next five years. To put the evolution into a historic context, I will also take a look back to the beginning of the SAR evolution, and how lessons learned led to trends.

COMING A LONG WAY

I somehow got engaged with SAR remote sensing when I started working in the space industry in 1980s, and very soon I felt a dedication to this matter – not so much because it is such an exciting technology, but rather because I had the impression that we have a measurement method at hand that could help solve a lot more problems than reconnaissance and scientific matters, the primary use cases of that time.

With Carl Wiley describing Synthetic Aperture Radar in 1959, and patenting the method in the U.S. in the 1960s, the foundation for the first space-based SAR was established: Seasat was launched in 1978, and demonstrated what was possible with SAR space, with 25-m resolution. In Europe and Canada, the space community hopped onto the train.

When I came into space, there were programs like ERS of ESA and CIR-C/X-SAR (U.S./Italy/Germany) that gave researchers the opportunity to develop SAR applications, evaluate which SAR frequency works best for detecting which features, and to work on evolving the SAR sensor technologies. The ERS 1+2 tandem mission paved the way for interferometric SAR applications, being further refined through airborne SAR campaigns.

Airborne SAR was also used for signature research, and to refine findings from SIR-C/X-SAR regarding picking the best frequency for an application. In the 1990s, airborne SAR operators started flying the first SAR mapping campaigns in the cloud-prone regions close to the equator where classical aerial photogrammetry failed or lead to long and costly campaigns.

While initiatives for commercializing satellite remote sensing with electro-optical cameras in the 1990s like IKONOS and Earlybird/Quickbird had their motivation in bringing photogrammetry into space and thereby becoming capable of delivering lower square kilometer prices than what was possible with aerial mapping, the same was happening with SAR. By the end of the 1990s, airborne SAR operators had demonstrated the topographic and thematic mapping capability that this method can deliver.

However, to bring SAR with such performance into space required a technological step, and the establishment of regulatory regimes to control such new capabilities in the context of avoiding political sensitivities. It also required, similar to the EO initiatives, establishing funding schemes, typically between public and private investors (public-private partnerships) to deploy the first commercial SAR satellites with a noticeable market impact in 2007: Radarsat-2 (MAXAR, formerly MDA), Cosmo Skymed (e-GEOS), and TerraSAR-X (Airbus Defence and Space). Each of these three systems came with specific strengths: image quality and location accuracy, temporal resolution based on a deployed constellation, large swath width, and optimization for maritime applications. Their operations required the establishment of new regulatory and licensing regimes.

The European/Canadian SAR community with its focus on maritime surveillance had early on selected C-band for their SAR missions. From ERS-1 and -2 this led to Radarsat-1, and later to Envisat with ASAR, and Radarsat-2.

The SIR-C/X-SAR community (U.S., Italy, Germany) had learned from their multi-frequency SAR experiment, flown on the Space Shuttle, that a high-SAR frequency provides textural information of the surface, while a low-SAR frequency contributes through its capability to penetrate the surface to thematic information. Combining a high- and a low-SAR frequency would therefore maximize the information content that SAR measurements from space can achieve. Consequently, the idea to install an X+L-band SAR in space became en vogue.

When I proposed the TerraSAR program in 1998, it was initially an X+L SAR. A U.S./German cooperation for a dual frequency SAR system

◀ FIGURE 1
Multi-temporal SAR image of Black Rock City, home of the Burning Man Festival in the Nevada desert, using amplitude change detection to show the same place at three different times. The color stems from red, green, blue (RGB) annotations to three images. The orange shows the area at the time of the festival. If a pixel is unchanged during all three times of image collection, then the composition of RGB combines to a gray-scale of the radar images. If a color occurs, then this indicates a change at that time. Black Rock City is a nice example, because the participants of the festival arrive on a clean dessert floor and leave it again clean. Image courtesy of Airbus.

▲ FIGURE 3
This SAR image near Kaufleuren in Bavaria, Germany, shows an air force base and many features, including fighter aircraft, the active airport tower, and power lines. The image shows 25-cm full-polarimetric SAR demonstrated by F-SAR, DLRís airborne system. Image courtesy of DLR, the German Aerospace Center.

followed the same objective, but had come to a hold before. Another dual frequency SAR proposal came then from Italy, combining the COSMO Skymed X-band SAR constellation with the Argentinian L-band SAR of the SAOCOM constellation. However, up to now, no X+L-band SAR is in orbit – but there are other ways to elicit thematic information from SAR.

SEEING THE FUTURE

With the current commercial SAR systems in orbit, it could be demonstrated that there are alternative ways (multi-temporal data collection, multi-polarization, and speckle diversity analysis) to get thematic maps out of SAR. Multi-temporal data merges are, however, dependent on revisit times. Constellations provide an advantage for this method. Very high-resolution SARs can also be used for pan-sharpening, thus fusing the SAR with multispectral optical data. See ***Figure 1***.

The bi-static SAR measurement approach that was demonstrated at global scale with the TanDEM-X mission, following up to the Shuttle Radar Topography Mission (SRTM), was a significant step in applying SAR to create a global, pole-to-pole, high-definition Digital Elevation Model (DEM). This step also formed a basis for worldwide coherent Digital Terrain Models (DTM), including Airbus' WorldDEM product. The controlled formation flight of this mission was also a step, which may find refinement in the future, based on the lessons learned.

Over the years it became more and more obvious that a commercial SAR would require more than just the space infrastructure, but rather would need value chains put into place to deliver geo-information derived from SAR, and would need to overcome the disadvantage of SAR over EO: SAR imagery just looks strange to the human eye; only experts can interpret them.

Space engineers that drive SAR system development tend to forget about these value chains, which are essential to convert SAR measurements into valuable information that earn money in the market. This missing element of the downstream services has only very slowly evolved through numerous pilot and applications research projects.

However, the market hesitated to adopt because of limitations, asking for better resolution (geospatial, temporal, thematic) and better reliability and stability of information services that lead to customer solutions without requiring SAR experts to elaborate solutions on a project by project basis. So the SAR market stayed at a fraction of 10-15% of the overall remote sensing market for years.

STEPS INTO A GLORIOUS FUTURE FOR SAR

A SAR resolution is determined by flight direction (in flight direction it is largely driven by integration time over a spot on ground) through the spectral bandwidth that is available. For X-band SARs in space, the allowance for bandwidth was at 300 MHz, when the first commercial SARs were designed. The 300 MHz enabled 1-m resolution. After an extension to 600 MHz, the World Radio Frequency Conference in 2012 finally approved 1200 GHz of bandwidth in X-band for satellite SARs, corresponding to quarter-meter resolution.

Recently announced multi-static and dual-wavelength SAR systems have the potential to significantly improve the topographic/geodetic SAR measurement perimeter and the thematic mapping capabilities offered to the market. Digital elevation models measured from space could have a posting of less than 5 m and vertical accuracies of better than 1 m. Companies with this plan include e-Geos, Airbus, Urthecast with OptiSAR, and XpressSAR.

Simultaneous collection of AIS signals and SAR imagery to detect uncollaborative vessels is becoming available (e.g. PAZ of Hisdesat, and coming soon Kompsat-6 of KARI/ SIIS, RCM of CSA, and Capella Space).

The trend of getting high-performance SAR satellites in very compact and light designs had been announced before as early as 2001, assuming that all the required technologies would over time come into place. This trend now seems to be materializing due to smart antenna deployments, advanced power and computing equipment. Such concepts will be the basis for constellations with up to more than 30 satellites, ensuring revisit time of a few hours and repeat cycles for interferometric analytics of less than a day. By entering this new category of timeliness, some of the long-pursued SAR use cases start becoming relevant in the market.

Finally, the significant increase in numbers of SAR data sources will lower the price for the SAR "raw material" to levels that help the downstream services to become a lot more cost efficient and attractive in terms of pricing. While there is reliable C-band continuity in Canada and Europe, there is a clear trend for X-band in the commercial sphere. See chart in ***Figure 2***.

Besides the high-end X-band SAR systems, there is this new category of larger constellations, also mainly going for X-band SARs. While high-end SARs strive for very high resolutions (target 25 cm), maximum image quality with high signal to noise ratios (NESZ < -19 dB), applying digital beam forming for VHR over a wide swath, multi-polarization, or with multiple phase centers in the SAR antenna supporting Ground Moving Target Indicator (GMTI), the constellation SAR sensors are characterized by compromises for compactness.

These SARs are being stowed into a tiny volume for launch and go through a metamorphosis after separation from the launcher to deploy to a well-sized SAR. These constellation SARs are therefore fitting onto a micro satellite (< 100 kg). This new compactness is the basis for fitting 4-8 satellites, or more, onto a launch vehicle and supporting the concept of larger constellations. Numbers of 12 to 50 satellites into a constellation are being announced. Launch service providers gain their experience for such fleet sizes to be launched from the telecommunication sector, where the constellations go up to 1000 satellites, and from the optical satellite constellations like the one of Planet. See ***Figure 3***.

There has been doubt among the SAR community if such compact designs can deliver any useful imagery and this with endurance over adequate orbit times and lifetime. Now the first of its kind has been launched in January this year by ICEYE, and it works: 10-m resolution SAR imagery from a prototype, and a plan of reaching 3-m resolution with future satellites. Further players in this segment include Capella Space, MicroX SAR of JAXA, MicroSAR System of Space Norway with KSAT, and Umbra Labs. All of them are striving for high temporal resolution and faster INSAR cycling in support of reliable monitoring.

The venture capital community has spotted the trend for X-band SAR constellations establishing the grounds for real and reliable monitoring from space. From the fundraising announcements, it is expected that private equity and loan investments could exceed $100 M this year.

Object analytics and recognition under the broad range of SAR sensing parameters (viewing and aspect angles, operating mode, signal/noise, frequency, polarization) is a candidate to benefit significantly from artificial intelligence. Machine learning has been initiated to demonstrate how space-based SAR can in the future be translated on-the-fly into valuable and actionable information.

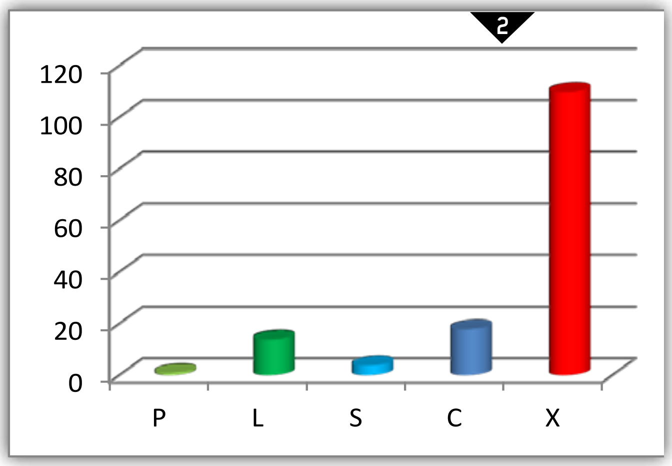
It has been demonstrated that geodetic control points can be measured from space radar (e.g. DLR's DriveMark), for instance as contribution to the future navigation maps, in particular in support of autonomous driving. The method capitalizes on persistent scatterer analysis of very high-resolution SAR.

Value added service providers that apply interferometric SAR (INSAR) analysis can benefit from free Sentinel-1 SAR data to grow their business. Consolidation and integration into vertical sector groups has likely improved the production efficiency and operational capabilities among these players.

CONCLUSION

The performance, number and diversity of satellite-based SAR sources will go through a significant improvement and growth in the next five years, while accessibility to data and information services will reach a quality and level of reliability that should put the commercial SAR community into a position that is close or equal to that of the commercial electro-optical satellite imaging community. Fingers crossed, friends of radar! ∧σ

▼ FIGURE 2
Number of SAR sensors announced to be in space (vertical axis) by 2023 by spectral band (horizontal axis).



Myrna James Yoo
Publisher, Apogeo Spatial

Alex Greenberg
Co-founder and Head of Operations, Loft Orbital
www.loftorbital.com

LOFT ORBITAL HAS INTRODUCED A UNIQUE BUSINESS MODEL THAT IS MAKING SPACE ACCESSIBLE TO COMPANIES AND ORGANIZATIONS THAT SIMPLY DO NOT HAVE THE RESOURCES OR EXPERTISE TO LAUNCH THEIR OWN SATELLITES. THEY HAVE TAKEN ADVANTAGE OF STANDARDIZATION AND MASS MANUFACTURING OF MICROSATELLITES TO OFFER A WAY FOR ORGANIZATIONS TO COLLECT PROPRIETARY DATA WITHOUT HAVING TO BECOME A SPACE COMPANY. LOFT DOES THE HEAVY LIFTING, INCLUDING MANAGING THE ENTIRE SATELLITE MISSION, WHILE THE CLIENT COMPANIES ON THE GROUND CONTROL PAYLOAD TASKING, RECEIVE DATA SECURELY, AND INVEST LESS FINANCIALLY.

JAMES YOO What does Loft Orbital do?

GREENBERG Loft's mission is to make space simple for customers who want to collect information about the Earth. We provide space missions-as-a-service, meaning we own and operate microsatellites and fly payloads on behalf of our customers. We handle the entire satellite mission including procuring a satellite, managing a launch campaign, and operating the satellites as well as licensing, insurance and financing.

We started Loft Orbital because we saw an insatiable demand for space-based data, yet immense challenges in executing a satellite mission: technical complexity, schedule, cost, and red tape. We believe customers whose business case or scientific value is in the data should not have to spend time and resources dealing with these challenges.

Now is the time for this kind of model as many satellite manufacturers are investing millions, if not billions, in the infrastructure to mass manufacture satellites. Constellations and mega-constellations have changed the game, pushing satellite manufacturers to build truly standard satellite platforms, ranging in size from 50-150kg and offering superior performance and longer lifetimes than cubesats. We saw how the standardization of the cubesat form factor triggered massive adoption, and we believe the industry is poised to benefit massively from the advent of standard, higher performance platforms that can be delivered quickly and at a low cost.

JAMES YOO Why is your business model unique in the space industry?

GREENBERG We are different than most space startups in the market right now. We aren't manufacturing satellites, we aren't doing launch, we aren't a subsystem supplier, nor are we a data analytics company. We are a satellite operator that flies customer payloads as a service. Our offering is enabled by technology we develop in house: First, the Payload Hub is a universal interface that can accommodate a wide range of payloads. Second, Cockpit is satellite operations software that enables customers to have full operational control over their payload. Everything else we outsource to partners.

We can fly dedicated, single-payload missions; however, our interface is built to accommodate

MakingSpace Simple

Inside Loft Orbital's Plan to Offer Space Missions-as-a-Service

"New Blue Marble" image courtesy of NASA, January 2012 multiple payloads. The rideshare model, long a standard practice in the launch industry, enables each tenant customer to share in the mission costs while flying on a larger more capable satellite bus than they would in a dedicated mission configuration. You can think of it as 'UberPool to space.' We are also developing the optimization frameworks to 'mix and match' payloads on a given mission, maximizing performance and minimizing risk.

Pricing is another area in which we are unique. Right now, the upfront working capital requirement of a smallsat mission, mostly in the satellite and launch, is prohibitively high for many. Loft solves this problem by charging the customer a minimal down payment, and then most of the customer's payment comes in the form of annual subscription fees. This model enables commercial customers to pay for the mission with revenues generated by their space infrastructure and government customers to smooth out lumpy satellite mission budgets. On our end, we obtain financing to address the upfront working capital requirement of the mission.

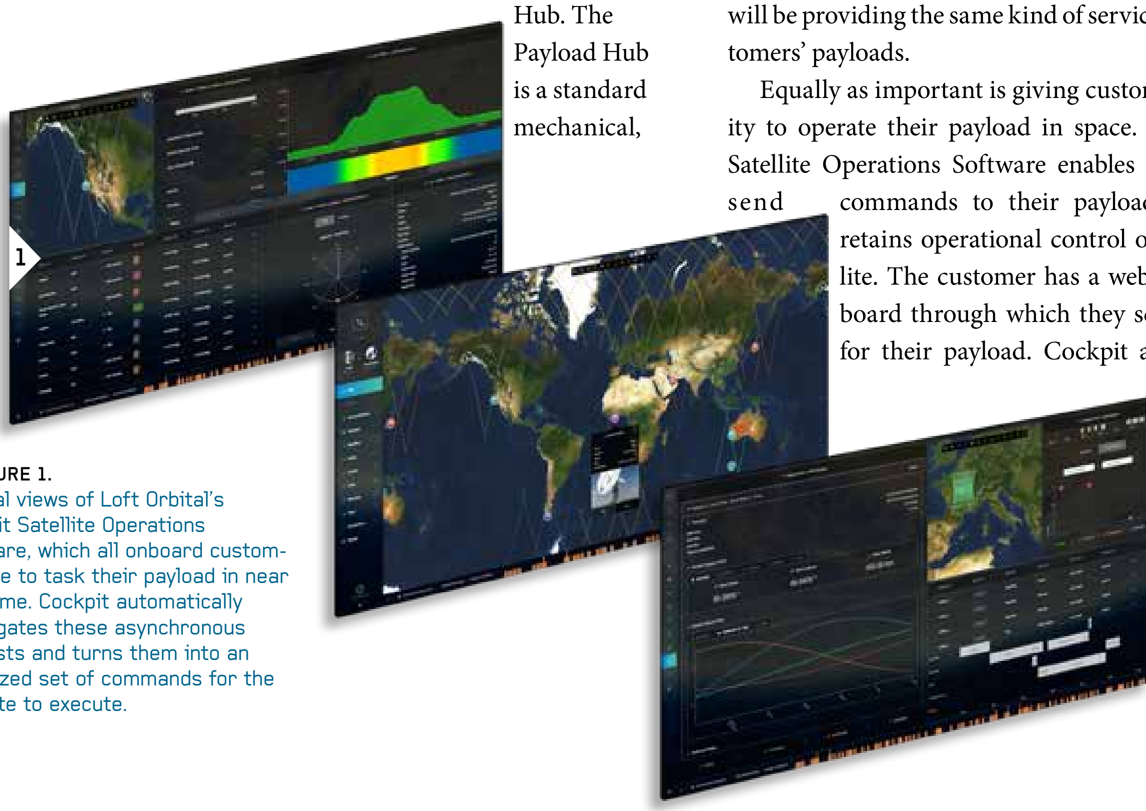
JAMES YOO What is Loft Orbital's core innovation and technology that makes this possible?

GREENBERG Our first major innovation is our standard payload accommodation interface, the Payload Hub. The Payload Hub is a standard mechanical, thermal, electrical and power interface, serving as the sole point of communication among all onboard payloads and the satellite bus. All payloads integrate onto the Hub and from the bus's perspective, our Hub is the only payload onboard. You can think of the Payload Hub as a Rosetta Stone, translating data inputs from payloads to the bus and vice versa, without requiring them to 'speak the same language.'

The value of this model is that we can accommodate multiple payloads without requiring costly nonrecurring engineering (NRE) on the satellite bus. NRE is the primary driver of cost and schedule overrun in satellite missions. Even the slightest change in the software code on the bus side has a compounding schedule impact, where additional time is required for verification and testing. With our Payload Hub as an abstraction layer between bus and payloads, we can purchase a standard satellite as-is, avoiding the need for expensive, payload-specific software and hardware customization.

Yet the Payload Hub is more than just a Rosetta Stone. We are creating a computing environment onboard where customers can upload algorithms to store, process and analyze their data. It will be similar to the way that Amazon Web Services works; it doesn't run the business for you, but it enables you to run all of your business processes in the cloud. We will be providing the same kind of service for our customers' payloads.

Equally as important is giving customers the ability to operate their payload in space. Our Cockpit Satellite Operations Software enables customers to send commands to their payload while Loft retains operational control over the satellite. The customer has a web-based dashboard through which they schedule tasks for their payload. Cockpit aggregates all



▶ FIGURE 1.
Several views of Loft Orbital's Cockpit Satellite Operations Software, which all onboard customers use to task their payload in near real-time. Cockpit automatically aggregates these asynchronous requests and turns them into an optimized set of commands for the satellite to execute.

task requests from the onboard customers and automatically creates an optimized satellite operations plan, ensuring compliance with our SLAs. The system is fully automated, precluding the need for an army of satellite operators. This model can scale to 'constellation tasking,' where the customer requests something like "image all of North America" and Cockpit calculates the most efficient plan for the constellation to fulfill that request.

Cockpit is meant to give the customer the experience of command and control of their own proprietary space asset, even if Loft actually owns and operates the satellite and their payload is ridesharing next to others. Our approach with Cockpit touches on a nuance that many in the NewSpace industry do not understand: More important than data itself is control over the infrastructure that collects the data or provides a service. Customers are willing to pay a premium to be able to task their payload and dictate operations.

In fact, the market for 'space-based infrastructure' – where Loft is playing – is many times larger than the space-based data market. Think of how much money the U.S. government spends on weather satellites, only to give away the data for free. Consider countries that spend hundreds of millions of dollars on their own Earth observation satellite programs, when there are plenty of commercial data services in the market, or startups that need their own constellation to offer a differentiated analytics service. These are our current and future customers, which benefit from our standard, low-cost alternative.

JAMES YOO Which industries are most likely to benefit in the greatest ways because of this new way of getting access to data from space?

GREENBERG Initially, our approach is to make space simple for both current and would-be users of space. Our initial clients vary wildly, and for example include startups with business cases that require space-based data, government agencies with monitoring missions that need a more robust platform than a cubesat, large corporations looking to demonstrate a technology in orbit, and academic institutions that have developed a novel payload and need a ride to space.

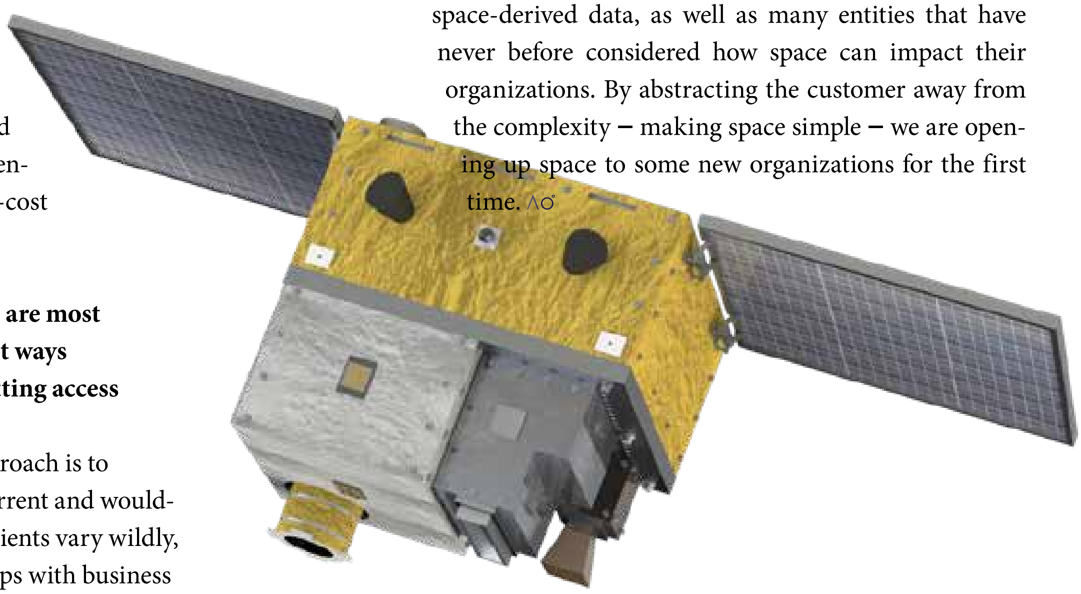
One customer segment I'm particularly excited about includes developing countries that in the past 5-10 years have gotten serious about their space programs. Over 70 countries have active space programs, and many are spending between 10s and low 100s of millions of dollars per year on space. While these budgets do not align with the types of exquisite satellite systems marketed by large aerospace companies, they are a perfect fit for our low-cost offer, which prioritizes getting customers to space quickly.

In the long run, we believe that our service caters to any organization that requires a proprietary, taskable feed of space-based data, even if their DNA isn't "space." This can include large commercial enterprises, NGOs, and any government agency with bespoke geospatial data requirements, who previously did not have the means to acquire and operate their own satellite.

JAMES YOO What's next for Loft Orbital?

GREENBERG We are driving towards our first mission, which will occur in 2019. We'll be sharing more information on this in the next few months. At the same time, we will soon begin to manifest 2020 missions and we intend to select bus partner(s) for those by the fall. In the long term, it will be constellation orders – customers asking us to fly a sensor – that will enable us to truly scale. We see enough demand in the market that by 2022 we could be flying seven or more satellite missions per year.

This unique business model will benefit current users of space-derived data, as well as many entities that have never before considered how space can impact their organizations. By abstracting the customer away from the complexity – making space simple – we are opening up space to some new organizations for the first time.



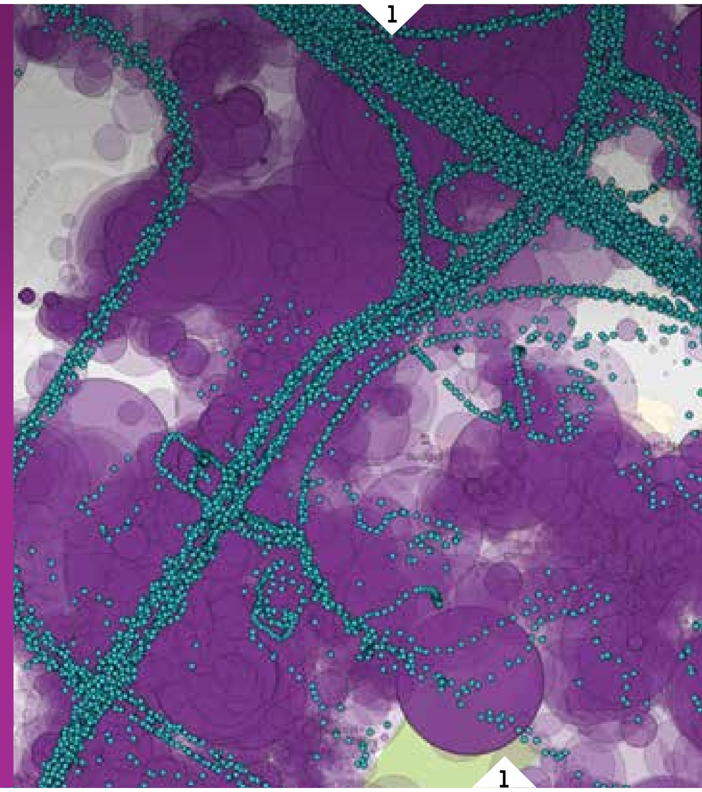
▲ FIGURE 2.
This image shows a rendering of a typical Loft Orbital satellite with multiple customer payloads onboard integrated directly to Loft's Payload Hub. The Hub is integrated as a single payload module onto a partner's standard satellite bus.

TellusLabs, co-founded by Drs. David Potere and Mark Friedl in 2016, builds systems for environmental intelligence, mostly using satellite Earth observation (EO) data to help monitor food production. Potere is now the company's CEO and Friedl its Chief Science Officer. The company predominantly stores its data on Amazon Web Services, but also uses Google Cloud.

StreetLight Data, founded by Laura Schewel in 2011, builds systems to help transportation planners and others understand travel patterns, mostly using crowdsourced data acquired from third parties. It stores its data on Google Cloud. In the crowded market for cloud-based, big data, geospatial analytics, these two companies represent two different but overlapping approaches.

For this fourth installment in the series about companies that are using geospatial and other data as inputs for complex analysis, I talked to:

- **Nick Malizia, Head of Data Science at TellusLabs, and**
- **Laura Schewel, CEO and founder of StreetLight Data**



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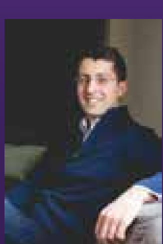
TellusLabs



Nick Malizia, Head of Data Science at TellusLabs

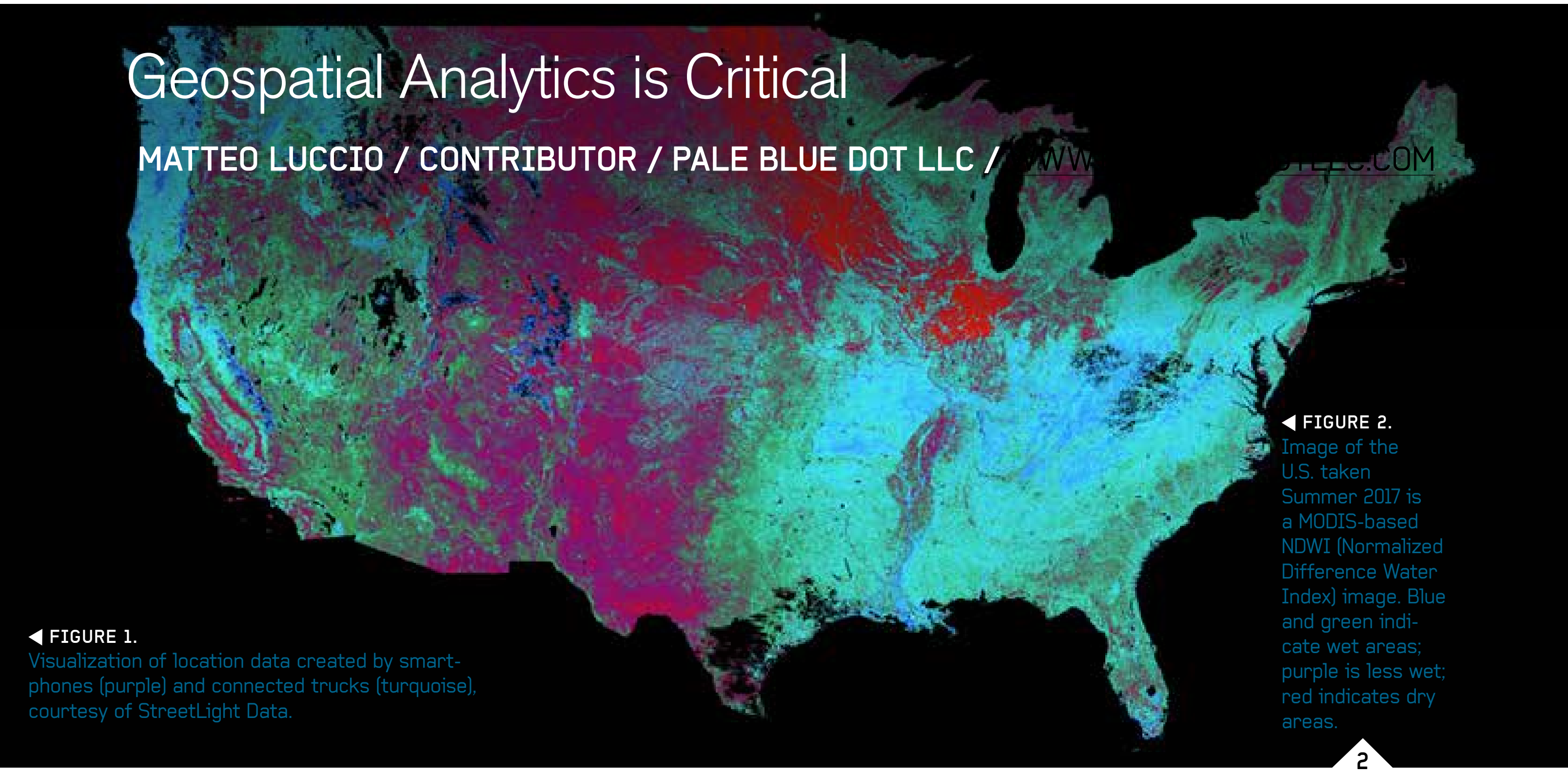
VISION

Malizia has been in geography for almost 20 years. He earned bachelor's and master's degrees in geographic information science and a Ph.D. in geography with a focus on spatial analysis. "I studied under a spatial econometrician, building explanatory and forecast models using traditional econometrics methods that take space into account, but I also did a fair bit of work on spatial optimization," he recalls. He worked for a few years at the Boston Consulting Group as one of the early members of its geospatial analytics team, then joined TellusLabs.

There is a vast amount of accumulated EO data, now growing at a faster rate than ever, and computing resources are available to analyze it, which were not broadly available five or ten years ago, Malizia explains. "You couple that with a lot of the machine learning methods that have been developed and democratized and you set yourself up for a very interesting period, where this really has the opportunity to take off. David and Mark saw that opportunity and wanted to take advantage of it," he says. "We are trying to revolutionize what is possible with regards to monitoring the world's food supply, using the tools that are now available to us."

Geospatial Analytics is Critical

MATTEO LUCCIO / CONTRIBUTOR / PALE BLUE DOT LLC / WWW[illegible]DTLLC.COM



◀ FIGURE 1.
Visualization of location data created by smart-phones (purple) and connected trucks (turquoise), courtesy of StreetLight Data.

◀ FIGURE 2.
Image of the U.S. taken Summer 2017 is a MODIS-based NDWI (Normalized Difference Water Index) image. Blue and green indicate wet areas; purple is less wet; red indicates dry areas.

2

ON MONITORING ANSPORTATION

> "We are trying to revolutionize what is possible with regards to monitoring the world's food supply, using the tools that are now available to us."
> -Nick Malizia, TellusLabs

BUSINESS MODEL

Tellus has a subscription product, called Kernel, which enables users to monitor the condition of certain crops around the world every day of the year. "You can log in in August and see the condition of the soy beans and the corn in the United States and see how the wheat harvest is going, or you could log in in February and see the same crops in South America," says Malizia.

Kernel also has a modeling component, which the company uses to forecast the health of crops over the course of a year based on observations in previous years and current conditions on the ground. "That allows people who are interested in these commodities to take an educated position in terms of how they are trying to manage their risk on them," Malizia explains.

TellusLabs is also working with a group of partners, such as large agribusinesses, seed companies, and food producers, to integrate its technology into their businesses. These companies have a vested interest in getting a very granular look at how their crops are doing or how crops are doing globally. "It runs the gamut from people who are interested in the global supply and demand balance sheet, to people who are interested in specific field-scale insights, where we are trying to work across that spectrum," says Malizia.

DATA SOURCES

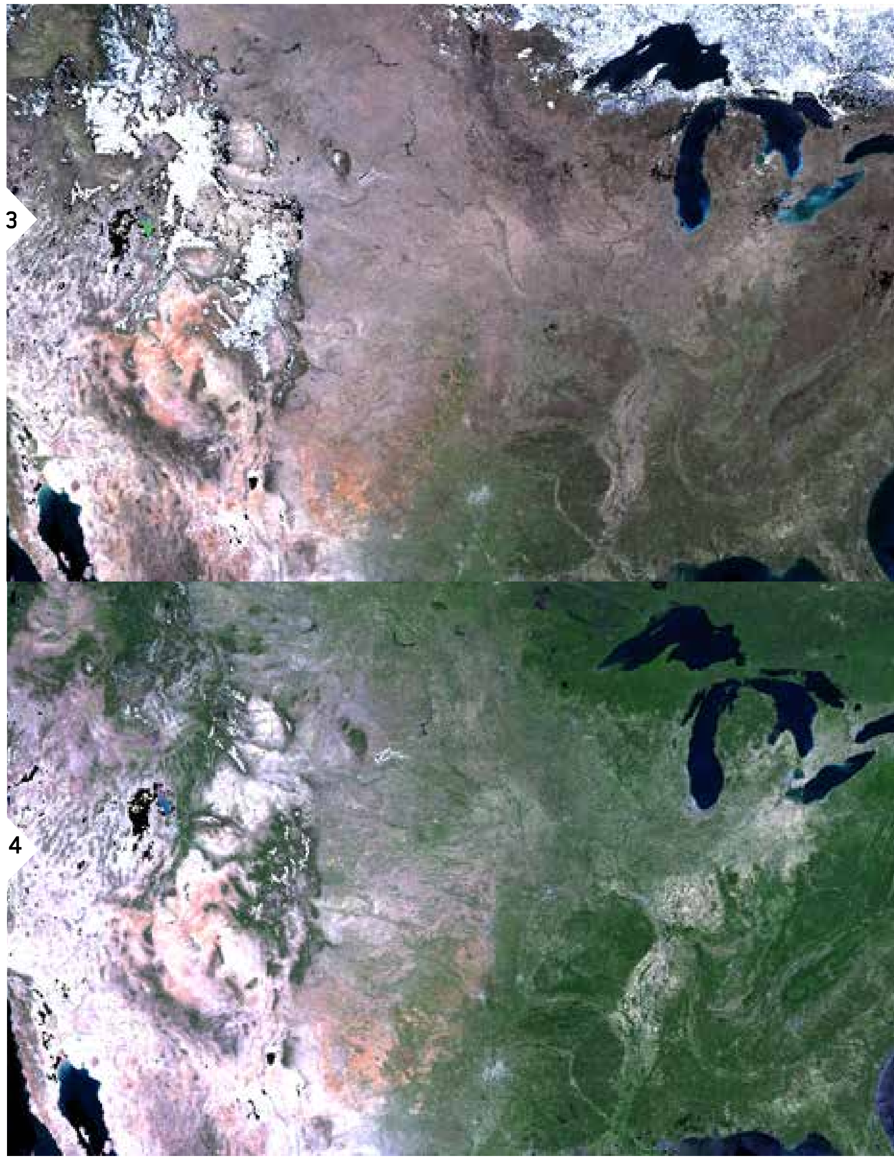
TellusLabs mostly uses satellite data, especially from MODIS, Landsat 7 and 8, and Sentinel-2. It also uses data from several weather sources, as well as on-the-ground truth data where available. "The lion's share of what we use for our global monitoring product is the MODIS sensor, because it gives us the longest continuous record at a scale that is manageable in terms of computing and because the imagery's spatial resolution provides the directional answer that we need to do our global monitoring work," Malizia explains.

Tellus does not make use of the latest crop of cubesats from private companies, preferring to rely on large, legacy, government-built and -operated satellites. "At TellusLabs, we are all scientists," says Malizia. "These instruments were built to do science. They are very well calibrated, they have a long history, there is a large community of scientists and users that have been ironing out all the kinks on them. They are science-grade instruments, so we are very comfortable using them."

However, the company considers itself sensor-agnostic and is exploring partnerships with other data sources. "Our aim is to use the right tool for the job," says Malizia. Their customers, he points out, don't necessarily care about, say, the return rate of Sentinel-2. Rather, they just want to know how their fields are doing, what they can expect out of this year's crop, and whether there is anything about which they need to worry.

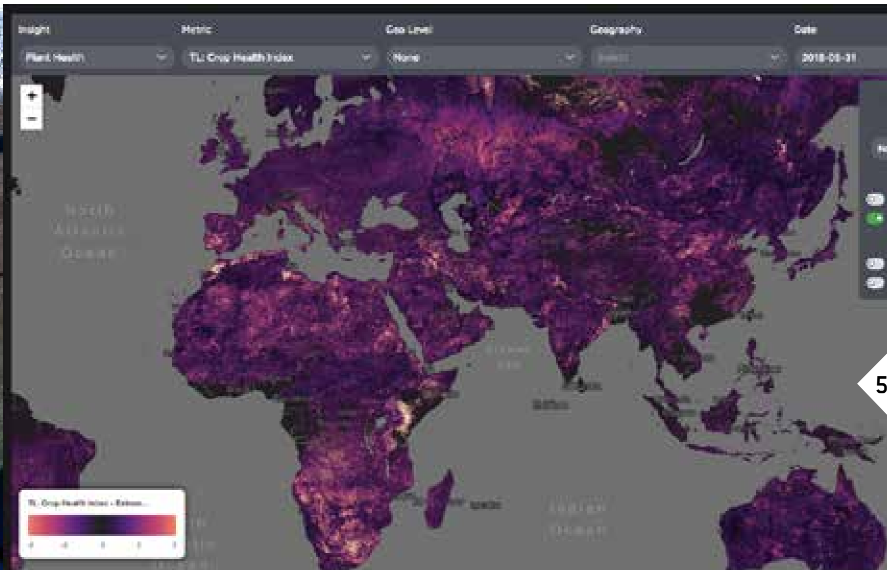
ANALYTICS

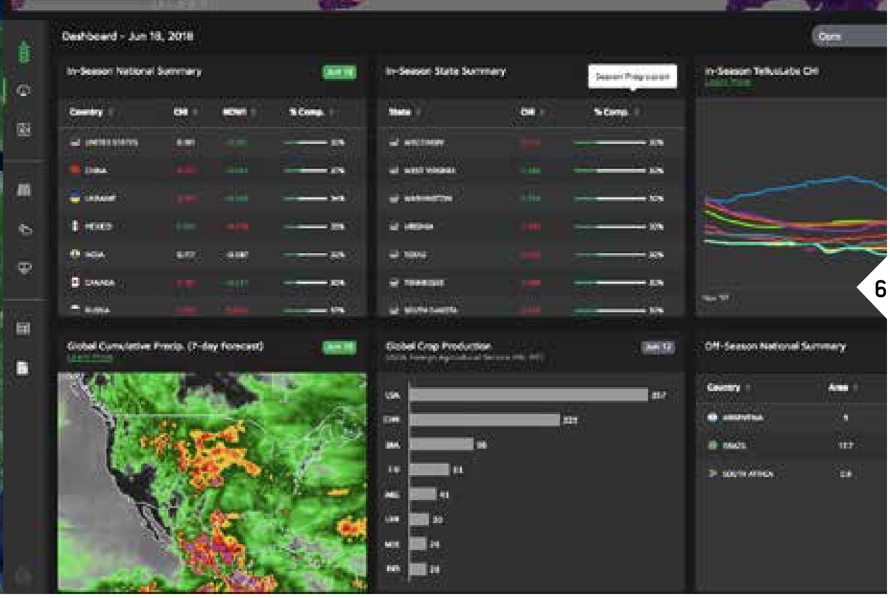
TellusLabs is building out Kernel to expand its scope and depth, the number of countries and crops it covers, and its global- and field-scale integration. "We want to fill out the suite of product components that we are offering to our customers," Malizia says. "We want to be the source for remote sensing analytics for agriculture across the globe. So, everything that we are doing is in the service of that goal."



▲ FIGURES 3-4.
MODIS true color images of the central United States. Figure 3 was in Winter with snow and lack of vegetation is visible along the corn belt. Figure 4 was in early Summer, at the beginning of the "greening-up" phase.

The company makes available to its customers all the data that it uses for its modeling and that go into its model feature construction, so that they can query it. However, it does not enable them yet to use some of its tools like Web services. "You cannot feed some of your own data and get a whole host of data back," says Malizia. "We are offering up the data that we think is most valuable and just seeing how people are using it."





▲ FIGURE 5.
Image from the TellusLabs Kernel product, showing an Extreme Anomalies layer applied to the TellusLabs proprietary Crop Health Index mask.

▲ FIGURE 6.
Image of the Kernel dashboard, showing a variety of crop health insights across the globe.

However, he adds, "in the not too distant future," the company might enable customers to upload their own spatial data, such as their fields or other geographies that they want to analyze, and answer their queries.

The types of analytics that TellusLabs does runs the gamut, from correcting raw satellite imagery to analyzing it to summarizing images over specific geographies, then doing more analyses on top of that.

MODELING

A particularly interesting area of TellusLabs' work with its field-scale partners is to identify certain phenomena on the ground, such as diseases and water stress, and to understand the different qualities of the crops that are being grown, such as grains or oil seeds. "We have done a fair bit of modeling on that," says Malizia.

In agriculture, location matters; however, mapping crops correctly is very labor-intensive. "One of the things that we are doing is understanding where the crops are being grown in season and what crops they are," says Malizia. "That allows for a fair bit of innovation on the modeling side."

For yield modeling, TellusLabs uses several modeling and forecasting techniques, ranging from standard linear models to neural networks. "Ultimately, what drives the decision of what we are going to use, in practice, is how our models perform historically, in a given setting," Malizia explains. "We think that there is a lot of value in the feature engineering, so, we are building features that we think are going to be valuable, as opposed to just feeding in raw data. We try to be deliberate about what we're putting into the models."

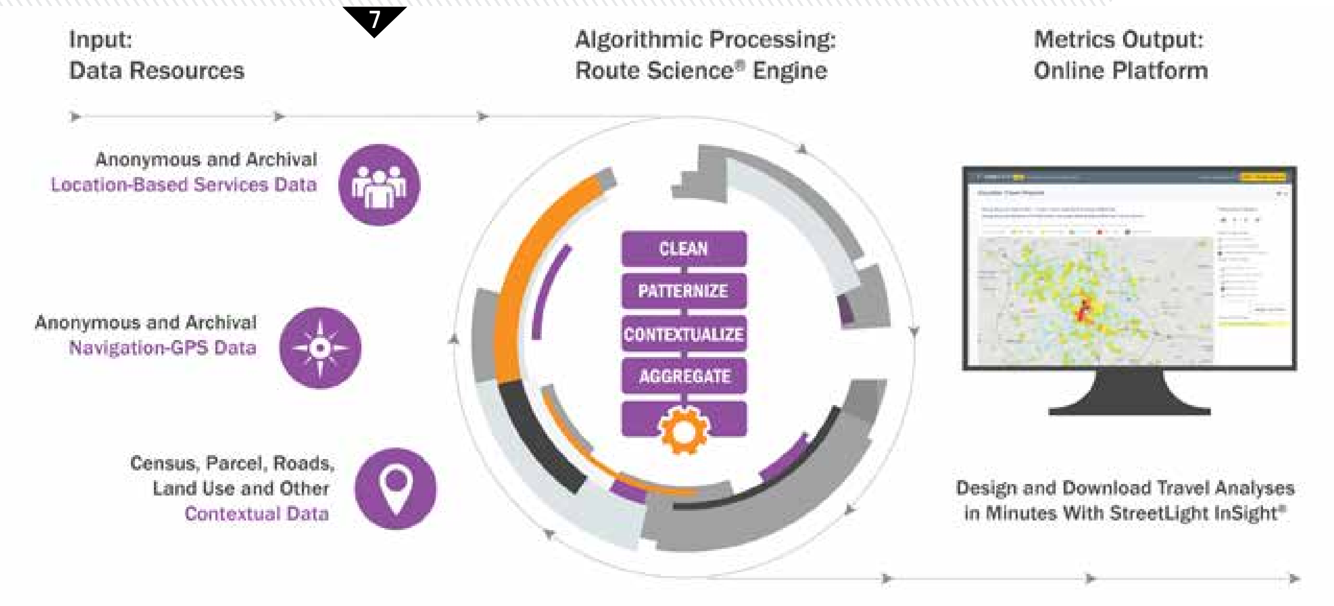
StreetLight Data

INDUSTRY NEEDS

"We are the first and only analytics company that allows the transportation industry to put big data to work," says Schewel. "We combine access to the best data resources that describe mobility behavior with the software to make it useful."

Laura Schewel, CEO and founder of StreetLight Data

The transportation industry – which includes state and regional public transportation agencies, the transportation consulting and engineering sector, and the new and emerging private transportation sector, including Uber, Lyft, and bike sharing companies – has a high need for geospatial big data. However, Schewel argues, it does not make sense to develop deep data science and geoanalytics capabilities in every government agency or engineering firm. Instead, her company developed software to make it easy for transportation professionals to use big data to answer their most frequent questions, regardless of their degree of geospatial expertise.



▲ FIGURE 7.
Diagram of StreetLight Data's locational and geospatial data inputs, algorithmic processing steps, and online platform for querying processed data.

> "Machine learning in transportation is 'a little overhyped' because it requires having a truth dataset from which your machine learns. In transportation, there is almost no truth data." -Laura Schewel, StreetLight Data

Dedicated spatial sensors, which are increasingly common, are fine for some applications. However, Schewel points out, they duplicate the capabilities of the billions of dedicated geospatial sensors that are already in everyone's pocket, namely cell phones, soon to be supplemented by connected car technologies. "So, we targeted ways to get our hands on that type of data, by doing deals with people who are already collecting it for their own purposes. These include people who make smartphone apps to collect anonymous location data and connected cars and connected trucks companies and fleet management companies that collect data about vehicle behavior." Her company then pulls trillions of those points into its system to develop detailed analytics about the mobility behavior of large aggregate groups. Its clients access these analytics by logging into StreetLight Data's website and using them to make decisions about transportation.

BUSINESS MODEL

StreetLight Data's business model is based on two propositions, Schewel says. The first one is that transportation decision making and planning has historically been based on almost no data, even for such billion-dollar decisions as where to expand a highway. "People were basing major decisions on assumptions or on a survey from nine years earlier that covered .003 percent of the population affected." Therefore, her company endeavors to provide "much bigger, better, and more robust and expansive data options from big spatial data."

The second proposition is that the marginal cost of running each additional query in the cloud is virtually zero. Therefore, transportation planners and decision makers who were previously inhibited by the cost of analyzing conditions on each road segment can now feel free to analyze and compare conditions on thousands of roads. For example, Schewel says, clients are now searching for the best route for a bus lane by first scanning every road in a city to find where bus lanes are most needed. The "ubiquitous availability of geospatial data is changing how transportation decision making flows."

StreetLight Data licenses data from a variety of sources who are creating them for their own purposes, then combines them with more conventional sources of spatial data to create a SaaS business model. The company's clients subscribe to its online portal and can run analytics within it. Its largest users are Departments of Transportation – including those of Virginia, Ohio, Minnesota, and New York City – as well as engineering firms and other private sector companies.

ANALYTICS

"We take very messy data that describes the mobility behavior of more than 70 million devices and we turn it into useful analytics that transportation professionals care about," Schewel says. To protect privacy, her company only generates aggregate analytics. Examples include:

* the percentage of people driving across the Bay Bridge who end up in every neighborhood in San Francisco;
* where the greatest number of short-distance trips take place in New York City;
* where tourists hang out in L.A. between 3PM and 8PM on a typical weekday;
* in what neighborhoods people who cross the border in Texas end up and how that differs between commercial trucks and personal vehicles.

"These are all types of analytics that describe mobility and that people who are planning the transportation system care about," Schewel says. The types of questions they are trying to answer vary from huge, such as where to route a multimillion dollar highway, to very small, such as "whether the stop light should go on 4th Street or 5th Street, or the toll price should be $2.50 or $2.75."

FUNCTIONALITIES

Users cannot write generic queries against StreetLight Data's data, but they can create their own queries from a menu of queries that the company provides. "That self-customizability is important to making it useful," Schewel says. For example, they can analyze transportation behaviors in neighborhoods for which they uploaded shapefiles. "It is not a generic spatial platform; it is very particular for transportation planning."

StreetLight Data inputs data and outputs metrics, such as an origin-destination matrix for the entire state of California. "A metric is an aggregate, processed, value-added data product," Schewel explains. Customers can visualize their metrics in the company's portal as maps and charts or download them in various formats, such as csv, that they can then import into their own system. The company also provides an API that allows users to create metrics and pull them directly into whichever software they use, or deal with them via the user interface.

DATA SOURCES

The company obtains all its big data, such as those that describe mobility behaviors, from commercial partners, which crowdsource it. "Our whole business model is based on the explosion of crowdsourced data," Schewel says. "We wouldn't exist if that did not exist. It is facilitated by the LBS aggregation industry, which aggregates crowdsourced data."

The company looks for data that is complete with regards to transportation behavior. "I'd rather have a more complete description of a transportation behavior, such as a trip, than a high number of partial pieces of transportation data. Now we are also looking for partnerships that can give us data on special types of transportation, such as data that is specific to walking, biking, or bus riding."

MACHINE LEARNING

According to Schewel, machine learning in transportation is "a little overhyped" because it requires having a truth dataset from which your machine learns. "In transportation," she points out, "there is almost no truth data." Therefore, for most of its core analytics, StreetLight Data relies on heuristic, decision tree-style algorithms. "However, for certain types of things, such as mode inference (whether someone is biking or walking) we do use machine learning. So, we mix and match the right techniques, depending on the question at hand and the calibration data that is available."

The name StreetLight Data is a metaphor. The company brings real-world travel patterns to light. Just as streetlights illuminate our roadways at night, StreetLight Data creates analytics that shine a light on mobility behavior.

CONCLUSIONS

Whether analyzing global trends in food production or local traffic patterns, geospatial analytics continues to evolve rapidly, taking advantage of the explosion in crowdsourced and satellite data, ever-faster computer processing, and the latest machine learning techniques. The next quantum leap will probably be due to the proliferation of data from Internet of Things (IOT) devices, with applications from self-driving cars to kitchen appliances. Buckle up and relax, as your refrigerator gives your car the groceries shopping list.

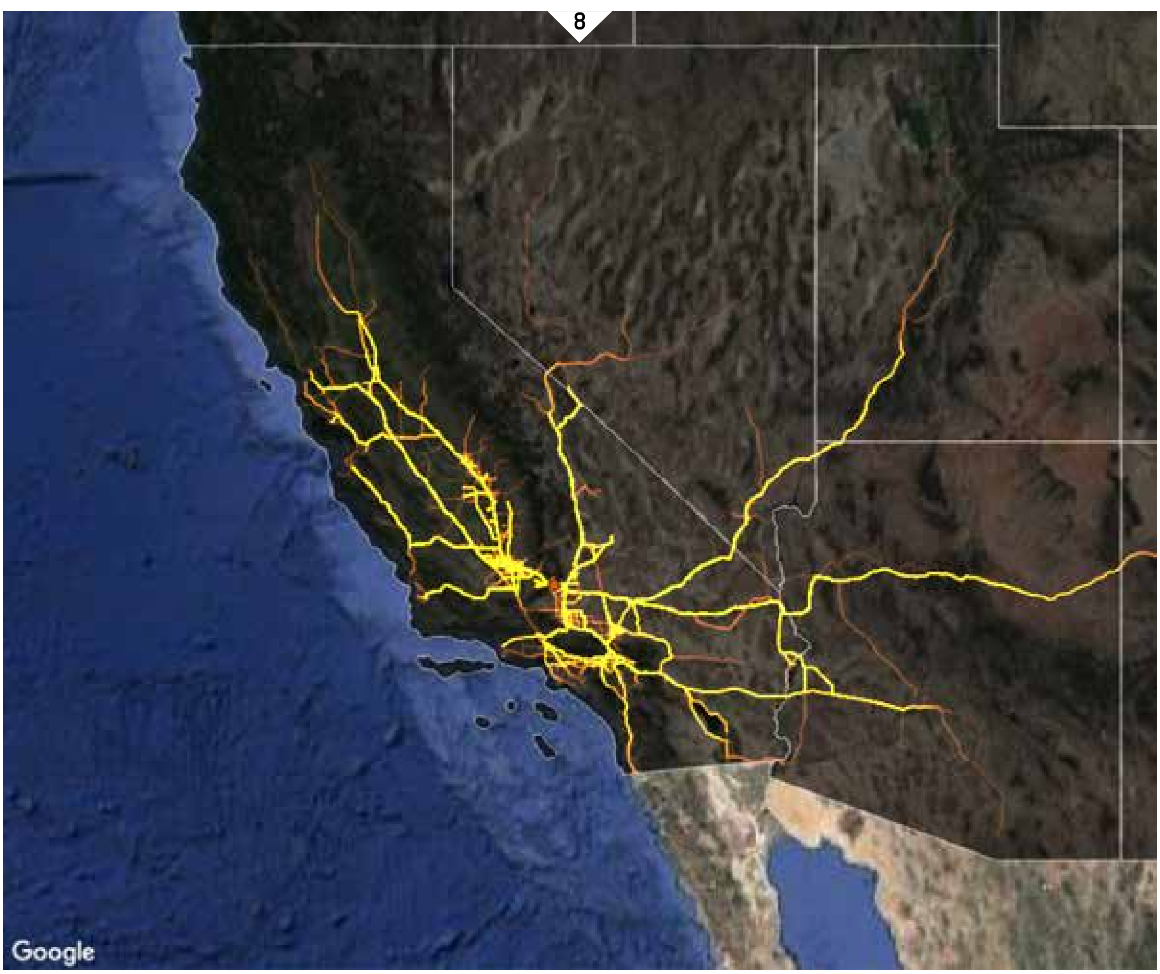


FIGURE 8.

This image visualizes the routes of heavy-duty commercial trucks leaving the Port of Los Angeles-Long Beach, courtesy of StreetLight Data.

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