Imaging NOTES

EARTH REMOTE SENSING
FOR SECURITY
ENERGY AND
THE ENVIRONMENT

Winter 2010
Vol. 25 » No. 1

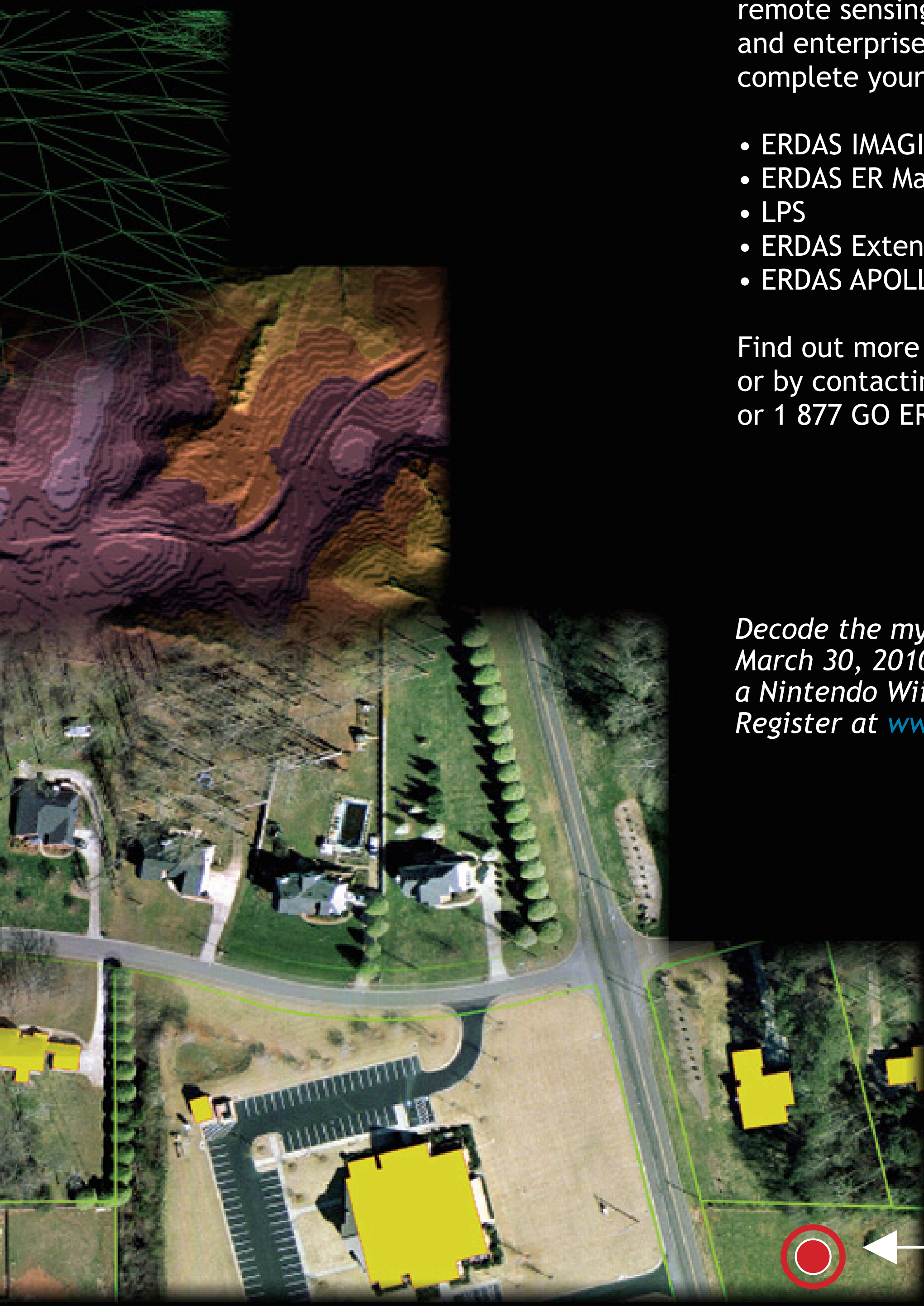
WorldView-2 in living color

3D & LIDAR REPORTS

NCAR'S ERIC BARRON

CLIMATE & MANGROVES

Are You Creating the Map of the Future?



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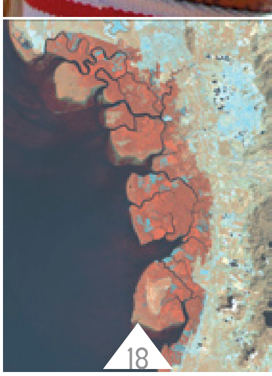
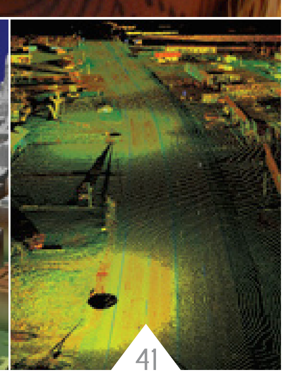
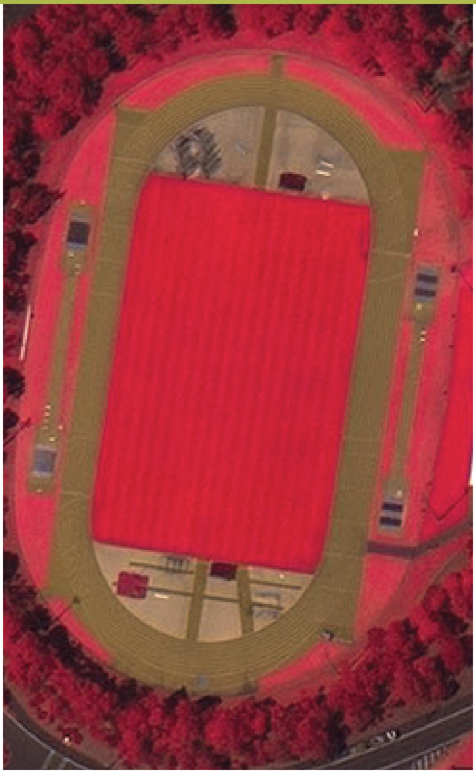




Sydney Olympic Park

COVER IMAGE



This WorldView-2 satellite image is of Sydney Olympic Park, the home of the 2000 Summer Olympic Games in Sydney, Australia. This image features the Olympic Boulevard and The Olympic Stadium, as well as various other smaller athletic centers and facilities.

This is a near infrared image on the cover, an image band combination used to easily find the healthiest vegetation as bright red. In this image, the grassy sports fields are evidently well maintained in bright red and the remaining vegetation throughout the park is red as well.

Additional new images from WorldView-2, which was launched on October 8, 2009, appear in the feature article beginning on page 24.

This image was collected on October 20, 2009, just 12 days after launch. The satellite has reached full operational capability as of January 4, 2010, on schedule.

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Our Mission

Imaging Notes is the premier publication for commercial, government and academic remote sensing professionals around the world. It provides objective exclusive in-depth reporting that demonstrates how remote sensing technologies and spatial information illuminate the urgent interrelated issues of the environment, energy and security.

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Trends to End a Decade

DIGITAL RIOTS & NOUNS AS VERBS

As we end one decade and begin another, two trends have emerged that are changing media and indeed all of business. One will impact business directly and meaningfully, and the other is, well, interesting.

Social Media in Business

Impacting business directly is the trend of using social media in business, not just in your personal life. Using social media in business is now imperative, but sometimes it feels as if I'm being forced to do it at gunpoint. Are businesses actually getting value from having people "follow them on Twitter"? Of course, posting regularly keeps your brand in front of your followers... which would be great if you knew that your followers were also your customers. The true business value remains to be seen.

I use Twitter primarily for conferences. Tuning into the Twitter conference feed is like hearing all the comments that are whispered among audience members. This is most popular at conferences where everyone is using laptops or smartphones (Where 2.0, Web 2.0, and ESRI User Conference, to some extent). But the Twitter pages were not as active in conferences such as GeoInt, where the culture dictated that laptops were generally not used in the audience. The only conference I attended in 2009 where no Twitter page was available was in Beijing – no surprise – at the International Symposium on Digital Earth.

Using social media at conferences has evolved from being virtually nonexistent in 2008, to being almost ubiquitous in 2009, and even to a point in November where an unfortunate event that could be called a "digital riot" occurred.

LBx Journal editor Natasha Léger was attending a keynote speech at the Web 2.0 Conference in New York, where conference organizers were showing the live conference Twitter feed onstage behind the speaker, who did not realize this was occurring. Everyone in the room could read (and comment on) reactions to the presentation by using the Twitter page.

What happened next was inevitable. The speaker was confused, unaware of the comments behind her. This reaction caused even more tweets – more digital tomatoes. A digital riot ensued because a digital mob gained power over a defenseless victim. As people began criticizing the content of her presentation, she literally lost control of the speech, and of the audience.

Organizers probably could have stepped in to regain control for the speaker, but, unfortunately, they did not. There can be value in everyone having a voice, but in some instances, when one voice has value for everyone, it does not make sense to allow multiple others to take over. Trusted editors and experts are still needed – the audience cannot be in control of the show.

This debacle offers an example of the difficulty in managing and properly using social media for business. What we have now is too much information. Not everything said is worth hearing. There are too many posts, and many of them are irrelevant.

One purpose of professional media that we at *Imaging Notes* take seriously is to sort through the information that is out there, to help edit for our readers, and to share what is really important. This need for editing is perhaps more crucial than ever, now that anyone can say anything at any time (and we are all very very busy).

Nouns Are Verbs – Oh My!

The second trend is perhaps less important but still worth noting. Nouns are increasingly being used as verbs. As a grammarian, I am quite disturbed by this, though I realize that language evolves naturally and no one is in control of how this happens. Examples abound. "Google" is now a verb: "Just Google it!" "Text" was once print on a page; now we are "texting."

There's "map it" for those of us in the geospatial industry. We used to "create a map" or "draw a map," but these phrases are no longer needed. So we are simplifying or streamlining our language, but it is still very hard for purists like me (and our copy editor) to "stomach" the use of nouns as verbs, especially in print.

That said, we are beginning to allow this usage in our magazines.

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In this issue, on page 46 of the in-depth report on LiDAR, you'll see this sentence: "…imagery can be used to quality control LiDAR data." In the current Fall/Winter issue of *LBx Journal*, Dr. Mark Feldman of Space-Time Insight uses both "walled-off" and "islanding" as verbs, meaning almost the same thing.

Everyone has a voice due to Web 2.0's mass distribution of content. And there is still a place for editors who take their job seriously – editors like us. Email your comments to publisher@imagingnotes.com.

–Myrna James Yoo
publisher@imagingnotes.com

Water

AND SPACE SYSTEMS

Water. I've been thinking a lot about water recently, especially since my wife and I completed our house in the high desert plateau of Southwestern Colorado. Water is always in short supply in the desert Southwest, where annual rainfall seldom exceeds 12 or 13 inches (30 or 33 cm). Coping with recent heavy snows has obscured the basic fact that the landscape is generally parched, and if the spring and summer rains don't come at the right times, unirrigated dryland crops fail. Lately, perhaps as a result of climate change, those rains have come late and sparsely.

The supply of clean potable water, always an issue in traditionally dry parts of the planet, has grown more uncertain throughout the world as the climate changes and countries continue to degrade and pollute freshwater supplies. Water experts such as Peter Gleick of the Pacific Institute in Oakland, California, warn of impending water shortages and increasing conflict as a result.

"There is a long history of conflict over the world's scarce freshwater," notes Gleick. "Identifying and addressing the risks of violence over these resources is critical to understanding how to reduce such risks in the future as populations grow, climates change, and pressures on limited water resources worsen."

In theory, satellite imagery should be of great assistance in monitoring water availability throughout the world. Satellites orbiting in polar orbit are the most efficient and accurate way to acquire a consistent, calibrated set of data across the entire globe. In fact, the data acquired from satellites is very important for certain aspects of hydrology, the study of the distribution, movement, and quality of water.

Digital terrain maps of a region, combined with information on the distribution of buildings, pavement, and trees and other plant species on the landscape, provide very powerful means of estimating water sources and sinks throughout the area. Satellite imagery combined with other measurements can also assist in estimating the amount of water contained in snowpack, lakes and rivers. Such information is important for agriculture.

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For agriculture, especially in most arid parts of the world, however, the measurement of moisture in the soil is generally even more important. And it is not just total yearly precipitation that is significant, but also when and at what rate it occurs. Moisture has to be there at the right time to germinate seeds and promote growth. For government officials, such information provides estimates of future regional food availability. For farmers, knowledge of current and potential future soil moisture helps them plan their planting and irrigation strategies for the season's crops.

Soil moisture is also a key element of the scientific understanding of the global water cycle, from moisture content of the atmosphere to precipitation to eventual uptake of moisture into the atmosphere again.

Until recently, satellites have done a poor job of measuring soil moisture accurately because such measurements depend on very weak signals detected by means of a microwave radiometer. Scientists and farmers have depended largely instead on direct in-situ measurements of the water content of soil. That works at the scale of the average farm field, but provides only spotty estimates across large areas.

Although these in-situ measurements can be supplemented with data garnered from microwave instruments on the NOAA series of National Polar-Orbiting Environmental Satellites (NPOES), Eumetsat's METOP satellite, and the more sensitive instrumentation aboard NASA's experimental AQUA satellite, such data can provide estimates only and are not sufficiently sensitive for use in agricultural models.

The launch of ESA's latest Earth observing spacecraft, the Soil Moisture and Ocean Salinity (SMOS) satellite seeks to change that. Part of ESA's Earth Explorer series of satellites, SMOS is likely not only to revolutionize the study of Earth's water cycle, but also to provide key operational information for farmers in Europe and around the world. Its revolutionary interferometric radiometer, the Microwave Imaging Radiometer using Aperture Synthesis (MIRAS), will capture two-dimensional images of the Earth's surface, measuring changes in land surface moisture by observing variations in the natural microwave emission radiating from the surface.

Soil moisture is an important component of Earth's water cycle, and it influences regional weather patterns. Hence, measurements of this element will contribute to scientists' understanding of Earth's hydrology and help to track desertification.

MIRAS will also measure variations in the salinity of seawater across the planet, measurements that are important for better understanding of ocean currents and their role in moderating climate. Salinity and temperature together determine the density of seawater, which is a factor in creating ocean currents. Like soil moisture, ocean salinity is poorly understood throughout the world.

The measurements from SMOS could provide not only important data for understanding the global water cycle, but also crucial information for managing Earth's dwindling sources of fresh water. If fully successful, it will point the way toward the development of more sensitive future soil moisture and salinity instruments.

Two more scientific satellites are expanding our understanding of Earth's water resources. NASA's twin Gravity Recovery and Climate Experiment (GRACE) satellites, launched in 2002, were designed to generate gravity maps of Earth. Among other things, the twin Grace satellites monitor tiny month-to-month changes in Earth's gravity field caused primarily by the movement of water in Earth's land, ocean, ice and atmosphere reservoirs.

As announced in a press conference at the American Geophysical Union's annual meeting, scientists Jay Famiglietti, of the University of California Center for Hydrological Modeling, and colleagues Sean Swenson, NCAR and Matt Rodell, NASA Goddard Space Flight Center, have discovered that between 2003 and 2009, the volume of water resources stored in the Sacramento and San Joaquin River Basins of Central California decreased by some 31.3 cubic kilometers. Most of that decrease comes from losses in groundwater storage. In the opinion of these researchers, such losses are unsustainable.

This fall, ESA launched its own gravity satellite, the Gravity field and steady-state Ocean Circulation Explorer (GOCE). Over the next 20 months, this satellite will map global variations in Earth's gravity field with extreme detail and accuracy, which will add to the mass of information about global groundwater resources.

The data acquired from all three satellites will contribute to our ability to accomplish climate studies and to understand the global water cycle. However, they are not enough. As global warming becomes more of a factor in determining the frequency and global distribution of precipitation, it is crucial to be able to monitor the performance of Earth's water cycle operationally and to develop better management of existing water resources. Satellites can assist with that. However, collecting and putting satellite data to use will require new, improved systems and the institutional mechanisms needed to turn those data into operation for the benefit of humankind. That is a challenge not only for the space agencies of the world but also for the governments that supply the means to improve water resources management. «

Beijing to Bioneers

TECHNOLOGY FUELING GRASSROOTS MOVEMENTS FOR A BRAVE NEW WORLD

The Chinese did not invent Digital Earth, but their consistent promotion of it is responsible for an international community of ardent supporters. The Chinese Academy of Sciences recently hosted the 6th International Symposium on Digital Earth (ISDE) in Beijing. Hundreds of scientists, students, and business and government managers convened this past September to examine the progress made since China organized the first ISDE in 1999.

Google Earth, the omnipresent poster child for Digital Earth, was almost lost among the glitzy crowd of vendors hawking their three-dimensional Earth viewing products. Aggressive start-up firms, as well as leading satellite data vendors, presented an impressive array of technologies and satellite data wares that would have seemed beyond belief a short decade ago. How this potential is expressed in the daily lives of educators, students, and citizens, as well as government and industry, will make up the great story of the 2010 decade.

1

The next decade will be the time for major societal shifts due to increasing pressure for economic transparency and reregulation, to international policing and visibility of terrorist-criminal enterprises, and to climate change impacts. Spatial information will increasingly be used to bring communities together to discuss and confront disruptions in economic-social systems. Globalization concerns will become more evident as the transfer of goods and money become readily apparent and traceable using Digital Earth technologies.

How do we know these trends will happen? Because educated and capable people now know that high-visibility observation and documentation are possible and provide demonstrative impacts on media and social movements. Dramatic examples from Google Earth applications are growing by hundreds of thousands each month. Engaged citizens are learning how to monitor and broadcast the great calamities of our time in vivid 3D living color through the Internet.

A refreshing range of applications was exhibited and discussed in Beijing. Two graduate students from the University of Abuja, Nigeria, Fanan Ujoh and Isa Kwabe, were exploring how to apply multi-temporal remote sensing data to assess the land tenure controls on one of the world's largest slums outside Lagos. With limited tools and fewer financial resources, they could envision accomplishing their research and using the results to promote policy changes in the government. NASA'a Worldwind or Google Earth represent freely accessible software platforms that these humble Nigerian students can apply with highbrow-corporate results.

An inspirational professor of humble means, Dr. R.S. Kumar of Annamalai University in Tamil Nadu, India, shared with the Beijing audience his efforts to provide better emergency response planning and operations for his community using satellite data and Digital Earth tools along the southeast coast of India, south of Chenei.

His efforts have helped the Indian farming community to literally improve their chances of survival by providing them a better understanding of the landscape and by deriving optimal methods for seeking elevated flood shelters during monsoons or tsunamis. Using satellite-based maps, this dedicated professor has begun discussing other issues, like water-well locations and optimal crops that can benefit vulnerable people. Digital Earth approaches can, and do, open opportunities to stimulate community dialogs that influence self-governance behaviors.

Across the Pacific from the Beijing conference, Bioneers celebrated their 20th year with keynote speakers sharing their recent exploits using Digital Earth methodologies. Bioneers is a diverse community of scientists, philosophers, socially responsible business leaders, community leaders, and caring Earth stewards whose ranks are growing into the tens of thousands. Topics of discussion exchanged at this year's annual conference ranged from toxic chemicals in infants' blood to green job entrepreneurs, from fair trade economics to socially responsible corporate leadership, and from Amazonia natives using Google

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◀ **FIGURE 1.** *Chief Almir of the Surui Amazon tribe. Courtesy of Google Earth. Photo credit: Denise Zmekhol, ZD Films.*

▲ **FIGURE 2.** *Rebecca Moore of Google Earth Outreach training Surui tribal leaders. Courtesy of Google Earth. Photo credit: Andrea Ribeiro.*

▲ **FIGURE 3.** *Two young Surui using a laptop. Photo credit: Fernando Bizerra, BG Press, courtesy of the Amazon Conservation Team, Brazil.*

Earth technology to creating sustainability maps for New Mexico's future.

One universal lesson carried over from the Apollo moon landings is to look at the Earth as a whole living ecosystem, one that is self-contained with critical life support systems. Digital Earth technology is enabling the Bioneers community to share this whole-world perspective through engaged field work and network partnerships.

Chief Almir Narayamoga Surui captivated the Bioneers community with a stunning story of his experiences in the western Brazilian state of Rondônia. His Surui Amazonian tribe has been combating aggressive loggers to protect the tribe's way of life and save remnant rain forests. Eleven tribal chiefs have recently been murdered there, allegedly by powerful loggers and miners usurping the Surui's land. Chief Almir, a 32-year-old tribal chief ***(Figure 1)***, organized his fellow chiefs to fight this destruction by conducting surveys on the history of the Amazon, and on the current situation and by leveraging an unusual partnership he forged with Google. He is using Google Earth's high-tech tools to help his Surui people visibly tell their story to protect their forest and culture.

Google Earth's Rebecca Moore, who helped train the Surui tribe leaders ***(Figure 2, 3)***, also spoke at Bioneers about using Google Earth's Outreach program to support nonprofits, communities and indigenous peoples around the world. Chief Almir and Ms. Moore convincingly validated applying Google's mapping tools to address the systemic problems of environmental conservation, human rights, and cultural preservation.

Remote sensing convincingly portrays the raw demarcation of land use development surrounding and encroaching on the pristine Amazon rain forest ***(Figure 4)***. Indigenous people are now using online mapping and Digital Earth technology (3D visualization tools such as Google Earth, Maps and SketchUp) to communicate across cultural bridges regarding the high stakes involved with Amazonian deforestation. Chief Almir believes that mapping tools and the GeoWeb can empower the Surui and other tribes to "take control of their own destiny" and improve their chances of survival.

Up north, New Mexico is also experiencing a self-governance experiment called Dreaming New Mexico. This project is boldly mapping the sustainability options for New Mexico's citizens "to imagine a positive future for the people, the energy systems, land, waters and the future generations" ***(Figure 5)***. Co-led by Kenny Ausubel, Bioneers' founder, and Peter Warshall, this project is applying the same methodologies, and much the same remote sensing/Digital Earth technology, to focus the state's citizens and leaders on both practical and visionary solutions towards sustainability. The Dreaming New Mexico Initiative is an innovative program that uses best practices and social activists' networks to bring about positive ecological and social transformation at the local and regional level. Project leaders are leveraging Google Earth applications to communicate successfully these complex landscape-level challenges ***(Figure 6)***.

The second decade in the 21st Century should prove exciting. We have acknowledged the practicality of sustainability practices in the face of climate change. We are witnessing previously disenfranchised, indigenous people of the Amazon raise their voices and visible profile over the Internet to protect their very existence. Evidence is building on how communities in America, both north and south, can use Internet mapping technologies and methods to marshal support and redirect their futures. We will surely witness more wondrous and widespread applications of remote sensing and Digital Earth technology in this brave new world. We are witnessing the Digital Earth pioneers. «

▲ **FIGURE 4.** *Surui tribal lands denoted by the full forest canopy cover (courtesy of Google Earth).*

▲ **FIGURE 5.** *Dreaming New Mexico Futures map (courtesy of Bioneers).*

▲ **FIGURE 6.** *San Juan power plant, New Mexico (courtesy of Bioneers).*

For more information on these topics, please visit the following web sites.

http://earth.google.com/outreach/amazon3.html

www.amazonteam.org/

http://bioneers.org

www.dreamingnewmexico.org/

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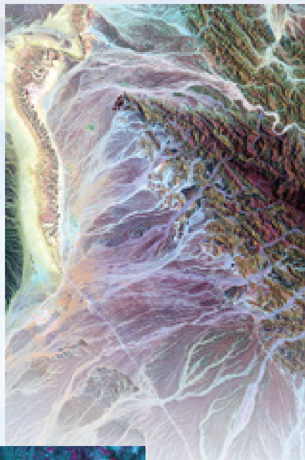
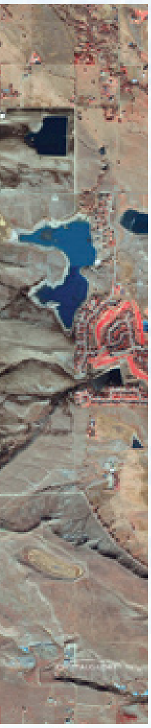
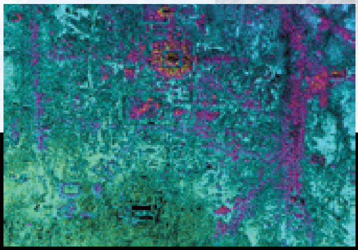


Exciting new remote sensing capabilities and commercial applications are developing around the world.

The United States Geospatial Intelligence Foundation (USGIF) and the Department of Commerce's (DOC) National Oceanic and Atmospheric Administration (NOAA) are partnering to bring international business and government leaders as well as academia together to explore the current issues facing this important community.

The 2010 International Commercial Remote Sensing Symposium affords attendees 2 ½ days of discussions on topics such as user community experiences, industry providers and capabilities, and policy concerns.





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- Benefits of commercial remote sensing to society, the global economy and academia
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Who Should Attend?

U.S. and International GEOINT Community stakeholders interested in networking with other commercial remote sensing professionals, learning about the current and future state of the industry, and discovering the diverse applications and uses of these powerful tools should not miss this event!

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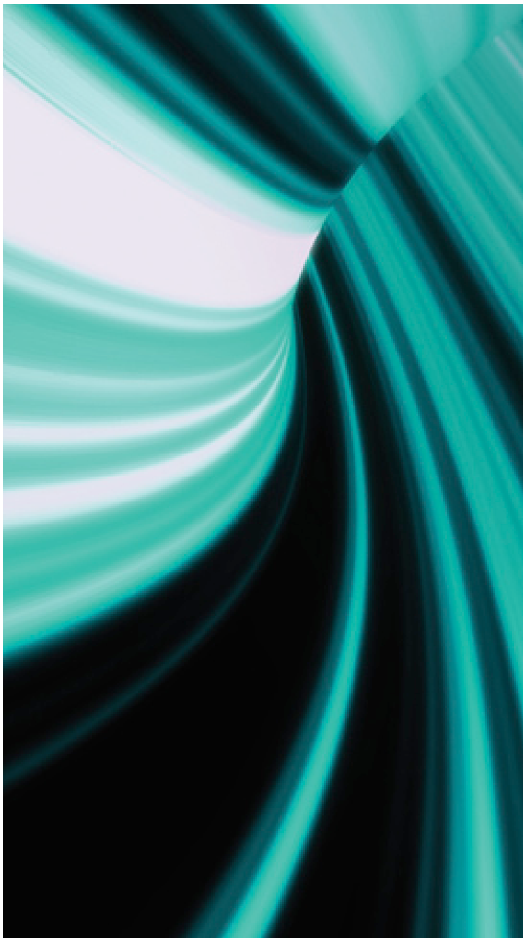
Data Velocity: The Race to Zero

THE SEEDS HAVE BEEN SOWN… AUGMENTED REALITY AND BEYOND

NEXT-GEN MAPPING *a column from LBxJournal.com*

The year 2009 was a remarkable year by any measure. Now that the world is sharing information in real time, the velocity of millions of bits of data is creating an environment that is challenging even the best thinkers on how to make sense of it all.

Clearly, instant communications and the ability to access any data, any time have also become expectations. Tweets, texts, IM, posts – they are all about instant reporting, whether stream of consciousness or an important piece of news, from tornado or earthquake damage to political manifestations to corporate activity (either good corporate citizen or corporate malfeasance).



As storage costs continue to drop and software development (or, more appropriately these days app development time) decreases (100,000 iPhone apps and counting!) the world appears to find itself in a "race to zero." What is this race to zero? It is a frictionless world, whereby not only the time but also the money once needed to accomplish seemingly complex tasks is grinding down to zero.

Have you noticed that the digital generation is churning out new apps on almost a daily basis? The founder of Digg said at the Enterprise 2.0 conference this past fall that "…if you can't turn out a prototype without outside investment, there's a problem." Companies like Nike that invested billions of dollars in expensive system integration projects are now turning to cheap consumer web tools for more effective global collaboration. Tom Friedman's book, *The World is Flat*, described the global IT infrastructure that ushered in the first level of "cloud" applications and massive cost savings potential. Friedman's work, Enterprise 2.0, and social networking applications such as Jive and Twitter, along with geospatial mashup platforms such as Google Earth, JackBe and others, have sown the seeds for any business, government, NGO, or individual to aggregate almost any piece of data needed to analyze almost anything – except possibly what makes sense.

CRAIG BACHMANN & NATASHA LÉGER are partners in ITF Advisors, LLC, an independent consulting firm with a focus on next-generation strategy and on translating the increasingly complex new media business environment's impact on business models, markets and users. Natasha is also editor of the new spin-off publication, *LBx Journal.*

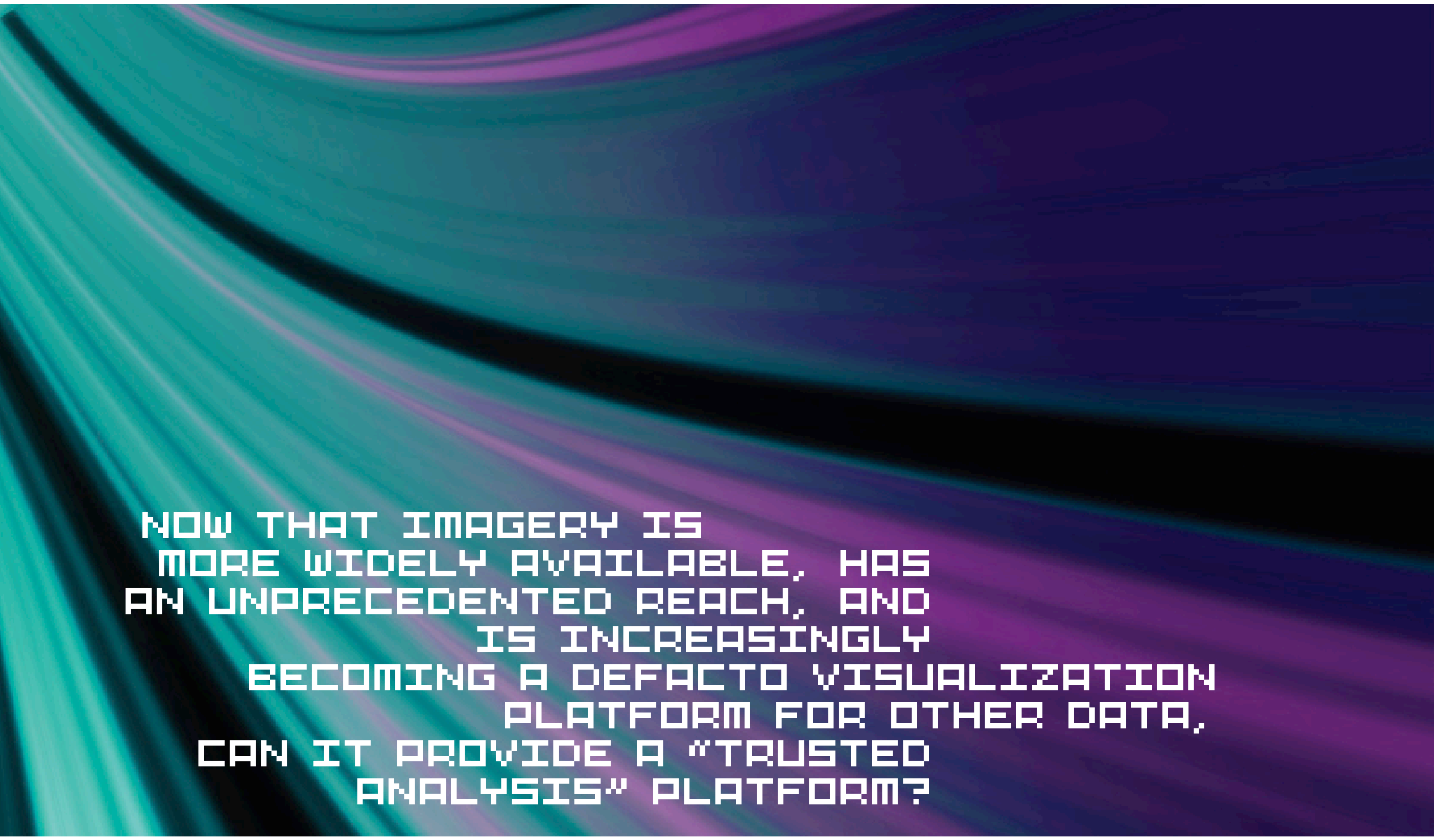
Why is technology grinding to zero?

The most influential of many factors have to do with Moore's law and with the advent of user-generated content and new web-based business models that are driven by advertising. With user-generated content, companies from Google to Waze to OpenStreetMap are benefiting from free labor, an advantage that gives the illusion of providing a "free" or "cheaper" product or service.

This race to zero has its pros and cons. One pro is the dissemination of real-time information that can save and improve lives. The cons are the destruction of jobs that keep the economy going and a lack of critical thinking on issues that require more time than a bullet on a PowerPoint, a 140-character tweet, and a 20-minute decision so that one can move on to the next task to hit that all-important KPI.

What comes after the "race to zero" when commodity-based tools are readily available through a simple drag and drop exercise? More importantly, how do today's providers of dumb pipes (think telephone company), dumb data (raw imagery), and dumb storage (a hard drive), add value and remain relevant in a world of new players?

For example, the iPhone has decoupled the phone company from the network service provider in the minds of the consumer, Google Earth has made imagery a backdrop, and cloud computing is turning hard drives and flash drives into clutter. Becoming a trusted platform is critical to creating value. With the iPhone, Apple monetized interactivity and an inte-



grated environment; Google monetized search and tied data to advertising, and Amazon has turned commodity storage into a cloud service.

Imagery offers a significant opportunity to provide a context for "real time" trusted analysis. The distribution of imagery (the data); the processing of imagery (the software); the integration of imagery (the implementation and workflow); and the visualization of imagery have all become relatively frictionless in the last few years with Internet distribution and with more cost-effective and easier-to-use software processing and feature extraction applications. Now that imagery is more widely available, has an unprecedented reach, and is increasingly becoming a defacto visualization platform for other data, can it provide a "trusted analysis" platform?

Augmented reality (AR) may offer such an opportunity, because it provides for the merging of a real-world environment with other data and imagery to create an enhanced, augmented, and more "intelligent" view of the original environment. This concept was highlighted in the James Bond film, *Quantum of Solace*.

The ability to access multiple databases of information that connect the dots in real time between seemingly disparate data points, and thus to paint a virtual canvas of insights, is the future of data velocity. We hope to see in 2010 the further integration of satellite imagery into such frontiers as AR. The notion of "connecting the dots – real time" is a reality in itself. «

FORESTS OF THE SEA

GLOBAL DISTRIBUTIONS AND DYNAMICS OF MANGROVES

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http://lca.usgs.gov/lca/globalmangrove/index.php

FIVE YEARS AFTER THE DEVASTATING Asian tsunami of December 2004, researchers and practitioners are still wondering if mangrove forests played any role in saving lives and property. A majority of studies on the question provided evidence that a high-density mangrove forest better attenuates tsunami waves than a low-density forest and highlighted the need for better information on the status and conditions of mangrove forests. Information on the extent, spatial configuration, density, height, and species composition were deemed essential. At the same time, funding agencies, governments, and non-governmental organizations (NGOs) were looking for potential areas to rehabilitate mangroves. In this context, USGS/EROS, with support from USGS Director's Venture Capital Fund, started this project to study the distribution and dynamics of mangrove forests in the tsunami-impacted region of Asia. (See ***Figure 1***.)

The tsunami-impacted region consists of coastal areas of Indonesia, Malaysia, Thailand, Myanmar, Bangladesh, India, and Sri Lanka. The region comprises ~10% of the total mangrove forests of the world, including the largest remaining contiguous tract of mangrove forests, the Sundarbans in Bangladesh and India. Strong demographic pressure and diverse climatic conditions have created a mosaic of mangrove diversity in this region, which is undergoing constant changes. In fact, the Asia Pacific region is the epicenter of mangrove biodiversity and consists of many existing and planned national parks, biosphere reserves, and world heritage sites.

The objective of the USGS study was to determine the rate, causes, and distribution of mangrove forests using multi-temporal Landsat data and field observations. Analysis explored simple research questions such

▲ **FIGURE 1a.** *Mangroves in Sri Lanka*

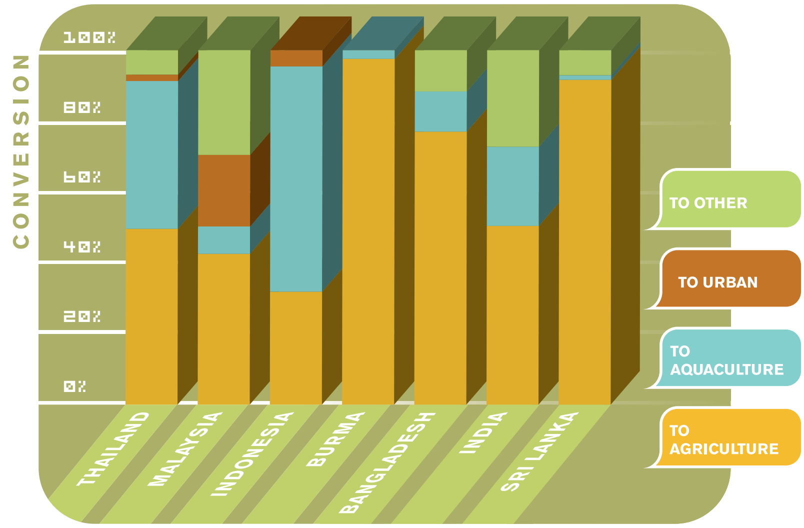
◀ **FIGURE 1b.** *Mangrove forests destroyed during Asian Tsunami of 2004, Southern Thailand.*

as how much mangrove forest remains, where is it located, what is the spatial and temporal rate of change, and what are the main reasons for the change? More importantly, the study identified potential areas for rehabilitation and regeneration.

We interpreted Landsat MSS, TM, and ETM+ satellite data using hybrid supervised and unsupervised digital image classification techniques. Geometric correction was performed to improve the geo-location to ± ½ pixels needed for the change analysis. Each image was normalized for variation in solar angle and Earth-sun distance by converting the digital number values to the top of the atmosphere reflectance. Ground truth data and existing maps and databases were used to select training samples and also for iterative labeling. Change analysis was performed using post-classification approach.

Our analyses show that the region lost 12% mangrove forests from 1975 to 2005 to its present extent of ~1,670,000 hectares (ha.). This rate is much less than earlier estimates. As expected, the rate of deforestation varied in both spatial and temporal domains. Burma experienced the highest rate of annual deforestation (1%) and the highest regional rate of deforestation occurred during 1990-2000. Major factors responsible for regional deforestation were agricultural expansion (81%), shrimp farming (12%), urban development (2%), and other factors (5%) (See ***Figure 2***.) This finding is contrary to the widespread belief that shrimp farming is the primary cause of deforestation.

The deforestation rate varied during observation periods. The annual rate of deforestation from 1975-2005 was highest



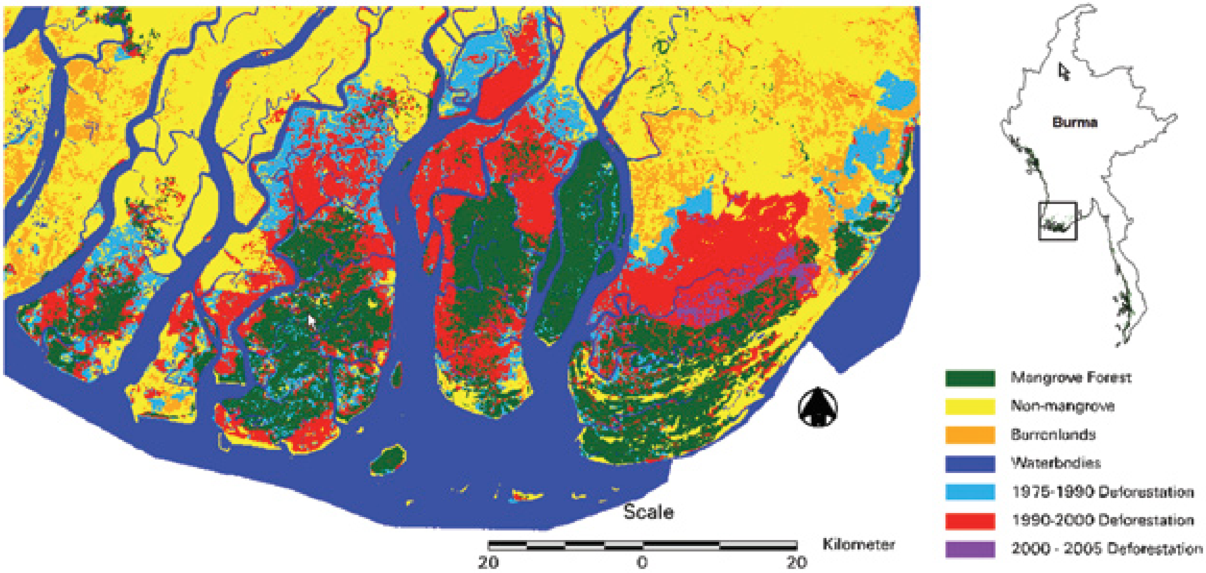
(~1%) in Burma (see ***Figure 3***) compared to Thailand (-0.73%), Indonesia (-0.33%), Malaysia (-0.2%), and Sri Lanka (-0.08%). In contrast, mangrove forests in Bangladesh (+0.14%) and India (+0.04%) remained essentially unchanged or slightly expanded during this period. The increase in mangrove area that we found in India is consistent with reports from the Forest Survey of India, which stated that mangrove forest cover has increased or remained unchanged since 1995. However, almost all the mangrove areas in India are severely degraded, with reduced or negligible vegetation cover. Bangladesh has started ambitious mangrove rehabilitation programs, and mangrove forest areas have also increased by aggradation. The reforestation programs in both India and Bangladesh were initiated by the government and local communities.

At the local level, both deforestation and forest regeneration occurred with varying intensities, with localized hotspots of rapid change. We identified the major deforestation fronts that are located in the Ayeyarwady Delta, and in the Rakhine and Tahinthayi provinces of Burma; Sweetenham and Bagan in Malaysia; Belawan, Pangkalanbrandan, and Langsa in Indonesia; and Southern Krabi and Ranong in Thailand. Major reforestation and afforestation areas are located on the southeastern coast of Bangladesh, and in Pichavaram, Devi Mouth, and Godavari in India.

Our spatio-temporal analysis shows that, despite having the highest population density in the world in its periphery, areal extent of the mangrove forest of the Sundarbans (see ***Figure 4***) has not changed significantly (approximately 1.2%) in the last 25 years. However, the forest is constantly changing due to erosion, aggradation, deforestation and mangrove rehabilitation programs. The net forest area was increased by 1.4% from the 1970s to 1990 and was decreased by 2.5% from 1990 to 2000. The change is insignificant in the context of classification errors and in the dynamic nature of mangrove forests.

The strong commitment of governments under various protection measures such as forest reserves, wildlife sanctuaries, national parks, and international designations, is believed to be responsible for keeping this forest relatively intact (at least in terms of area). This lack of significant loss in terms of area is an excellent example of the co-existence of

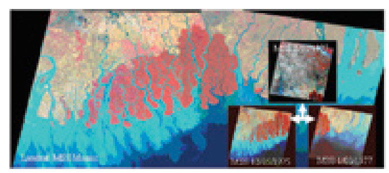
It is estimated that the forests, including associated soils, can sequester approximately 22.8 million metric tons of carbon each year.



◀ **FIGURE 2.** *Major causes of mangrove deforestation by country (Giri et al. 2007).*

▲ **FIGURE 3.** *Spatial distribution of mangrove deforestation in Ayeyarwady Delta, Burma, from 1975-1990, 1990-2000, and 2000-2005.*

▶ **FIGURE 4.** *Landsat mosaic of Sundarbans. Mangrove is easy to classify because of its distinct signature and high contrast with its surroundings.*



humans with terrestrial and aquatic plant and animal life. While the measured net loss of mangrove forest is not high, the change matrix shows that turnover was much greater than net change, and the forest is under threat from natural and anthropogenic forces leading to forest degradation, primarily due to top-dying and overexploitation of forest resources.

Lessons learned from this study proved useful enough to expand the study at the global scale. NASA's Land Cover and Land Use Change Program and the U.N. Environment Programme supported the global study with the following research questions:

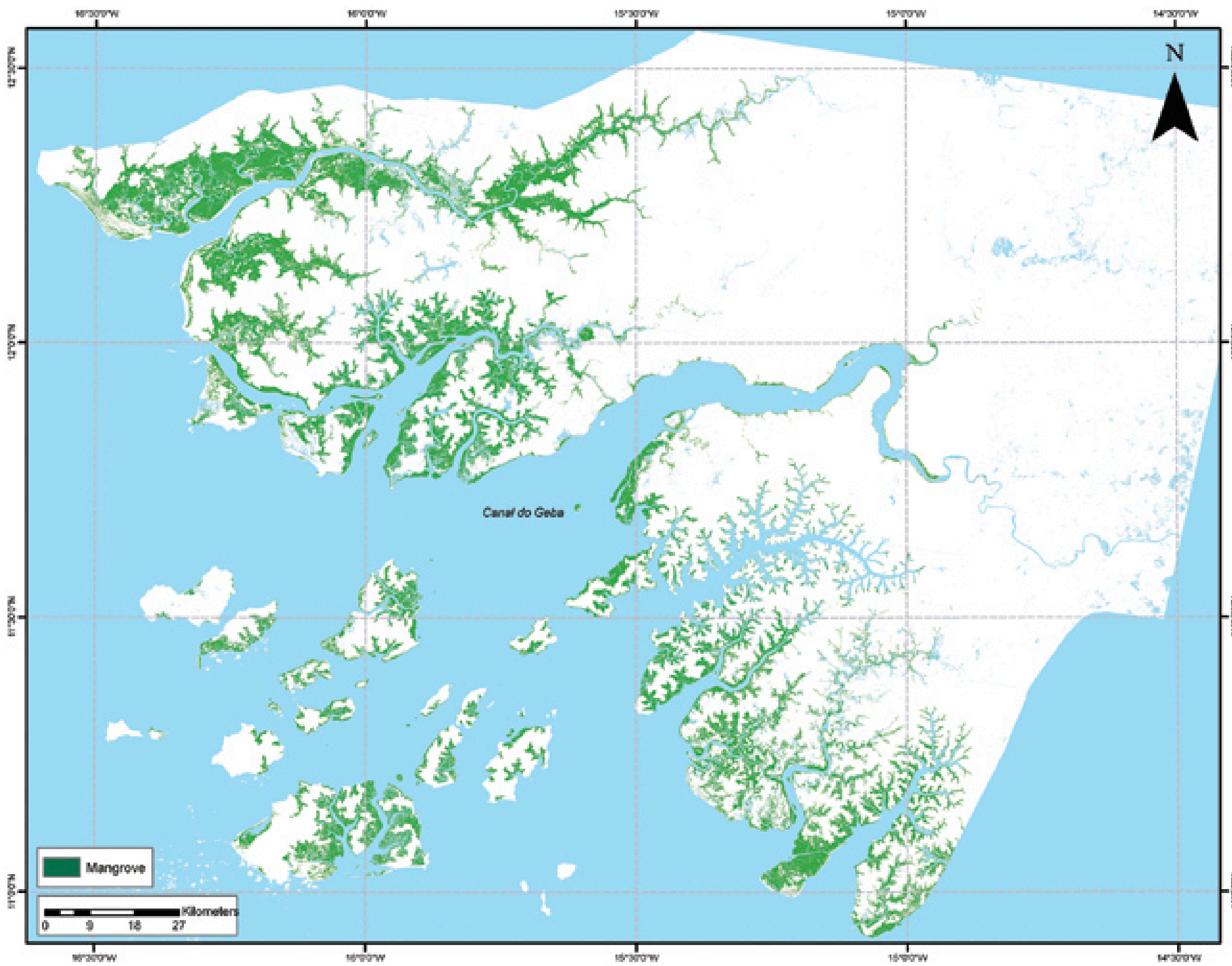
1. **How can we use historical and current satellite data and state-of-the-art image processing and geospatial modeling tools and methods to characterize mangrove forest attributes and dynamics more effectively?**
2. **What is the present status of mangrove forests of the world and how have the extent and characteristics of mangrove forests changed in the last 15 years?**
3. **What are the causes and environmental and socio-economic consequences of mangrove deforestation?**

The global study is important because current estimates of mangrove forests of the world range from 110,000 to 240,000 km^2. It is believed that the present extent of the forest is less than half of what it once was, and much of what remains is in degraded condition. The forests continue to decline due to conversion to agriculture, aquaculture, tourism, and urban development. About 35% of mangroves have been lost over the last two decades alone, and the forests have been declining at a faster rate than inland tropical forests and coral reefs. Predictions suggest that 30-40% of coastal wetlands and 100% of mangrove forests could be lost in the next 100 years if the present rate of loss continues. As a consequence, important ecosystem goods and services (e.g. natural barrier, carbon sequestration, biodiversity) provided by mangrove forests will be diminished or lost.

Mangrove forests are among the most productive and biologically important ecosystems of the world. The forests help in stabilizing shorelines and in reducing the devastating impact of natural disasters such as tsunamis and hurricanes. They also provide breeding and nursing grounds for marine and pelagic species, and food, medicine, fuel, and building materials for local communities. It is estimated that the forests, including associated soils, can sequester approximately 22.8 million metric tons of carbon each year. Covering only 0.1% of the continent's surface, the forests account for 11% of the total input of terrestrial carbon into the ocean, and 10% of the terrestrial dissolved organic carbon (DOC) exported to the ocean.

Global Mangroves Forest Map

We have been using recently available Global Land Survey (GLS) Landsat data of 2000 to prepare the first wall-to-wall map of the mangrove forests of



the world. The GLS is a global dataset of Landsat 30-m resolution satellite imagery prepared in a partnership between USGS and NASA in support of the U.S. Climate Change Science Program (CCSP), Group on Earth Observations (GEO), and the NASA LCLUC Program. These data are freely available from http://glovis.usgs.gov. Without GLS data, this study would not have been possible, because for a single researcher it is extremely difficult and expensive to process thousands of Landsat data for the tropical and sub-tropical regions of the world where persistent cloud cover is an issue.

We have been interpreting ~1,000 Landsat scenes using a hybrid supervised and unsupervised digital image classification technique. The GLS 2000 data were collected between 1997 and 2000. The multi-satellite, multi-year and multi-seasonal data used in our study are typical of global and continental land use and land cover change studies. It is unrealistic to obtain a global coverage of Landsat data of the same season or year.

Geometric correction was performed to improve the geo-location to Root Mean Square error of ± ½ pixels needed for subsequent change analysis. Each image was normalized for variation in solar angle and Earth-sun distance by converting the digital number values to the top of the atmosphere reflectance. Ground truth data and existing maps and databases were used to select training samples and also for iterative labeling. Results validation was performed using existing GIS data and published literature.

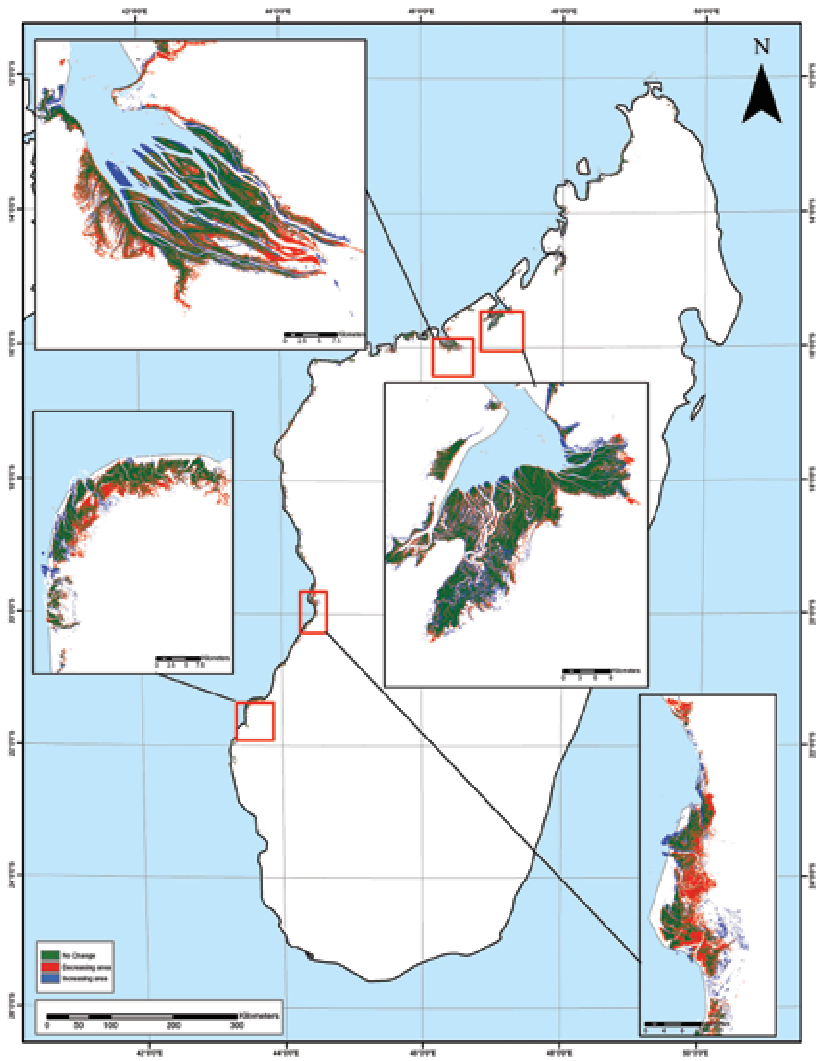
We have been mapping "true mangroves" defined as trees, shrubs, and palms that exclusively grow in the tidal and inter-tidal zones of the tropical and sub-tropical regions of the world. The minimum mapping unit used in this study will be .08 ha. (See ***Figure 5***.)

Madagascar Map

Besides preparing a wall-to-wall map of the globe, we are also performing in-depth analysis for some countries, including Madagascar. The mangrove forests of Madagascar are declining, albeit at a much slower rate than the global average. The forests are declining – logging activities, over-exploitation, clear cutting, degradation, and conversion to other land uses all are occurring at the expense of the forests. However, accurate and reliable information on their present distribution, and their rates, causes and consequences of change is not

◀ **FIGURE 5.** *Mangrove forest distribution map of Guinea Bissau in 2007.*

▶ **FIGURE 6.** *Mangrove forest changes of Madagascar from 1990 to 2005 from Landsat.*



available. Earlier studies used remotely sensed data to map and, in some cases, to monitor mangrove forests at a local scale. Nonetheless, a comprehensive national assessment and synthesis was lacking.

We interpreted time-series Landsat data of 1975, 1990, 2000, and 2005 using a hybrid supervised and unsupervised classification approach. Landsat data were geometrically corrected to an accuracy of +/- 0.5 pixel, an accuracy necessary for change analysis. We used a post-classification change detection approach (see ***Figure 6***).

Our results showed that Madagascar lost 7% of mangrove forests from 1975 to 2005, to a present extent of ~2,797 ha. Deforestation rates and causes varied both spatially and temporally. The forests increased by 5.6% (212 square kilometers) from 1975 to 1990, decreased by 14.3% (455 square kilometers) from 1990 to 2000, and decreased by 2.6% (73 square kilometers) from 2000 to 2005. Similarly, major changes occurred in Bombekota Bay, Mahajamba Bay, Coast of Ambanja, Tsiribihina River, and Cap St. Vincent. Main factors responsible for mangrove deforestation include conversion to agriculture (35%), logging (16%), conversion to aquaculture (3%), and urban development (1%).

Our preliminary findings suggest that the moderate resolution satellite data such as Landsat contain enough detail to capture mangrove forest distribution and dynamics. However, very small patches (<900 square meters) of mangrove forests found along the coast and canals will not be identified from this data. High-resolution satellite data (e.g. IKONOS, QuickBird) or aerial photographs are needed to assess and monitor those areas. However, those very small areas will not make a big difference in the global total. We will incorporate the missing information from available GIS and statistical data. Availability of pre-processed and free data such as GLS is critical to generate important information needed for resource conservation and planning. The methodology developed and the resulting database provide guidance for regional and global efforts to allocate conservation resources, to perform carbon accounting, to implement ecosystem-based management, and to inform mangrove spatial planning, education, and basic research. ≪

SOURCES:

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At the tipping point

HOW DIGITALGLOBE'S LATEST SATELLITE LAUNCH IS BREAKING DOWN BARRIERS

A DECADE AGO, THE WORLD WATCHED WITH AMAZEMENT AS THE FIRST COMMERCIAL high-resolution satellite launched. The launch promised to open up the world – and its governments, businesses, organizations, and individuals – to a whole new "view" of the earth, enabling new technologies and offering a new level of insight into our surroundings. In the ten years since that launch, the industry has delivered on that promise, showcasing just what is possible with satellite imagery. We have learned that satellite imagery is a game-changing innovation that can provide value unknown before its advent, value beyond that of words and numbers, ultimately changing the way we make decisions.

▲ **FIGURE 1, RIYADH, SAUDI ARABIA.** *This WorldView-2 satellite image of the King Fahd International Stadium in Riyadh, Saudi Arabia. The stadium's roof is the largest stadium cover in the world, shading over 65,000 seats, large enough to fit the Astrodome inside. The stadium was completed in 1986 at a cost of $80 million. The image was collected on Oct. 21, 2009.*

BY CHUCK HERRING
Director of Marketing
DigitalGlobe
Longmont, Colo.

Today, following the October launch of WorldView-2, DigitalGlobe's latest high-resolution satellite, the industry sits at a tipping point. No longer is it a question of whether an image is available or whether it is current. High-resolution, accurate, and current imagery is available in larger quantities than ever before. But being able to access imagery is no longer enough; now, unlocking the true value of the imagery so that it can tell a meaningful, relevant story has become the driver that is pushing imagery beyond its bounds.

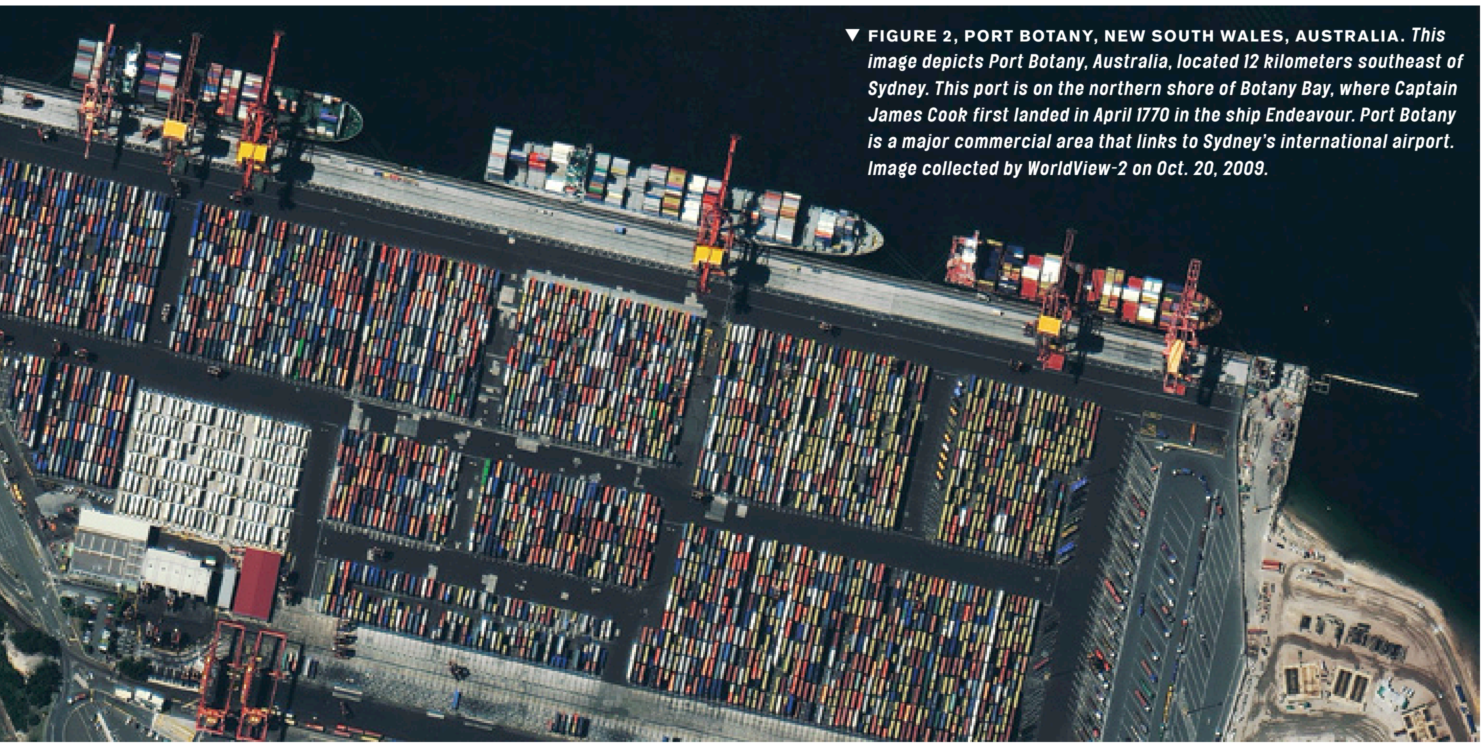
WorldView-2: In a Class of its Own

On October 8, 2009, WorldView-2 joined its sister satellites, WorldView-1 and QuickBird, in orbit. Ninety days later, on January 4, 2010, WorldView-2 achieved full operational capability – right on schedule. On its own, WorldView-2 is a feat of innovation, offering a unique combination of large collection capacity, high spatial resolution and 8-band spectral diversity.

WorldView-2's large-area collection capabilities and rapid retargeting are two important pieces to the puzzle. WorldView-2's immense collection capacity and near daily revisit capabilities offer an improved assurance in the availability of current, relevant imagery. Enabled by the combination of the satellite's 770-km orbiting altitude, its state-of-the-art Control Moment Gyroscopes (CMGs) and bi-directional push-broom sensors, WorldView-2's enhanced agility and bi-directional scanning allows for the collection of over 10,000 sq km in a single overhead pass, plus efficient in-track stereo collections of over 5,000 sq km.

Collection capacity, of course, is only as good as the imagery collected. Panchromatic resolution is 46 cm. (Distribution and use of imagery at better than .50 m GSD pan and 2.0 m GSD multispectral is subject to prior approval by the U.S. Government.) WorldView-2's advanced geopositional technology provides significant improvements in accuracy as well. The accuracy specification has been tightened to 6.5m CE90 right off the satellite, meaning no processing, no elevation model and no ground control, and measured accuracy is expected to be approximately 4m CE90. (CE90 is "circular error of 90%," which is the minimum diameter of the horizontal circle that can be centered on all photo-identifiable Ground Control Points (GCPs) and images that are CE90 also contain 90% of their respective twin counterparts acquired in an independent geodetic survey.)

As the first high-resolution commercial satellite to provide eight spectral bands, WorldView-2 offers imagery with a high degree of detail, unlocking a finer level of analytical discernment that enables improved decision-making. In addition to industry-standard blue, green, red and near-infrared, World-View-2 includes four previously unavailable bands, collected at 1.8 meter resolution: coastal blue, yellow, red edge and near-infrared 2. These bands offer a range of benefits to analysts, who will be able to identify broader ranges of classification, (e.g., more varieties of vegetation or water penetrated objects), to extract more features (e.g., cotton-based camouflage from natural ground cover), to view a truer representation of colors that match to natural human vision, and to track coastal changes and infractions.



▼ **FIGURE 2, PORT BOTANY, NEW SOUTH WALES, AUSTRALIA.** *This image depicts Port Botany, Australia, located 12 kilometers southeast of Sydney. This port is on the northern shore of Botany Bay, where Captain James Cook first landed in April 1770 in the ship Endeavour. Port Botany is a major commercial area that links to Sydney's international airport. Image collected by WorldView-2 on Oct. 20, 2009.*

WorldView-2 includes four previously unavailable bands, collected at 1.8 meter resolution: coastal blue, yellow, red edge and near-infrared 2.

▶ **FIGURE 3, ABU DHABI, UAE.** *This WorldView-2 satellite image depicts the north part of the city of Abu Dhabi, UAE. It is the capital and second largest city of the United Arab Emirates, which has been experiencing rapid growth and urbanization. The image was collected on Oct. 29, 2009.*

Joining The Constellation

Of course this isn't a story of a lone satellite orbiting the earth. When it launched, WorldView-2 joined two additional high-resolution satellites from DigitalGlobe, WorldView-1 and QuickBird. With its high collection capacity, WorldView-2's launch doubled DigitalGlobe's collection capacity and offered intraday revisit. With an ImageLibrary that already houses more than 815 million sq km of imagery (as of December 2009), the new capacity of the constellation will allow DigitalGlobe to map the entire globe at least once each year, in essence eliminating the question of whether or not a timely, relevant image is available.

Unlocking A New World View

As imagery becomes ubiquitous, more and more industries have discovered the value it can offer. Today, imagery drives decision-making across a wide range of situations. Warfighters rely on current imagery to illuminate safe routes in dangerous areas. Relief workers turn to imagery to view the impact of natural disasters. Scientists look to imagery to understand the extent of coastal erosion. Travelers rely on imagery to navigate a foreign city. In each of these cases, the value is not the imagery on its own, but the information that it can provide that makes the difference. Thus, while access to current, accurate imagery is important, equally important is how it is accessed and used.

Until recently, unlocking the value of imagery has proven both complex and time consuming. Imagery is still too much in its infancy to have addressed standard formats, and thus, each user has been dependent on expert analysts to process and format any imagery to the specific requirements of any given situation. DigitalGlobe is working to make imagery more consumable – removing the barriers to entry as it offers imagery faster, better, and more easily.

We live in a world where time is the new currency, whether you are that warfighter making life and death decisions or

▶ **FIGURE 4, BANGKOK, THAILAND.** *The "Mega Bridge" in Bangkok crosses the Chao Phraya River with two striking cable-stayed spans supported by diamond shaped pylons. The bridge opened in 2006 as part of the Bangkok Industrial Ring Road to solve traffic problems around Bangkok. This WorldView-2 image was collected on Oct. 30, 2009.*

that traveler in a new city simply trying to get to a meeting on time. Our society dictates speed; waiting days or weeks for intelligence is no longer an option.

We have established that the imagery is available – but how quickly can it be accessed and does it become usable? DigitalGlobe has developed a series of web services that eliminates the need for in-house processing expertise, reduces costly storage requirements, and allows users to embed imagery directly into geospatial applications. Through this platform, customers can search for imagery, access imagery in a range of compressed and uncompressed formats that can be integrated into geospatial applications, and integrate imagery with additional data. Anyone can be an expert, opening the doors of imagery to a whole new group of users.

DigitalGlobe has used its web services to provide valuable services that address the timeliness of data. Through the "Rapid Delivery of Online Geospatial-Intelligence" (RDOG) program, DigitalGlobe is providing the National Geospatial-Intelligence Agency (NGA) with unclassified imagery-derived products and services for its imagery and map-based intelligence solutions aimed at the U.S. national defense, homeland security and safety of navigation.

Let's return to that warfighter looking for safe routes for his convoy. What if that warfighter were able to get current imagery immediately rather than waiting days, if not weeks, or rather than relying on out-of-date imagery? It could mean significant time – or even lives – saved.

Enabling near real-time access to daily image collections, DigitalGlobe's Web services offer rapid dissemination of the latest NextView-licensed imagery of specified areas to the National System for GEOINT (NSG) within 24 hours of collection. In addition to delivering commercial imagery via web mapping services (WMS), DigitalGlobe also provides a nearly cloud-free foundation layer of tonally balanced, country-wide, one-degree geo-cells on a new quarterly collection schedule.

Looking Ahead

With more to view than ever before, imagery is the here and now, shifting the way we live and work, informing our decisions and offering new insight into all that we do. Importantly, advancements and innovation in how we use imagery have changed the economics in a way that makes imagery accessible to a wider audience achieving a significant range of results. We are indeed at a tipping point.

STATE of the WORLD FORUM

2020 CLIMATE LEADERSHIP CAMPAIGN

FEBRUARY 28 - MARCH 3, 2010
WASHINGTON DC HILTON HOTEL

Global warming has reached a crisis point. If unaddressed, rising global temperatures will trigger dramatic increases in extreme weather events and cause the oceans to rise, threatening all coastal cities, displacing hundreds of millions of people, and destroying thousands of species. At the very most, we have about ten years to act before natural forces spin out of any human capacity to control events.

Make no mistake: this will impact you and *certainly* all of our children.

The State of the World Forum and a growing coalition of groups worldwide are coming together to develop a ten year plan to green the world. We must move beyond rhetoric to action.

The urgency of global warming mandates that each and every one of us become *climate leaders.* For the first time in our lives, indeed for the first time in history, all of us must take responsibility for our climate, whether at the individual, community, company, institution, state, or national level. We are all responsible for global warming. We must all share in the leadership required to solve it, for nothing less than the fate of human civilization is at stake. The crisis is that stark, the choice is that clear, the leadership required is that urgent.

This may be the most important campaign in which you have ever participated.
Your future and the fate of our civilization is at stake.

Please join us. Every person counts.

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STATE of the WORLD FORUM

Executive Interview: Eric Barron Director of NCAR

CLIMATE MODELING FOR GREATER GOOD

RECENTLY, *IMAGING NOTES* REPORTER KAREN NOZIK CAUGHT UP WITH ERIC Barron, who took the helm as Director of the National Center for Atmospheric Research (NCAR) in July 2008. NCAR was established in 1960 to support research on atmospheric, ocean and Earth science, and to study the impacts of climate and weather. It is a scientific research lab sponsored by the National Science Foundation. This represents a full circle for Barron, whose early career in climate studies began with a Cray Supercomputing Fellowship at NCAR in 1976.

IMAGING NOTES Would you talk about using Earth remote sensing in unique and novel ways? How do geospatial technologies fit into NCAR?

BARRON They fit in extraordinarily diverse ways. For example, satellite data are absolutely critical to validate the predictive models that we produce. If you are going to develop a climate model to predict decades into the future, you really better make sure that you do a good job of predicting the present day. We have an abundance of surface measurements, but they don't cover the entire planet, and they certainly don't cover the vertical structure of the atmosphere.

NCAR also probably produces the most advanced weather forecast models in the world. And one of the things that make weather forecast models good is their ability to simulate the current state of the atmosphere. Because basically what these models are doing is sitting there with a particular condition, a pressure temperature that defines the next step in the motion of the atmosphere. So the better you are at having the current structure of the atmosphere, the better you're able to calculate the next step based on the equations that define the atmosphere. We call this a simulation. So your ability to simulate data is a critical factor in your ability to make a good weather forecast.

The satellite information is a critical element, and of course, attribution of the degree to which the planet is changing, how it's changing, and what is causing it to change, are also data-critical elements of our program. It's hard to find parts of NCAR for which remote sensing and geospatial technologies aren't significant.

IMAGING NOTES Are there enough technically trained people to be able to utilize the data and to design the models?

BARRON I would say we're much more budget-constrained than talent-constrained. Most of our dollars come directly from the federal government to support NCAR's mission, and a substantial amount comes from federal grants and contracts that are based on proposed ideas. That limits the number of people that we can hire.

We do have an advantage that makes us successful on the talent side of things. We have 73 partner universities with whom we have tremendous collaboration. Eighty-five percent of the proposals that we write have a university collaboration in one fashion or another. NCAR is part of an enormous talent pool that contains a very significant number of people.

IMAGING NOTES Are universities doing enough to get people up to speed in areas that you need them to be?

BARRON Universities have trouble contributing to the workforce in large-scale models and in observational systems, because those are large expensive enterprises that require a significant number of years to accomplish. For instance, if you were going to look at NASA awards and instrument development, I suspect there are fewer universities that are capable of playing in that game today than there used to be, because to work on a mission may require, from beginning to end, a decade of effort. And then it stops. How do you maintain that faculty and workforce within a university environment?

There's a scale issue there in that, if you're large enough, you can maintain. But a lot of universities are just not in that game anymore. If you're not in that game, how do you train students? You know, there are a lot of people who say that your career can be made or not made just on whether you actually get an

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Photographs by Karen Nozik

> We have people out there who are working on the problems (of climate change), but there's been almost no investment in making those connections to solve problems.

instrument launched in your career. This is challenging for a university environment, and as a consequence we're probably not developing the talent pool that we'd really like.


ERIC BARRON

IMAGING NOTES How does NCAR plan to align itself with national needs in global climate change?

BARRON The most fundamental contribution that we will provide is advancing our capability to produce and develop climate models and to use them for various applications. The knowledge that is powerful to a society is an ability to anticipate what's going to happen next. It's that ability to anticipate, to forecast, to predict. If you can anticipate, you can take advantage of it, either to work on environmental stewardship, to do something economic, or to help protect life and property.

In terms of focusing on societal needs, that's just one of the elements we use our models for. When it comes to things like the International Climate Change Assessments, no institution in this country provides more information than NCAR.

The second thing is that, increasingly, society is recognizing that we're going to make decisions about climate change. There is interest in adaptation, because there's increasing evidence that we're incapable of stopping global warming. We can slow it down, we can make it not as large, but we've already stepped into it, and we've gone far enough down the road where we're going to experience significant changes. We're going to have to adapt.

Decisions about climate change will require much higher resolution models, because people are making decisions on a regional level. It's a city, a particular business in a state, or a water resource manager who's making up his mind. If you talk to people, they will tell you that one of the most important things they need is very high-resolution regional climate models.

NCAR is one of the few institutions in the world that's capable of developing models like that, because we have a weather forecasting community and a climate modeling community in the same institution. You need them both in order to be able to do things like simulate how stormy it might be or what the hurricanes might be like in the future. This is an area of significant emphasis within this institution – to try and take that next step with our models that will enable society to use the information.

The third thing is that discussions about how vulnerable society will be to climate change involve how you cross climate with human health or with hydrology or with agriculture. Some people have the sense that institutions like NCAR have to be more "whole earth."

But it's impossible to grow an institution that can tackle all those different problems, especially when you're called the National Center for Atmospheric Research, and your funding comes from the Atmospheric Sciences Program in the National Science Foundation.

Should we hire health experts using dollars from the Atmospheric Sciences Program at the National Science Foundation? It's not part of what the foundation does. And our community of 73 universities is not expecting us to spend in this way. There are a lot of important problems to solve and things to accomplish in the atmospheric sciences without trying to do everything.

Our attitude is that we should make a good partner. We have the climate and weather expertise, and we can interface with the health community and with the hydrology community, and let those existing communities take on the value that we bring, because we have fifty years of experience in climate modeling. We've been developing programs to partner with CDC and to partner with the hydrology community, and this is a new area of emphasis for NCAR.

Another element is how we can enable people to make good decisions. The nation has a national weather service that puts out its weather forecasts, and everybody under the sun uses it. Private companies look at the model results and tailor them to a particular need – a farmer, or a hotel, for instance – and offer a weather forecast for any agricultural area or any hotel in the country.

Currently there is no equivalent prediction for climate – there's no place to go for climate information that one can know comes from some authoritative place. It doesn't exist. So one of the other things that is going to have to happen if you're going to enable private enterprise or enable decision-makers, is to be able to make sure that the information is out there in an authoritative enough way that you could go to a place, find it, and know these were all the models developed in the United States that predict climate, and here's what they say. And here's the range, here's the uncertainty, here's the probability of this happening, here are the assumptions that went into this, so somebody can make decisions.

▲ *A model of NCAR's facilities in the foothills of Boulder, Colo.*

We think that we have a role to play there, because one of the chief bits of information is a climate model output, and one of the chief developers of that output is NCAR and our community partners. So that's another area for which we see ourselves serving society. We just don't know what our role will be yet, because the Feds also have to decide what their role is if they're going to enable it to happen.

IMAGING NOTES On climate change, the conversation seems to have shifted from, "maybe it's happening," to, "it's a given that climate change is happening." Do you agree?

BARRON Yes, a lot of people out there feel like the wraps have come off. Just a short time ago, it wasn't something you really talked about, and now everybody is talking about it. It's really quite fascinating that it has become such an open debate.

I think in the previous decade the topic was, "Well, we're not going to contemplate any changes because this is uncertain. So you reduce the uncertainties." And yet, at that sort of granularity, it was very clear that we were going to end up with certainty with significant warming, but it didn't seem to matter. The research dollars, the focus, the topics of discussion were about reducing uncertainties. That has switched to, "We know we have a problem, now what are we going to do about it?" Of course, you hope the research doesn't get lost in between. We

If you talk to people, they will tell you that one of the most important things they need is very high-resolution regional climate models.

know enough to make some decisions, but we don't know enough to really be helpful to society in solving some of the problems.

IMAGING NOTES Could you speak to that a little more, in terms of what tools you wish you had at your disposal?

BARRON You need to have this climate service. You need to have the information available to people in an understandable and accessible credible format; otherwise it's going to be very hard for people to do things differently.

There's a whole group of sciences out there that connect to climate: ecosystems, health, and water, for example. We have not focused on that intersection between climate and health in order to be able to say, "This is what's going to happen to mosquitoes, this is what's going to happen to infectious diseases, this is what's going to be the real impact of heat waves." We need to be able to discuss the impacts of change on air quality, and then of air quality on human health.

We've gone for a very long period not making those connections. We have people out there who are working on the problems, but there's been almost no investment in making those connections to solve problems.

Many of the problems that people focus on and decisions that are going to be made are regional. When they're regional, climate isn't the only thing that's happening. Climate is coupled with how people are using the land, with what pollutants are added into the systems of water and air, and with all sorts of management decisions that are local. We have to get to the point where we combine all of those. That means that we have to take a very different or surprisingly global look at this topic of climate change, and there is this strong suggestion that you have to regionalize it.

You need the global perspective because the atmosphere is connected. But you're going to have to bring it down to the local regional planning level, which changes the type of models that you have. This regionalization, this localization, implies very different science strategies.

IMAGING NOTES Going forward, is it NCAR's job to get ahead of the curve?

BARRON That's the whole idea. What predictive capacity can we bring to bear to solve society's problems? I see this as really exciting and interesting. We have a job of understanding fundamentally how this atmosphere and ocean system works. We turn that science knowledge into a predictive capability. That's what our mission is and our mandate is, plus to enable better observations and a whole host of other things. What we're talking about is partnering with other people so that our skill set and our discipline of forecasting can be translated to other fields and become useful.

Air quality is quite natural, because we have a weather forecasting group, an atmospheric chemistry group, and a group that is interested in the urban environment. These things work together naturally. Others, with aspects of human health, are not NCAR's strength. We have an interest, but we need to have more partners.

I'll give you two examples of predictive capability in human health. Have you ever heard of anyone doing a prediction for Lyme disease? Well, right now, we know that warm days and little snow cover in the northeastern United States in the fall predicts what Lyme disease will be like a year later, because of what weather does to the tick population and to the host population. And in Africa, meningitis along the drought belt ends with the rainy season. Whatever is going on there is probably being transported by wind, or associated with dust, or perhaps the dry conditions and dusty conditions are enabling meningitis.

Can we get to the point where one can actually forecast the start and stop of meningitis? If we could, it would really help a set of nations to deal with the problem much more effectively than they can now.

That's the type of thing that one can imagine… the ability to predict adverse health outcomes, outbreaks that occur. Disease is associated with the environment, and one can predict environmental conditions. NCAR won't do all that by itself. It can't. But we have this predictive foundation that can help other disciplines. That's the idea, and the potential is huge.

You need groups like CDC or NIH that support work on infectious diseases or health effects associated with pollution. I know I can go to Hershey Medical Center and find a scientist who looks at how ozone damages lung tissue. That person is there. I know that there's a research group there. We don't share any common funding envelope. We don't share anything that would allow us to put the pieces together. And so we wonder if we can start, because we're a national lab, to put those pieces together? I'm willing to play to put those pieces together. «

A New Era in Elevation Models

3D WITH LIDAR, OPTICAL AND RADAR

▲ *This LiDAR-like colorized 1-decimeter photogrammetric DSM elevation model of Philadelphia was extracted from optical data. The aerial image was collected by Pictometry International Corp. and the DSM extraction processing was done by Harris Corporation ImageLinks.*

EARTH ELEVATION MODELS HAVE EXPERIENCED TRULY DRAMATIC IMPROVEMENTS in recent decades. Various technologies and algorithms applied to both satellite and airborne platform sensors have pushed the limits of resolution of the best currently available elevation models by orders of magnitude beyond what was previously available. Today's capabilities for the production of elevation model data truly define a new era in several respects, with new applications rapidly emerging and many more that are yet to be discovered.

Historical Methods of Collection and Representation of Elevation Models

Prior to the application of modern remote sensing approaches to elevation modeling, techniques used to measure elevation data were manual and laborious. The time required to conduct surveys placed inherent limits on the amount of data that could be collected. More automated techniques, and in particular those involving remote sensing, needed to be fully developed before realization of a significant expansion in the amount of data that could be collected.

Aerial film photography permitted photogrammetric approaches to be applied to the task of elevation modeling over larger areas. Application of advanced photogrammetric techniques to digital imagery today can produce extremely high-resolution digital surface models (DSMs) and digital terrain models (DTMs). Examples of what is possible using state-of-the-art photogrammetric techniques will be shown later in this article. Due to industry-wide investment in digital image sensor technology and its use in commercial high-resolution imaging

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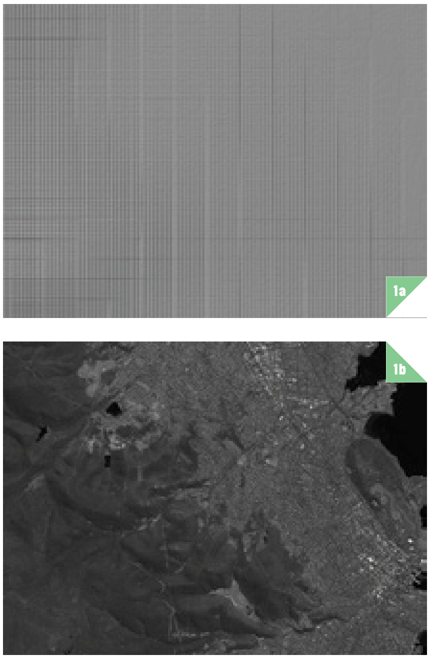
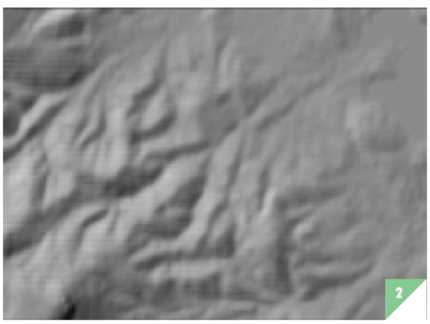


◀ **FIGURE 1.** *GTOPO30 Elevation Model (top) with satellite image of Hobart, Australia. (GTOPO30 is a product of USGS; 0.5 meter GSD GeoEye-1 panchromatic image of the area is shown on the bottom).*



▲ **FIGURE 2.** *Same location of Hobart, Australia, as SRTM (3 arc second) Elevation Model (SRTM is a product of NGA and NASA).*

satellites, photogrammetry currently can provide the highest-resolution elevation models at the greatest distances.

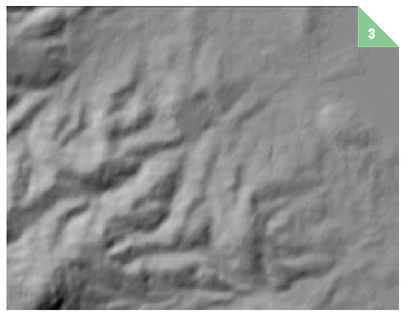
Other sensors and technologies provide elevation model information in forms that are complementary to photogrammetric techniques. The invention of the laser in 1960 enabled the development, beginning in the 1970s, of airborne laser scanning (LiDAR, Light Detection and Ranging), which calculates the distance to the ground more directly through time-of-flight measurement of pulses of emitted laser light. The density of points captured by LiDAR sensors has steadily increased in support of topographic mapping requirements. Use of different laser wavelengths enables such applications as topographic-bathymetric elevation model capture, among others.

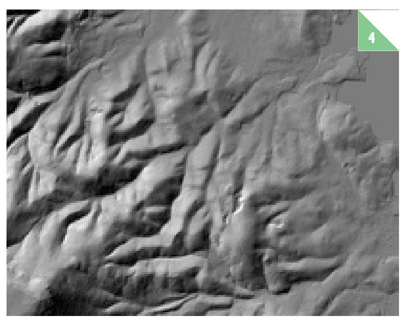
The first International LiDAR Mapping Forum (ILMF) convened less than ten years ago in 2001 and has been growing steadily along with advances in the technology. One of the important characteristics of LiDAR is its ability to collect multiple returns from each pulse, which helps improve determination of the true ground surface. Due to its much smaller wavelength, LiDAR is able to detect smaller objects than radar can. Current research in LiDAR technology will result in higher density collection capabilities leading to further advances in mapping our earth and neighboring planets.

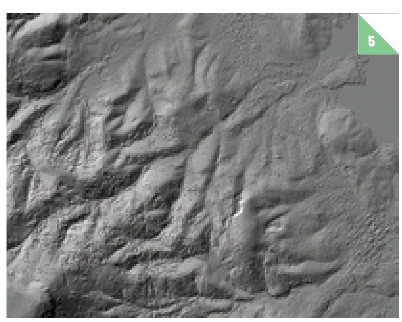
Distance measurement using radar has similarly evolved. Resolution of imaging radars has improved, and will continue to improve. Radar of appropriate frequencies can penetrate foliage, supporting better determination of the ground surface, and even can provide penetration below ground. Radar, like LiDAR, is an active self-illuminating system that supports collection day or night. Interferometric radar processing techniques use the phase difference of the returned radar energy from multiple radar images, rather than the amplitude, to compute topographic height more accurately.

Elevation models have been represented by various means according to their intended purposes. They have long been represented by two-dimensional descriptions; typical of these are contour lines, engineering drawings using an "elevation" view or profiles, or even early cartographic products enhanced with artistic oblique renderings of terrain or cultural features. The first three-dimensional elevation models, predating digital computers, were physical models of the terrain. These were produced from stacked layers of material, such as wood, or made as plaster casts. Relief pantographs were used to reproduce and cut models using a contour map as reference.

In the 1940s, the U.S. Army Map Service first used thermoplastic vacuum forming to construct physical models more rapidly. Red-blue anaglyph stereo images have been superseded by holographic printing, which can render full







▲ **FIGURE 3.** *ASTER GDEM (1 arc second) Elevation Model (ASTER GDEM is a product of METI and NASA).*

▲ **FIGURE 4.** *5-Meter DTM Elevation Model (Source data is GeoEye-1 imagery, DTM extraction processing by Harris Corporation ImageLinks).*

▲ **FIGURE 5.** *1-Meter DSM Elevation Model (Source data is GeoEye-1 imagery, DSM extraction processing by Harris Corporation ImageLinks).*

color terrain models in 3D and do not require the viewer to wear special glasses. Using similar technology, dynamic displays that render holographic models in real time have been demonstrated. Today, 3D printing techniques used for rapid prototyping of 3D models can be used to produce more complex and detailed physical elevation models, and to incorporate application of imagery to the surface in the same process.

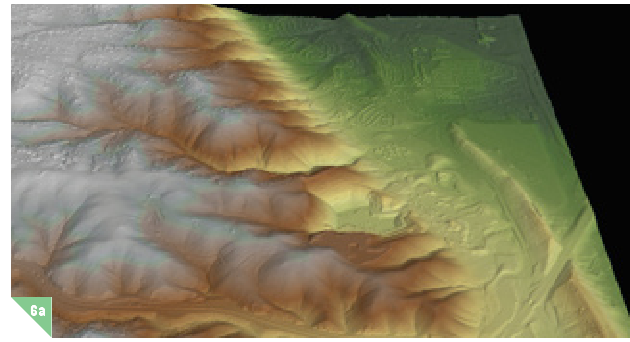
To support digital processing and visualization, elevation models may be stored in different forms. In traditional GIS applications, elevation data are primarily stored as a grid or TIN (Triangulated Irregular Network). As terrain data sets have grown to very high resolution, representing elevation models in formats previously applied to imagery such as TIFF, GeoTIFF, or NITF has become more common. Specialized formats, such as LAS for LiDAR, have evolved to address the need to capture elevation data and metadata that is important at today's higher resolutions.

Also, in the same way that image pyramids have been used for efficient display of very large image files in the past, elevation models of higher resolution now must employ similar techniques for efficient processing and visualization. Pyramids, level of detail, and data streaming are applied to terrain data increasingly as the resolution improves. Historical distinctions between elevation models, imagery, features, and attribution intermingle as elevation models reach the fidelity currently achievable. Applications of elevation data in the new era will be progressively more complex and demanding and will drive further innovation in data representations necessary to support them.

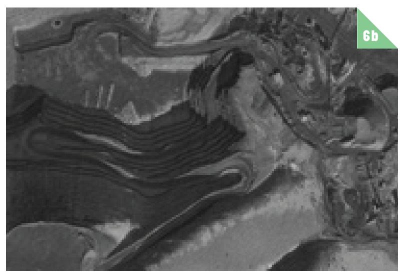
From Kilometer to Decimeter "X"treme Elevation (100,000,000 "X")

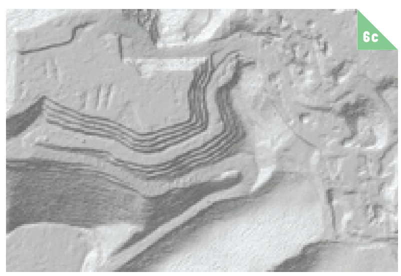
Earth elevation models have experienced truly dramatic increases in resolution in recent decades. In the public domain, the only global coverage elevation model just ten years ago was the 30 arc second post spacing data set, GTOPO30. ***Figure 1*** is a shaded relief model covering a portion of Hobart, Australia, approximately 65 sq km in size. Although global in scope, the GTOPO30 elevation data are very low resolution by today's standards, with the elevation sample spacing of approximately one kilometer. (For comparison, see the same geographic area in ***Figures 2-5***.)

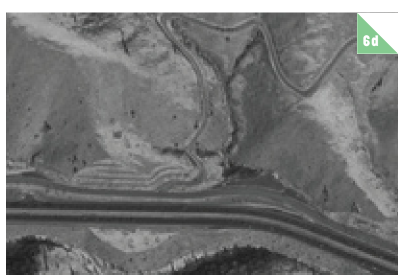
In less than a decade, we now have multiple near-global elevation data sets that are almost one thousand fold denser than GTOPO30, providing post spacings of 1 arc second. The Shuttle Radar Topography Mission (SRTM), flown aboard the Space Shuttle Endeavour in February 2000, generated earth terrain model coverage at 1 arc second from 60 degrees north latitude to 56 degrees south latitude, a feat that was unprecedented in scope and resolution at the time. ***Figure 2*** shows SRTM terrain data, the 3 arc second public release of the same area covered by GTOPO30 in ***Figure 1***. The GTOPO30 data set has been subsequently upgraded (SRTM30) using the SRTM data.

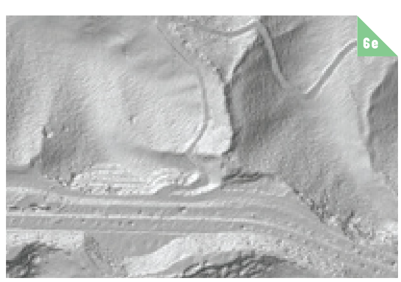


▲ **FIGURE 6.** ***1-Meter Photogrammetric DSM Elevation Model of Golden, Colorado (Source data is WorldView-1 imagery, DSM extraction processing by Harris Corporation ImageLinks). These 1-meter DSMs are about one million times the density of GTOPO30.***



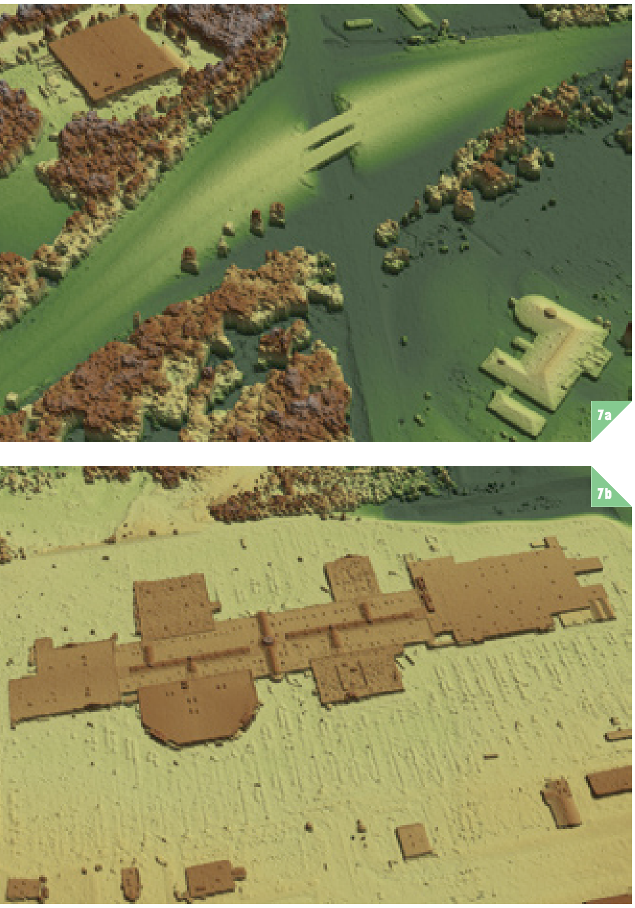






On June 29, 2009, NASA and Japan's Ministry of Economy, Trade and Industry jointly released GDEM terrain data derived from the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) instrument on the Terra satellite. The GDEM terrain models are 1 arc second resolution. This data set incorporates additional area not covered by SRTM; GDEM data spans from 83 degrees north latitude to 83 degrees south latitude. ***Figure 3*** shows an example of GDEM over the same area as ***Figure 2*** for comparison. Note the significant improvement in resolution of both the SRTM and GDEM data as compared to the GTOPO30 data.

If that resolution were not enough (and it's clearly not), various sensor and processing technologies applied using both satellite and airborne platforms have pushed the limits of resolution of the best currently available elevation models even



▲ **FIGURE 7.** *1-Decimeter Photogrammetric DSM Elevation Models of Rock Hill, South Carolina (Source data is Pictometry imagery, DSM extraction processing by Harris Corporation ImageLinks).*

further. ***Figures 4*** and ***5*** show a 5-meter DTM and a 1-meter DSM, respectively, of the type that Harris Corporation routinely produces from stereo satellite imagery using state-of-the-art photogrammetry. Our DSM extraction algorithm has been designed to use multiple stereo pairs viewing the same scene. The major benefit of this is that portions of the scene that are occluded in one stereo pair may be seen in stereo in another pair. In this way, we can produce more complete DSMs with fewer occlusions.

The source used to create the products in ***Figures 4*** and ***5*** is 0.5-meter GeoEye-1 satellite imagery collected by GeoEye. The 1-meter DSM is a two-dimensional array of points that contains the elevation of the earth's surface at each point. In this context, it is referred to as a reflective surface model because the height is for the objects that reflect visible light. As such, man-made features such as buildings and bridges are included in the DSM. The 5-meter DTM is similar to the DSM product, except that vegetation and man-made features have been removed and replaced with the bare earth underneath.

See ***Figure 6*** for examples of similar resolution surface models generated using WorldView-1 satellite imagery collected by DigitalGlobe. The color image is a 1-meter DSM. The gray scale figures are detail images (center) and the corresponding detail 1-meter DSMs (bottom). These 1-meter DSMs are approximately one million times the density of GTOPO30.

These imaging satellites, and others, combined with appropriate photogrammetric extraction technology, provide for generation of similar high-fidelity elevation models practically anywhere on the earth. Elevation models generated from these sources do not possess accessibility limitations of airborne LiDAR or IFSAR.

This same state-of-the-art photogrammetric technology is also applied to aerial imagery to yield DSMs with one-decimeter resolution. Decimeter post spacing elevation models produced today have approximately one hundred million times the density of GTOPO30. The source used to create DSMs in ***Figure 7*** is aerial imagery collected by Pictometry International Corp.

Applications in the New Era

In view of the history and the current state and variety of elevation model sensor and production technologies, focusing this discussion on photogrammetric approaches and applications is appropriate. With visible light photogrammetry, the main concern is the effect of clouds and other atmospheric conditions. Fortunately, visible imagery is most often simultaneously the most commonly available source, most current, and highest resolution – particularly with respect to satellite sources.

Areas of high interest are imaged for other purposes at high frequency relative to the timescale of changes to the terrain, allowing terrain models to be built up and improved over time and exploiting largely redundant information. When available, other sensor data (LiDAR, IFSAR, etc.) may be used to augment photogrammetric elevation models; the type of information other sensors provide can be highly complementary to the imagery source.

Elevation is used in numerous applications, and the need is growing fast. It is used in the GIS/Mapping, Military, Oil & Gas, and Wireless Telecom industries and in many more applications. The world's need for energy and "green" initiatives has put pressure on the geospatial technology community to produce high-resolution and accurate elevation models. High-resolution terrain data provide essential information when planning for corridor right of way, land restoration, damage prevention, risk management and emergency response.

High-resolution elevation models play a major rule in the demanding requirements of the wireless telecom industry. DSMs are used for point-to-point microwave analysis and DTM, along with other geospatial data layers such as 3D building models and clutter data, are used for WiFi and WiMAX applications. Using such datasets minimizes surveying costs and offers efficient ways to expand existing networks.

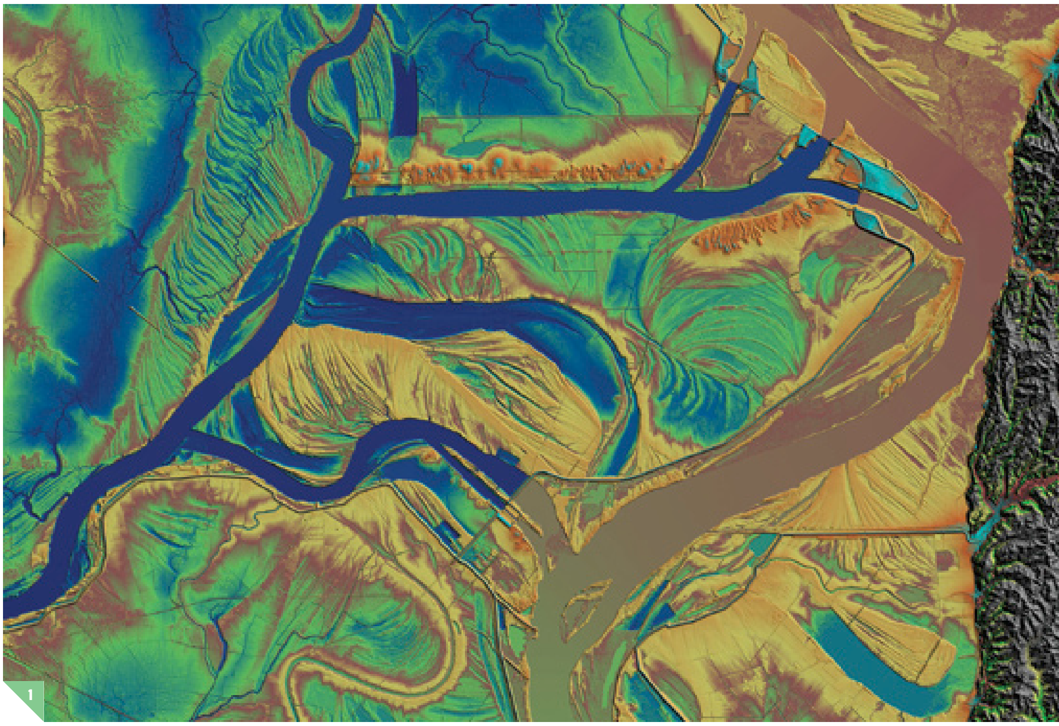
Height "Z" Matters

Elevation is foundational for many geospatial applications. Without elevation data, features extracted from imagery have relief displacement, and processed data are not accurate. When it comes to elevation models, it might be that even one decimeter spacing is not good enough. In this new era, the challenge is processing and managing so many millions of elevation values efficiently and accurately for the many wide-spread applications. «

Beyond Terrain Models: LiDAR Enters the Geospatial Mainstream

PROCESSING CHALLENGES REMAIN

EDITOR'S NOTE: This article is a follow-up to the in-depth LiDAR story in the Spring 2008 issue, which can be found in our online archive.



▲ **FIGURE 1.** *LiDAR digital elevation model of Turnbull Island. Courtesy of Northrop Grumman.*

FIRST USED BY NASA IN THE MID-1980s, light detection and ranging (LiDAR) has become an essential complement to photogrammetry for mapping and analyzing a vast range of surfaces. LiDAR started as a topographic tool on large scale projects, such as flood plain mapping, but in the past few years it has gained wide acceptance throughout the geospatial industry for a myriad of projects – including 3D urban modeling, feature extraction, tree identification and volumetrics, mapping bare earth under thick canopy, road delineation, forward looking for vehicles, mobile mapping, and carbon inventory. Ground-based LiDAR is becoming as common as aerial applications.

The pulse rate of LiDAR sensors continues to increase rapidly, producing huge datasets. This growth in data is outpacing the ability to analyze them, and software applications will need to catch up. Meanwhile, LiDAR data is now being routinely fused with data from other sensors, especially multi-spectral and hyper-spectral cameras.

Sensors

The increase in the pulse rate of LiDAR sensors will continue as long as LiDAR vendors find creative ways around system limitations, according to Matt Bethel, manager of systems engineering at Merrick. At the ASPRS/MAPPS Fall Conference in San Antonio, Texas, in November, Optech released its new ALTM Pegasus HD400 active imaging system. According to the company, it is the first commercial 4-channel LiDAR mapping system and, at 400 kHz, it has the highest sampling rate in the industry. It is coupled with digital cameras ranging from 5 to 60 megapixels. This combination of sensors allows users to colorize the LiDAR point cloud and then model it in 3D, using the LAS 1.2 data standard.

"We are promoting the Pegasus platform as an open concept," says Mike Sitar, Optech's product manager for airborne survey products. "It allows clients to come up with a configuration. The HD400 is the first version; it produces density for the sake of density. Down the line, it opens up the possibility of using different wavelengths. In the past, to get more density you had to increase the rep rate and fly lower. So, we came up with continuous multi-pulse that allows us to keep track of two pulses in the air and to fly twice as high at the same rep rate. Another approach is to fly two sensors together. With Pegasus' multichannel approach, both sensors use a single mirror, so the quality of the data is better."

The increase in the sensors' pulse rate creates new challenges, explains Bethel. Because the maximum allowable field of view is fixed, one typically can't go wider to cover more ground in a single

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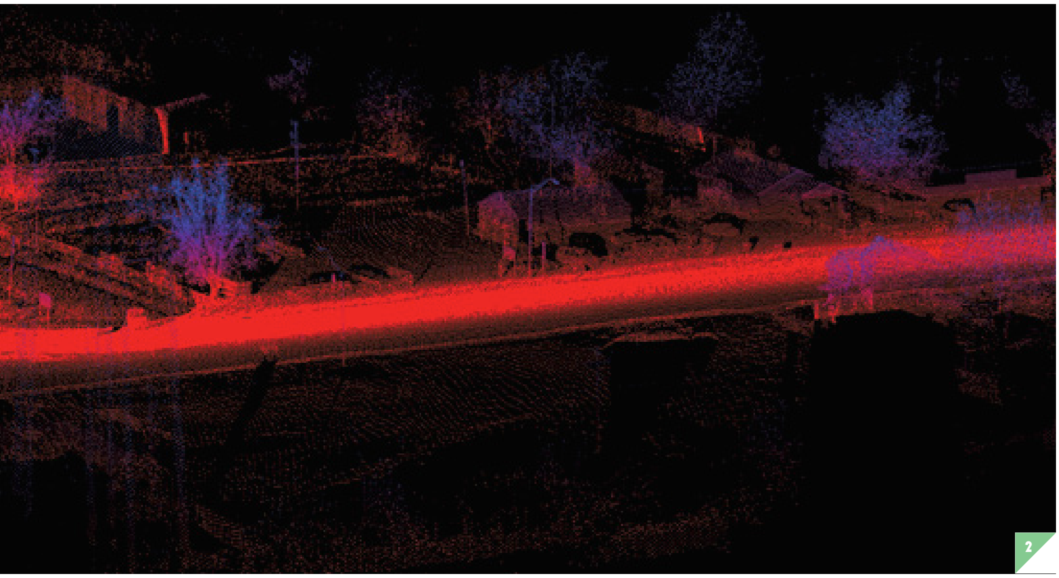
pass. Flying higher is possible to make the most of the increasing pulse rates, but that means an increased percentage of down days due to clouds. Higher above ground levels (AGLs) also mean a decrease in IMU (Inertial Measurement Unit) positional accuracy. Higher accuracy IMUs could allow for the better use of higher pulsing LiDAR systems flown at higher AGLs. So instead, as the pulse rates increase, assuming that the project specs don't change, collection flights can be flown faster at the typical flight AGLs. This capability reduces the time it takes to acquire a project, until the airplane's maximum speed is met. At that point, one must consider upgrading to a higher class aircraft to make best use of the increasing LiDAR pulse rates.



▲ **FIGURE 2.** *Point data collected from ground-based Optech LYNX mobile mapper LiDAR. Courtesy of Aerial Data Service.*

▶ **FIGURE 3.** *LiDAR point data for Dames Point Bridge in Jacksonville, Florida. Courtesy of Northrop Grumman.*

Software

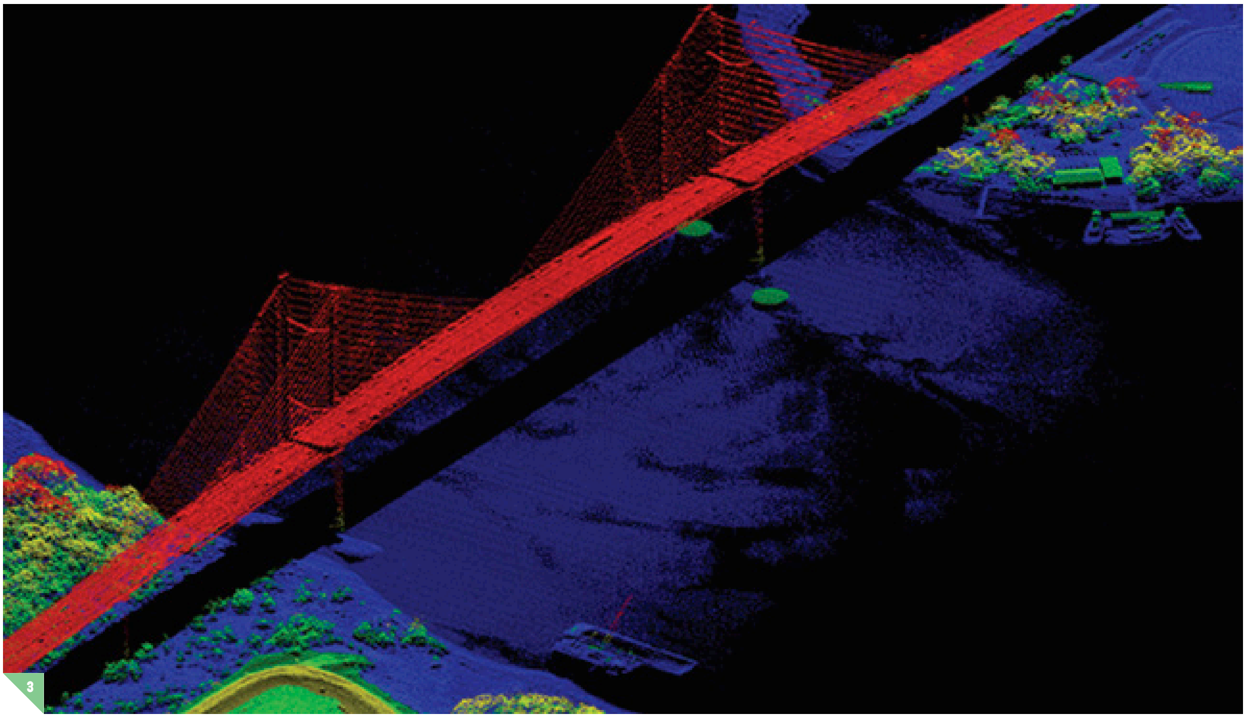
The key function of LiDAR software is to manage efficiently the massive amounts of data collected by LiDAR sensors. "As sensors advance, we are constantly dealing with the challenge for software of dealing with the volume of data that they produce," explains Torin Haskell, director of sales and marketing for QCoherent Software (acquired in December 2009 by GeoCue). "Until recently, we were dealing only with discrete points. Now, as an increasing number of our clients want to use the entire waveform, we have an enormous data management challenge. A huge step forward has been the expansion of the LAS standard to incorporate an option to include waveform properties. Once that format is incorporated into production and all vendors are using it, it will be easier for us to incorporate it into products for end users." QCoherent's core product is LP360, which allows users to import point clouds into GIS, so that they can work with the data directly.

Another way in which QCoherent Software is addressing the data management challenge is with its LiDAR Server product, which allows different software to look at LiDAR data on a server. For example, says Haskell, it allows state-wide data to be hosted on a single server, rather than having to be chopped up and distributed to users. Also, two OGC standards, WMS and WCS, allow users to manage massive LiDAR data over the Web.

Acquired a year ago by Northrop Grumman, 3001 International uses commercial off-the-shelf (COTS) hardware and software, says Bart Bailey, Director for Northrop Grumman Information Systems and formerly 3001 International's CEO. However, "...the software doesn't always do what you want it to, so inevitably we end up building add-ons and work-arounds. For 3D building extraction, the software we bought did not work automatically as well as we wanted, so we built our own software."

To Sitar, the problem is that third-party software is lagging behind the explosion in LiDAR data and applications. For example, he points out, "There has been a huge adoption of mobile LiDAR, but there are few commercial packages that can exploit it effectively. For a department of transportation that needs road delineation, LiDAR is a very effective tool, but the software does not necessarily exist for that application." However, that's changing, he admits.

Many local governments in recent years have spent a lot of money on collecting LiDAR data but lack the software and expertise to make full use of it, says Kevin Opitz, Sales Operations Manager for Overwatch Systems. Likewise, Bethel points out that the majority of clients don't fully understand how best to use LiDAR data. "A ground sampling distance of 10-15 feet used to be standard ten years ago, but now we are at three-to-five feet and in the near future we might be down to one-to-three feet. We go through so much effort to collect and keep good accuracy, but when we deliver we might find out that our client is making 10-20 feet grids because the software that they use cannot handle the density that they specified. We might collect data at one-to-five meter resolution; then they



might plug it into flood modeling software at much lower resolution." For this reason, Merrick's approach is to deliver the data together with software that can enable its clients to use it.

Another way to deal with massive amounts of data is through compression. Jon Skiffington, an engineer with LizardTech, a company known for its work with image compression software used in GIS applications, compares the challenge posed by the increasing popularity of LiDAR data with that posed a few years ago by large raster images. "Our customers have been asking us over the past three years if we can do something similar with LiDAR data. File sizes are now in the hundreds of gigabytes. We can compress them to a quarter of their size, so that customers can use that point cloud in their normal applications. We released the initial version of LiDAR compressor in the summer. We are now trying to make sure that third party applications – such as ESRI, Global Mapper, and Merrick – will support our compressor, and we are expecting others to add support in the near future."

ITT VIS takes yet a different approach. "We are working on making data size irrelevant, via intelligent pre-processing and visualization," says Beau Legeer, the company's director of product marketing. "Even though the dataset might have billions of points, our software will load only those that are valid at a given resolution." The company makes the ENVI software packet and will be releasing additional LiDAR support in ENVI 5.0. "Initially," says Legeer, "LiDAR was a part of our solution only to generate 2D products: terrain models, digital surface maps, intensity images, etc. It is becoming more important to retain and exploit the 3D data instead of just using it in 2D."

> *"There is a new term in the market: LiDARgrammetry, or using LiDAR to come up with two different models, then throw them both into the photogrammetry process."*
>
> **-MIKE SITAR, OPTECH**

ITT VIS has a three-phase strategy to evolve its approach to LiDAR, Legeer explains. First, it is utilizing all of the 3D point cloud without any decimation, loss, or limit. It is aiming to release a point cloud viewer in ENVI by the end of 2010. This is made possible by the fact that ENVI is underlined by the IDL programming language. "Customers can use IDL to customize and enhance ENVI. In this phase, we will also allow users to write their own LiDAR algorithms," says Legeer.

Second, over the next two years, the company will dive into the point cloud with exploitation algorithms. "We will extend feature extraction into 3D, then fuse proven multi-spectral and hyper-spectral algorithms, which we will supplement with LiDAR data. Extraction tasks, such as target detection and material identification, will become more accurate by adding LiDAR point clouds to the equation. It will make our tools better." Finally, the third phase will depend on user feedback and where the market goes.

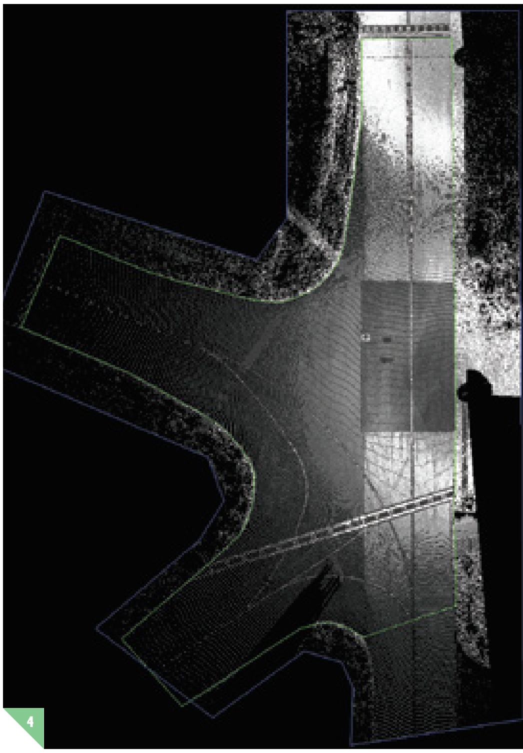
According to Legeer, one potential bottleneck in the strategy is the LAS format (the standard file format for LiDAR data). "As sensors grow and the data content becomes more rich, the format needs to catch up. It will work itself out, but the format might not have all we need for feature extraction. We will work with ASPRS to evolve that as fast as the data is growing. All other bottlenecks are disappearing."

Merrick uses LiDAR to collect bare earth, power lines, corridors, shorelines, borders, and rivers; to model flood plains; and to generate 3D models for very high-precision data in automated vehicle navigation. The company writes all of the software it uses, says Bethel, and sells its Merrick Advanced Remote Sensing (MARS) software designed to manage, visualize, process, and analyze LiDAR data. "We designed MARS from the ground up, to handle large amounts of LiDAR data, throughout the whole production process: checking the bore calibration and coverage, batch processing, editing the DTM, some feature extraction, auto filtering, manual filtering, break-line collection, and exporting to different file types to produce the final deliverable."

Woolpert, a design, engineering, and geospatial firm, uses LiDAR software mainly to calibrate the data, tie flight lines together, and classify points, says Jeff Lovin, the company's vice president and director of photogrammetry and remote sensing. However, that has changed in the last couple of years, he points out. "We used to just want the ground points, but now we are doing more with the rest of the data, and classifying it is more important to us. We are creating derivative products, such as raster images, using the intensity of the returns. For example, in Panama a couple of years ago, due to extensive cloud cover, we collected imagery by flying LiDAR at night."

Many people don't realize that most LiDAR software will only allow them to visualize LiDAR data and not to analyze it, points out Opitz, of Overwatch Systems. The company makes LiDAR Analyst, which enables users to convert raw LiDAR data to a format from which they can extract features, as vectors or polygons. The software was originally developed for the U.S. military by the Advanced LiDAR Exploitation System (ALES) Consortium; then Overwatch commercialized it as its core LiDAR exploitation product. The company, Opitz says, looks at LiDAR not just as a visualization tool but as a rich data set from which to extract features – including building heights and widths. For example, he says, an army platoon might use LiDAR data to determine how tall a ladder they will need to get on the roof of a building. The company is now also working on terrestrial LiDAR, which produces very dense, large file sizes that allow users to locate windows and doors on buildings and identify vehicle types, says Opitz.

Efficient processing of huge LiDAR data files also requires a lot of computing power. "We have completely re-written our LiDAR software to make it better suited for high performance and to enable faster coding," says Bethel. "Our key recent advance has been 64-bit processing, using virtually unlimited amounts of RAM, and



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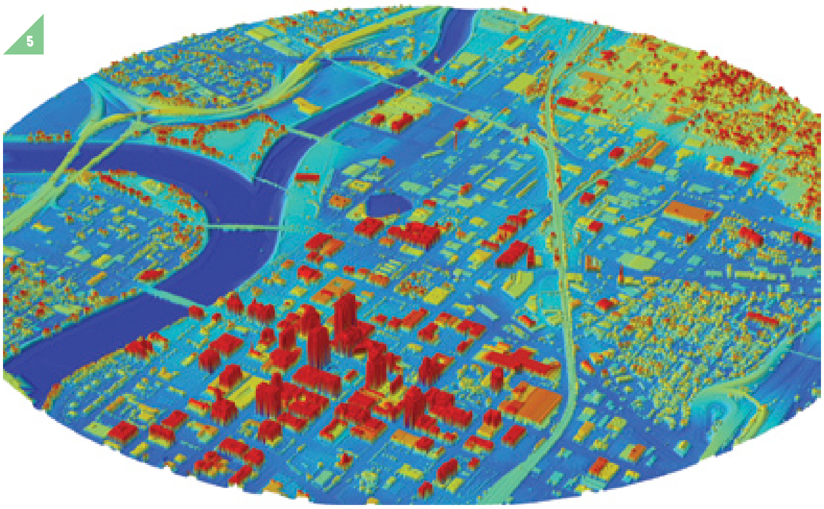
▶ **FIGURE 4.** *Raster image created using the intensity of LiDAR returns. Courtesy of Woolpert.*



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▼ **FIGURE 5.** *Aerial image of Dayton, Ohio. Courtesy of Woolpert.*

up to 16 co-processors per machine, all from within one program. In a production environment such as ours, we must keep all the data in a central file server, so we do all of the processing on the server side. Another growth area is the use for processing of a GPU – which is a high-end graphics card – rather than a CPU. The bottleneck is the disk R/W (read/write) speed."

ITTVIS, Woolpert, and QCoherent are all working to take advantage of multiple processors. "We plan to take advantage of multi-core for pre-processing and GPU for the rendering," says Legeer. "We use distributed processing and multiple work stations," says Lovin. "The limiting factor," he adds, "is how much data the software can handle. Feature extraction is constantly becoming more automated. How many points can we load at once? One square mile? Twenty?" Advances in LiDAR sensors, Bethel explains, cut the collection time rather than yielding denser datasets. Customers, however, may start asking for higher density, requiring further improvements in processing. "Divide and conquer," he says, "is definitely the wave of the future."

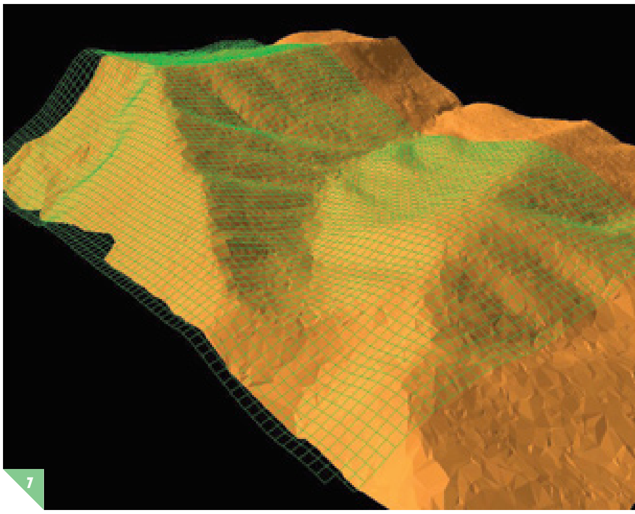
▲ **FIGURE 6.** *Point cloud of power lines. Courtesy of Woolpert.*

Data Fusion

LiDAR and camera imagery are ideally complementary sensors: direct orthorectified imagery from LiDAR can correct raster imagery, and imagery can be used to quality control LiDAR data. To illustrate the latter, Lovin cites the example of mapping Florida swamps: the tops of the vegetation will give such a consistent return with LiDAR that they can easily be confused for the surface, even though they are three or four feet up. Looking at photos while analyzing the LiDAR data will avoid this error. LiDAR can also miss contours and break lines, he says, so Woolpert technicians often add them by hand.

According to Sitar, more than half of the commercial mapping sensors that Optech sells go out the door with a camera. "Integrating LiDAR with medium-format cameras, which have a smaller footprint, improves the workflow," he says. "There is a new term in the market: LiDARgrammetry, or using LiDAR to come up with two different models, then throw them both into the photogrammetry process. A 60 percent endlap is used to augment a LiDAR terrain model. Point clouds may miss breaklines, which are important, for example, for drainage delineation."

Woolpert, Lovin says, will fly LiDAR in conjunction with imagery for any project that covers more than 10 square miles – which means nearly all of its projects – and involves any 3D modeling or feature extraction. "For the first six to eight years, we used LiDAR only to model; now we use it in nearly all photogrammetry projects," he says. "For example, we flew all of Ohio at 1-meter resolution. The state did not specify that we should use LiDAR, they just wanted rectified imagery."

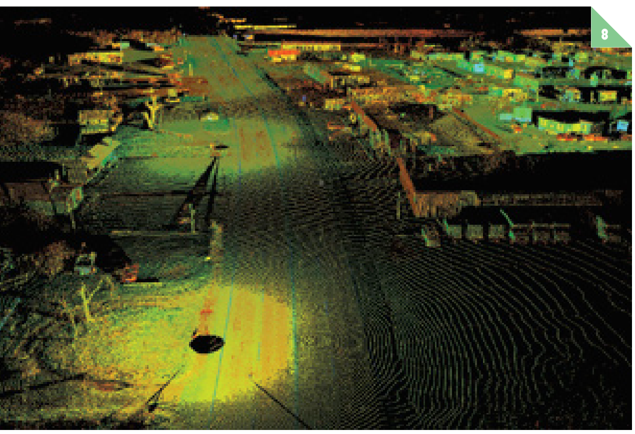


▶ **FIGURE 7.** *This is an interpolated grid draped over a TIN (Triangulated Irregular Network) of a bare earth surface. Both were generated using MARS (Merrick's Advanced Remote Sensing) software. Courtesy of Merrick.*

"We are now using LiDAR on the ground, too, and fusing the data," Lovin adds. "With ground LiDAR, the platform is moving slower, so there is greater point density and accuracy than with airborne LiDAR. The challenge is in post-processing – for example, loss of satellite lock. The hottest new thing we are doing is sensor fusing: oblique, vertical, satellite, aerial, and ground-based LiDAR. There is great potential for modeling and 3D GIS applications, true building facades, and attribution. We are spending a lot of our R&D on that. We have been doing this since 1998."

"Customers are increasingly appreciating the point clouds but also want the imagery," says Bailey, "so we are combining medium format camera with LiDAR. Fusing LiDAR and imagery gives a very accurate representation of what is on the ground." They are not going to do ground-based LiDAR until they can see the return on investment, he adds.

The most common combination of sensors used by Northrop Grumman is an Optech LiDAR sensor, a Rollei medium format camera, and a CASI hyper-spectral camera. The company has used that combination, for example, on flights for the U.S. Army Corps of Engineers (USACE), a project in West Texas, and work in Central America. It also has three years of experience with Scanning Hydrographic Operational Airborne LiDAR Survey (SHOALS), a system that consists of a topographic LiDAR, a medium format camera, a hyper-spectral camera, and a bathymetric LiDAR, developed by USACE to monitor near-shore bathymetric environments.



▲ **FIGURE 8.** *Terrestrial scan from low-flying aerial platform. Courtesy of Woolpert.*

"Integrating RGB values is in the future. It is definitely on our radar," says Jennifer Whitacre, national account manager for LiDAR solutions at MJ Harden, a geospatial company that is owned by GeoEye.

"I see LiDAR adding its own dimensionality," says Legeer. "For feature extraction in urban environments, we can combine LiDAR with our ENVI tool set. We talk a lot about data fusion as a focus of releases in the 2011-12 time frame. We would like to turn ENVI into a platform for multi-sensor data, so that if you bring multiple sensors to the project, we will allow you to register them together and create a rule that uses the properties of each sensor to describe the object. For example, the object is valid if it has a certain shape, temperature, size, etc. We will also add video to ENVI as one more factor in fusion-based processing."

There are three ways of extracting LiDAR data, explains Mike Kitaif, manager of software development and owner of Cardinal Systems. You can produce a 3D model using pure photogrammetry, then overlay the LiDAR data on top of it; you can orthorectify raster data and overlay LiDAR data on top of it; or you can just bring up the point cloud in 3D.

Unlike with an image, he points out, you can look at a LiDAR point cloud from any angle. His company is developing software to fuse data from LiDAR and cameras. "It will be another three months before it is an official product, but we have shown it to many customers," he says.

Looking Ahead

An emerging technology is that of 3D Flash LiDAR, being developed by Advanced Scientific Concepts, Inc. Its cameras can collect full 128x128 pixel frames of 3D point cloud data per single laser pulse, up to 60 frames per second, according to Thomas Laux, the company's VP for Business Development. They have the ability to image through dust, fog, and smoke, he explains, and provide accurate 3D measurement and real-time imaging, including video. This allows for detection of dynamic hazards, making them ideal for use in moving vehicles. The cameras co-register the range and intensity of each pixel, allowing such manipulations as filtering objects in an image by their distance from the sensor. So, for example, you could display a group of firefighters, enveloped in thick smoke, who are between 60 and 90 feet from the camera, filtering out anything that is closer or more distant.

The current ASC 3D camera has the equivalent of 16,384 range finders on its sensor chip and, unlike with scanning LiDAR, it captures an entire frame of data from a single pulse of light. Therefore, motion and vibration of the platform or the subject do not affect the measurements, says Laux. For example, helicopter blades spinning at supersonic speed will appear as stationary. Additionally, the system provides a direct calculation of range, unlike stereoscopic cameras, and is smaller, lighter, and more rugged than scanning LiDAR.

This technology allows users to acquire 3D movies at the laser pulse repetition frequency, making 3D video a reality and enabling real-time machine vision, Laux says. High frame rates allow faster acquisition of topographical mapping than with point scan technology, decreasing the amount of flight time required to scan and capture an area.

NASA has tested ASC cameras on orbit for automated rendezvous and docking, is funding further development of the technology, and iRobot has chosen them for use in unmanned ground vehicles. They plan to launch in 2010.

Looking ahead, Opitz, like Skiffington, sees compression of LiDAR data as a key development. "Anything that will make those files more manageable will make a huge difference, especially in the field," he says. His company is also developing tools to exploit full motion video, including LiDAR data.

For the foreseeable future, advances in LiDAR software will continue to chase after the explosive growth in LiDAR data produced by advances in hardware – by improving processing speed and by finding new ways of fusing data from different kinds of sensors, including video.

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