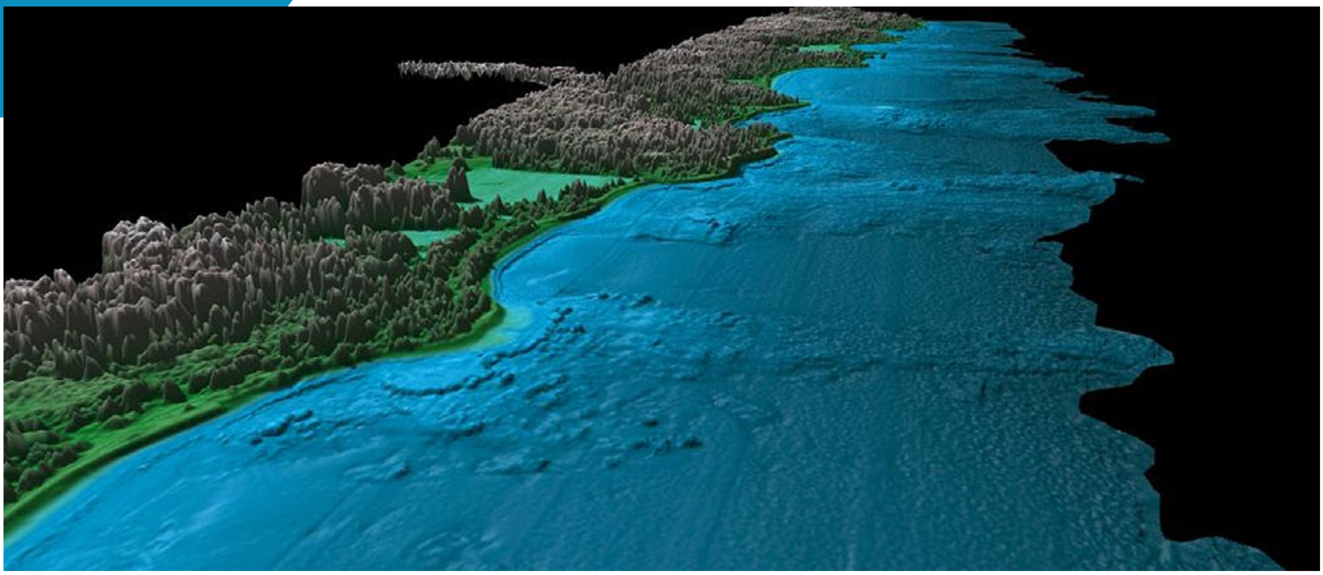

Figure 1: Topo & Bathy Lidar DEM of NH Coastline. Provided by Geomatics Data Solutions, LLC. Data shown courtesy of the USACE National Coastal Mapping Program.

Airborne Lidar Bathymetry **Sea, Shore and More**

A lesser-known airborne lidar technology comes into its *own*.

Over the past year there has been a number of announcements and industry news coverage of advances and innovations in airborne lidar bathymetry (ALB, also referred to as "bathy" lidar). In mulling over the interesting developments, I wondered if the current ALB growth path is on a similar trajectory to that of the airborne topographic ("topo") lidar industry/market back in the mid- late 1990's. Additionally, I have been trying to imagine the direction these developments might take the industry.

BY BILL **GUTELIUS**

In an attempt to make sense in reading the "tea leaves", I reached out to several experts including Dr. Grady Tuell of the Georgia Tech Research Institute Electro-Optical Sensing Lab (GTRI-EOSL). Dr. Tuell is one of the leading bathymetric lidar and active/passive EO researchers in the world and has been responsible for spearheading the development of sophisticated sensor capabilities and enhanced information extraction techniques for many years. Dr. Tuell opened my eyes to some fascinating facts regarding the evolution of ALB and where the future may lead.

A Little History

Imagine a lumbering P-3 Orion brimming with racks of laser-profiling electronics skimming the coastline, a CH-46 helicopter soaring over Swedish fjords carrying a ton of laser equipment, a Bell 212 with a massive lidar pod slung between the skids or picture a DC3 circling the frigid Canadian Arctic with a cargo load of laser remote sensing gear and you get an idea of the early days of airborne lidar bathymetry. (For a great in-depth background on the history of ALB, look at: Airborne lidar Bathymetry, by Gary Guenther)

It took aircraft like these and several on-board operators and researchers just

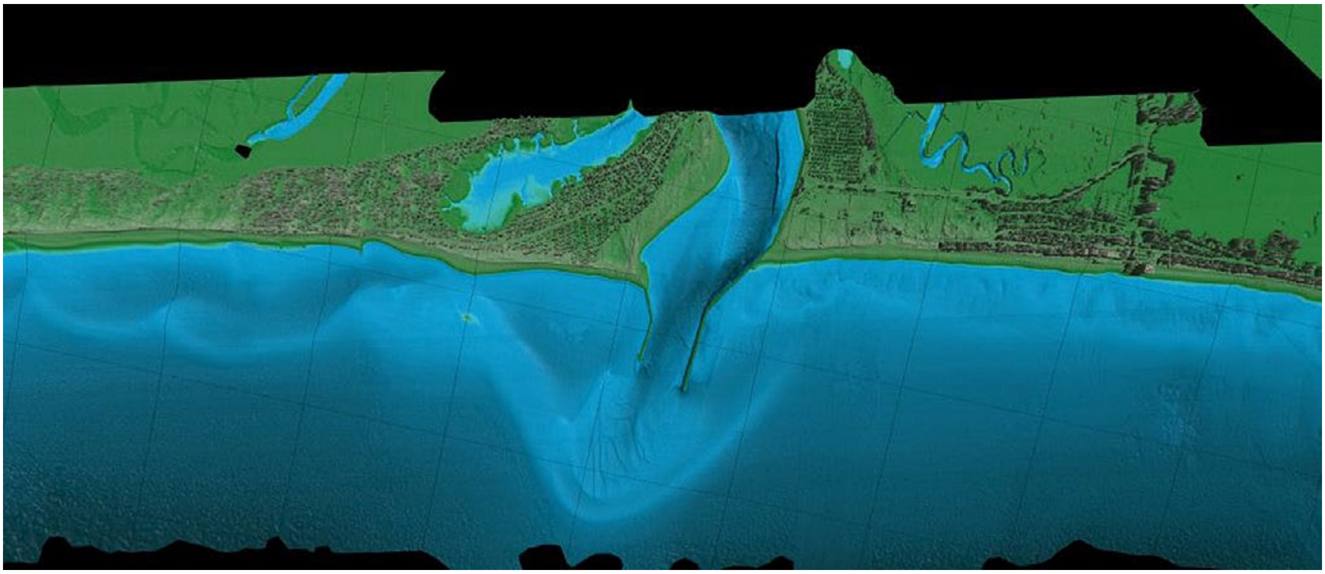

Figure 2: Topo and Bathy Lidar data providing a seamless DEM. Provided by Geomatics Data Solutions, LLC. Data shown courtesy of the USACE National Coastal Mapping Program.

to collect the data. Data processing was even more complicated and took much longer than the collection, requiring great skill to parse and tease out pertinent information. With systems that emitted laser pulses at rates in the low kilohertz or even hundreds of hertz, data points were very sparse. The technology focus of the early days on primarily mine and submarine detection eventually migrated to nautical charting applications (sometimes referred to as laser hydrography). ALB became an alternative, and even a substitute, for near-shore, intermediate to shallow depth sonar surveys. As Carol Lockhart, a hydrographer with Geomatics Data Solutions, LLC, put it, ALB's real strength is in "acquiring data over large spatial extents of shallow or remote areas in a short amount of time." This transition (sonar to lidar) took a long time and was met with a fair amount of resistance by long-time ship-based multibeam and side-scan sonar operators.

Government and defense research was the only path to ALB technology back then (e.g. NASA, NOAA, DARPA, foreign militaries and others). So, this was the scene in the late 1970's through late 1980's. In the 1990's, the progressive evolution of ALB picked up pace. Eventually, systems became somewhat smaller and more powerful, providing greater amounts of data. System manufacturers like Optech, Tenix LADS (now owned by Fugro) and Saab Instruments AB (now AHAB) began offering commercial sensors and services outside of government projects.

One of the interesting areas of research that began to emerge in the late 1990's was the application of ALB to near shore (shallow-water) coastal zones, rivers, streams and in-land water bodies. NASA's EAARL was a pioneer of this technique and it continues to fly as USGS EAARL-B. Figure 5 shows the ability of a shallow-water, low-power ALB system to capture topographic and bathymetric data simultaneously with a single pass.

Transitioning Technology & Applications

Fast-forward to 2012 and you see a very different landscape—or bathyscape as it were. There is now a secondary transition in applications taking place. We are witnessing the advent of powerful, lightweight, versatile and efficient systems that employ easy-to-use and fast post-processing packages which are generating greater detail and information extraction ability for researchers and commercial operators alike. The signal processing electronics on these new units have much faster response times, allowing resolution of very shallow water (0-2m) compared to the older, high-power ALB systems. Some of the new systems use just a single green-wavelength laser (usually 532nm) to collect BOTH topo and bathy data at the same time. Passive sensor technology is being integrated or combined with the latest ALB systems to augment the lidar waveform data. These ancillary passive sensors range

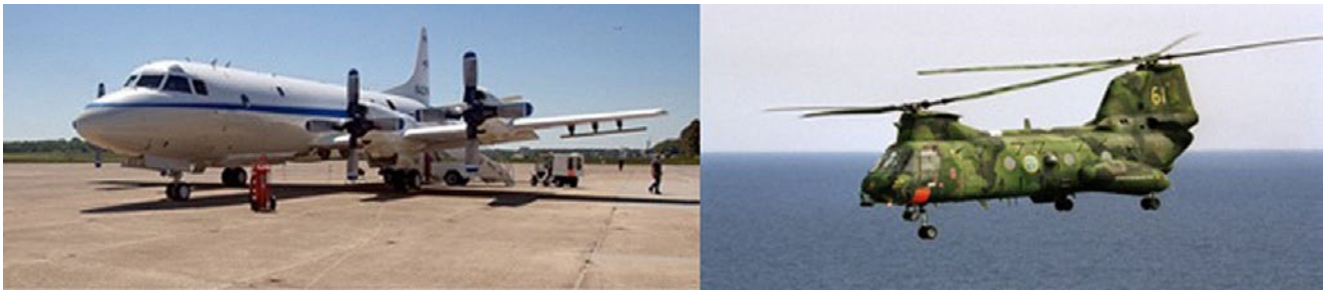

Figure 3: Examples of typical aircraft platforms in the early days of airborne LIDAR bathymetry.

from hyperspectral to standard imaging cameras. Even the lidar data itself is being enhanced by new return signal reflectance calibration techniques which are becoming standard.

Sensor system variety is plentiful: AHAB Chiroptera, NASA/USGS EAARL, Optech Aquarius, Riegl VQ-820-G, USACE CZMIL and more. These amazingly small sensor packages easily fit into smaller "aircraft of opportunity", rather than requiring the large planes and helicopters of the past.

Even though ALB technology has emerged from the realm of government-sponsored/built systems, much of the demand for the data they generate is still primarily driven by government and defense agency needs around the world. While some of these systems are purpose-built research units, the growth in system numbers has been in commercial-off-the-shelf (COTS) sensors and has been somewhat of a recent development.

It is easy to draw parallels to the rise of the small and sophisticated airborne topographic lidar systems in the late 1990's. In 2006-2007 there were about 7 or so ALB systems around the globe. It is projected that by 2013 this number will have more than doubled. In addition to agencies looking for information for nautical charting (e.g. NOAA Office Of Coast Survey, USACE), new types of data consumers are realizing tremendous value in the output products provided by the new types of ALB systems.

Some of the emergent applications areas are:

- shoreline mapping
- coastal inundation and storm surge modeling
- benthic habitat mapping;
- coastal engineering,
- coastal change analysis
- riverine environment mapping
- on-shore hydrographic feature analysis

All the experts who were interviewed agreed that the shoreline mapping community (e.g. NOAA, USACE, other coastal scientists and coastal zone managers) ought to really benefit from the latest generation of ALB systems. Dr. Tuell explained that, "Shorelines are the planimetric projection of the land/water interface at a specific stage of tide. These new systems should support high resolution topo/bathy surveys in ellipsoid heights, but these can be transformed to the required tidal datum. In clear waters, these systems can also be used to survey into deeper waters."

Key Drivers of Current ALB Growth

- Much lower system capital cost (reduced technological complexity)
- Lower system operational cost (wider choice of aircraft platforms, reduced manpower requirements, streamlined back-office workflow)

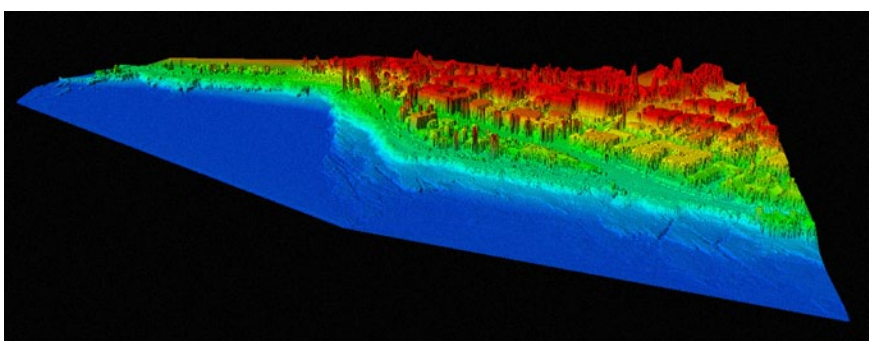

Figure 4: La Jolla, California coastline (simultaneous topographic/bathymetric surfaces). Collected by USACE JALBTCX, courtesy Dr. Chris Parrish, NOAA.

- IHO SP 44 standards specifically referred to bathymetric lidar in 2008.
- Greater expertise in, and understanding of, ALB principles and capabilities within the data contractor community (USACE JALBTCX and their contractors were a major force in driving this)
- Expanding applications areas, growing user-base beyond "traditional" users of bathy lidar data (i.e. nautical charting); general increasing awareness of/interest in data within coastal science and management communities.
- New, faster computer processing hardware to render information more quickly

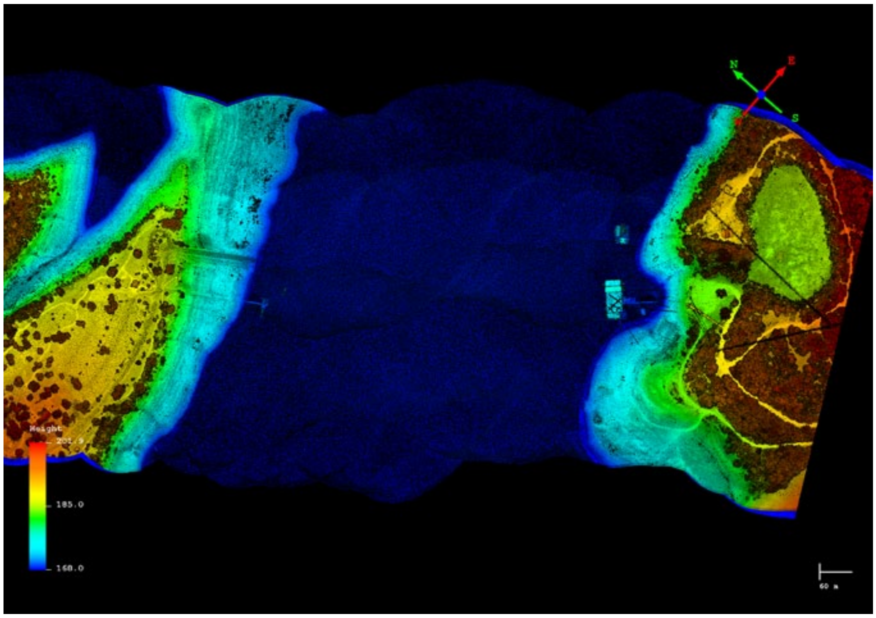

Figure 5: Topo/Bathy survey of Lake Travis near Austin Texas. 17.5 million points (5 points per m^2 bathymetric surface, 10 points per m^2 topographic surfaces). Courtesy of University of Texas Austin, Bureau of Economic Geology.

A Look at Bathy vs. Topo lidar

Some of the key fundamentals that differentiate a bathymetric lidar from an airborne topographic mapping system (besides the fact that one penetrates water and the other doesn't) fall into different categories.

Hardware elements

I asked Dr. Tuell to layout for me some of the key technology differentiators between a typical airborne topographic lidar and an ALB system. He responded, "Traditionally, bathymetric lidars have been large aperture, high power, waveform resolved systems. Frequency doubled Nd:YAG lasers have been the laser of choice because they have been so reliable. The high power lasers generate a lot of heat, so thermal management of the lidar is required.

Also, pulse repetition rates are typically lower than topo lidars, so the point cloud density is coarser. The large apertures require larger scanners, and this can lead to challenges in calibration and cooling as well. Many systems are engineered to maintain a constant incidence angle. Because the basic mensuration technique is based on waveform processing, the digitizers must be very good, and the receiver architecture must be designed to handle a very high dynamic range. Some designs are measuring waveforms for several channels for each pulse of the laser, so there is a lot more data to record and process than produced by a typical topo lidar."

Logistics/Economics of deployment

A traditional system (e.g. SHOALS, LADS, Hawkeye, CZMIL) is much larger, heavier, and requires more power than a topo lidar. Therefore, larger aircraft are typically used. Waveform processing has traditionally been more difficult than standard processing for topo lidar. This means that deployed teams on survey campaigns are larger. All-in-all, bathy lidar is a more challenging and expensive business than topo lidar. Sometimes the weather and sea conditions aren't right for using the technology. Folks who do this work have to be very good at knowing where on the planet to go, and when. They also have to understand the technology very well. Dr. Tuell opined, that, "I always tell interested customers to make certain they perform their due diligence on their business model. This is no place for amateurs. It's hard work."

ALB Data Handling

The modern approach is to create a point cloud on the seafloor in ellipsoid heights (for the vertical coordinate). Therefore, one job of the software is to accurately segment the waveform into

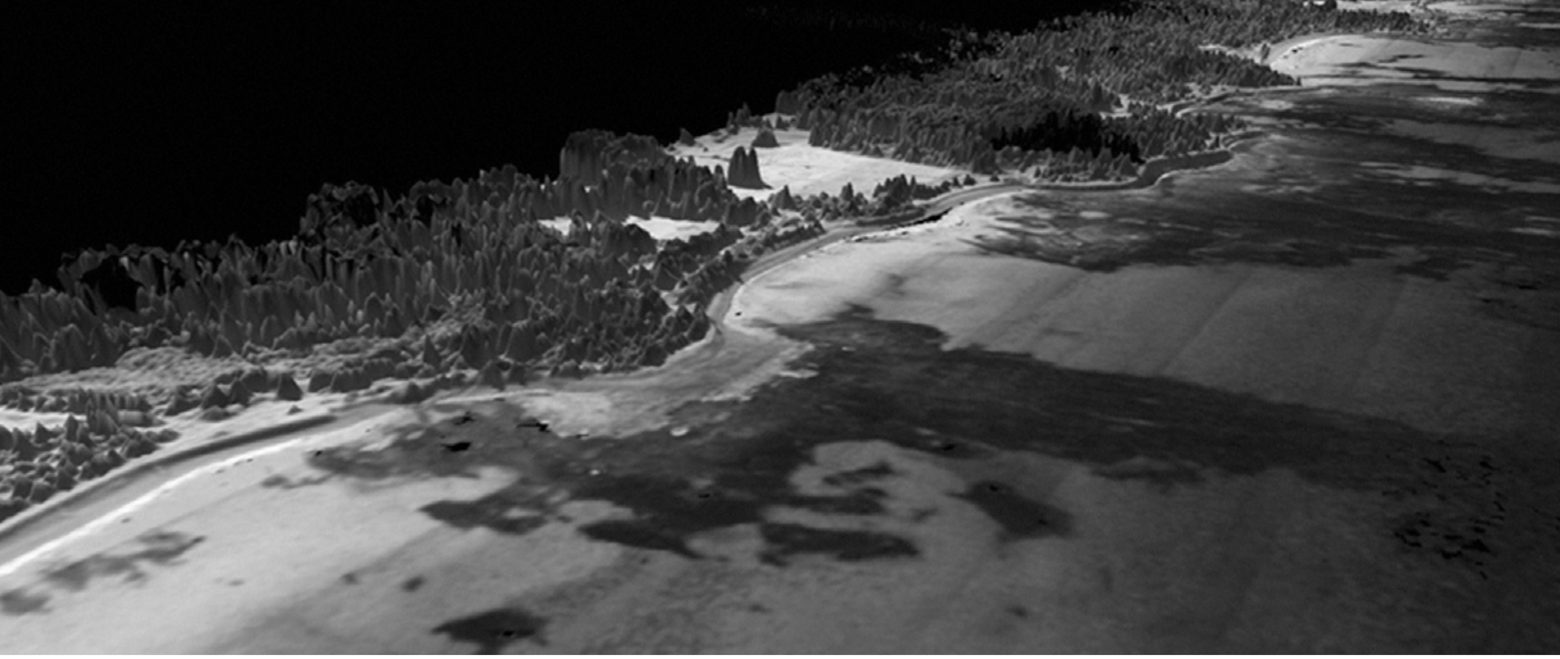

Figure 6: Coastal LIDAR reflectance map, New Hampshire coastline. Provided by Geomatics Data Solutions, LLC. Data shown courtesy of the USACE National Coastal Mapping Program.

its "in air" component and its "in water" component. Then, using the navigation data, the pointing angle information, and these two ranges, the seafloor coordinates are computed. Dr. Tuell related, that, "Over the years, I have been a proponent of also computing seafloor reflectance for each pulse. This requires that we radiometrically calibrate the lidar, and then invert the radiative transfer equation to convert the received power to an estimate of reflectance at the laser wavelength." So, the overall job of the software is to produce a lidar reflectance point cloud on the seafloor to IHO-Order 1 accuracy specifications in 1:1 ratio (or better) of processing to acquisition time. (see Figure 6)

What Does the Future Have in Store For ALB?

Smaller Aircraft

Clearly the next platforms for ALB systems will be unmanned aircraft systems/air vehicles (UAS/UAV). To make a step-wise change in size, weight and power demands to fit an ALB package on a UAV (at the same time retaining performance) requires substantial advances in several areas of engineering.

The key challenge, according to Grady Tuell, to developing a substantially down-sized system is in somehow maintaining current ALB performance. As seen in the latest small units released to the market, several performance elements were traded for lower power consumption, weight and form factor reduction, as well as thermal management. For example, to maintain the performance of a sophisticated system like the JALBTCX CZMIL, re-imagined in the form of a miniaturized sensor, will necessitate significant advances in air-cooled laser technology. Current low-power ALB systems traded away the high-power, deeper-penetrating lasers for lower-power, shallower-penetrating units that generate much less heat. The result is that they do not typically exceed a depth of more than 10-15m or so, even in clear water.

However, there are major advantages to mounting an ALB on a UAV platform. According to Dr. Tuell, beyond some of the obvious military advantages (e.g. stealth), there are significant drivers, not the least of which is economics. Field teams can command and control a UAV ALB systems from an office rather than in an aircraft. The future UAV-based ALB systems will be capable of telemetering a pre-processed set of data allowing operators to know real time the quality and completeness of area coverage, says Grady Tuell. Figure 7 depicts GTRI's notional UAV-based ALB in operation.

"To make a step-wise change in size, weight and power demands to fit an ALB package on a UAV (at the same time retaining performance) requires substantial advances in several areas of engineering."

Better Electronics & Signal Processing

Dr. Tuell described aspects of his research at GTRI-EOSL where they are designing a novel receiver architecture employing hardware-based algorithms for on board processing of

3D reflectance point clouds. The range resolution (the ability of the electronics to resolve one surface from the next) will be significantly higher than existing systems—meaning the new system will be more accurate in shallow waters while still reaching 30m or more. Tuell commented, “One great thing about GTRI is that we are tightly connected to the academic side of Georgia Tech. We’ve got a lot of great, young engineers with new ideas. We have some of them looking at new signal processing concepts for both the real time and post-processing algorithms, and we are investigating new telescope designs to preserve a large aperture lidar with a smaller telescope.”

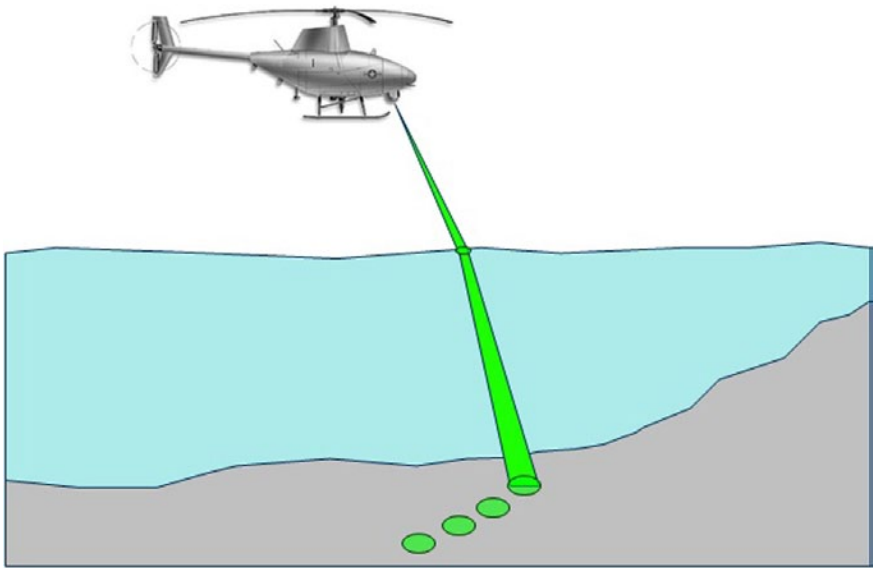

Figure 7: Courtesy of Dr. Grady Tuell, GTRI EOSL. Conceptual rendering of ALB operations aboard a UAV.

I asked Dr. Tuell why he thought GTRI-EOSL was ideally suited to undertake the challenge of pushing the performance boundaries of the “next generation” of airborne lidar bathymeters. He responded that, “Georgia Tech has a robust 25-year history in atmospheric lidar. In fact, just recently our atmospheric lidar group was awarded OSA’s Paul F. Forman Engineering Excellence Award. Atmospheric lidar and bathymetric lidar are similar in that both applications use pulsed lasers and high speed digitizers to produce lidar waveforms, and those waveforms are analyzed with various decomposition and inversion algorithms to produce estimates of environmental parameters of interest.”

Tuell continued, “ They differ in that atmospheric lidars are generally stationary, and are not usually portable, whereas bathymetric lidars are smaller, rugged, well-calibrated, and precisely navigated. But the basic engineering skill sets (optical engineering, mechanical engineering, electrical engineering, physics, mathematics, etc.) and the laboratory infrastructure required are exactly the same. So, at GTRI we are adding geomatics, miniaturization, and thermal management skills to a well-established laboratory infrastructure.”

Acknowledgements

Special Thanks to the following experts who provided guidance and insight on the technology and industry outlook:

Carol Lockhart, Hydrographer with Geomatics Data Solutions, LLC. “Geomatics Data Solutions are experts in developing geospatial work flows, with the capability to plan, acquire, process, analyze and quality control hydrographic lidar, topographic lidar and multibeam survey data for various and diverse projects around the world.”

Dr. Grady Tuell, Remote Sensing Group Lead/Principal Research Scientist, Electro-Optical Systems Laboratory, Georgia Tech Research Institute

Dr. Chris Parrish, Lead Physical Scientist, NOAA/NGS Remote Sensing Div., University of New Hampshire, NOAA-UNH JHC/CCOM

Kutalmis Saylam, Research Engineering/Scientist Associate, Bureau of Economic Geology, The University of Texas at Austin

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