

The Impact of Single Photon SLR Technology on Large Scale Topo-Bathymetric Mapping

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1. INTRODUCTION

Sigma's single photon lidars (SPLs) derive much of their heritage from early NASA work on the single photon sensitive SLR2000 system and the first generation "Microaltimeter" [1]. The SPL is the most efficient 3D lidar imager possible since each range measurement requires only one detected photon as opposed to hundreds or thousands in conventional laser pulse time of flight (TOF) altimeters and imagers. This high efficiency translates to either significantly less mass, volume, and prime power or orders of magnitude more imaging capability in terms of areal coverage, spatial resolution, etc. Single photon sensitivity, combined with our fast recovery (nanosecond) multistop detectors and timing receivers, enables the lidar to operate in daylight and penetrate porous obscurations such as vegetation, ground fog, thin clouds, water columns, camouflage, etc. The technology makes contiguous, high resolution topographic and bathymetric mapping on a single overflight possible with very modest laser powers and telescope apertures – even from orbital altitudes.

2. HERITAGE

Unlike the first generation NASA Microaltimeter, which used a single low power beam ($2 \mu\text{J} @ 3.8 \text{ kHz} = 7.6 \text{ mW}$), later generations use higher power lasers (up to 15 W at 532 nm) and repetition rates up to 60 kHz. In addition, a passive Diffractive Optical Element (DOE) in the transmit beam generates 100 beamlets per pulse, thereby increasing the surface measurement rates by two orders of magnitude over the laser repetition rate, i.e. up to 6 Million pixels per second for a 60 kHz pulse train. The 100 beamlets are typically arranged into a 10x10 array and the ground area is imaged onto a matching pixelated detector and multichannel timing receiver capable of recording multiple photon events per pulse separated by as little as 2 nsec. High speed and contiguous scanning has been accomplished using single or double wedge scanners, shared by both the transmitter and receiver and capable of generating a wide variety of scan patterns including linear, rotating line, conical, spiral, etc. Figure 1 provides a collage of sample data obtained by our second generation "Leafcutter" system designed to operate at 1 to 2.5 km AGL (Altitude above Ground Level).

Later Sigma SPL generations, pictured in Figure 2, were designed to operate at higher AGLs [2]. These included the moderate altitude High Resolution Quantum Lidar Systems (HRQLS-1 and 2) and the High Altitude Lidar (HAL). As the aircraft (AGL) increases, the pulse time-of-flight (TOF) increases, thereby resulting in an offset between the transmitter and receiver Fields-of-View (FOVs) and a subsequent loss of signal counts unless a corrector wedge, acting only on the transmit or receive beams, is attached to each of the rotating wedges. Although the corrector wedge is designed for a nominal pulse Time of Flight (TOF), alternative TOFs can be accommodated by varying the scan speed such that the product of the scan speed and TOF is a constant. Furthermore, the use of the green 532 nm wavelength, which experiences relatively little attenuation in water, allows both topographic and bathymetric measurements to be made by the same instrument. Most commercial lidars operate at the fundamental Nd:YAG wavelength at 1064 nm which is strongly absorbed in water. Our smallest SPL, the Mini-ATM, was designed to fit into a Viking 300 Mini-UAV and perform Cryospheric measurements in Greenland as a possible replacement for NASA's

venerable Airborne Topographic Mapper (ATM) and had its first successful flight in December 2010.

Non-scanning (or so-called “pushbroom”) versions of our SPL, as exemplified in NASA’s 24 beam MABEL lidar, have successfully generated multiple 2D profiles from the ER-2 aircraft at altitudes of 20 km [3]. MABEL serves as a test bed for the ATLAS SPL lidar on NASA’s ICESat-2 mission [4], which is scheduled to be launched in 2018. With a 10 kHz laser fire rate, the 6-beam ATLAS SPL will generate up to 60,000 surface returns per second compared to only 40 per second for the conventional multiphoton lidar on ICESat-1. Recent link analyses indicate that a 100 beamlet system based on the ICESat-2 transmitter and a nominal 50 cm aperture telescope, comparable to what was previously flown on the Mars Orbiter Laser Altimeter (MOLA), could generate roughly 1 Million measurements per second from a 100 km orbit about the Jovian moons [5].

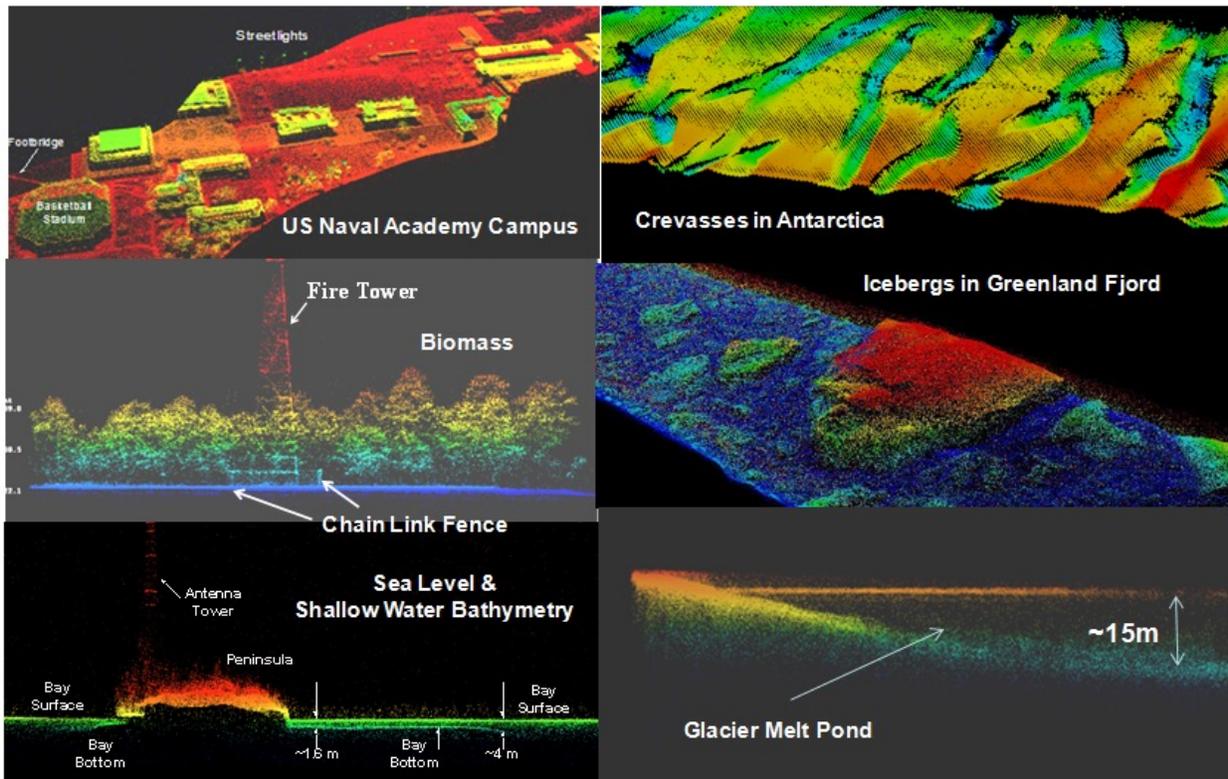


Figure 1: A collage of 3D lidar images collected by our 2nd Generation “Leafcutter” SPL which typically operated at an AGL of 1 km over mid-latitude terrains (left) and up to 2.5 km AGL in Cryospheric environments due to higher surface reflectances (right).

3. SAMPLE DATA

We now present several figures that represent special capabilities of the Sigma SPLs developed to date. The high measurement rates, measured in Megapixels per second, combined with the ability to generate contiguous maps on a single pass at aircraft speeds in excess of 200 knots (370 km/hr) make the systems ideal for rapid large scale mapping at high resolution. One early example was the mapping of Garrett County, a mountainous and forested area occupying over 1700 km² in Western Maryland USA, in just 12 hours in exquisite detail (see Figure 3).



Figure 2: Sigma SPLs built to date from the highest to lowest AGLs: (a) NASA MABEL Pushbroom Lidar; (b) HAL ; (c) HRQLS-1 and 2; and (d) Mini-ATM

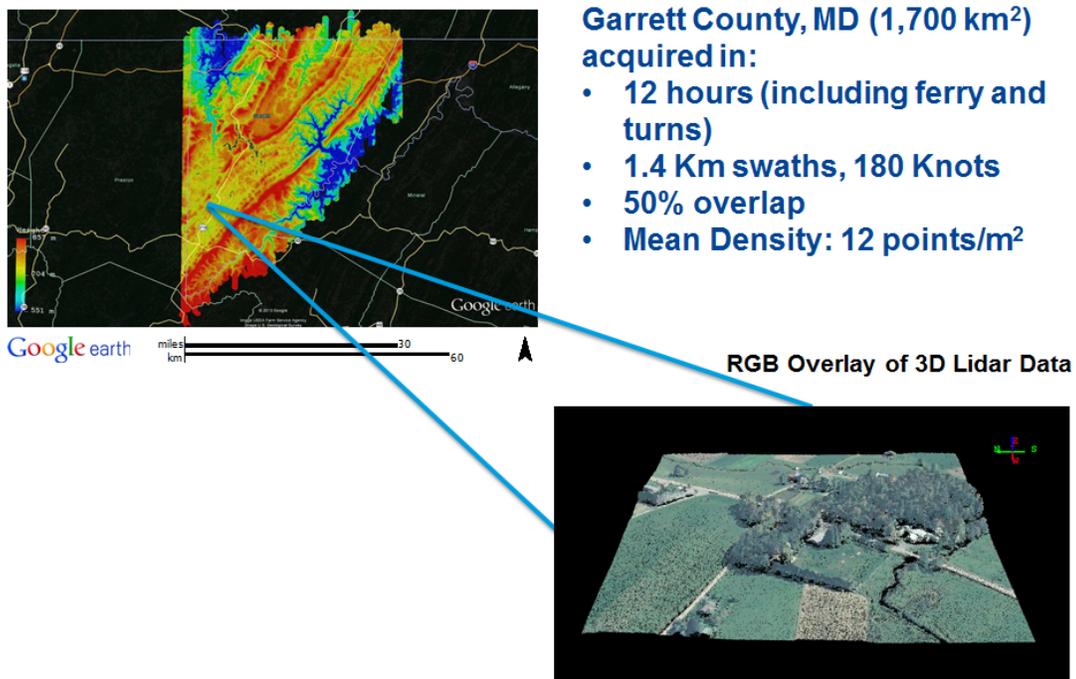
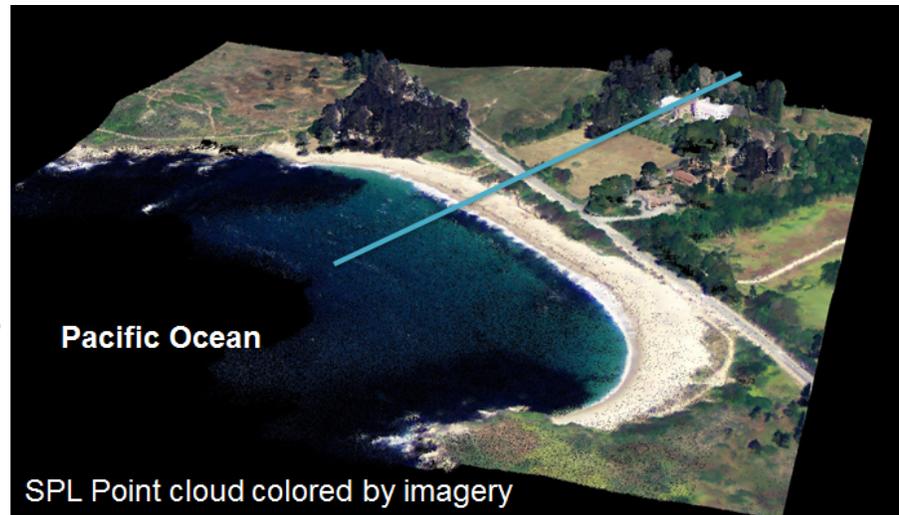


Figure 3: Rapid Large Scale Mapping: HRQLS-1 mapped an entire county in Western Maryland, USA in only 12 hours . The top left image provides an elevation map of the entire county (~1700 km²) but there is tremendous detail as indicated by the 3D RGB colored lidar image in the lower right corner.

Although most conventional photon lidars operate at the fundamental Near InfraRed (NIR) wavelength of 1064 nm, the Sigma SPLs operate at the frequency-doubled wavelength at 532 nm which has relatively low transmission losses in water. This permits the seamless gathering of both topographic and bathymetric data with a single instrument as illustrated in Figure 4.

Sample:
Double Pass
AGL: 7500 ft
Velocity: 180 knots



Profile

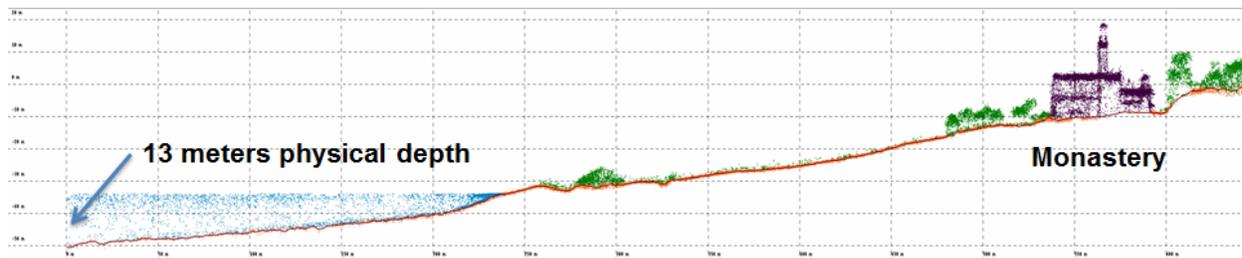


Figure 4: Topo-Bathymetric Capabilities: Top, Two pass HRQLS-1 3D lidar map of Point Lobos, California colored by imagery; Bottom. 2D topo-bathymetric profile corresponding to the blue line in the top map. The latter shows the complex structure of the monastery on the top of the hill to the right, some low level vegetation and the ground below it leading to the ocean beach. Both the ocean surface and the bottom are clearly mapped down to a physical depth of 13 meters.

Where extremely high resolution is required, multiple passes of the lidar over the scene can result in a very high concentration of measurements per square meter. In Figure 5, only two passes were required to map a cruise ship docked in Fort Lauderdale, Florida USA. In the same figure, a few passes over a power grid in the state of North Carolina from an AGL of 1.8 km resulted in an average point density greater than 40 points per square meter and a fairly detailed image of the overall grid.

Independent assessments of geolocation quality in a number of controlled field experiments have indicated that the data density and elevation accuracy of the HRQLS SPLs meet the highest standards (Quality Level 1 or QL-1) of the United States Geological Survey (USGS), i.e. density ≥ 8 points/m² and elevation accuracy <10 cm. For other insights into the SPL technique, its advantages over conventional multiphoton or competing Geiger Mode (GM) systems, noise filtering techniques, and additional data examples (tree canopy penetration, tree canopy structures, and the lidar visualization of both small and large manmade structures), please view the accompanying Power Point Presentation on this website.

HRQLS-1 image of a Cruise ship docked in Ft. Lauderdale, Florida

HRQLS-1 image of a powerline grid in North Carolina

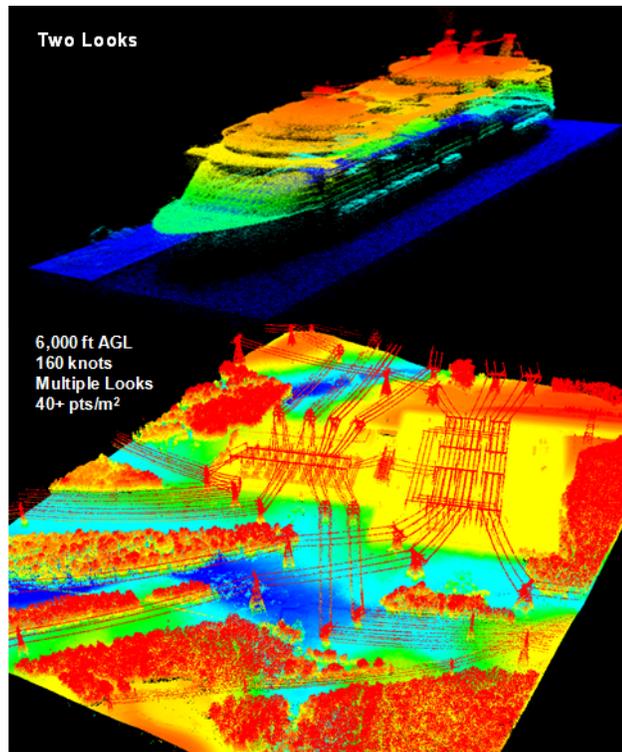


Figure 5: High density HRQLS-1 maps of a cruise ship docked in Ft. Lauderdale, Florida (2 looks) and a powerline grid in North Carolina (multiple looks with 40+ measurements per square meter).

4. SUMMARY

Our 100 beam scanning SPLs have provided decimeter level (horizontal) and few cm RMS (vertical) resolution topographic maps from aircraft AGLs up to 28 kft. Data rates to date have varied between 2.2 and 6 million 3D pixels per second., up to 60 times faster than conventional multiphoton lidars. Our smallest lidar, Mini-ATM, designed for cryospheric measurements, weighs only 28 pounds (12.7 kg), occupies 1 ft³ (0.028 m³), has a ± 45 degree conical scan, fits in a mini-UAV, and covers more area with higher spatial resolution than the much larger and heavier predecessor NASA ATM system. In addition, the 24 beam NASA MABEL pushbroom SPL has operated successfully at AGLs up to 65 kft. Using a laser comparable to that developed for the ATLAS SPL on NASA's ICESat-2 and a nominal 50 cm diameter telescope, one could globally map the three Jovian moons from a 100 km orbit with better than 5 m horizontal resolution in 1 month for Europa or 2 months each for the larger moons, Ganymede and Callisto.

Our low deadtime (1.6 nsec) detectors and range receivers permit daylight operation and multiple range measurements per pixel on a single pulse, allowing penetration of volumetric scatterers such as tree canopies, water columns, ground fog, etc. This gives SPL an important advantage over competing single photon sensitive Geiger Mode (GM) Systems where a detector dark count, a solar noise count, or laser photon backscattered from a tree canopy will disable the pixel until the next pulse. See the accompanying presentation on this website for direct comparison of SPL

with the GM technique. Our moderate to high altitude lidars built to date have been designed to provide contiguous topographic and bathymetric maps on a single overflight at aircraft speeds up to 220 knots (407 km/hr). Point densities (>8 points /sq. m and geolocation errors (<10 cm in elevation) are compliant with the top standards (QL1) of the United States Geological Survey (USGS). With multiple looks at an object or surface, more than 40 pts/m² have been collected, allowing thin (e.g., networks of electrical cables) or complex objects (e.g a cruise ship) to be mapped in detail.

REFERENCES

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