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1 Introduction

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To the Pioneers, and to those who keep the Faith

This book was written to document and share our updated knowledge of airborne lidar hydrography gained since Gary C. Guenther wrote the original seminal book *Airborne Laser Hydrography - System Design and Performance Factors* over 30 years ago. Like the first book, commonly referred to as *the Blue Book*, this *Blue Book II* updates the history, theory, and design challenges of bathymetric lidar. However, with over 30 years of advancements and most importantly with thousands of hours of operational experience from different international teams and system, *Blue Book II* provides knowledge gained through decades of operational experience over a wide range of applications and environmental conditions. Mr. Guenther's *Blue Book* laid the foundation that over 16 authors from a half dozen countries update in *Blue Book II*.

The Joint Airborne Lidar Bathymetry Technical Center of Expertise (JALBTCX) is a U.S. organization that focuses on lidar bathymetry and provides a U.S. focal point with international collaboration. Its mission is to perform operations, research, and development in airborne lidar bathymetry and complementary technologies to support the coastal mapping and charting requirements of the U.S. Army Corps of Engineers (USACE), the U.S. Naval Meteorology and Oceanography Command, the National Oceanic and Atmospheric Administration (NOAA), and the U.S. Geologic Survey (USGS). JALBTCX staff includes engineers, scientists, hydrographers, and technicians from the USACE Mobile District, the Naval Oceanographic Office, the USACE Engineer Research and Development Center, NOAA National Geodetic Survey, and the USGS Earth Resources Observation & Science Center.

JALBTCX executes survey operations worldwide and year-round using its third-generation systems named the Coastal Zone Mapping and Imaging Lidar (CZMIL) system as well as using other industry-based coastal mapping and charting systems. CZMIL is JALBTCX's in-house survey capability that includes a lidar instrument with simultaneous topographic and bathymetric capabilities integrated with a hyperspectral imager and a true-color high-resolution digital camera. JALBTCX research and development supports and leverages work in government, industry, and academics to advance airborne lidar and coastal mapping and charting technology and applications. The research is shared through various conferences, peer reviewed journals, and at the Annual Airborne Coastal Mapping and Charting Workshop sponsored by JALBTCX. The annual workshop participants typically include all the international teams and it is from this annual workshop that the collaboration for the *Blue Book II* originated.

In the 1980's and 1990's the majority of operational bathymetric lidar systems focused on hydrography for nautical charting and for surveying navigation channels to determine shoaling. These systems included the Laser Airborne Depth Sounder (LADS) in Australia, the Larsen 500 in Canada, the Scanning

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Hydrographic Operational Airborne Lidar Survey (SHOALS) system in the United States, and the HawkEye system in Sweden, see Chapter 2 for a full history of these and other systems. As Chapter 2 points out there were various predecessors to these operational systems and other similar lidar systems developed for military applications. The focus of *Blue Book II* is on bathymetric lidar for nautical charting and coastal mapping.

Airborne lidar bathymetry began in the Unites States and elsewhere primarily focused on hydrography because accurate depths needed only two-dimensional positioning of the aircraft, which was possible in the 1970's and 1980's using microwave transponders. Depth measurements were calculated as a function of the laser light's time difference between the surface reflection and the bottom reflection, then corrected for light propagation and water surface fluctuations (waves and tides, river stage), to produce a measurement that met nautical charting accuracy standards. It was not until kinematic GPS in the 1990's that aircraft could be accurately positioned in three dimensions and airborne lidar could accurately produce above-water or topographic elevations. Once able to measure topography and bathymetry (topo/bathy) bathymetric lidar systems became a very valuable tool for mapping the ever-changing coastal region, both below and above water to support coastal zone management and regional sediment management requirements. Today, the combined topo/bathy applications are driving the requirements for mapping and future system designs.

Airborne lidar elevations are produced as a function of the travel time of a pulse of laser energy. A survey is produced by scanning a rapidly pulsing laser across the flight path of the aircraft, thus covering an area typically several hundred meters wide at aircraft speeds of 70 m/s to 100 m/s. The faster the laser pulses, the closer the measurements are spaced. For a constant laser pulse rate, the aircraft flying slower or faster and flying higher or lower may also adjust measurement spacing. There is a lot of physics involved when light passes through one medium into another. To accurately calculate depths requires understanding the physics and making design decisions that minimize adverse impacts. Chapter 3 *Environmental Optical Properties* describes the physics and optical properties associated with light propagation through the atmosphere, water surface, water column and the bottom. Chapter 4 *Basic Concepts and System Design* gives detail on system considerations, constraints and tradeoffs for signal processing of lidar waveforms to produce accurate results.

Producing an accurate elevation from a lidar pulse requires georeferencing the sensor using satellite a navigation system and an inertial measurement sensor. Knowing the exact location of an elevation begins with knowing the position and attitude of the laser pulse as it transmits through the sensor, out of the aircraft, through the atmosphere, air/water interface, water column reflecting off the bottom and returning along a similar path to the aircraft. In addition to the elevation and position, radiometrically calibrated bathymetric lidar systems may produce return signals that provide additional information about the water column, sea bottom and other environmental factors. Chapter 5 *Basic Concepts in Data Processing* provides more information on how this is done and what may be extracted through additional data processing.

The final two chapters address operational characteristics that were not covered in the first Blue Book; Chapter 6 *Performance Evaluation* and Chapter 7 *Applications, Ancillary Systems, Fusion* provide insight and best practices based on operating several generations of lidar bathymeters over thousands of hours. They cover topics on sensor calibration and what to test routinely to determine system health as well as

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non-standard radiometric calibration and calibrations based on survey mission type. Chapter 7 transforms lidar bathymetry into coastal mapping and charting with the addition of other complementary sensors and the fusion of data across sensors. The examples show by adding additional sensors to the aircraft the combined or fused data may produce information none of the individual sensors alone are capable of. It is through this chapter that you see the transformation from a nautical charting focus to a coastal mapping and charting tool capable of supporting a wide range of applications.

Lidar bathymetry is an enabling tool that supports airborne coastal mapping and charting as well as other uses. What began in the 1970's with a focus on hydrography and nautical charting has charted thousands of square miles worldwide. Since the 1990's lidar bathymetry with complementary sensors has expanded to support coastal zone management and regional sediment management missions and already mapped thousands of miles. Actually, today it is likely that more missions are flown supporting these new applications than nautical charting, and the list of applications continues to grow.

It is interesting how the international bathymetric lidar teams challenged by the same physics, designed systems differently as the developers addressed the various tradeoffs to enhance system performance most important to their primary applications. This resulted in unique systems and design philosophies, each with slightly different operational strengths. An intrinsic value of *Blue Book II* is that the knowledge gained through these teams is included for the next generation to use to solve new challenges and create future systems. Also of note, what began in the 1980's with healthy competition has today become a global community that shares knowledge and lessons learned through various technical conferences, especially through the annual technical workshop sponsored by JALBTCX. Together these teams have pushed themselves, each other, and lidar bathymetry technology well beyond what was originally imagined. *Blue Book II* documents what we have learned and was produced to aid and encourage others who will continue to evolve lidar bathymetry and complementary sensors to measure and monitor the coastal and nearshore environment.

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AIRBORNE LASER HYDROGRAPHY II