Introduction to LIDAR

NPS Lidar Workshop
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Joe Liadsky
Optech Incorporated

Lidar topics

- Basic principle of operation
- Desirable attributes and features of a system
- Examples of data produced

LIDAR: Light Detection and Ranging

- In addition to ranging, Lidar systems can provide:
  - additional information about the target (for classification)
  - information about the transmission path (e.g. atmospheric lidar to measure concentration of elements in the atmosphere)
- Talk will focus on lidar system for obtaining spatial information about a target i.e. mapping and imaging systems

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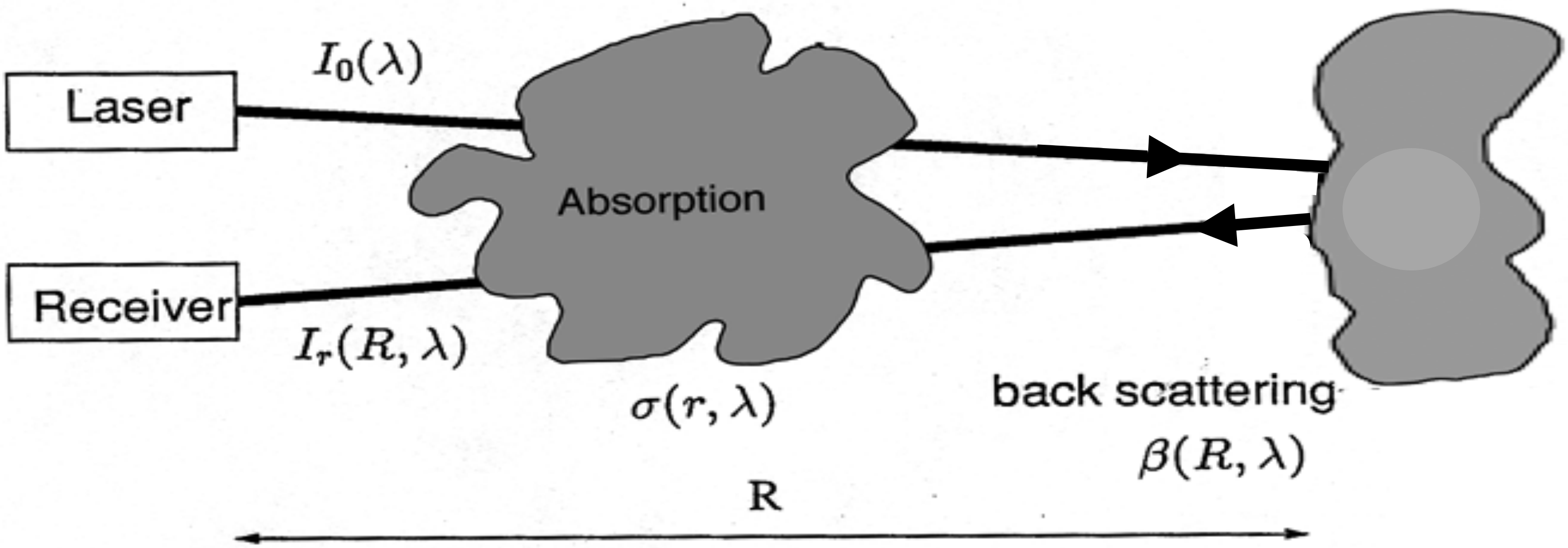
Lidar Principle of Operation



Lidar equation:

$$I_r(R,\lambda) = I_0\eta\frac{A}{4\pi R^2}\beta(R,\lambda)\exp\left(-2\int_0^R \sigma(r,\lambda)dr\right)$$

β → reflectance or backscattering coefficient (Rayleigh, Mie, Raman, fluorescence)

σ → extinction coefficient (absorption, scattering)

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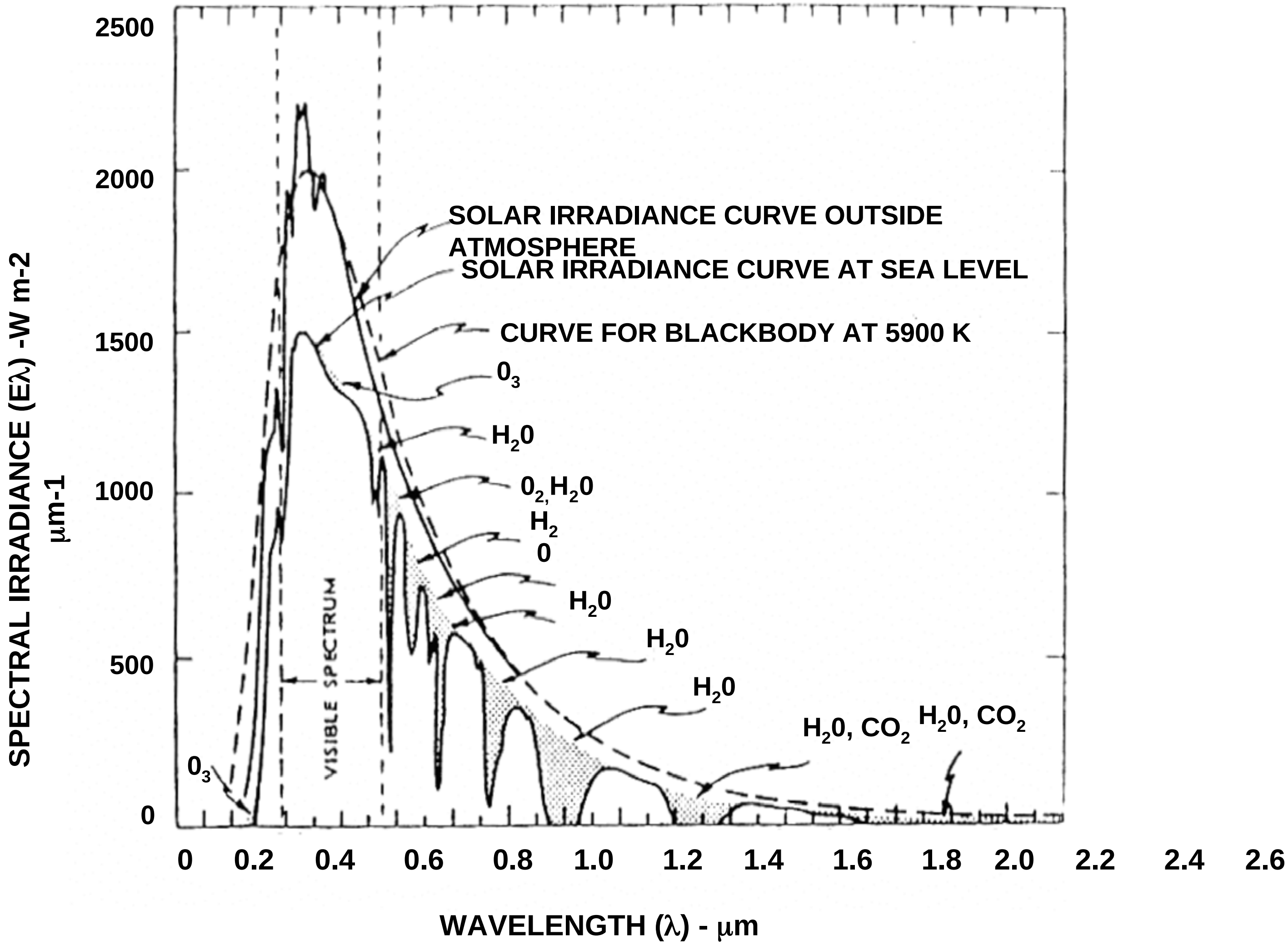
Choice Of Laser Wavelength

- Characteristics of transmission medium
  - Absorption of atmosphere
  - Transmission of water (bathymetry applications)
- Reflectance of targets
- Eye-safety considerations
- Availability of suitable lasers and detectors

Atmospheric Spectral Transmission



(Lidar applications must balance transmission and absorption)

The 'Jerlov' Curves

- Diffuse attenuation in sea water vs.wavelength

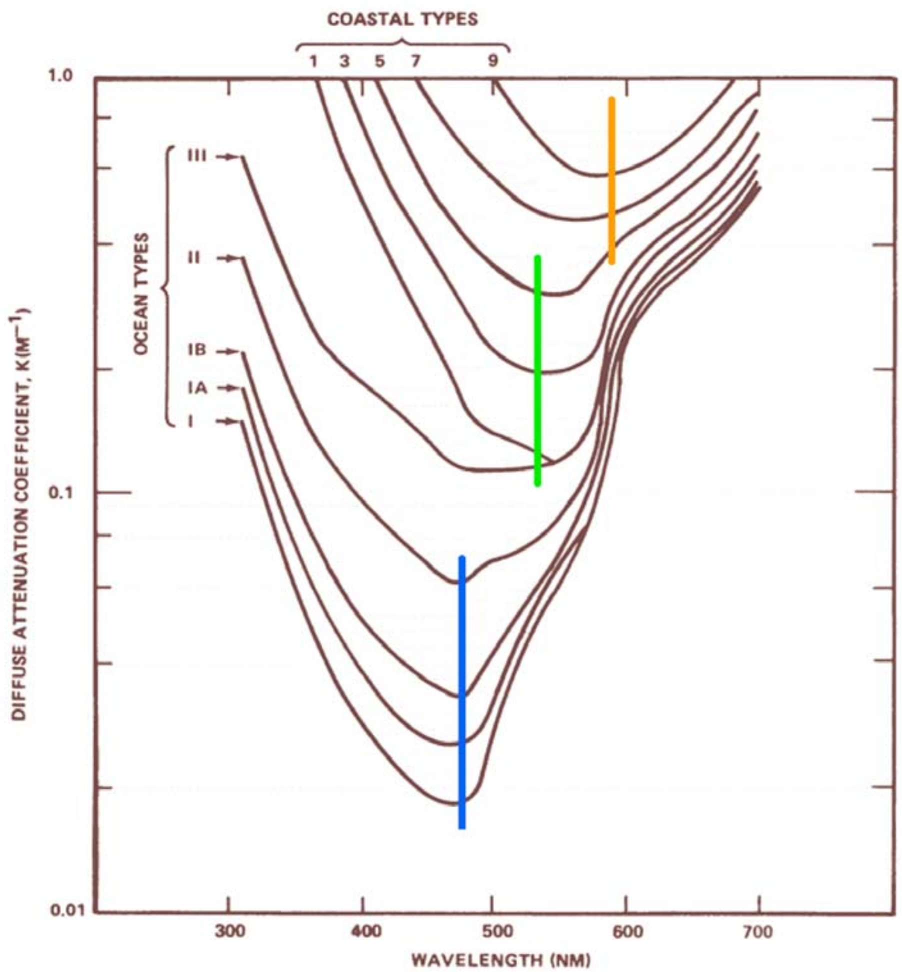
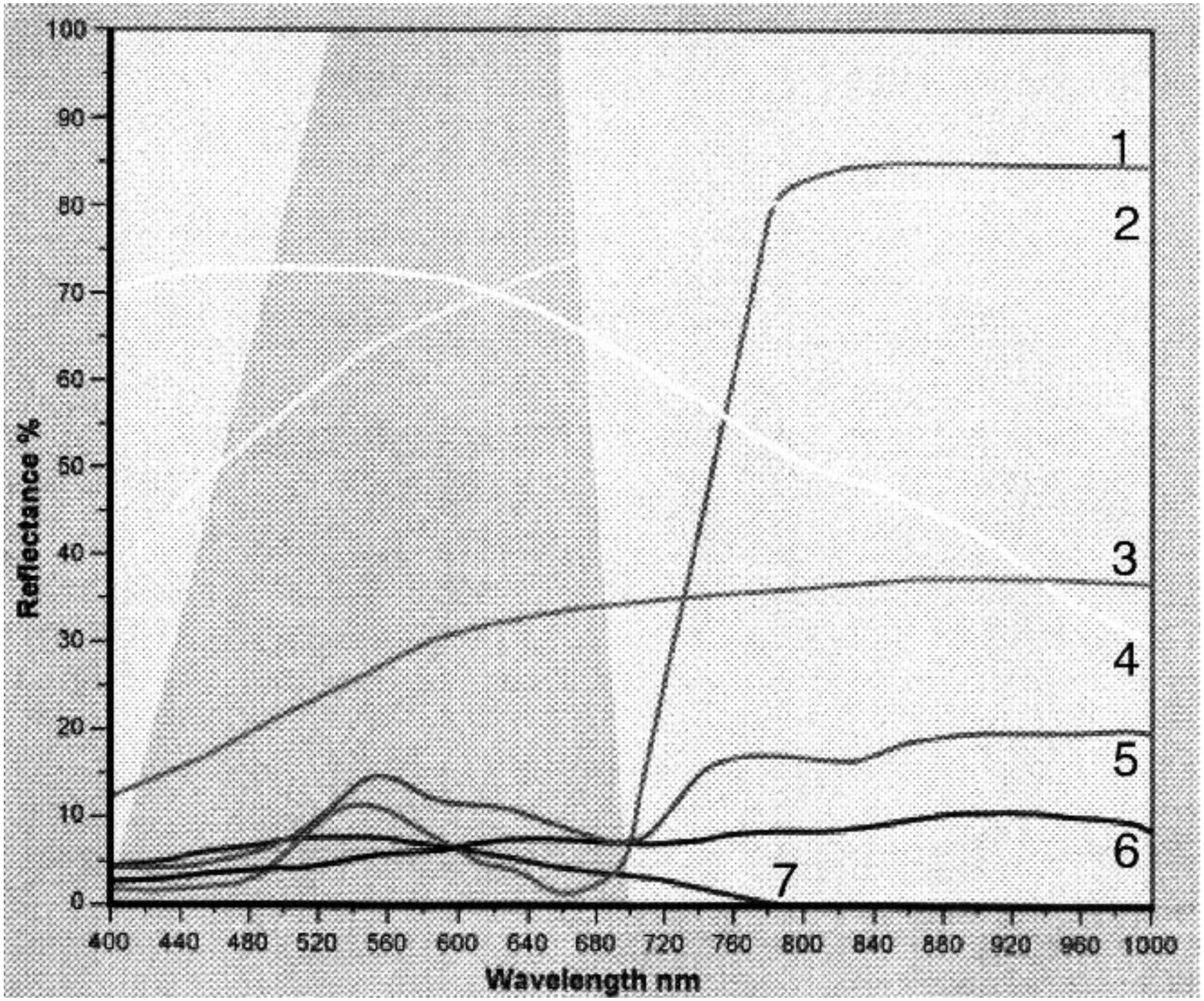


FIGURE 3–1. SPECTRAL DIFFUSE ATTENUATION COEFFICIENT FOR OCEAN WATERS (REF: JERLOV, 1976)

Credit: Jerlov, N.G., 1976. Marine Optics, Elsevier Scientific Pub. Co., Amsterdam, 231 pp.

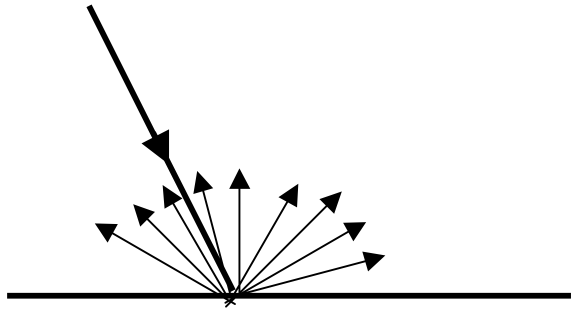
Spectral Reflectance Of Various Target Types



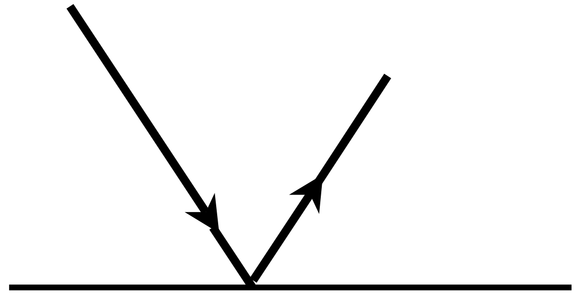
LEGEND

1 Grass
2 Lime Stone
3 Sand, dry
4 Snow, old
5 Fir tree
6 Asphalt, wet
7 Water

Radiometric Aspects: Target Reflectance



Lambertian-type surface
(most natural surfaces)



Specular-type surface
(glass, water….smooth-wet surfaces)

- Weather conditions affect reflectance properties: e.g. surface wetness changes reflectance from Lambertian to specular
- Maximum range decreases dramatically for combination of steep, smooth, wet and black surface properties

Ranging techniques

- Pulsed time of flight
- CW systems
  - Modulate amplitude and measure phase shift between received and transmitted beams
  - Modulate frequency (chirp) and mix the received signal with transmitted signal

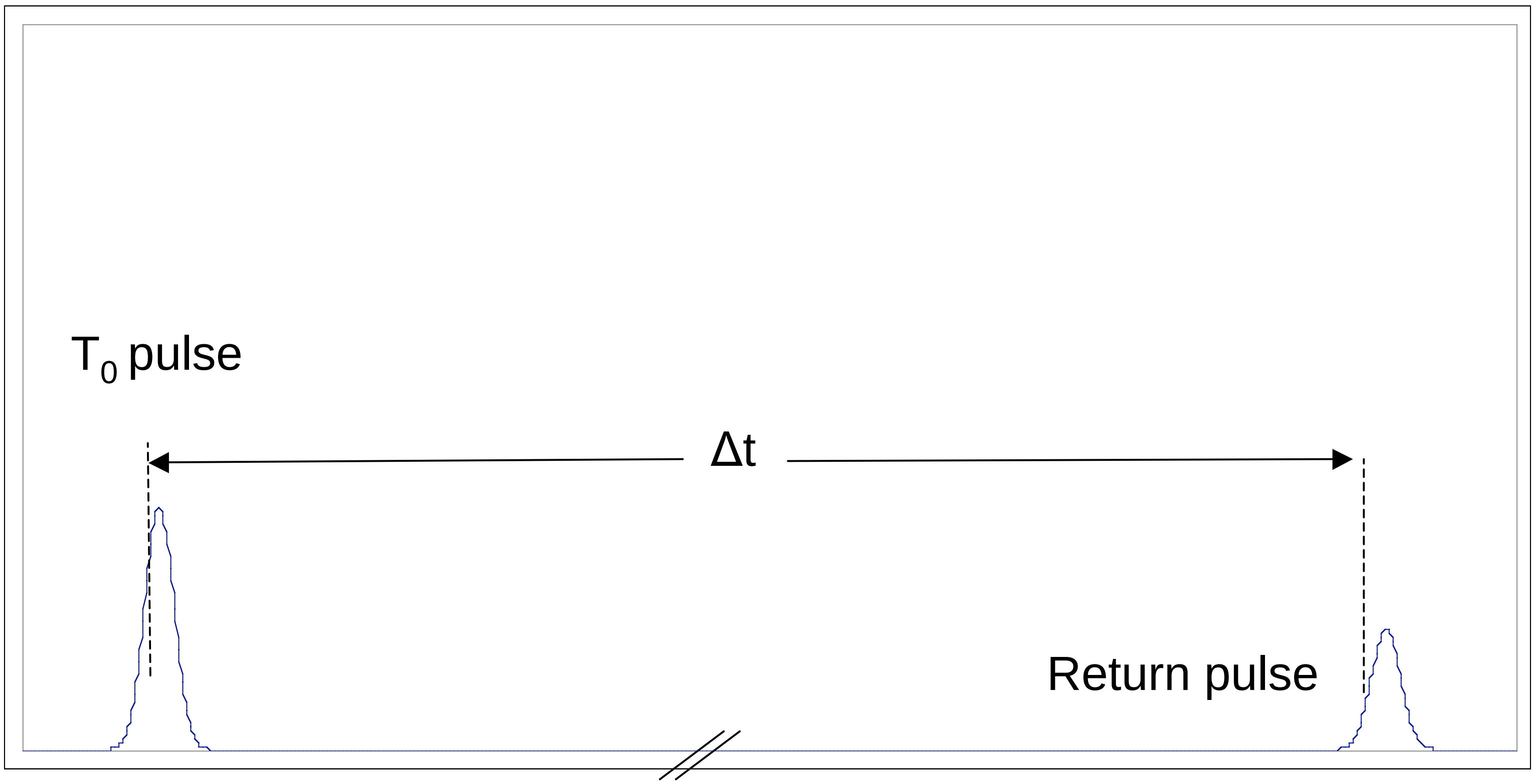
Detection schemes

- Direct detection
  - APD or PMT operating in linear mode
  - APD or PMT in Geiger mode (single photon detection; photon counting)
- Coherent detection

Direct detection time of flight

- Laser emits a short pulse which travels to the target and is reflected back to the receiver
- Range is determined by measuring the time of flight (using the speed of propagation, etc.)
- Time interval can be measured with a precision of 67 ps (corresponding to 1 cm range precision)

Time of Flight



Radiometric Apsects: Received Power

$$P_s(R) = P_\ell \frac{\rho_t A}{\pi R^2} \eta_o \eta_a^2$$

P_s = received signal power from transmitted laser pulse after scattering/reflecting from target

P_ℓ = power of the laser pulse

ρ_t = "effective Lambertian" reflectivity of the target

A_r = effective collection area of the optical receiver

R = slant range to the target from "sensor"

η_o = optical transmission efficiency of all optical components in the ALS

η_a = transmission efficiency of the atmosphere between sensor and target (at range R)

= exp (-σR) (e.g. σ ~ 0.3/km for 10 km visibility)

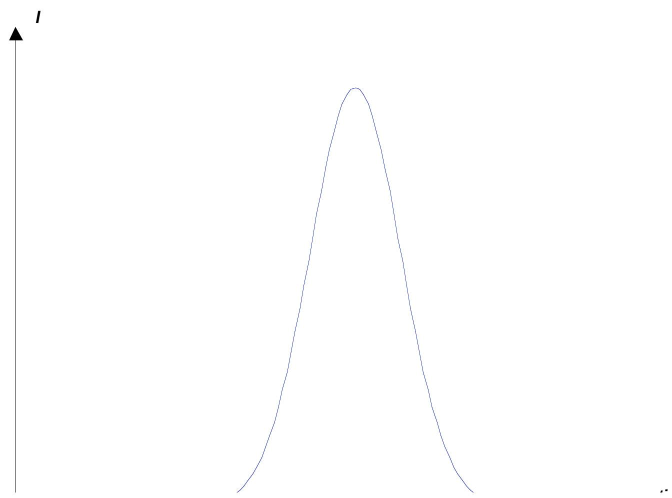
Note:

P_ℓ, A_r, η_o → **system hardware parameters**

ρ_t, η_a, R → **operating environment parameters**

Spatial Characteristics of Laser Beam

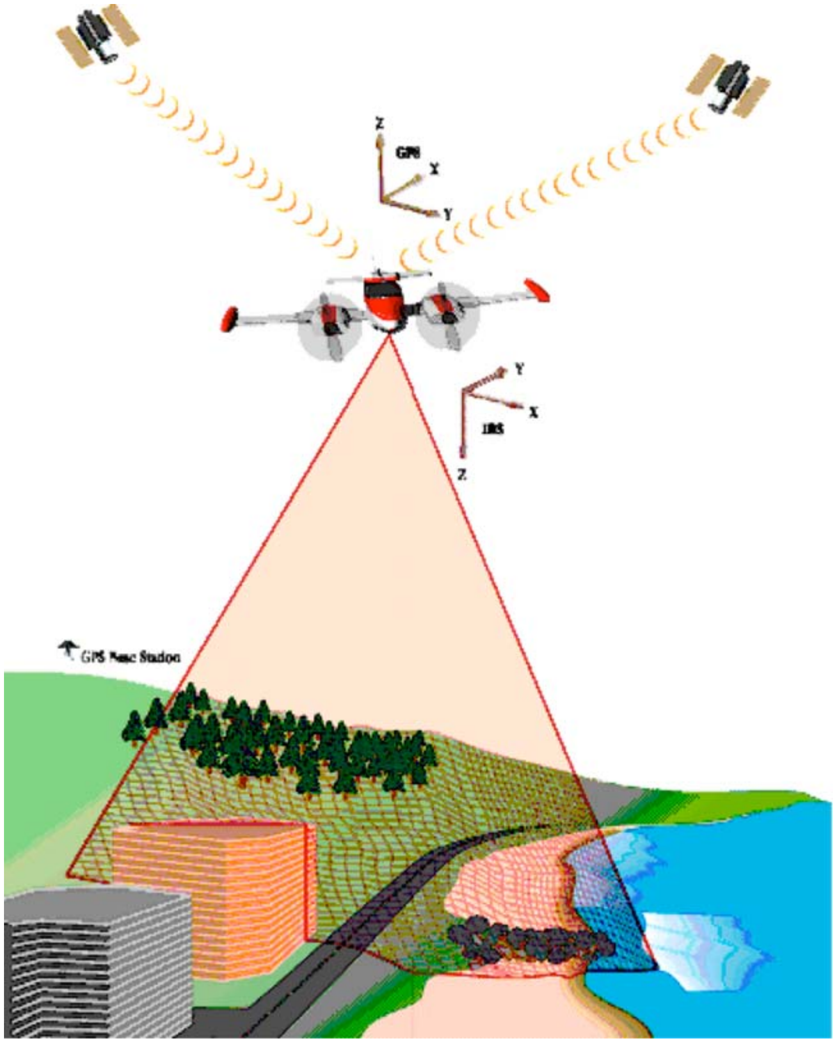
- Diverging Gaussian beam
- Spot size (footprint) at given range is typically given as the radius or the diameter of the contour where the intensity has fallen to either 1/e or to 1/e2 of the intensity of the peak.



Return Pulse Characteristics

- Return pulse shape is result of interaction of Gaussian beam
- Target characteristics influence return pulse shape
  - Sloping or rough terrain produces wider return pulses
  - Multiple targets separated by small distances produce
  - complex waveforms

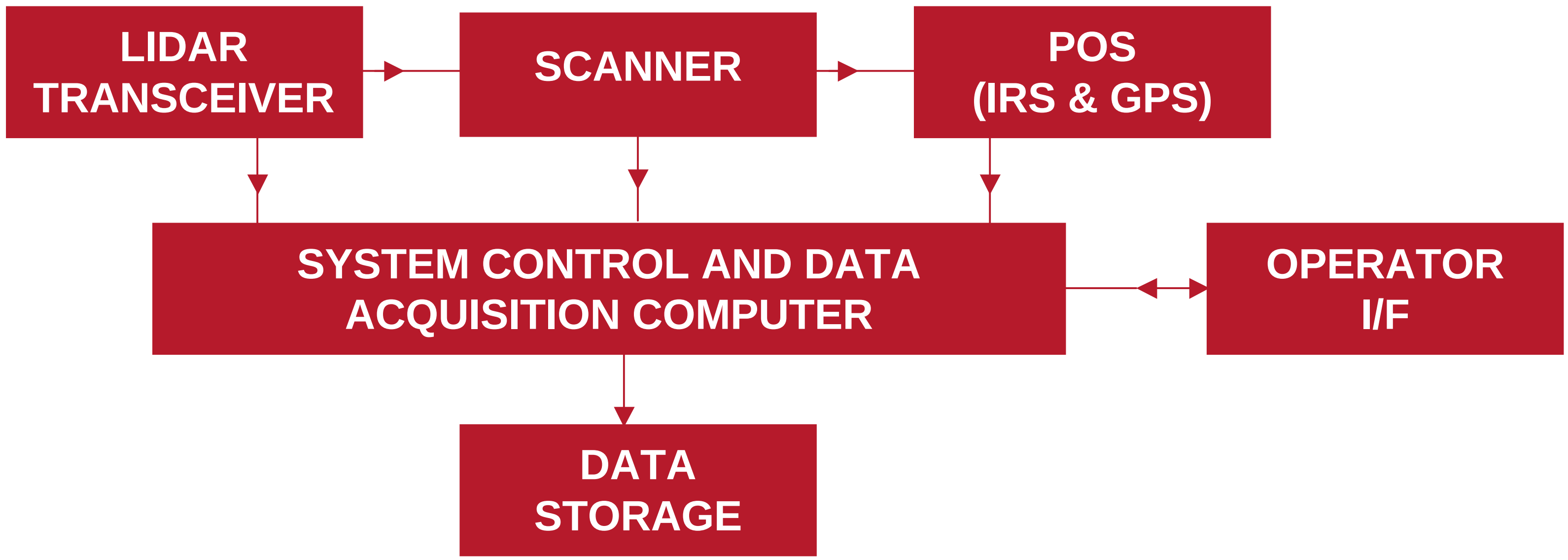
Airborne Laser Mapping System



Airborne Laser Terrain Mapper - ALTM 3100

- Rapid 3-D digital elevation data
  - Up to 100,000 measurements/sec
  - Fits in virtually any aircraft
  - Measures IR intensity, X,Y& Z
  - Vertical resolution: ~ 5 to 10 cm
  - Horizontal resolution: ~ 15 cm
  - Operational altitude: up to 3 km
  - Area coverage: up to 50 km²/h

Functional Block Diagram



Lidar Transceiver - Generates laser beam and captures laser energy scattered/reflected from target

Scanner - Moves laser beam across aircraft track

POS - Measures "sensor" position and orientation

Operator I/F - Permits operator interaction (control/monitor) with system

Data Storage - Captures all AIRBORNE system data required for generation of x, y, z "target" coordinates

Computer - Integrates/controls interaction of all of the above

ALTM (Airborne Laser Terrain Mapper)

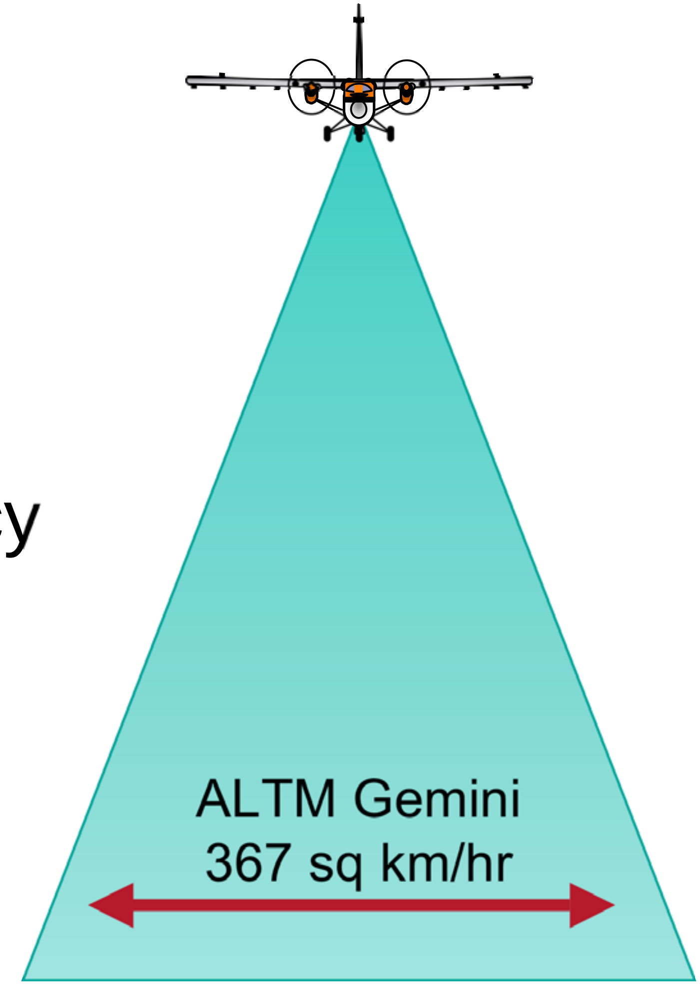
- System measures and outputs:
  - Range
  - Scan angle
  - Sensor position (in a given geodetic reference frame)
  - Sensor orientation (roll, pitch, heading)
  - Signal amplitude (intensity)
- Post processing software:
  - Calculates X,Y,Z coordinates (in the given geodetic reference frame)
  - Performs filtering and other functions

Data Processing Workflow

- Download data from removable hard drive
- Download GPS data from airborne system and base-station
- Compute aircraft trajectory from GPS & IMU data
- Compute laser points X,Y,Z
- Run (third party) application software

Key System Attributes

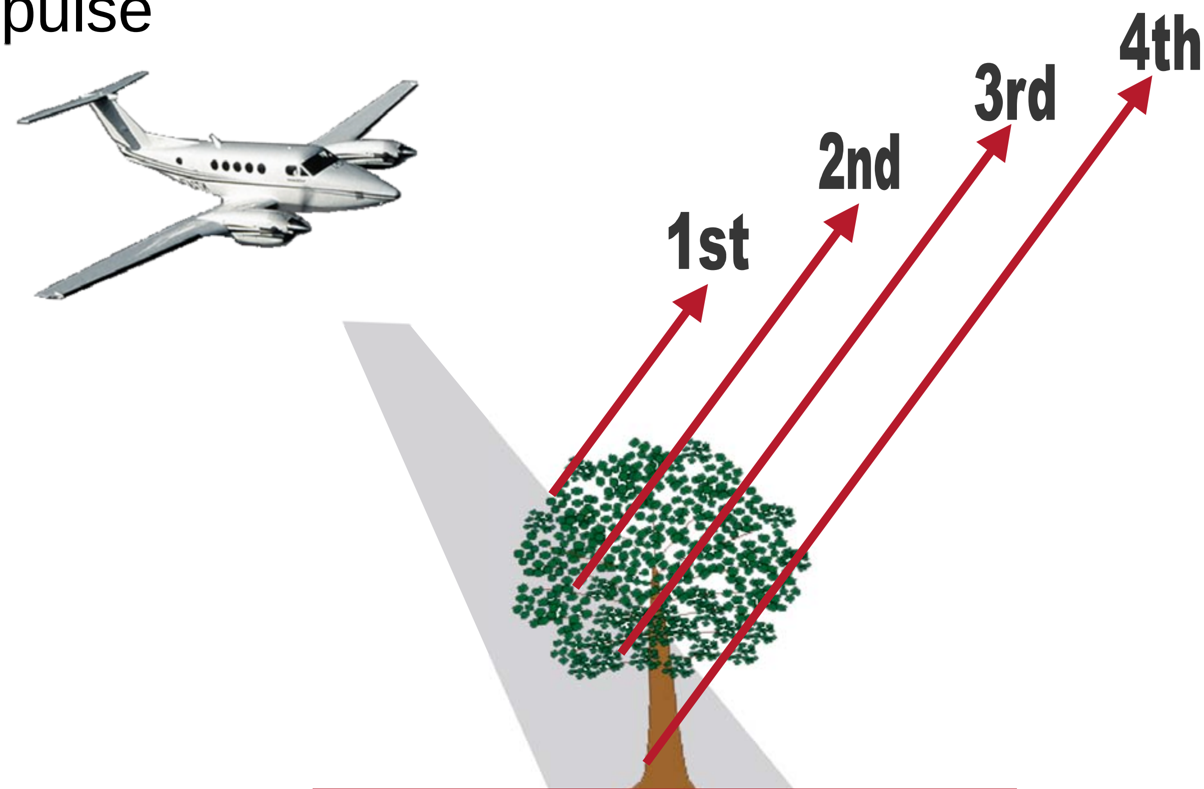
- Accuracy
- Maximum altitude
- Area coverage (swath width)
- Spot distribution/scan pattern
- Laser pulse repetition frequency
- Spot size (footprint)
- Multiple return pulse capability



The fundamental question : Why use LIDAR?

- LIDAR offers advantages over more conventional means of survey that include:
  - Day or night operation
  - Efficient acquisition of millions of elevation points per hour
  - Faster coordinate acquisition than traditional methods
  - All digital: no intermediate steps to generate digital XYZ
  - Rapid turnaround: Capable of “overnight” processing
  - Captures multiple returns per pulse with intensity information
  - Dense data
  - Accurate: Elevation +/- 10 cm (or better)
  - Airborne: Easy to mobilize and demobilize
  - Non-Intrusive method of survey (airborne) capable of accessing remote areas

- Optech's ALTM 3100 has the distinct feature of recording 1st, 2nd, 3rd, and Last returns + Intensity for each pulse



Very useful for forestry studies

Multiple Returns

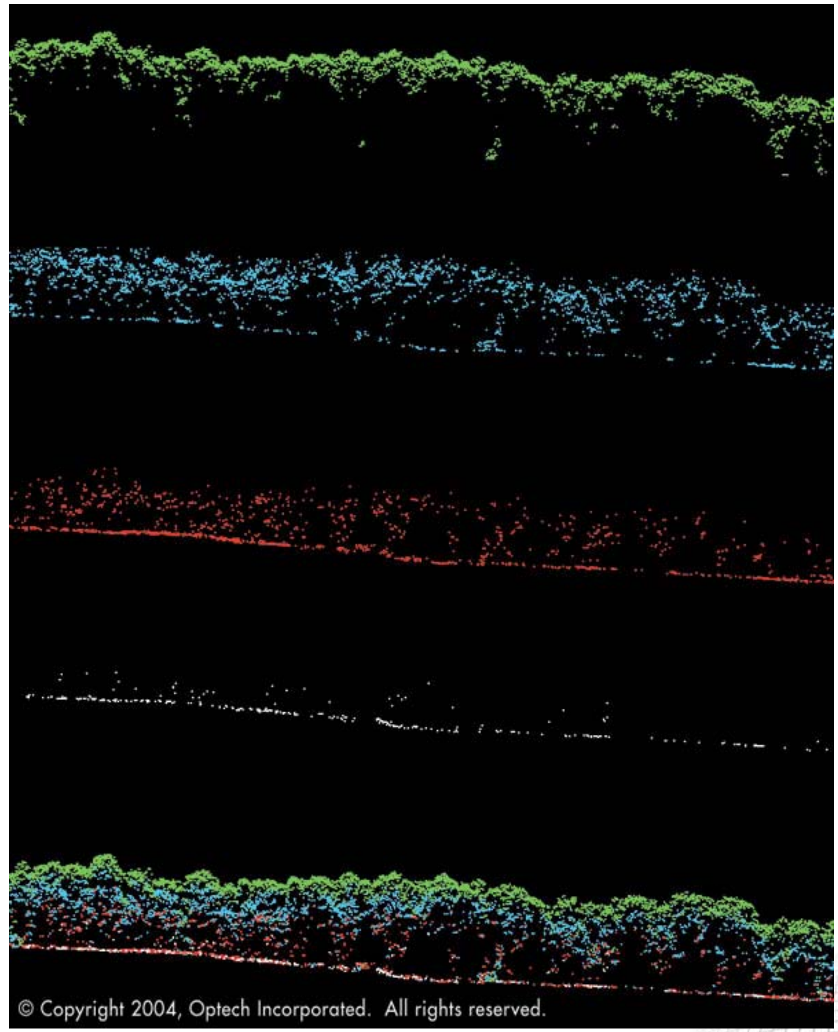
First Returns

Second Returns

Third Returns

Last Returns

All Returns



Multiple Returns

First Returns

Second Returns

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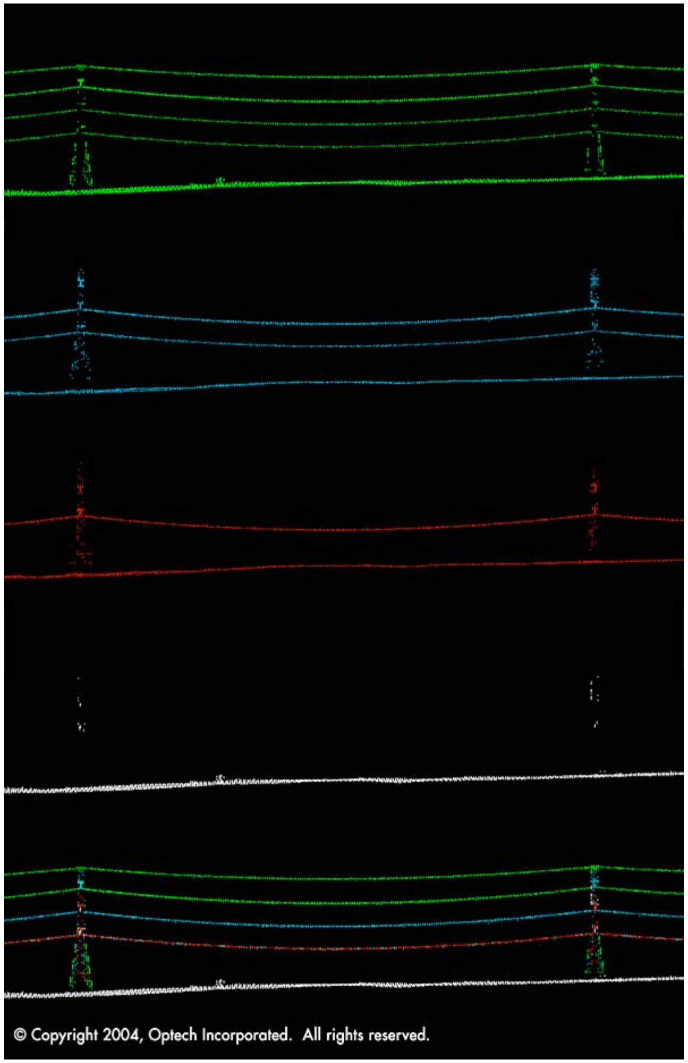
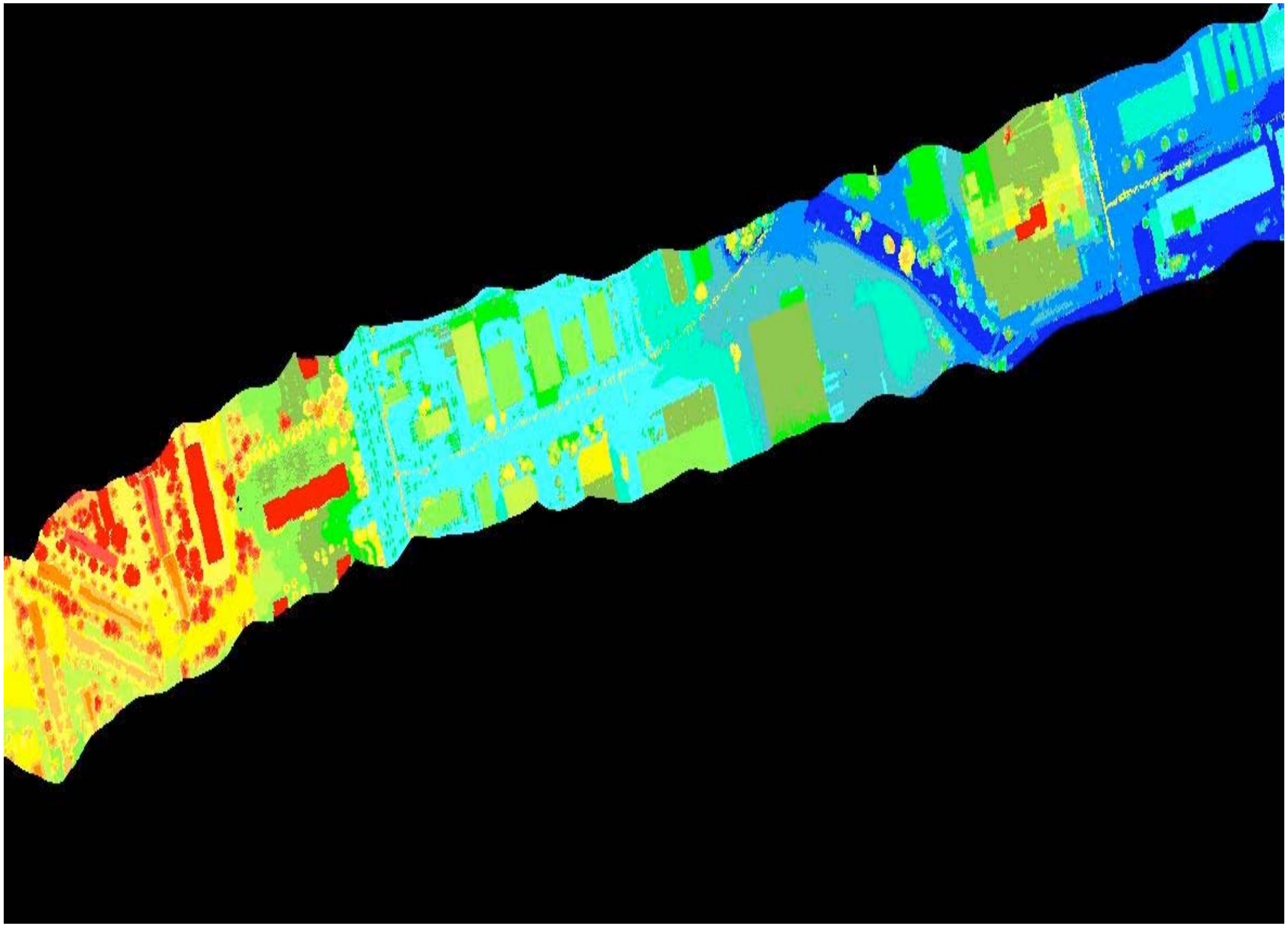
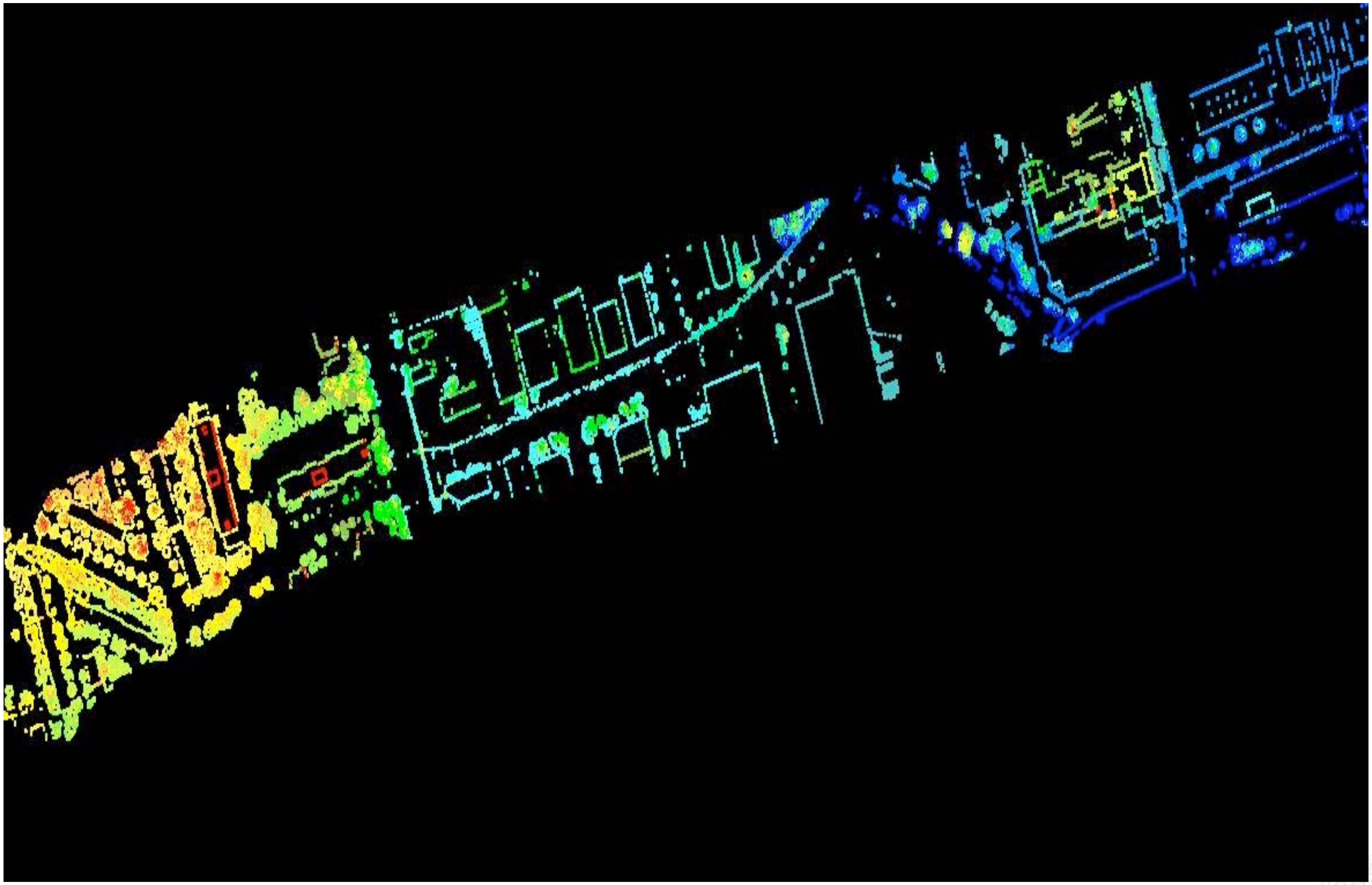
All Returns



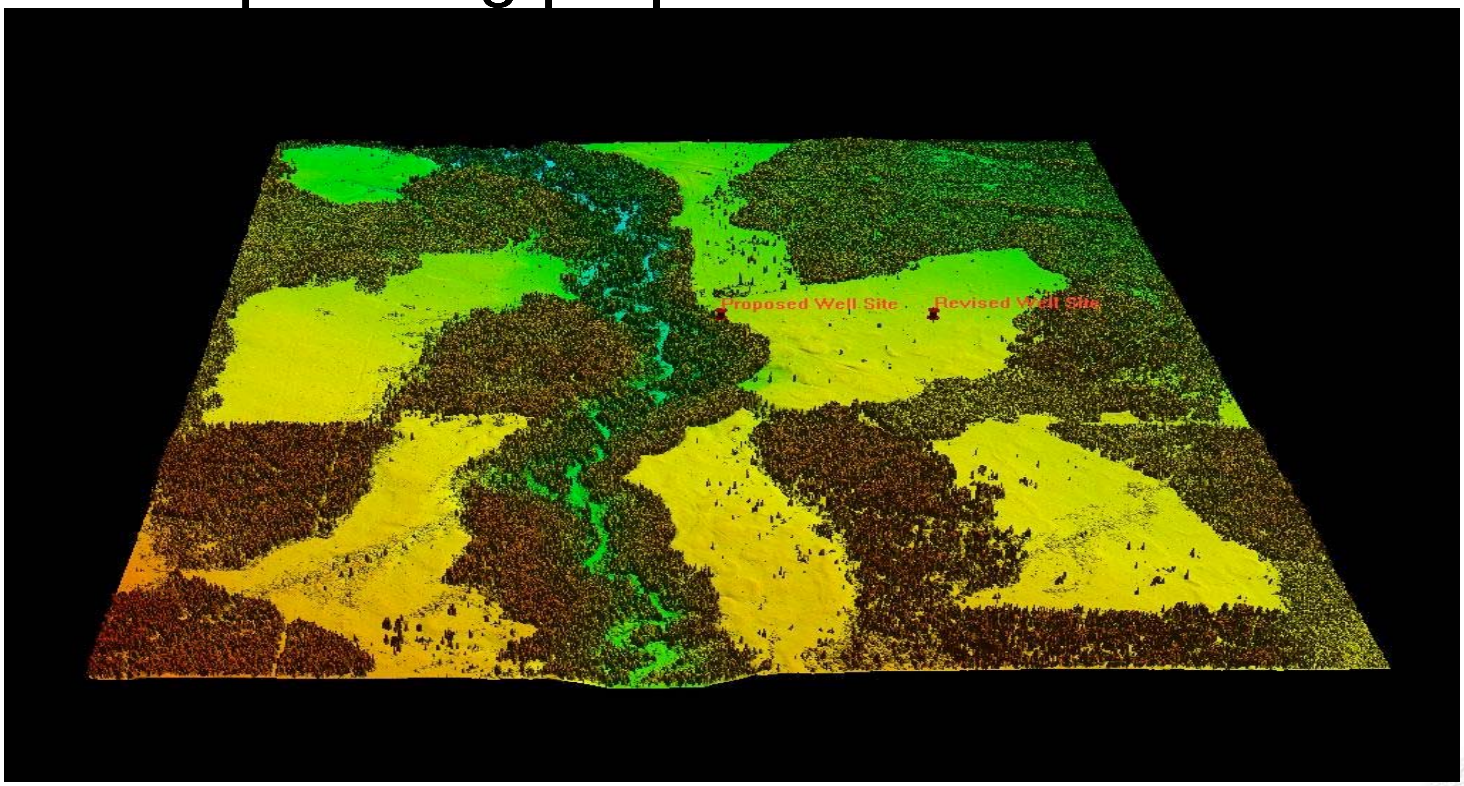
First return all data



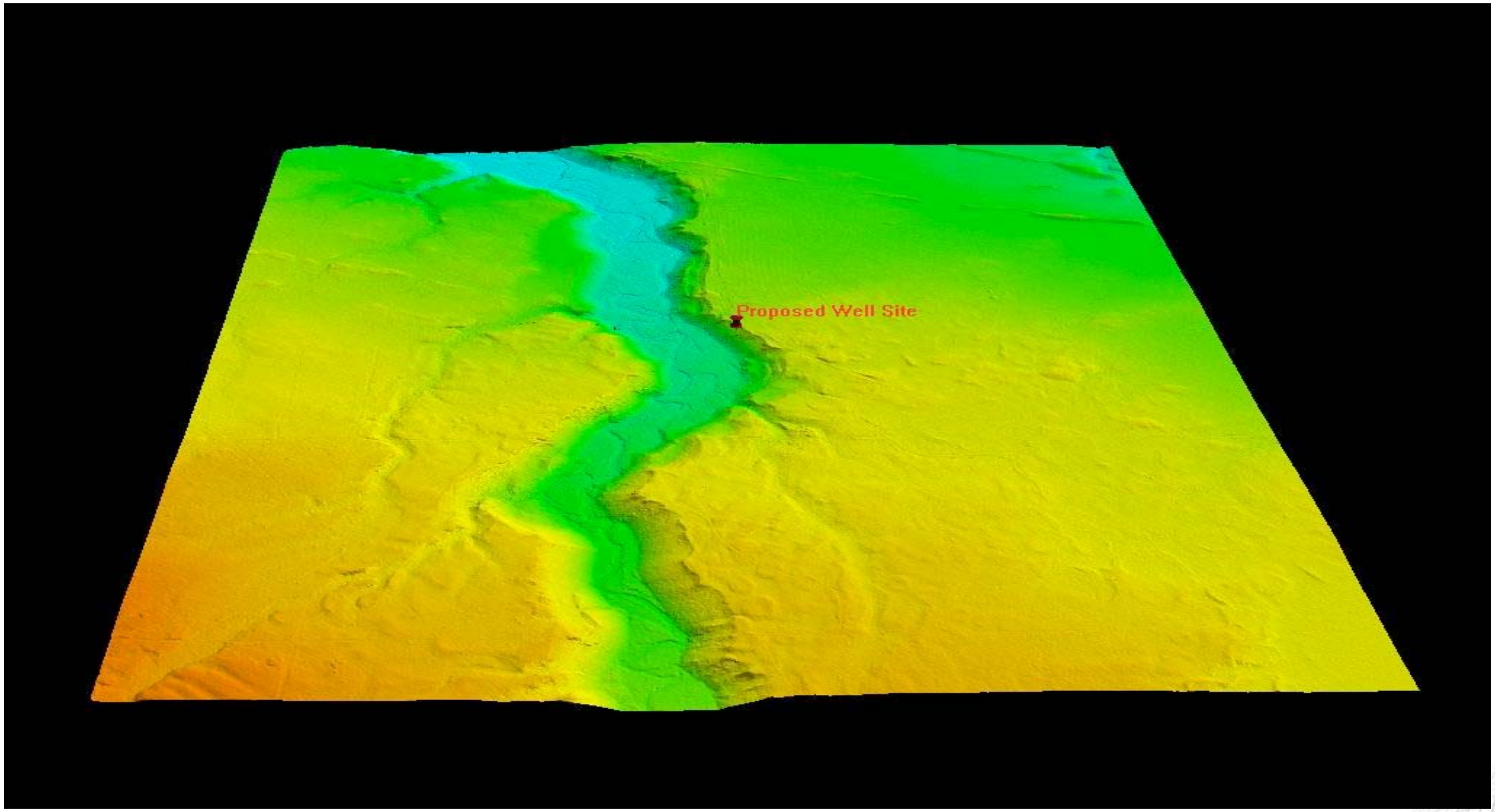
Second return
building outline, trees & wires



- Visualization software may aid in displaying detailed imagery and geo-referenced information for area planning purposes

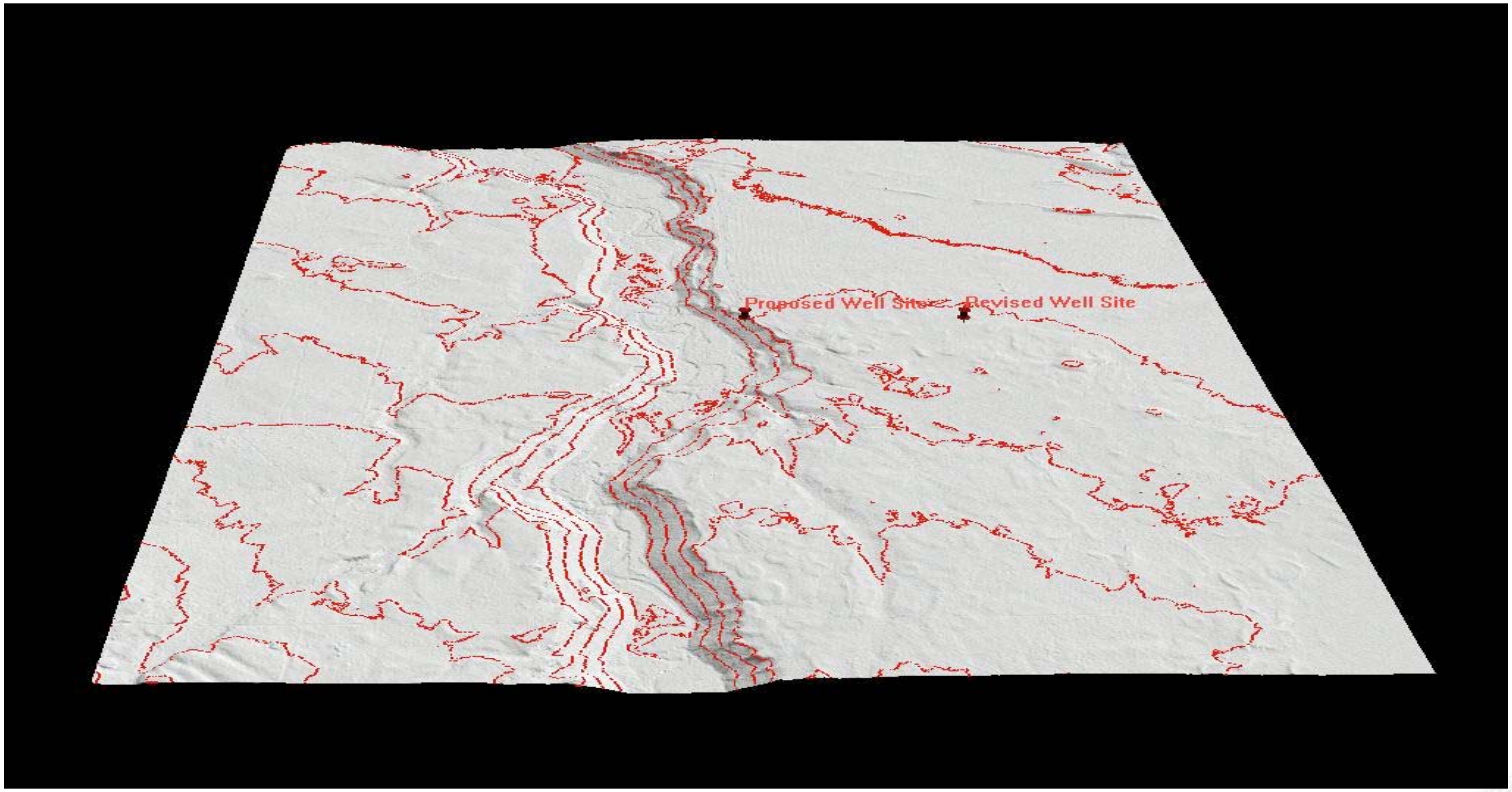


- Bare Earth models may be generated to sub-canopy details



Removing the Trees

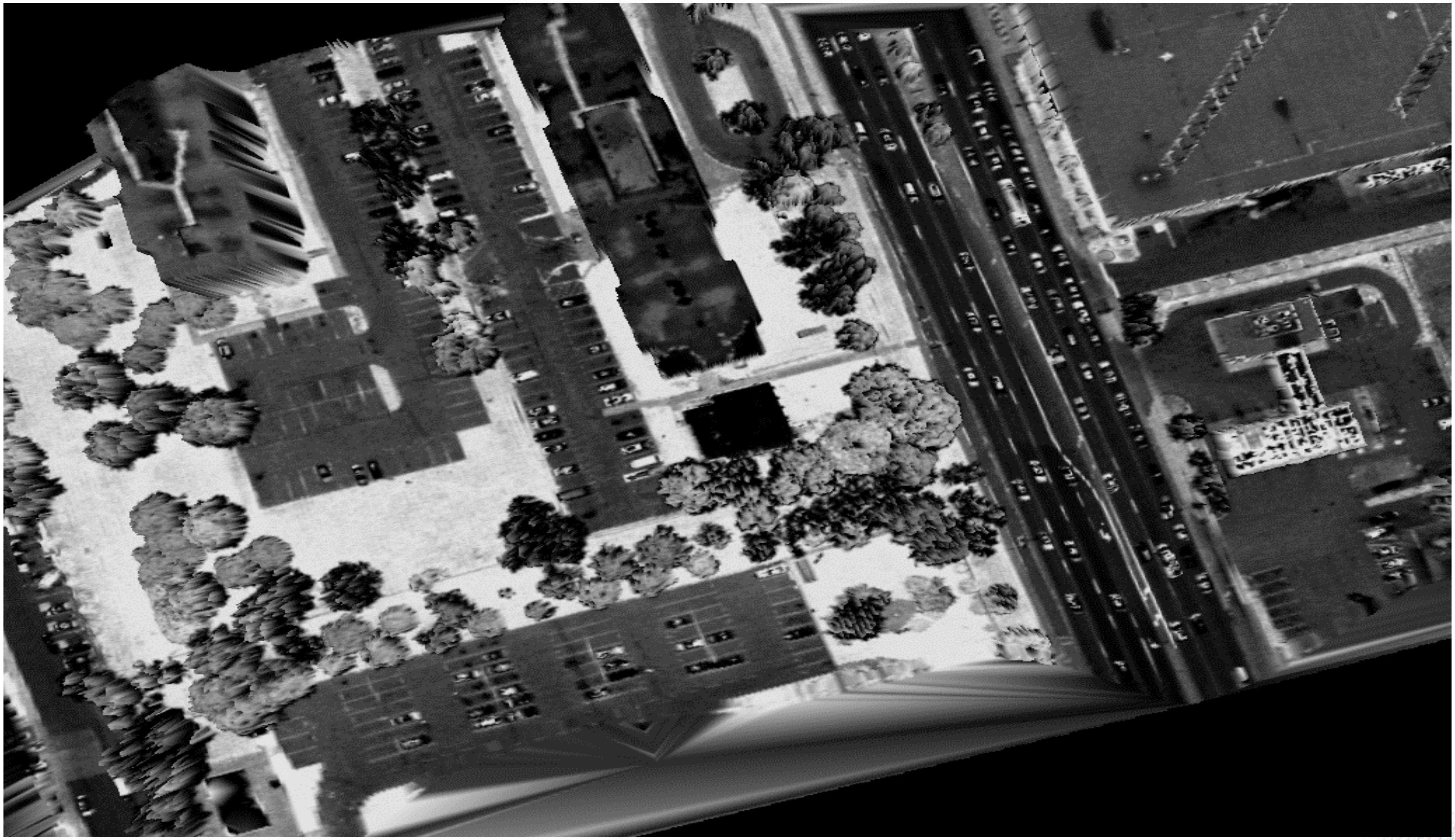
- Contours may be plotted for accurate depiction of surrounding areas



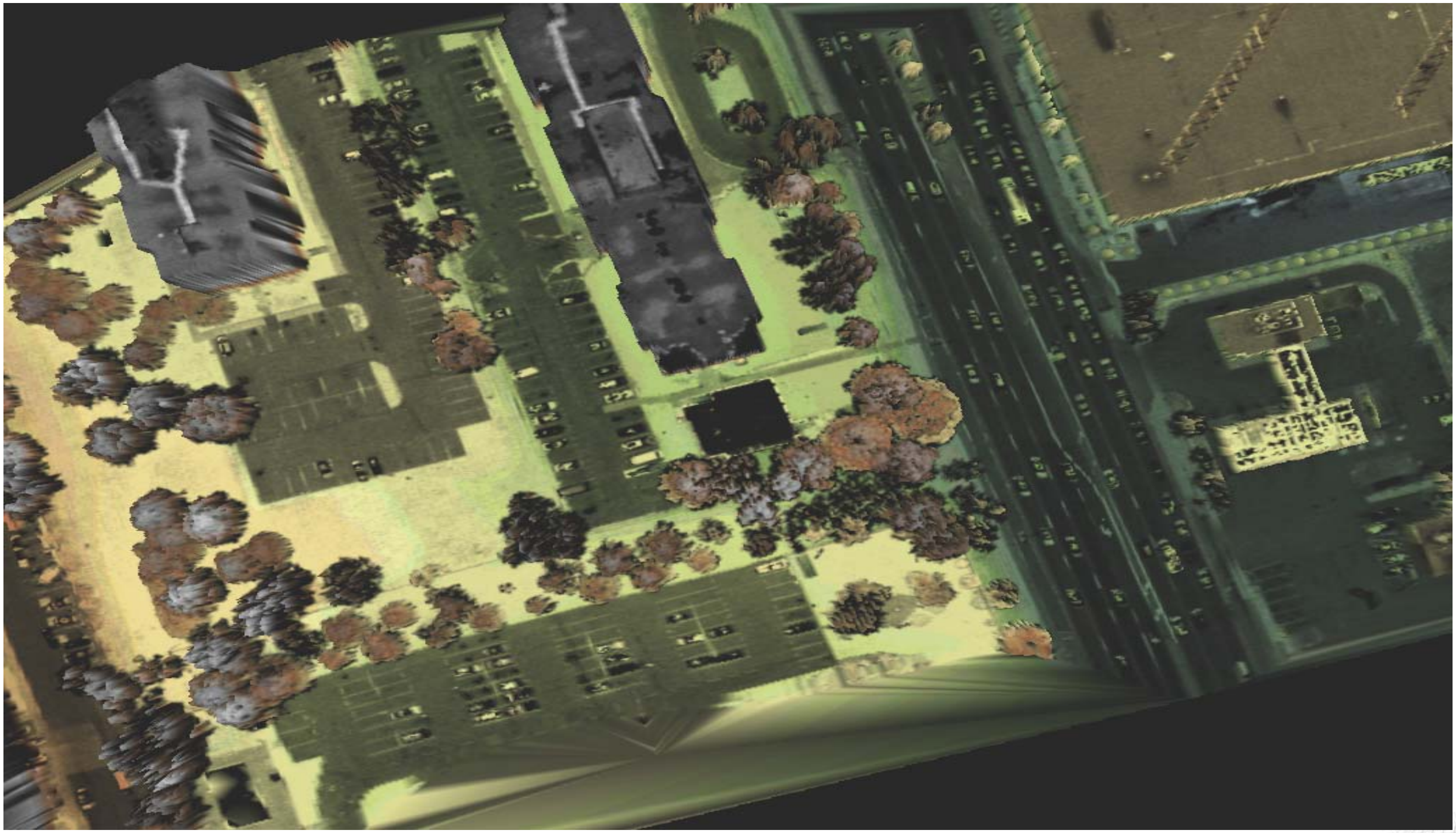
ALTM 3100's Intensity Capabilities

- 25cm spot spacing, 900m AGL

ALTM 3100's Intensity Capabilities

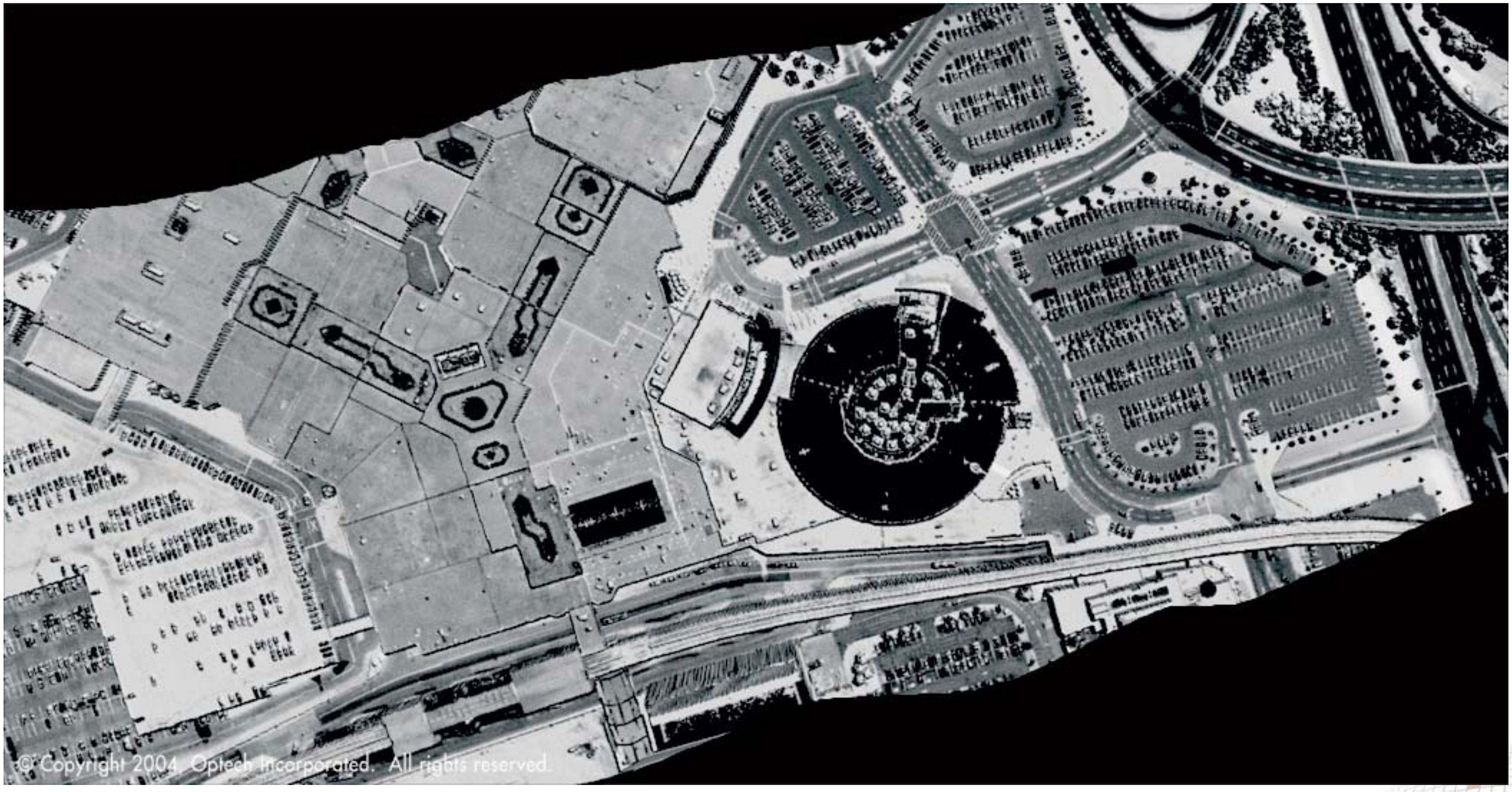


ALTM Composite Elevation Model



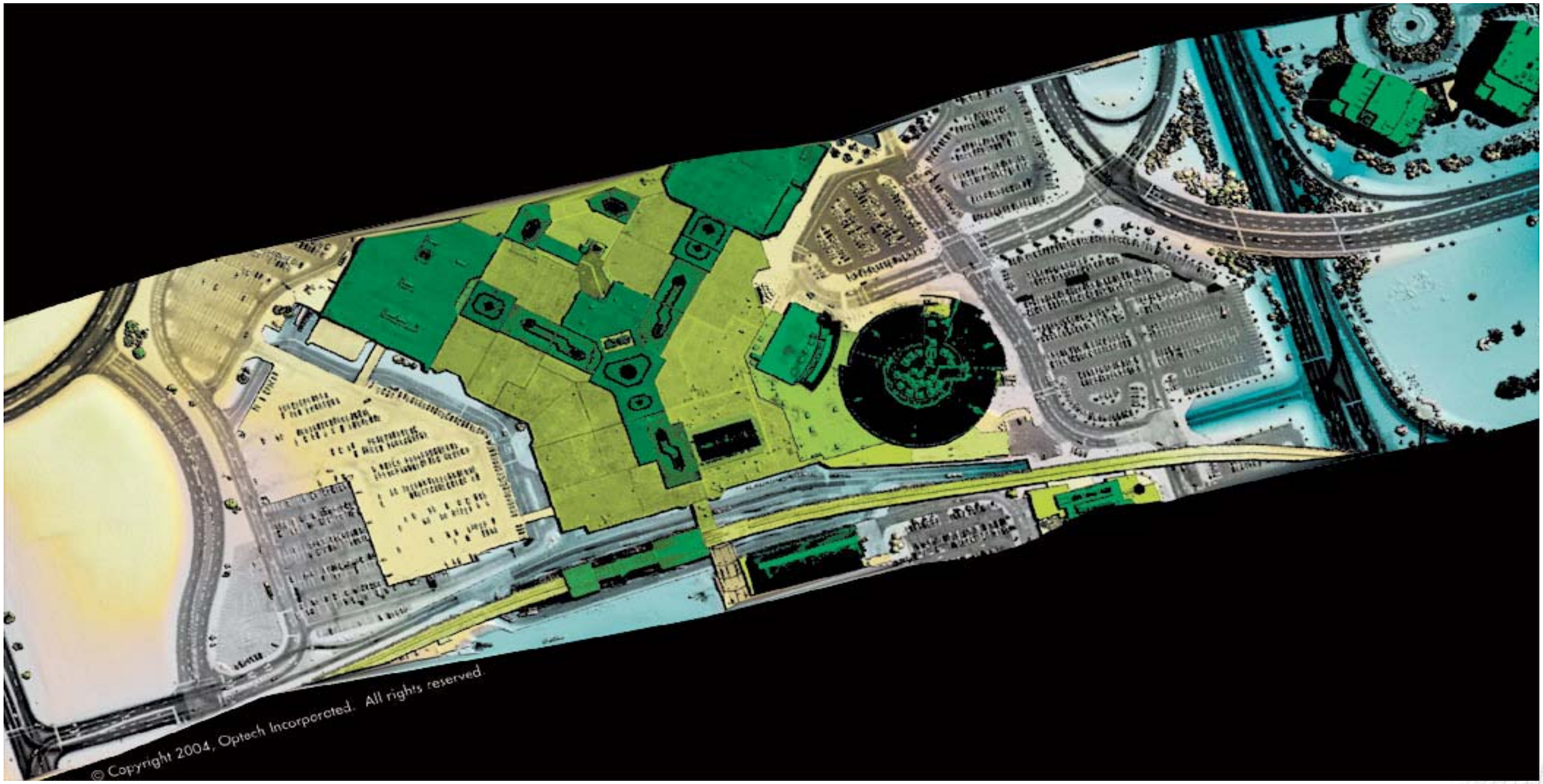
ALTM 3100's 4 Simultaneous Pulse Returns – plus intensity

- Grey-scale intensity image

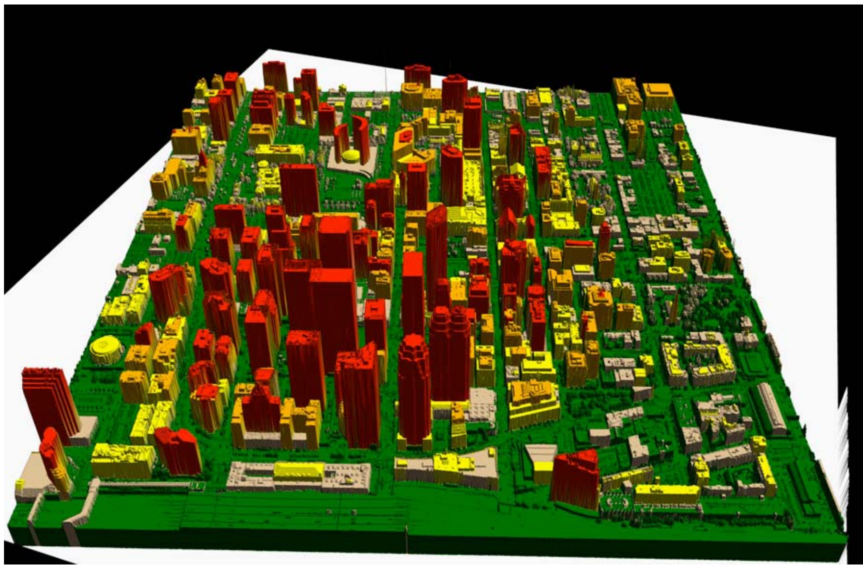


ALTM 3100's 4 Simultaneous Pulse Returns – plus intensity

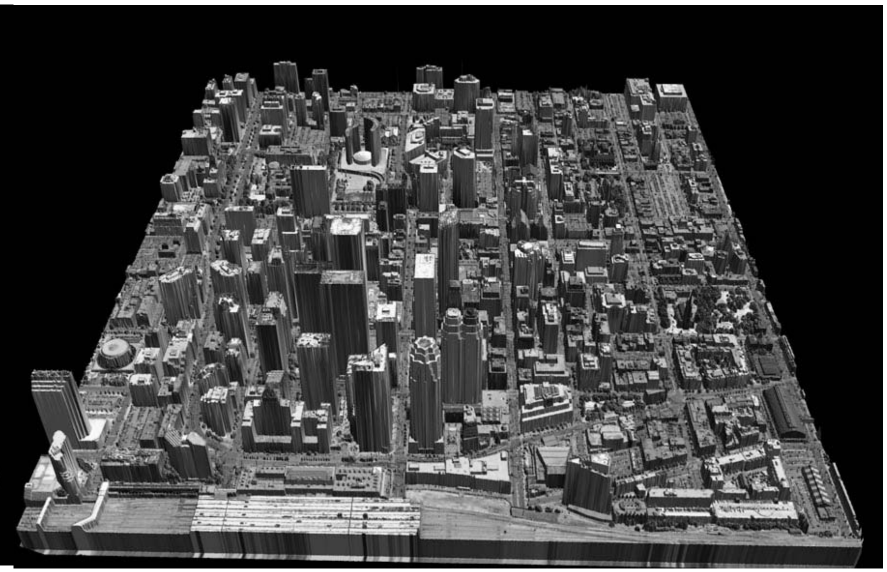
- Colour-coded elevation combined with intensity data



ALTM 3100 Capabilities



Digital Elevation Model



Active Laser Photo

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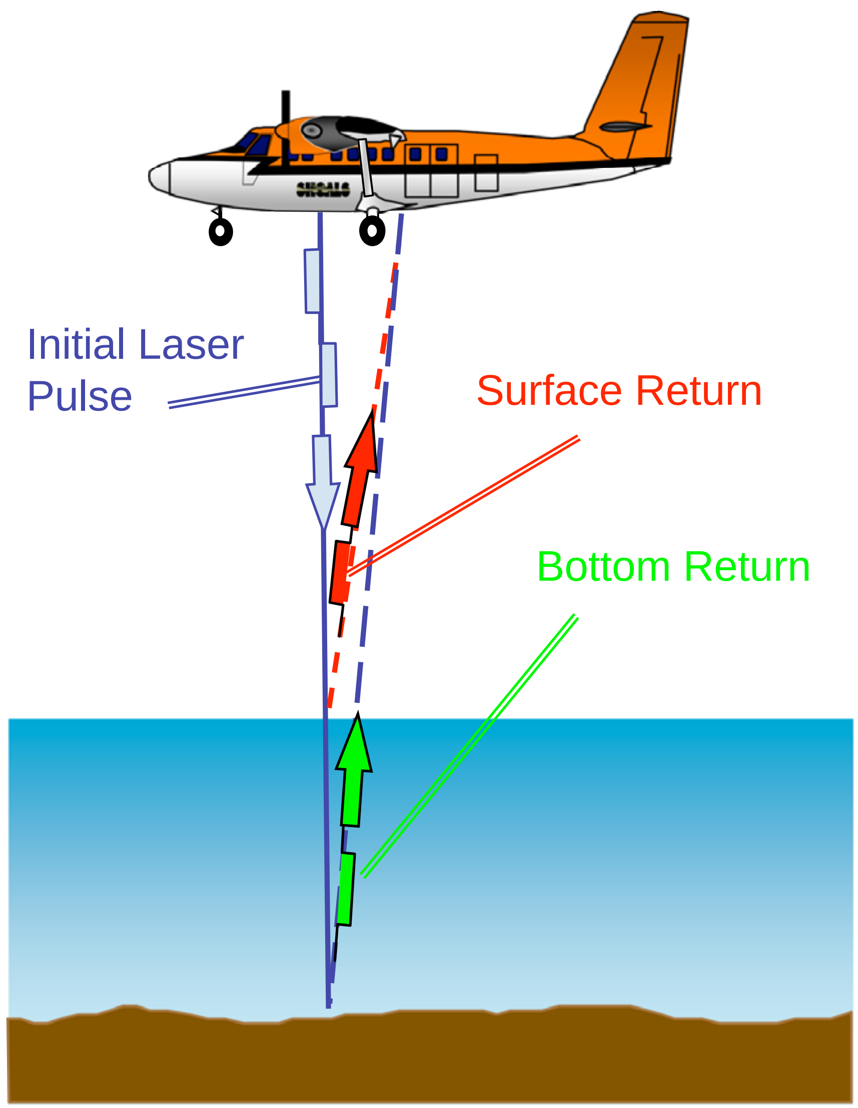
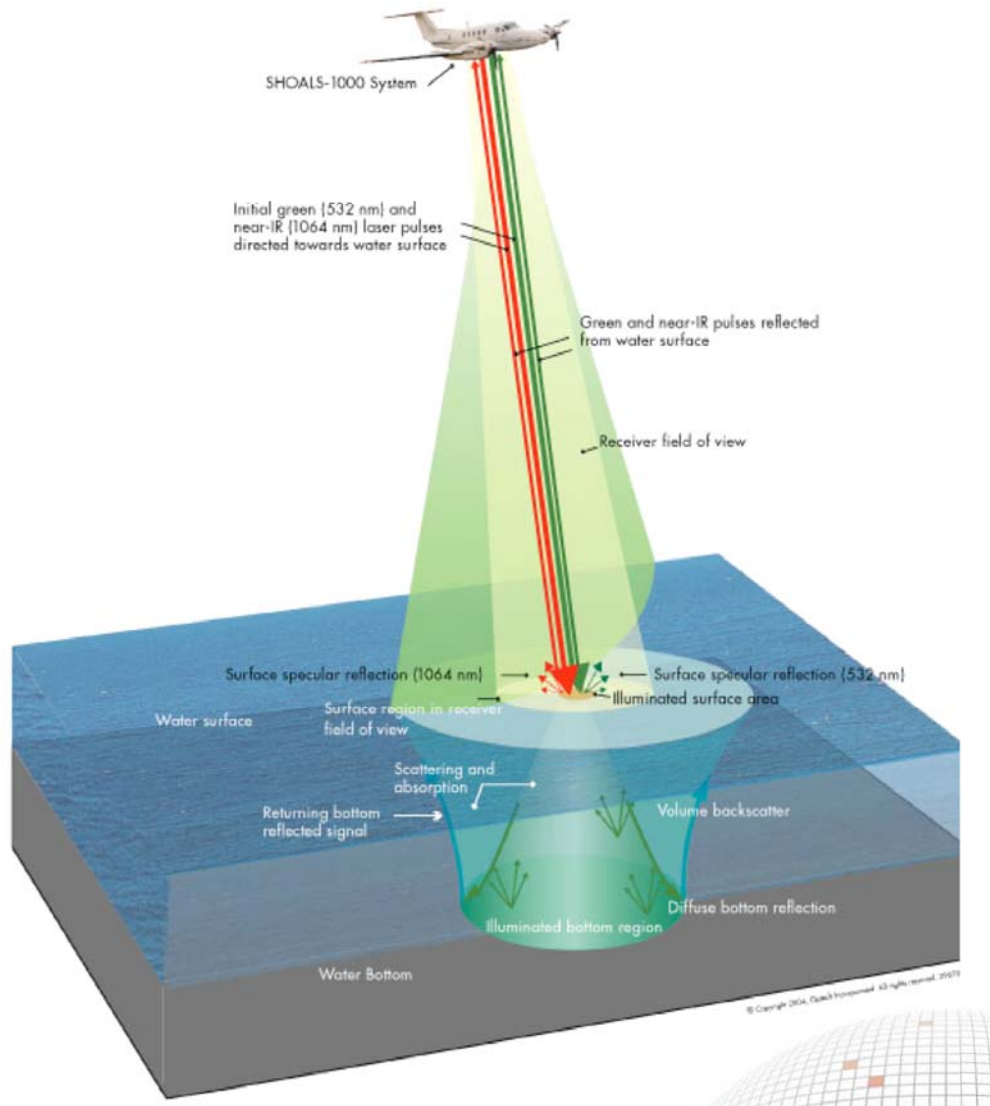
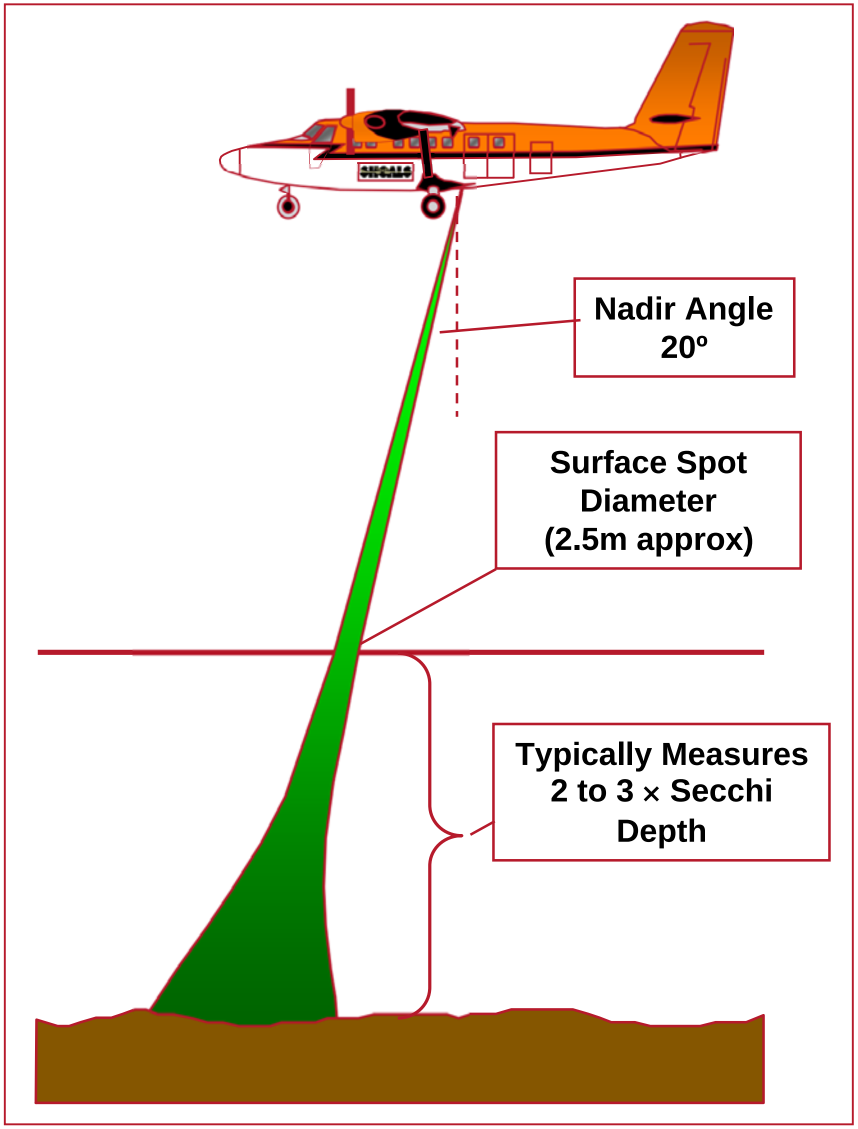
How SHOALS Works





Introduction



Performance: Depth penetration

- $KD_m \approx 3.5$ (day); ≈ 5.0 (night)

Coastal waters	$K(m^{-1})$	D_m(day)	D_m(night)
Very Clean	0.07	50m	71m
Clean	0.10	35m	50m
Typical	0.15	23m	33m
Typical	0.20	18m	25m
Dirty	0.30	12m	17m
Very Dirty	0.50	7.0m	10m

ALTM 3100 data