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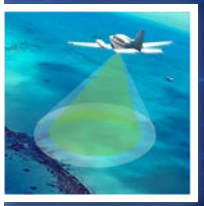
Meeting the International Hydrographic Organization Requirements for Bottom Feature Detection Using the Coastal Zone Mapping and Imaging Lidar (CZMIL)



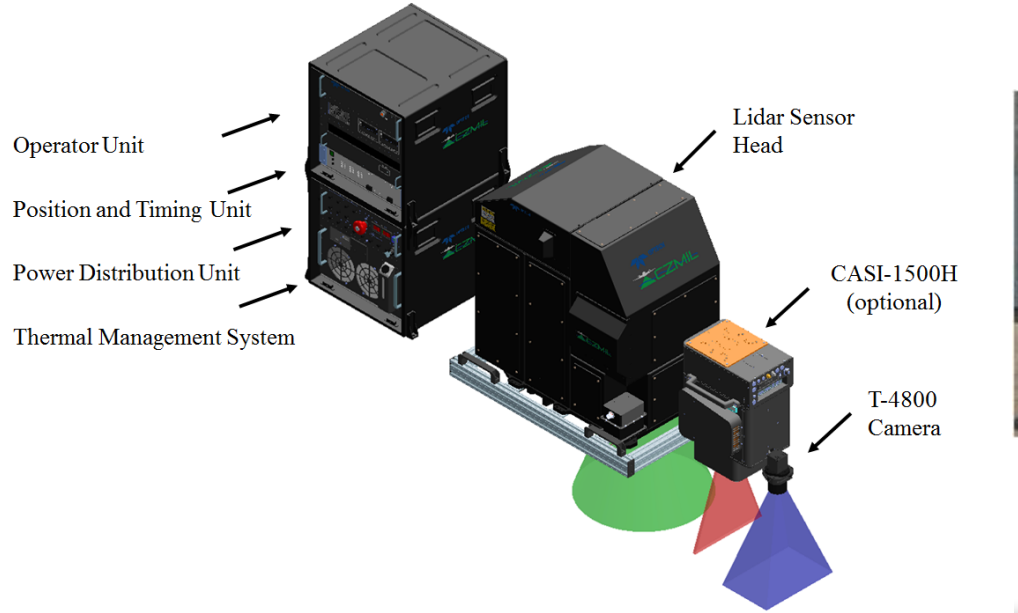
Vinod Ramnath, Viktor Feygels, Yuri Kopilevich, Hemanth Kalluri, Brant Smith, Norma Clark and Jennifer Aitken

17th Annual JALBTCX Airborne Coastal Mapping and Charting Technical Workshop
Silver Spring Civic Center, MD 20910,
July 19, 2016

Accuracy & Productivity Matter

CZMIL

- The Coastal Zone Mapping and Imaging Lidar (CZMIL) is an airborne multi-sensor system that exploits the data fusion paradigm to generate automated and high-resolution 3D environmental maps of coastal zones
- HydroFusion – Data processing software for CZMIL data



CZMIL in Piper Navajo

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Objective

- Develop a model that predicts the detection of International Hydrographic Organization (IHO) Order 1a sized objects for each lidar return, given a specific set of conditions (depth, the water IOPs, bottom specification, etc.).
  - IHO Order 1a criteria states that in addition to specific positioning requirements, a survey system must be able to detect cubic features (2 m × 2 m × 2 m) meters in depths up to 40 meters on the seafloor; 10% of depth beyond 40m.*

*Source: http://www.iho.int/iho_pubs/standard/S-44_5E.pdf

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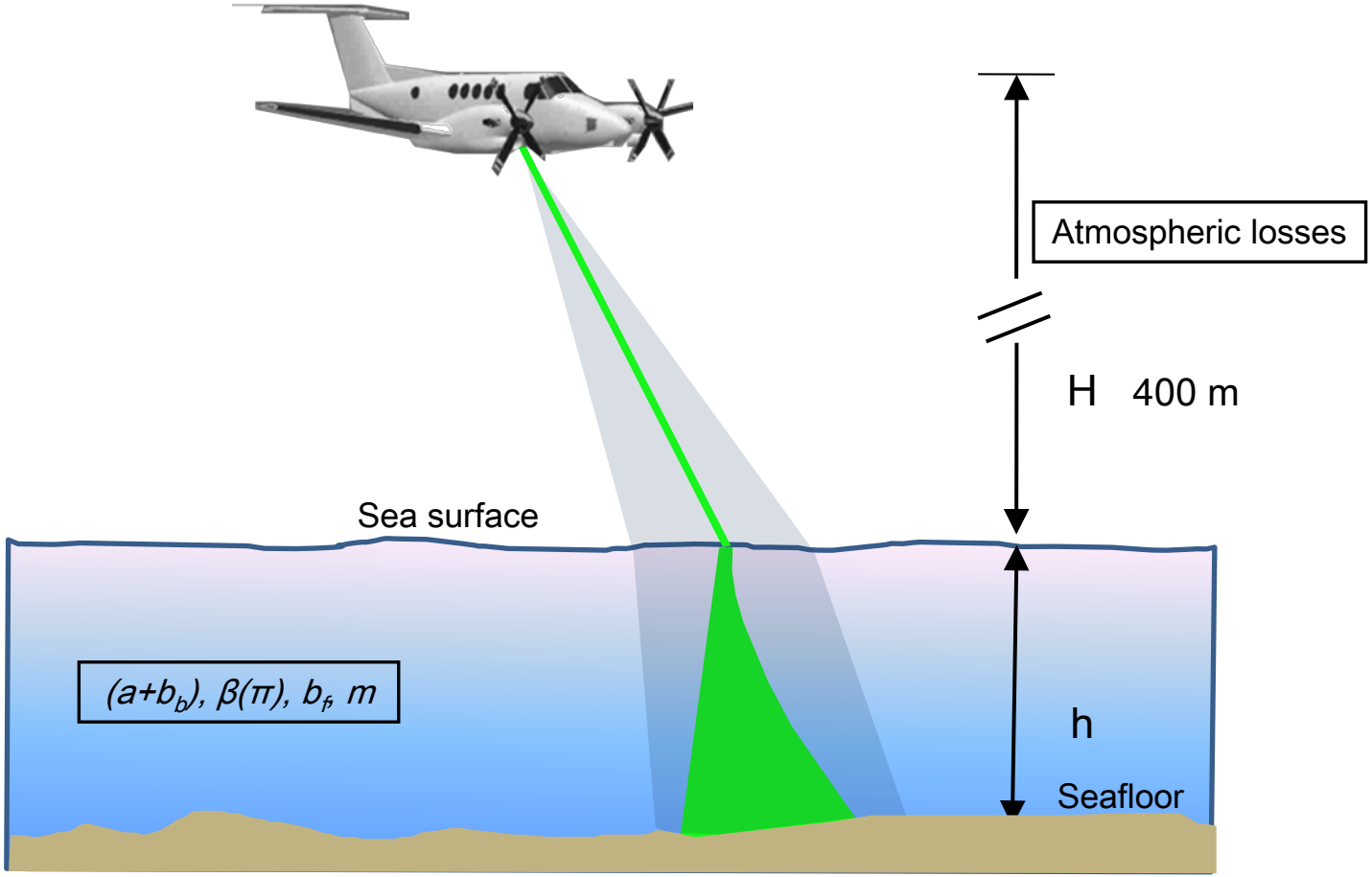
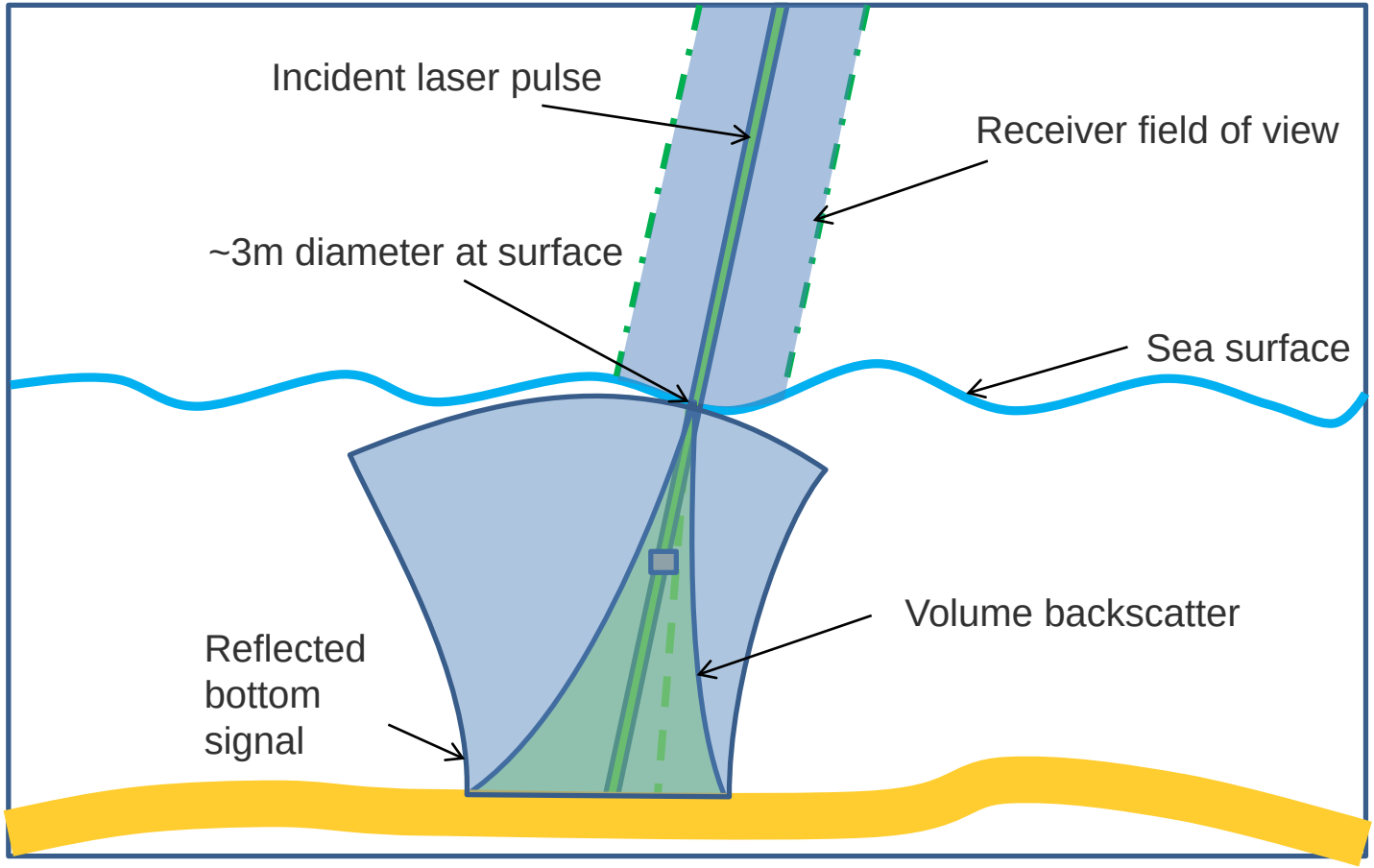
Factors that influence the return signal



Factors that influence the return signal



The Theory

$S(h)$

The horizontal resolution of an airborne lidar system is determined by the lidar sensitivity distribution throughout the plane transversal to the lidar axis at a given slant depth, *h.*
In the diffuse small-angle approximation, the effective radius:

$$R_{effective}(h) = \frac{R_{sounding}(h) \cdot R_{receiver}(h)}{\sqrt{R_{sounding}^2(h) + R_{receiver}^2(h)}}$$

$$R_{s,r}^2(h) = \frac{1}{4} H^2 \Theta_{s,r}^2 + \frac{b_f}{m^2} \cdot \frac{2}{3} \cdot h^3$$

Where,

- R_s and R_r are the radii of sounding beam and fictitious "receiving" beam
- H is the slant altitude of the lidar carrier, b_f is the small-angle forward scattering Coefficient, m is parameter of Dolin's VSF model, and
- $\vartheta_{s,r}$ are the sounding-beam divergence and the receiver field-of-view angle, respectively (both parameters are half angles at 1/e level).

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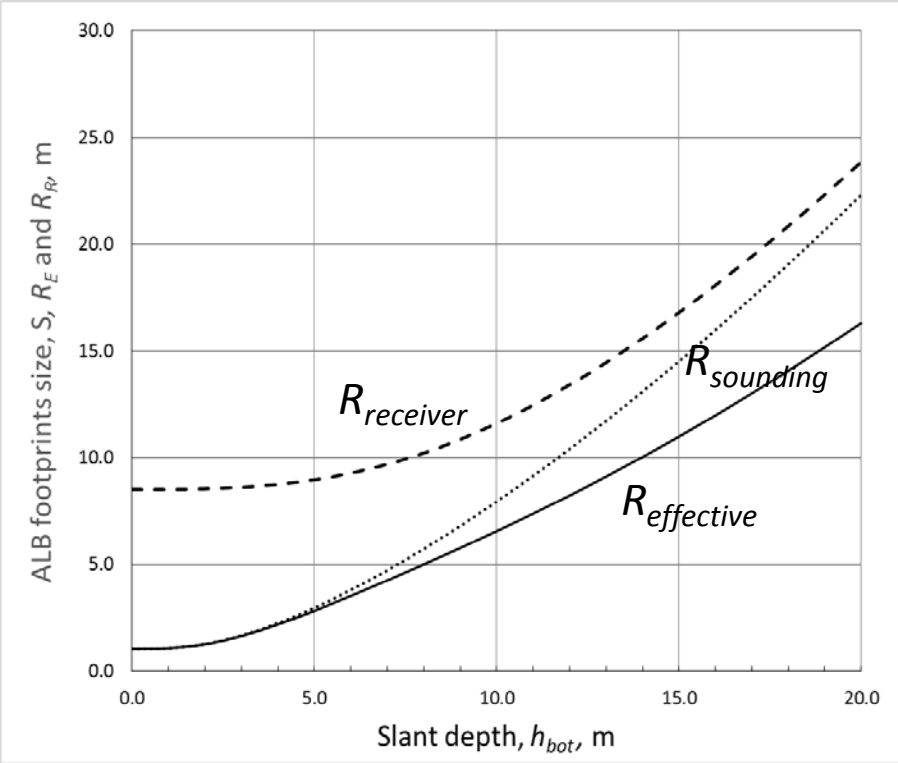
The Theory: The CZMIL sensitivity radii



The CZMIL effective radius, $R_{effective}$, as a function of slant depth h_{bot} (solid line) and corresponding characteristics R_E (dotted line) and R_R (dashed line) of emitted and receiving beams.

The small-angle forward scattering coefficient is equal to 0.7m-1, parameter m = 7.5. Other parameters: altitude = 400m, FOV = 40mrad, laser beam divergence (1/e) = 5mr.

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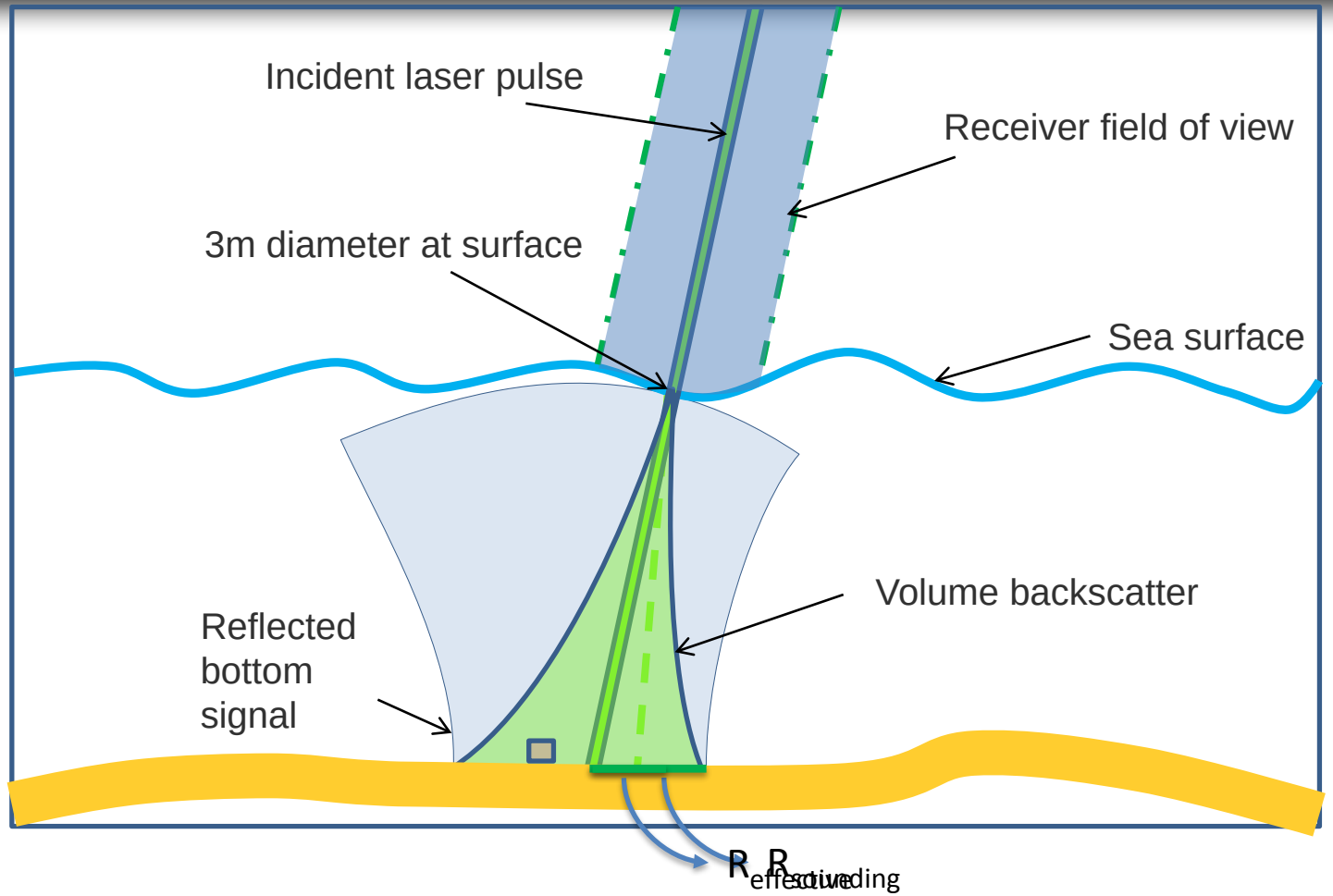
The Theory: The CZMIL sensitivity radii



The Theory

Input parameters

System parameters

FOV, Laser Energy…

Lidar derived

Optical parameters

$(a+b_b)$, $\beta(\pi)$, b_f, m, ρ_{bot}

Geometrical parameters

Altitude, depth…

Cube attributes

Size, ρ_{cube}, Cube location

Estimation of Cube Signal Level Program

Output

Cube signal level:

$$F\left(\rho_{cube}, Cube_{attr}.\rho_{bot}, R_{effective}, Geom.\right)$$

S_{cube} → D_{index} → P_{cube}

Radiometric conversion from Power to Counts (Electrical domain) and using noise estimate

For a given false alarm probability

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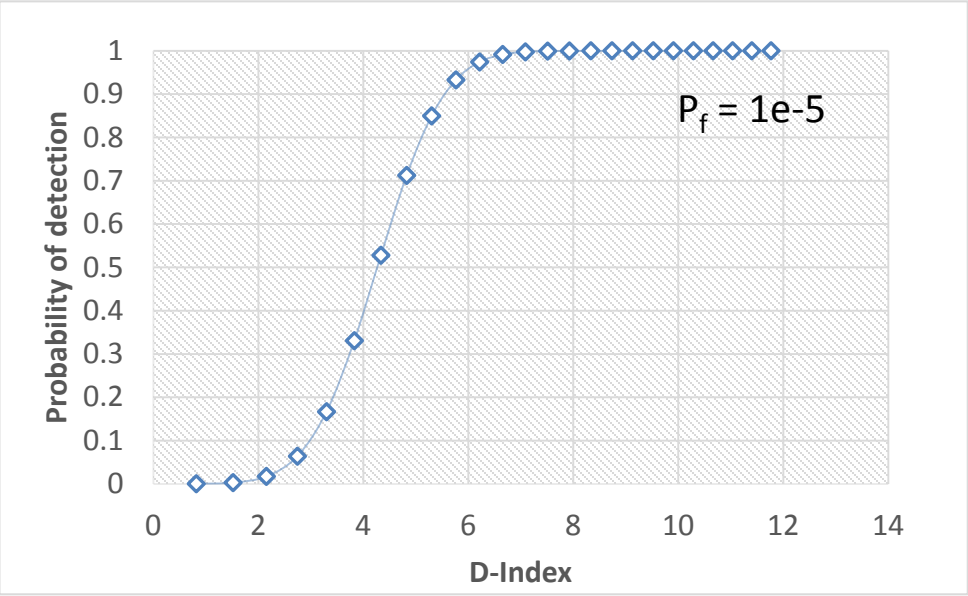
The Theory: P_d vs D_{index}

$$P_d = \tfrac{1}{2} Erfc\left[Erfc^{-1}(2P_f) - D_{index}\right]$$

Where P_f is false-alarm probability



D_{index} is a better discriminability index metric than Signal to Noise ratio for optical signals

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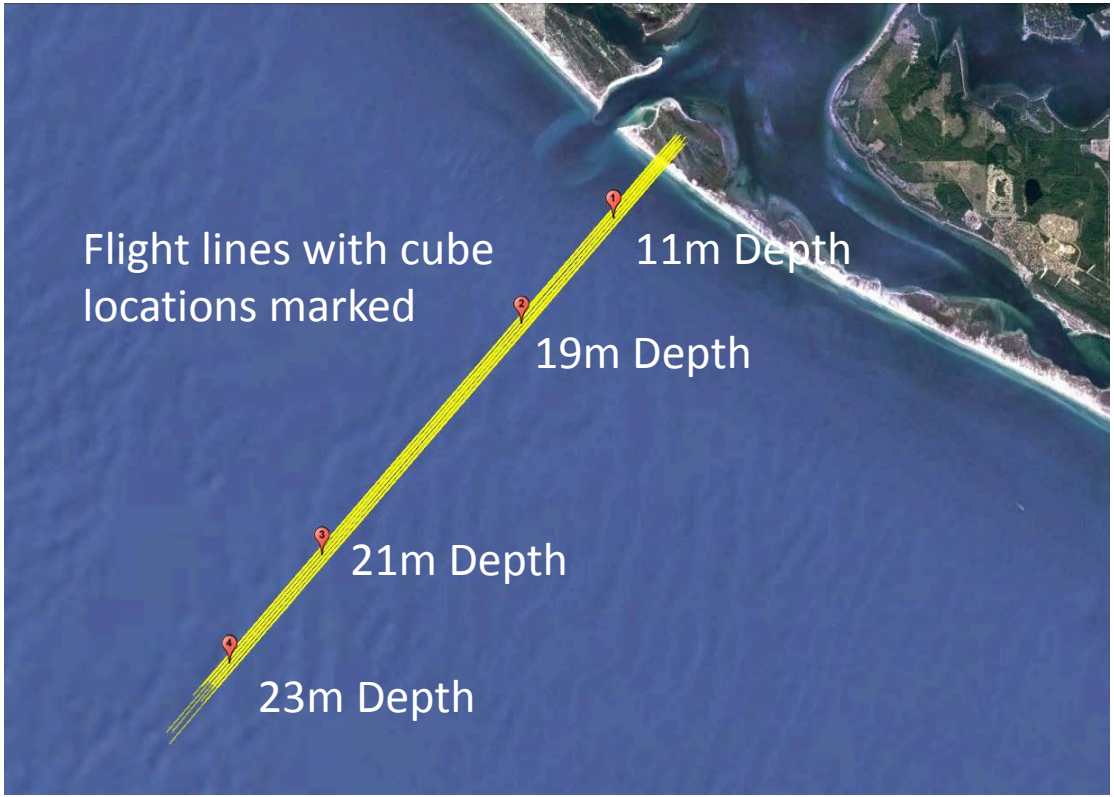
Test Area: Panama City, Florida

The test was conducted off the coast of Panama City, Florida in October 2015



2 x 2 x 2m Cubes

Cube reflectance = 40% (532nm)

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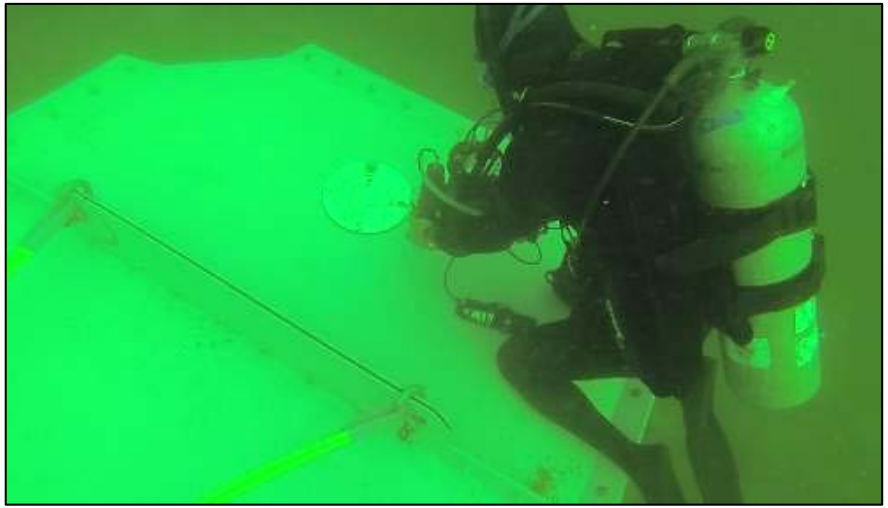
In-situ optical water properties measurements

Cube reflectance measurements using DiveSpec



WETLabs AC-9, CTD

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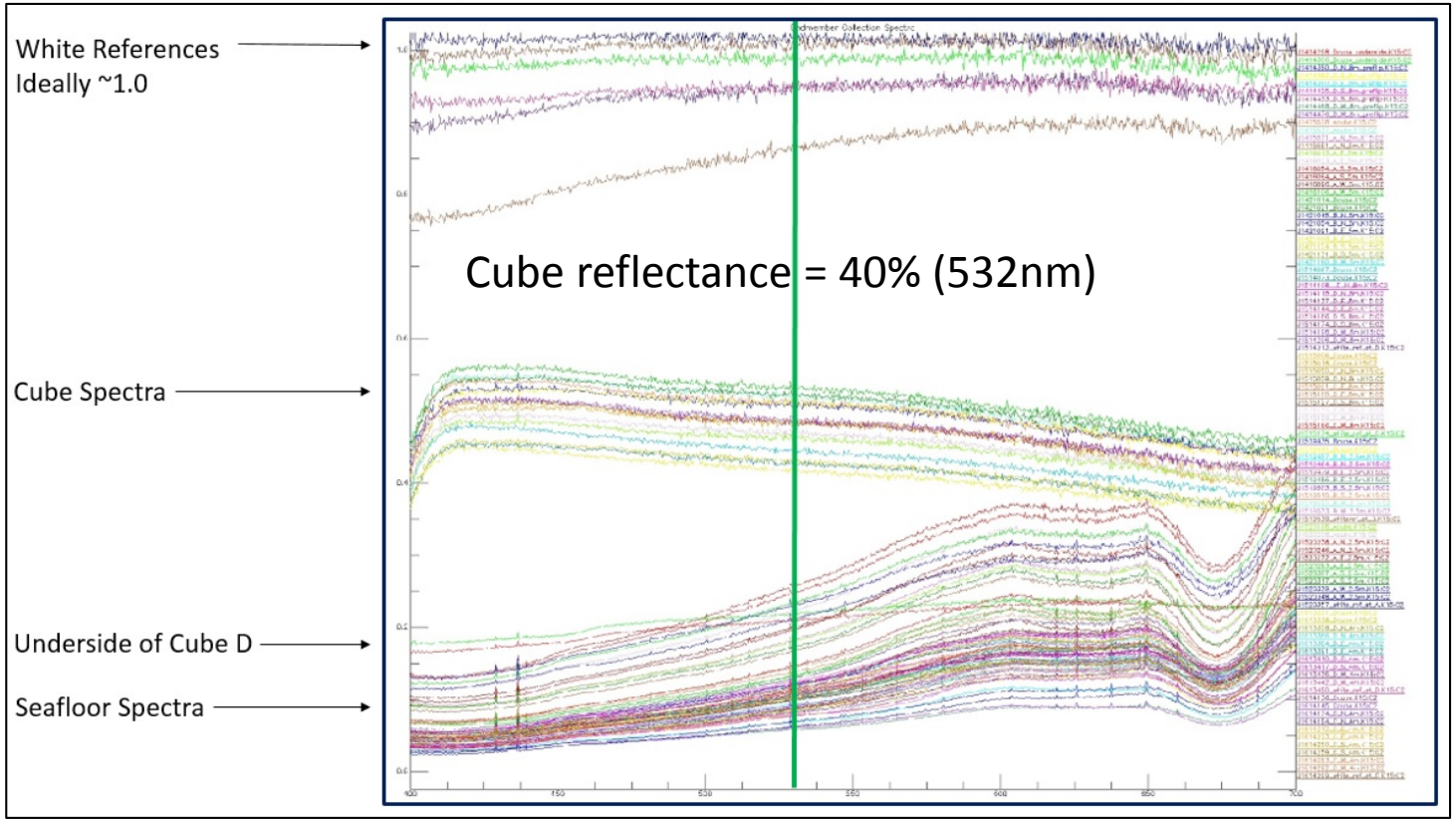
Cube and bottom reflectance



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Test Area : Optical properties

K_d, the diffuse attenuation coefficient, is 0.16-0.28 m^{-1}.

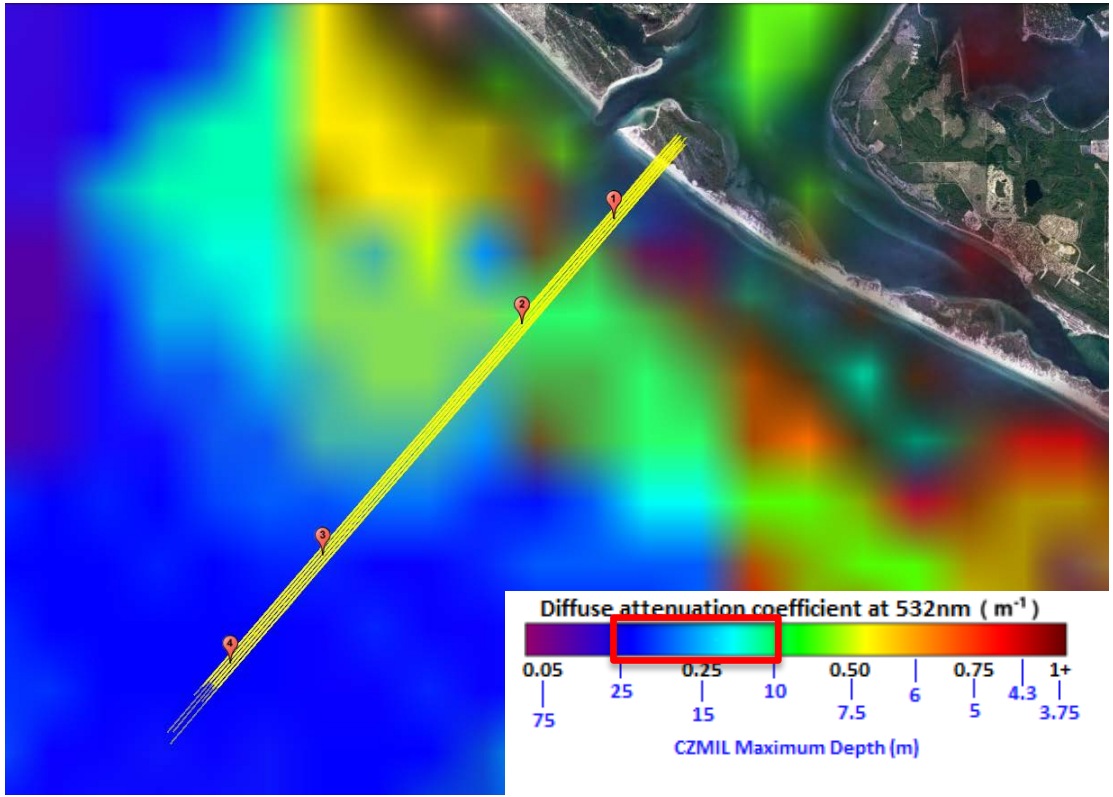
ρ_{532}, the reflectance coefficient, is 10 - 22 %

Cube locations with supporting data

Test region: Optical properties

Satellite derived K_d map*

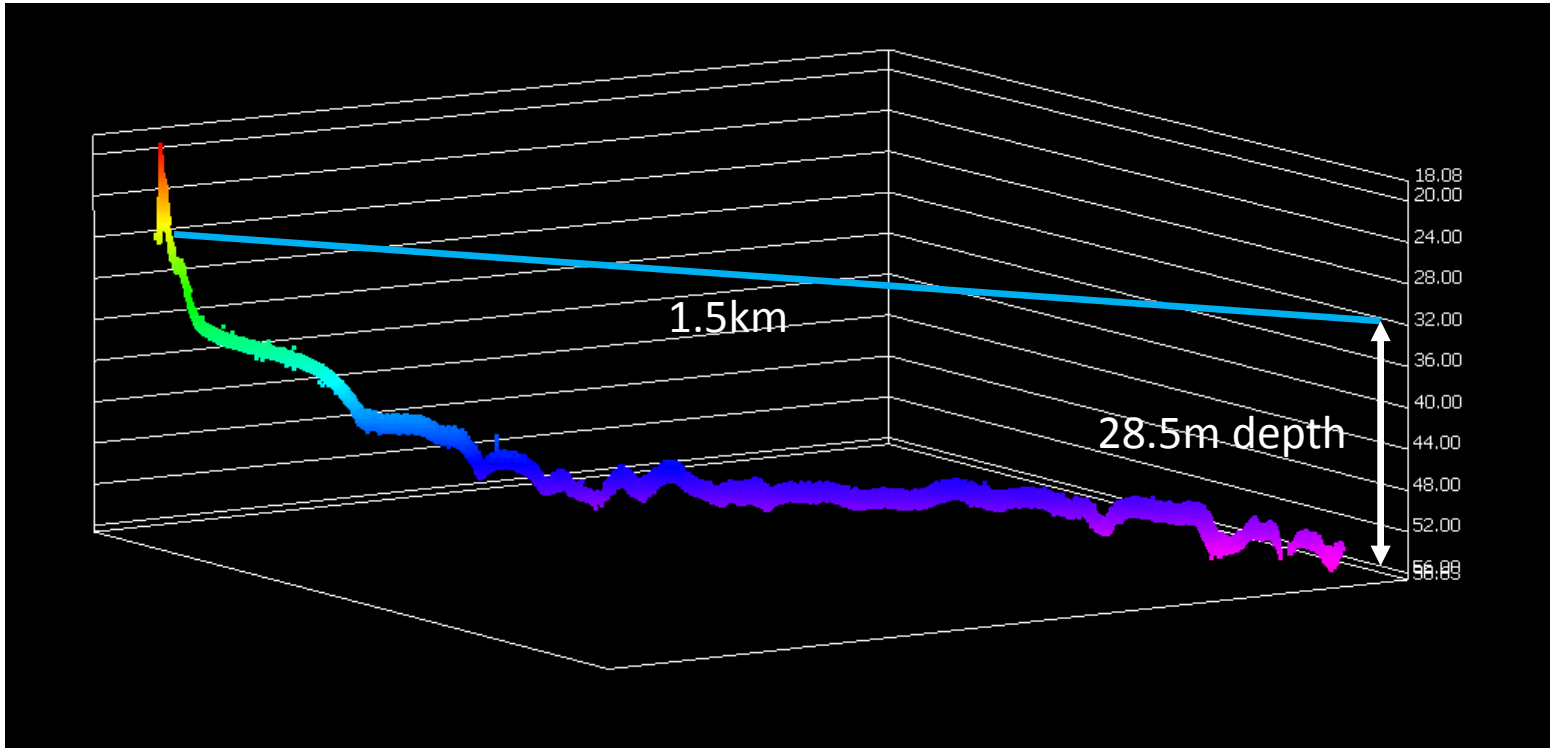
Based on the K_d map and CZMIL's system performance coefficient we expect depths close to 25m



* Source : http://oceancolor.gsfc.nasa.gov/

Test Area : CZMIL measured depths

Depth profile over the surveyed area



Cube Return Signal Level Estimation Example

Input/Estimated Parameters

ρ_{cube}= 40%

Cube size = 2mx2mx2m

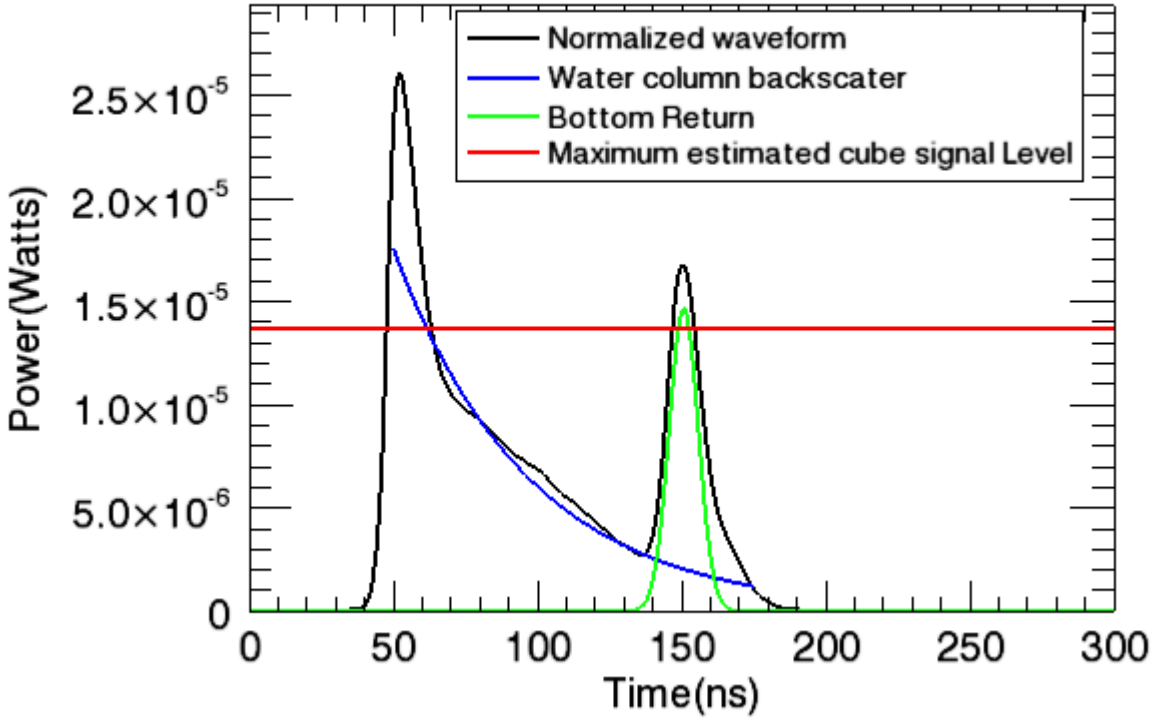
$\rho_{seafloor}$ ~ 10%

K_d ~ 0.10m^{-1}

Depth ~ 10m

Cube location : Center

Waveform from near Cube (1) location



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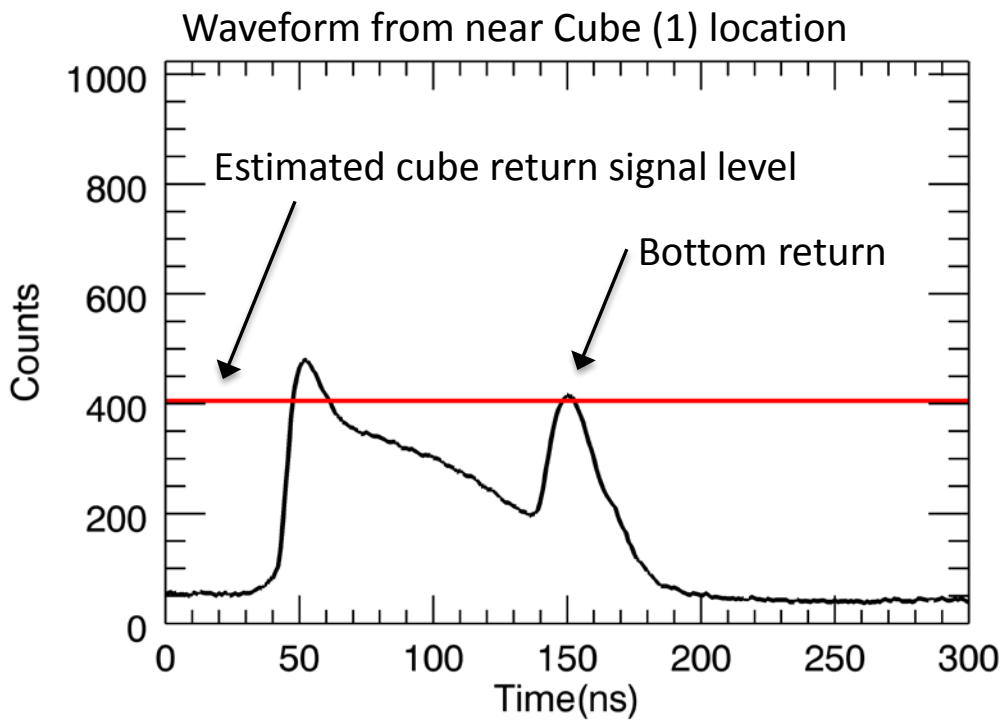
Cube Return Signal Level Estimation Example



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Cube Return Signal Level Estimation Example

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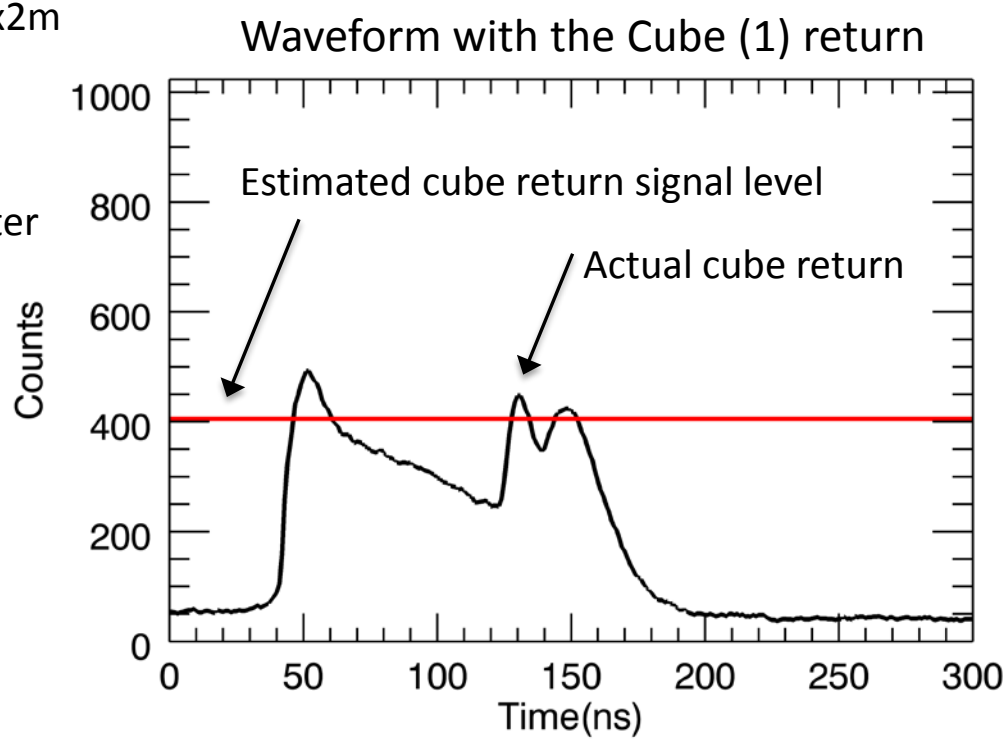

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Cube Return Signal Level Estimation Example

Input/Estimated Parameters

ρ_{cube}= 40%

Cube size = 2mx2mx2m

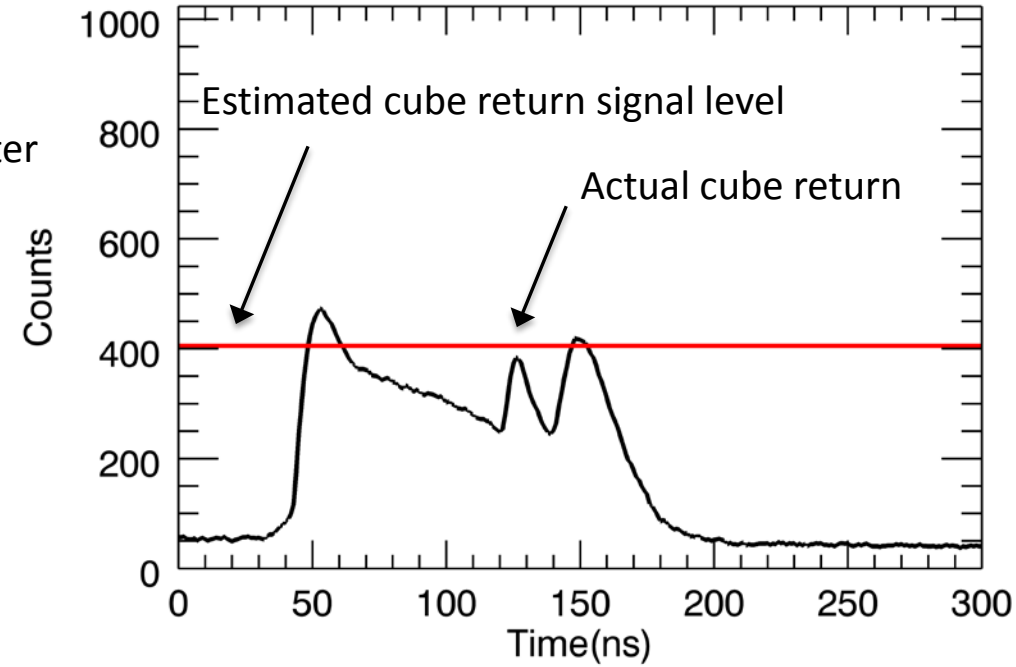
$\rho_{seafloor}$ ~ 10%

K_d ~ 0.12m^{-1}

Depth ~ 22m

Cube location: Center

Another example of Waveform with the Cube(1) return



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Cube Return Signal Level Estimation Example

Input/Estimated Parameters

ρ_{cube}= 40%

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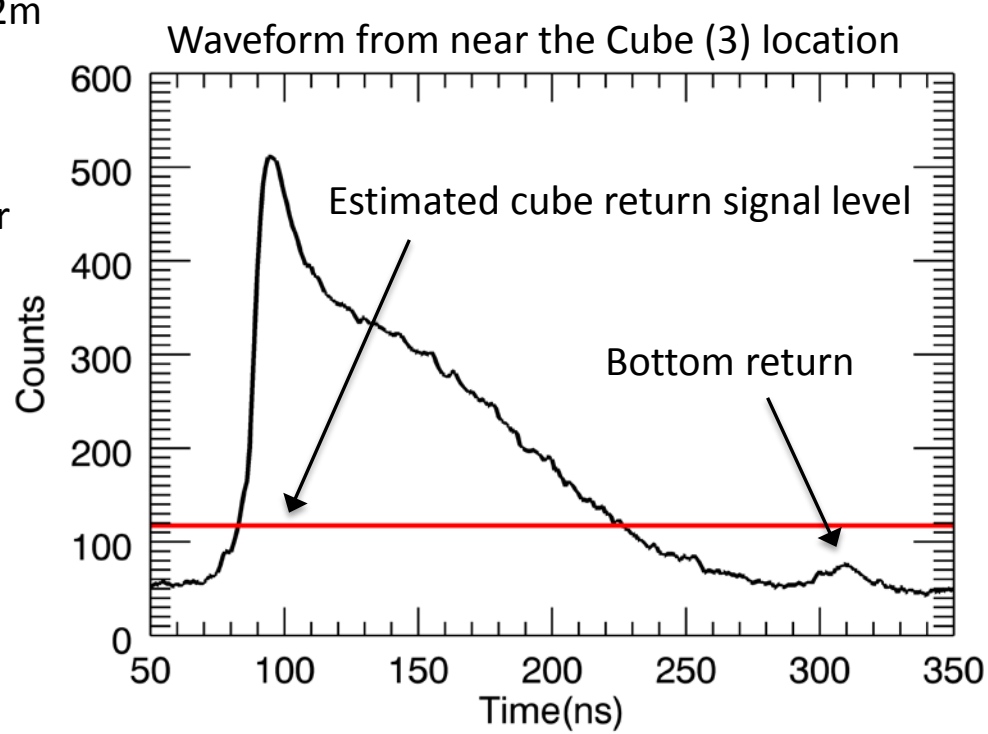
K_d ~ 0.12m^{-1}

Depth ~ 22m

Cube location: Center



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Cube Return Signal Level Estimation Example

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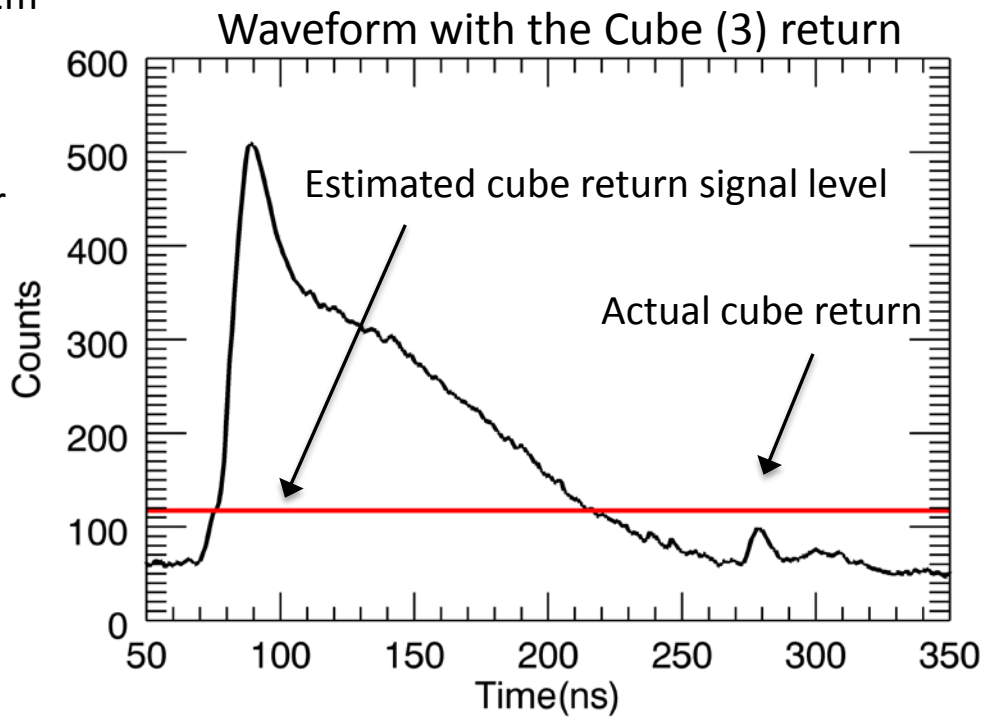
Depth ~ 22m

Cube location: Center



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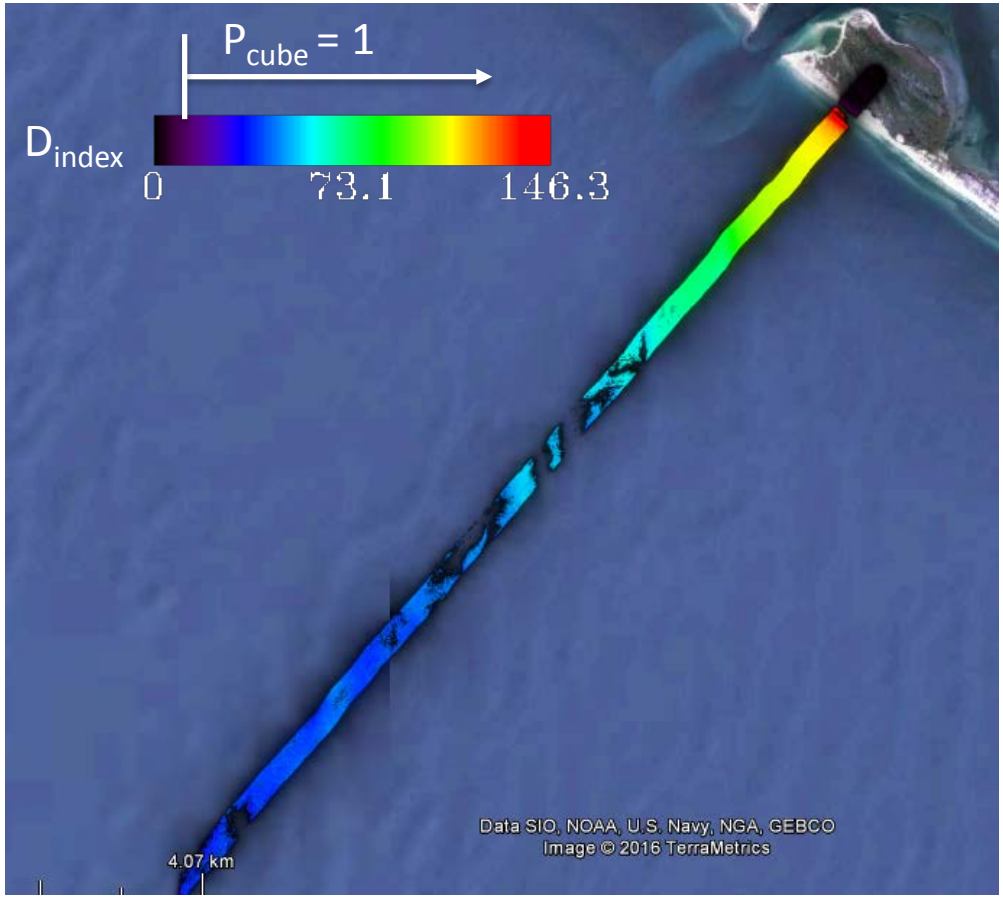
D_{index} Map

- Using the Estimation of Cube Signal Level Program we determine the P_{cube} for all the waveforms with a valid bottom return.
- As far as radiometry is concerned CZMIL can detect IHO Order 1a objects in optically deep waters.
- However, the location of the cube in the effective radius is also a critical factor in determining the probability of detection.



D_{index} map on GoogleEarth

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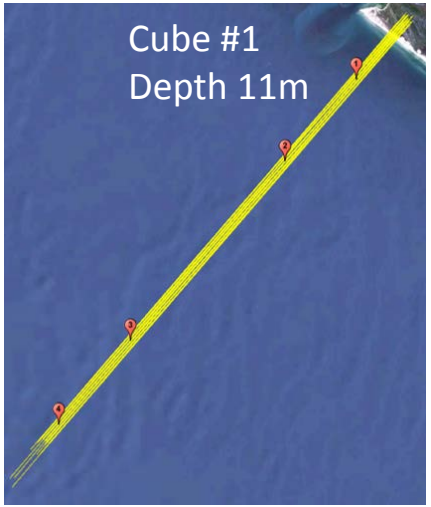
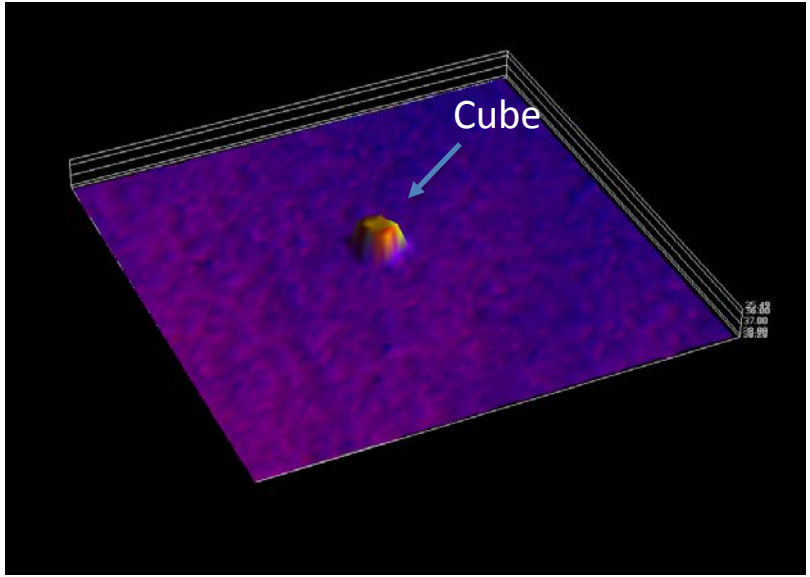
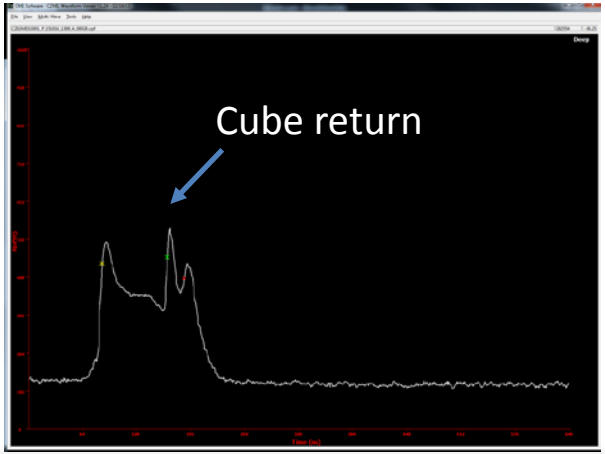
CZMIL Waveform: Cube 1



DEM

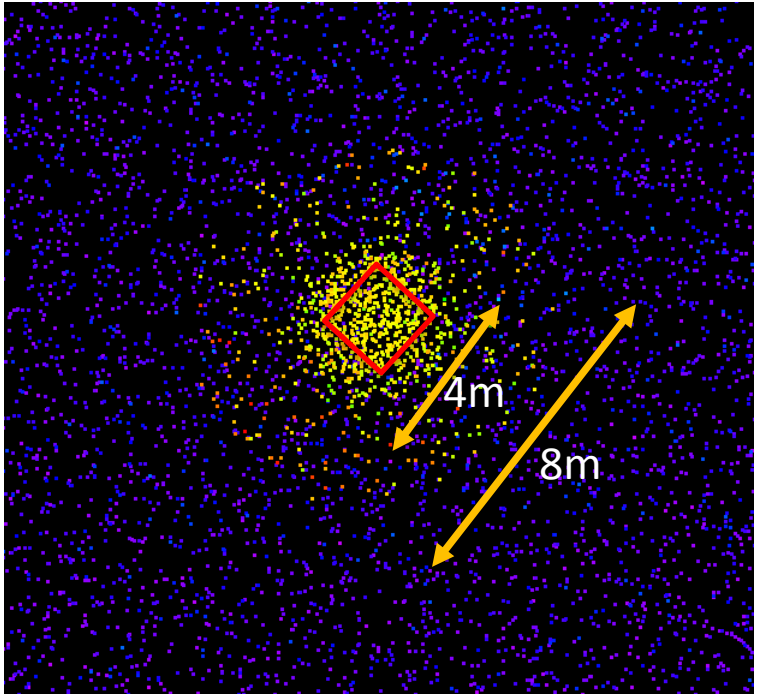


Deep channel waveform

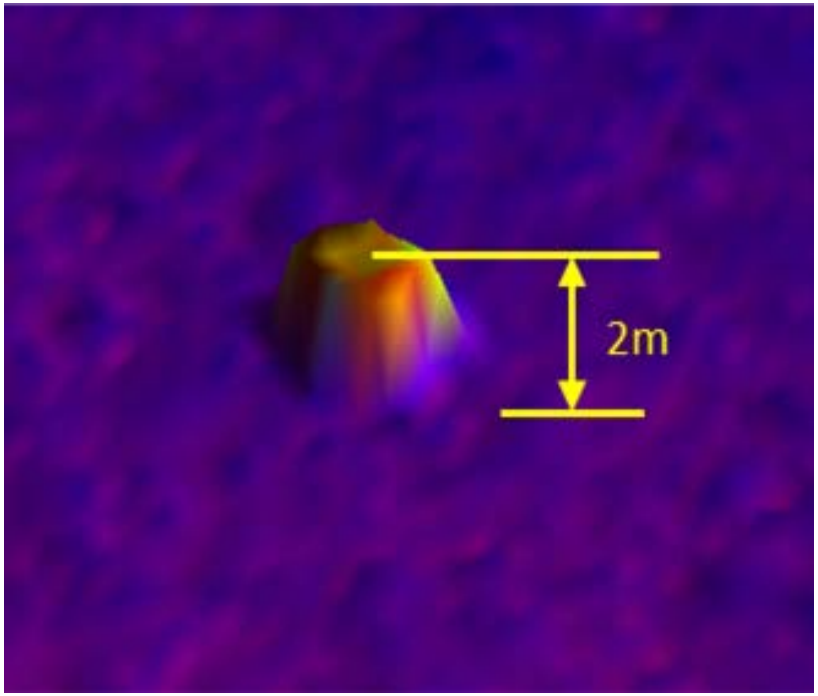


CZMIL Point Cloud: Cube 1

Red- and yellow-colored points correspond to the position of the cube on the seafloor measured by CZMIL.



Corresponding 3D perspective view



Points outside the marked region are a result of the measurement uncertainty of the cube location caused by the effective laser beam footprint.

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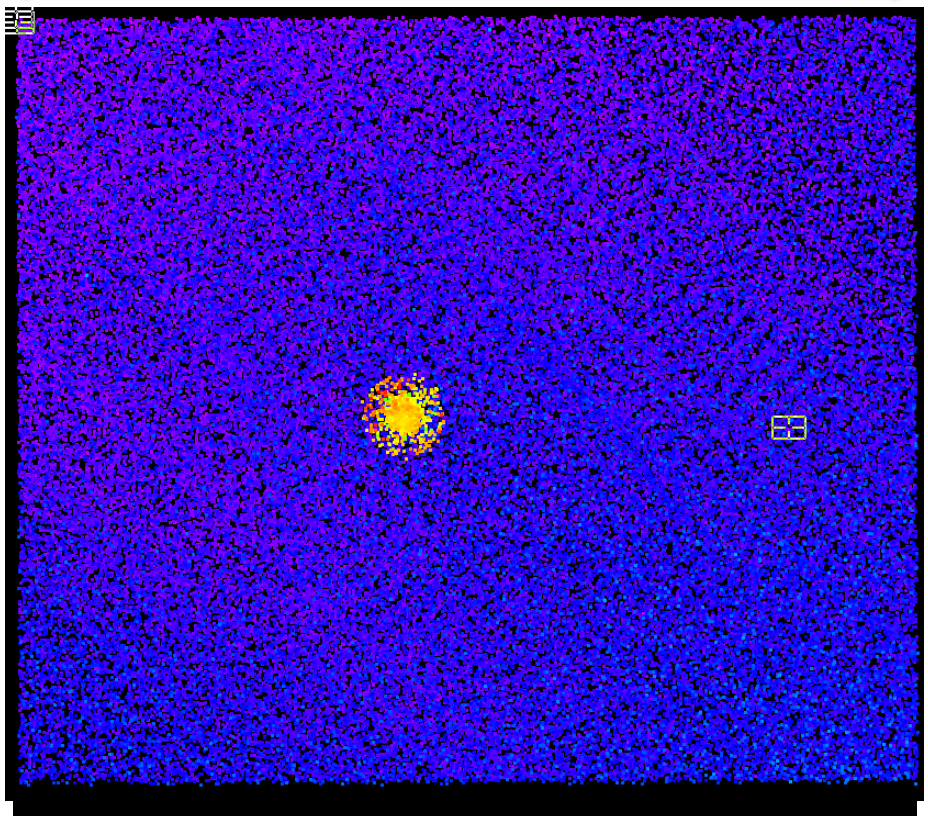
CZMIL Point Cloud: Cube 1

100m

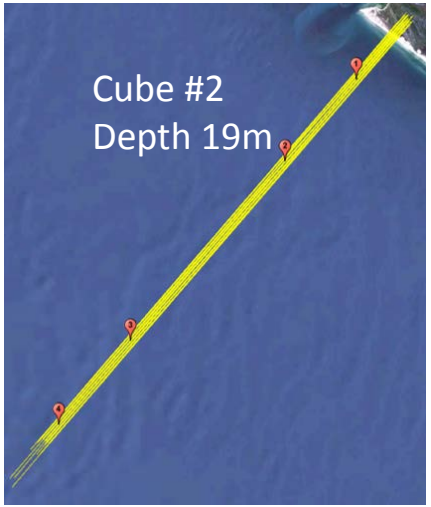


100m

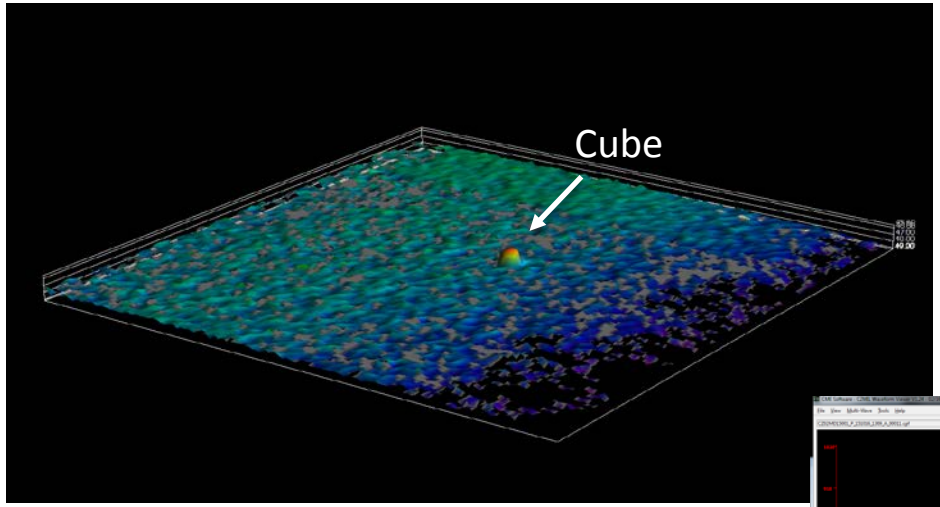
Shallow Channel, FOV = 401.9mrad

Deep Channel, FOV = 401.9mrad

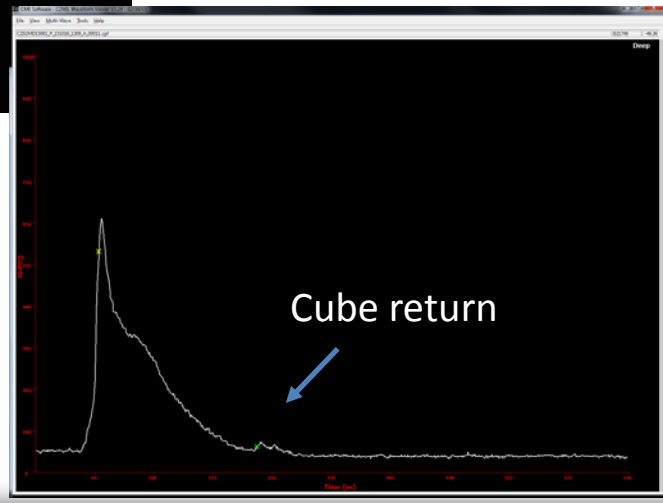
CZMIL Waveform : Cube 2



DEM

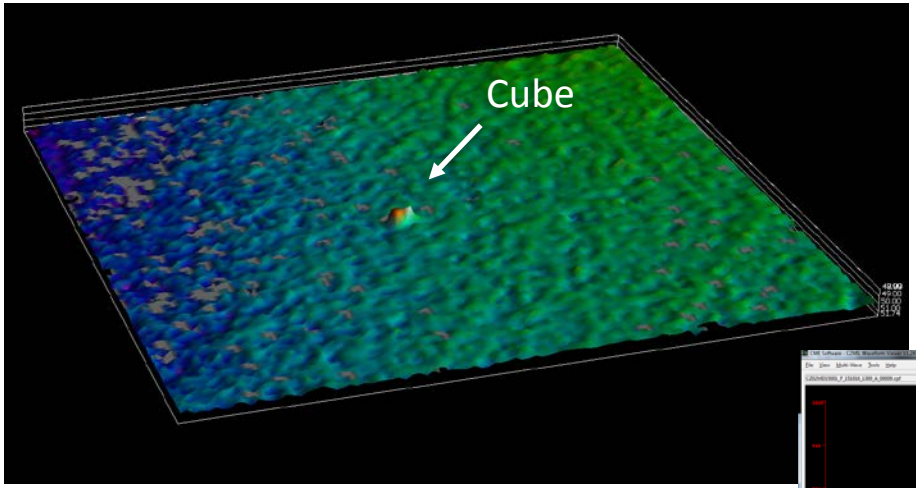


Deep channel waveform

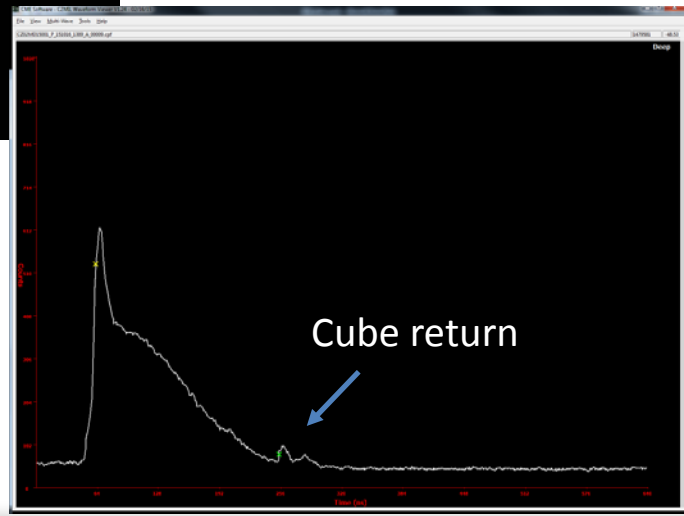


CZMIL Waveform : Cube 3

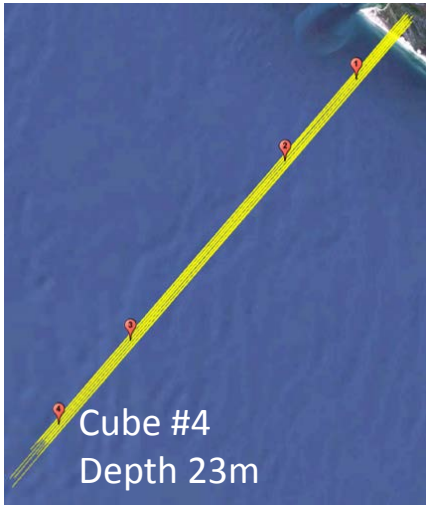
DEM



Deep channel waveform



CZMIL Waveform : Cube 4



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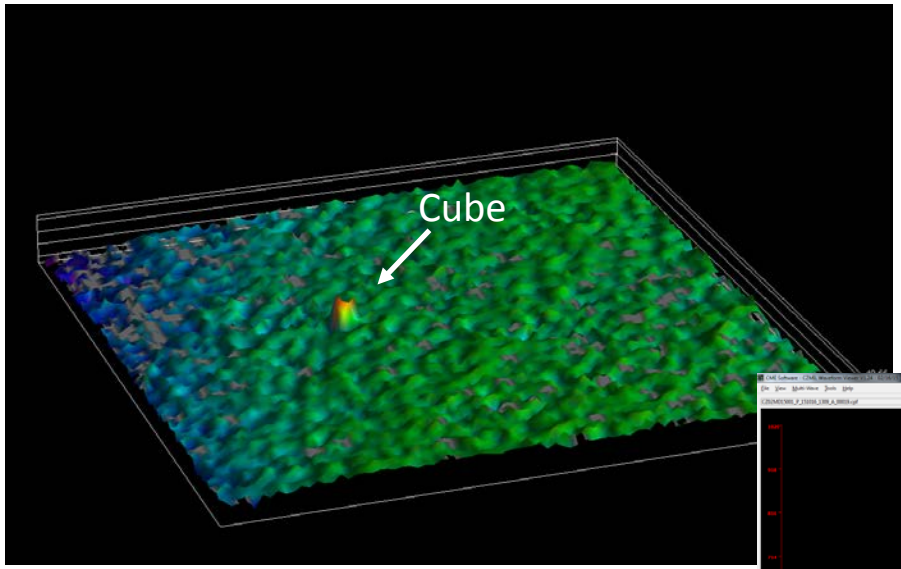
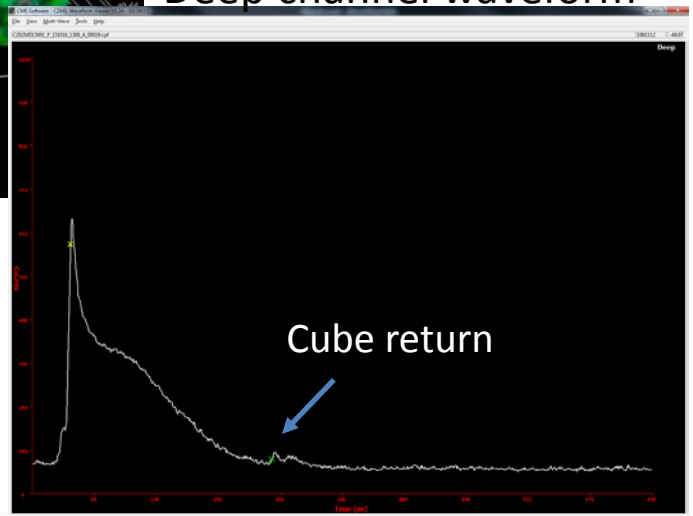
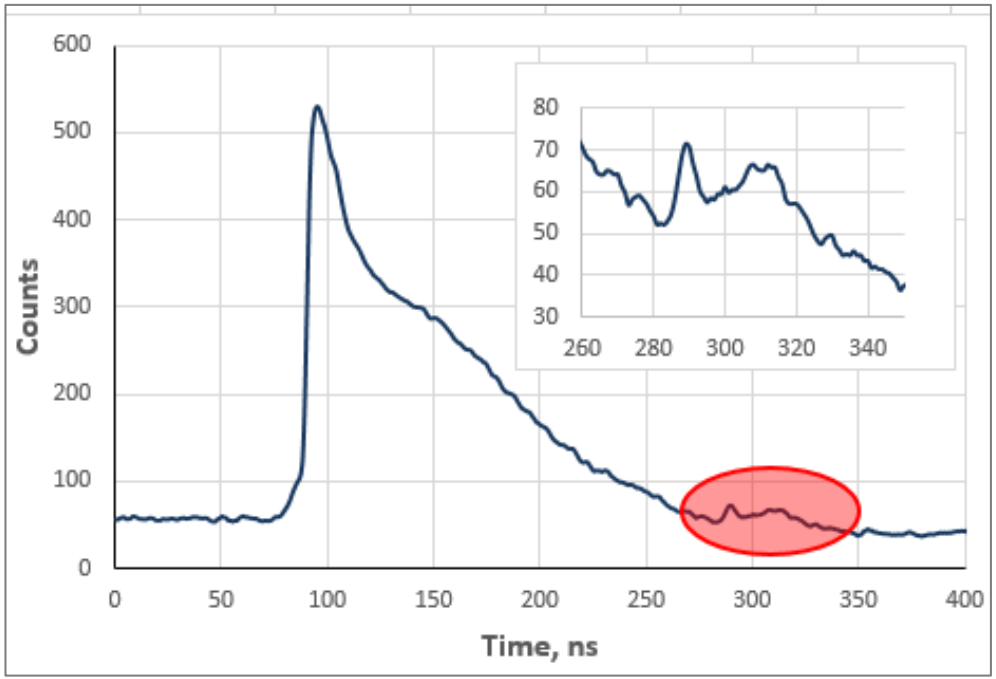


Deep channel waveform



CZMIL Waveform : Cube 4

A more detailed view of the waveform



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Conclusions

- A theoretical model that estimates the probability of detection of IHO order 1a-sized objects for each valid lidar bottom detection event was developed.
  - Incorporate geometrical factors to further improve the model for reliable prediction.
- CZMIL was able to successfully detect IHO order 1a-sized objects over the test site.
  - Enhance the detection algorithms within HydroFusion
- The enhanced target detection capability also suggests that CZMIL system has great potential for military applications : rapid reconnaissance of submarines, underwater mines and other “small” objects of interest.

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Acknowledgments

- We thank the Naval Oceanographic Office for facilitating the Panama City, FL collection effort by providing resources and labor from multiple participating departments including NP4 Hydrographic, NP3 Oceanographic, N6 Engineering, and 0TP Special Programs and Production Support, as well as the NAVO Dive Team.
- We would like to thank **Bill Elenbaas**, who authored the test plan, and **Rebecca McGuire,** who was responsible for execution of the collaborative data collection effort and also provided preliminary data analysis; their contribution is sincerely appreciated.
- This work was funded under Army Corps of Engineers Contract W91278-10-D-0104

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Thank you!

Questions?

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Cube Distance and Probability of Detection

Input/Estimated Parameters

ρ_{cube}= 40%

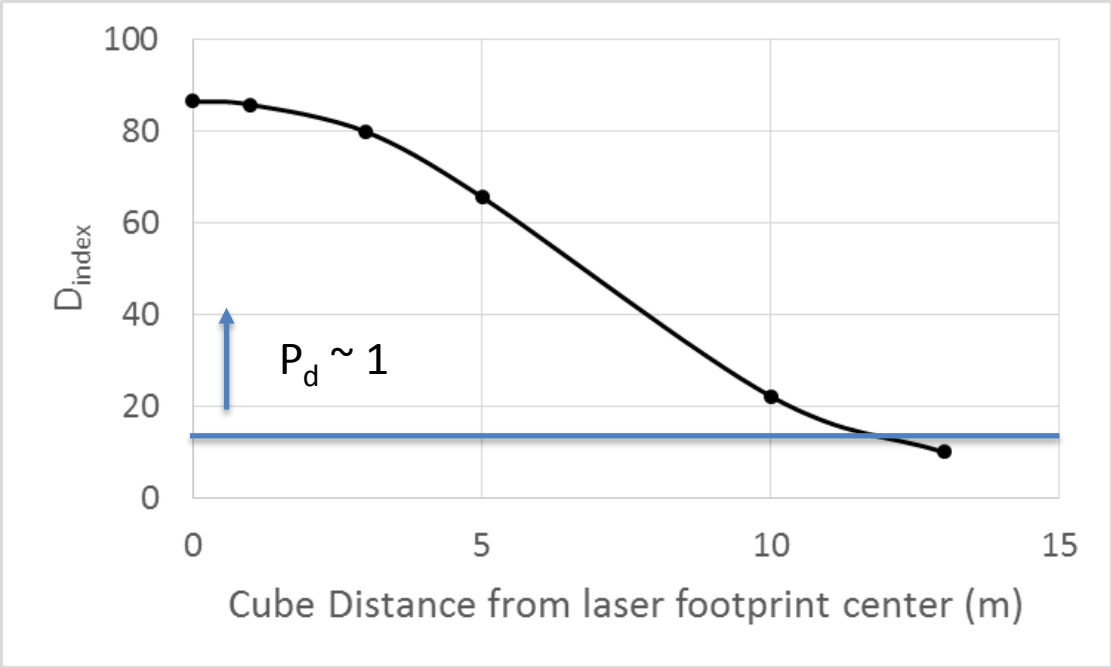
Cube size = 2mx2mx2m

$\rho_{seafloor}$ ~ 10%

K_d ~ 0.10m^{-1}

Depth ~ 22m

Cube location: Varying



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