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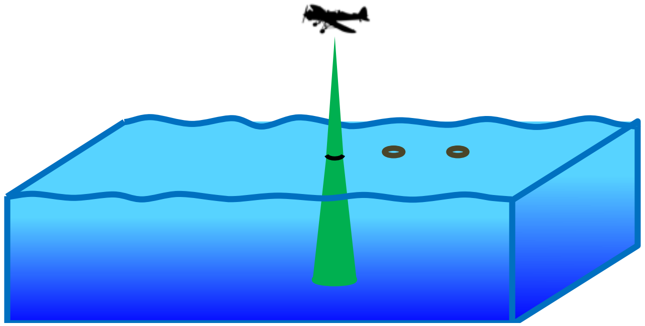
Multi-wavelength Ocean Lidar

Deric Gray
Remote Sensing Division
Naval Research Laboratory

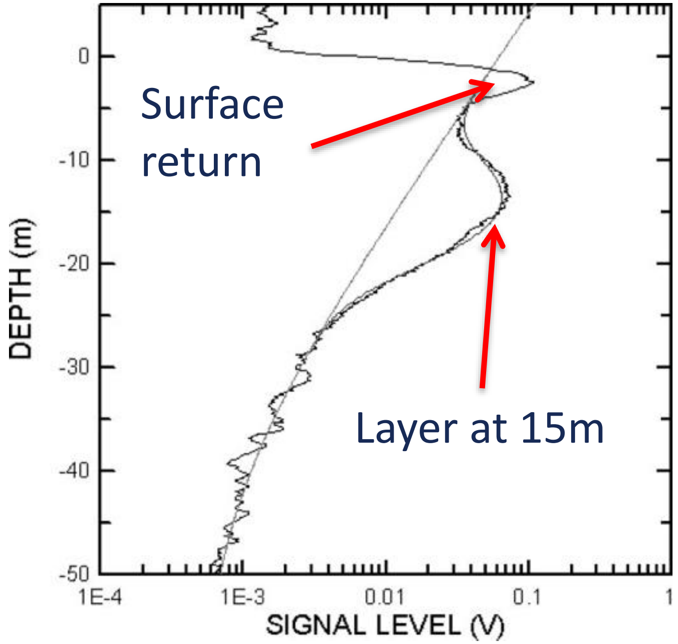
Introduction

Profiling ocean lidars provide estimates of vertical profiles of backscattering and attenuation in the ocean



Generally operate at 532 nm

- Proven technology (cheap)
- Good water penetration
- High Energy
- High Repetition rate
- Short pulse width

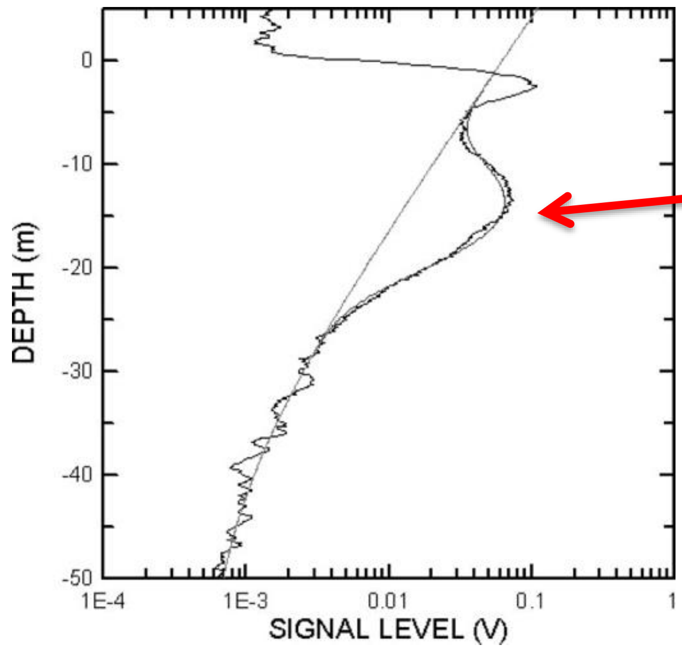


(Churnside 2001)

Introduction

lidars are good at finding layers…

…But not so good at identifying them



(Churnside 2001)

What is this layer?

- Fish?
- Zooplankton?
- Phytoplankton?

Introduction

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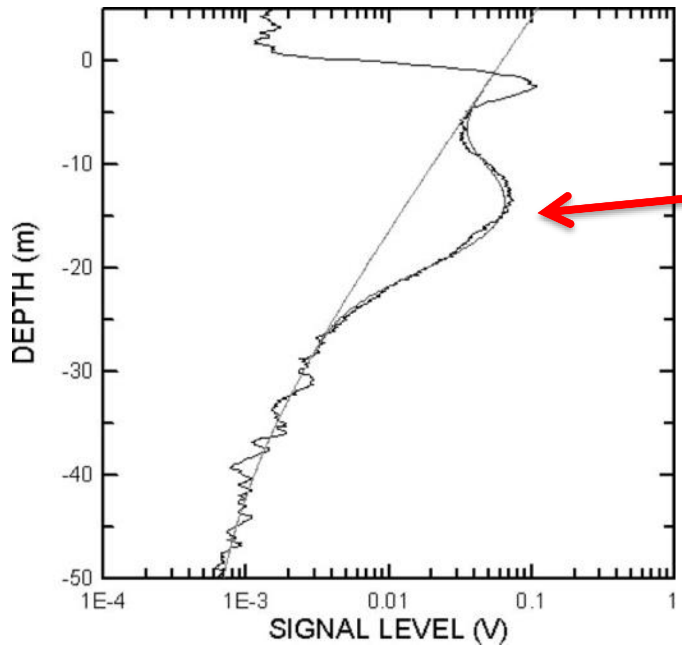


(*Churnside 2001*)

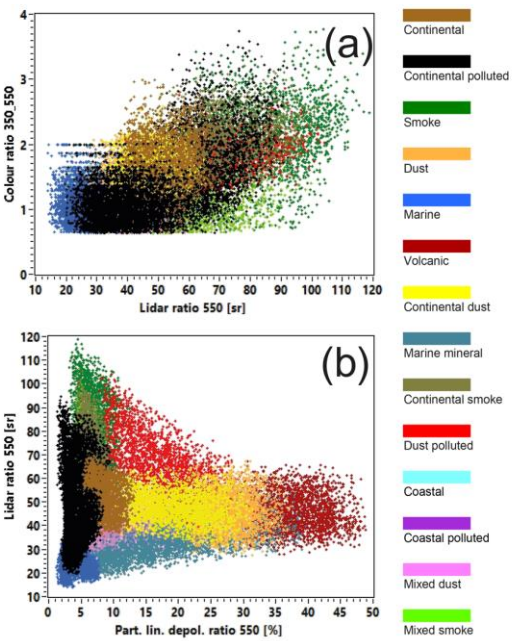
What is this layer?

- Fish?
- Zooplankton?
- Phytoplankton?

What about a multiple-wavelength lidar?

Multiple-wavelength lidar is being used to discriminate aerosol and dust types in the atmosphere

Cao *et al* could distinguish nearly all types of pollens and dust (27 types) using 3 – 4 laser wavelengths and the depolarization ratio



Work with European Aerosol Research Lidar Net- work (EARLINET) data show aerosol discrimination using a three wavelength approach

$$3\beta + 2\alpha + \delta$$

Number of wavelengths	Wavelengths (nm)	Non-discrimination (%)
4	355, 532, 1064, and 1570	1
3	532, 1064, and 1570	4
	355, 1064, and 1570	3
	355, 532, and 1570	1
	355, 532, and 1064	4
2	355 and 532	5
	355 and 1064	6
	355 and 1570	4
	532 and 1064	10
	532 and 1570	5
	1064 and 1570	8
1	355	17
	532	17
	1064	24
	1570	18

(Cao, Roy, Bernier 2010)

Nicolae et al 2018

What about a multiple-wavelength ocean lidar?

Continuously-tunable OPO lasers and ”white” light lasers are commercially available

What can a multi-wavelength lidar do in the ocean?

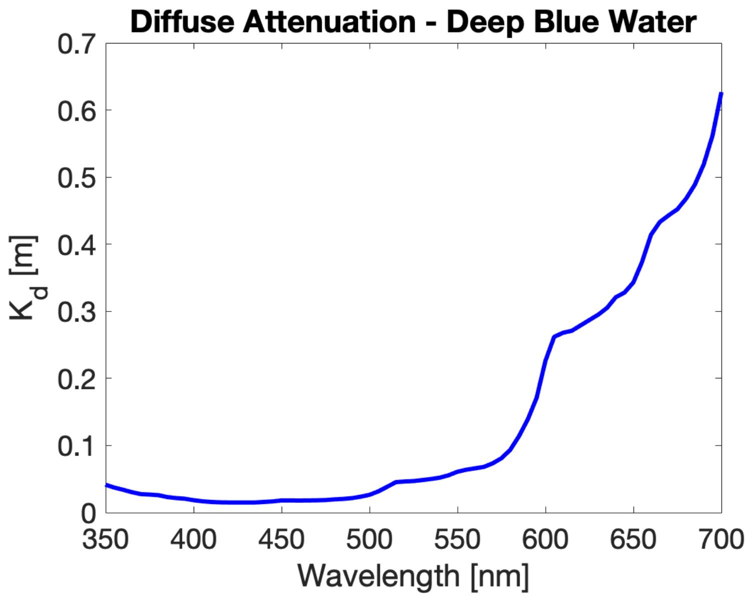
Questions:

- What is the best wavelength for a given water type?
- Can we determine particle size/composition?
- How many wavelengths can we use?
- How many wavelength do we need?
- What are the trade-offs?

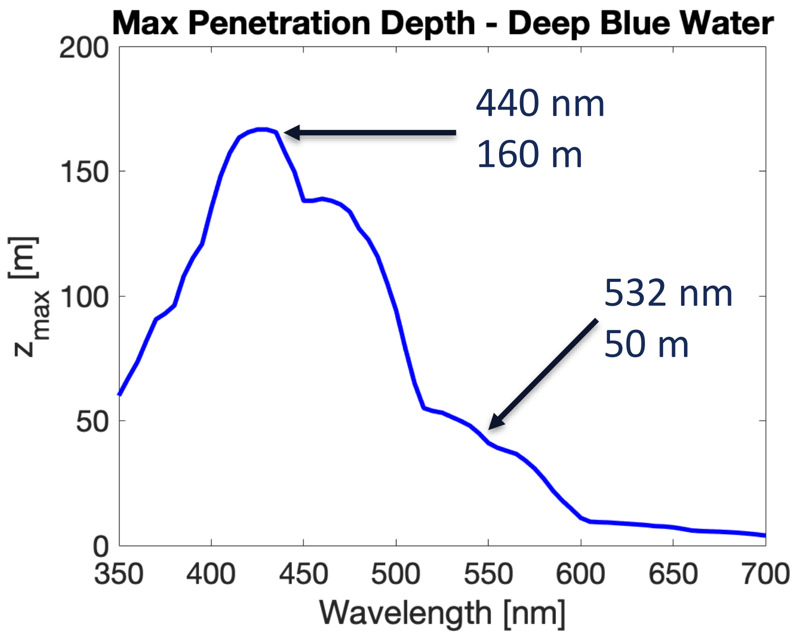
Optimum Wavelength for Different water types

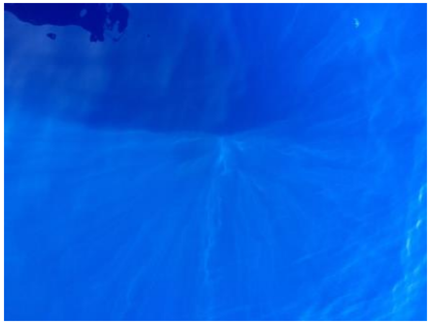
The maximum depth penetration for a lidar is normally 2 - 3 times the diffuse attenuation coefficient

$$z_{max} \approx \frac{2-3}{K_d}$$



(Lee et al 2005)





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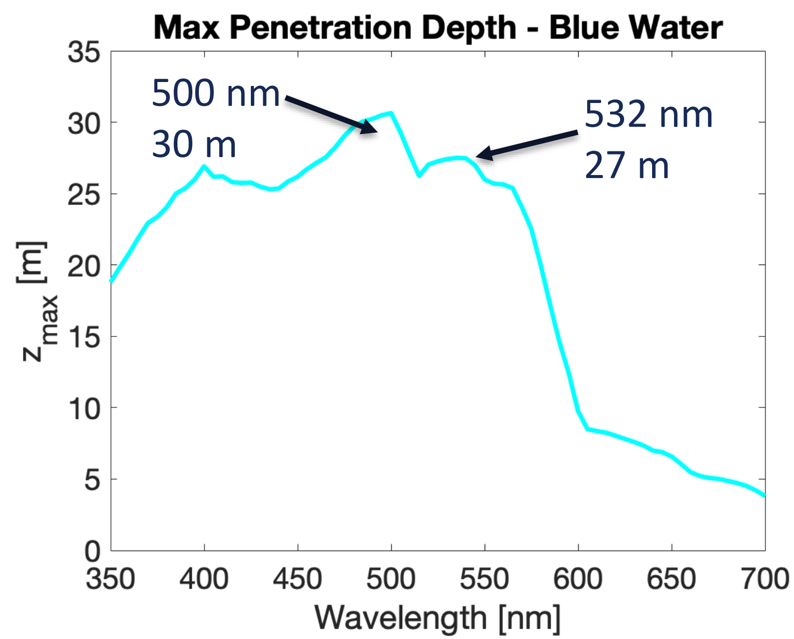

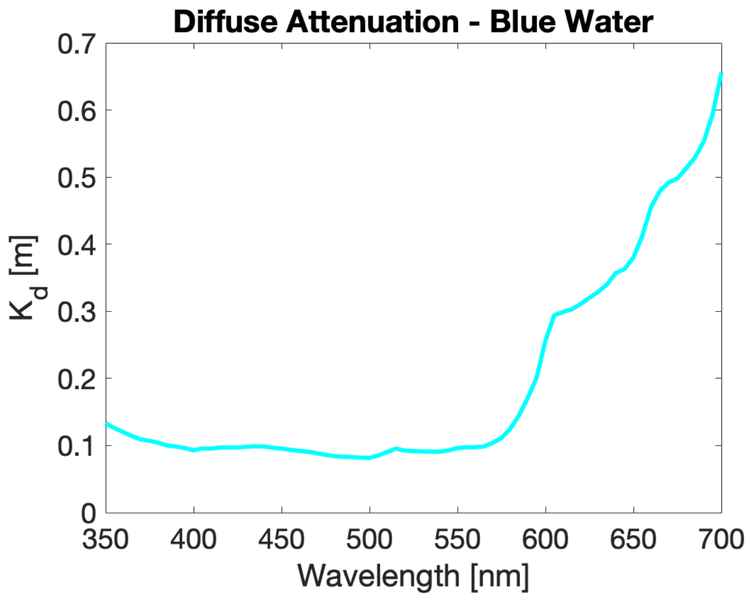

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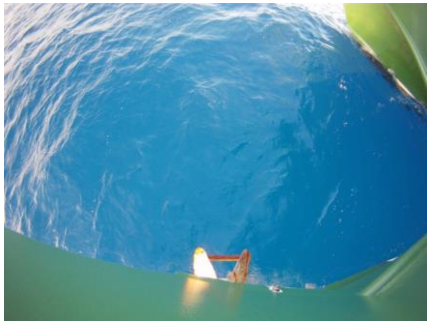

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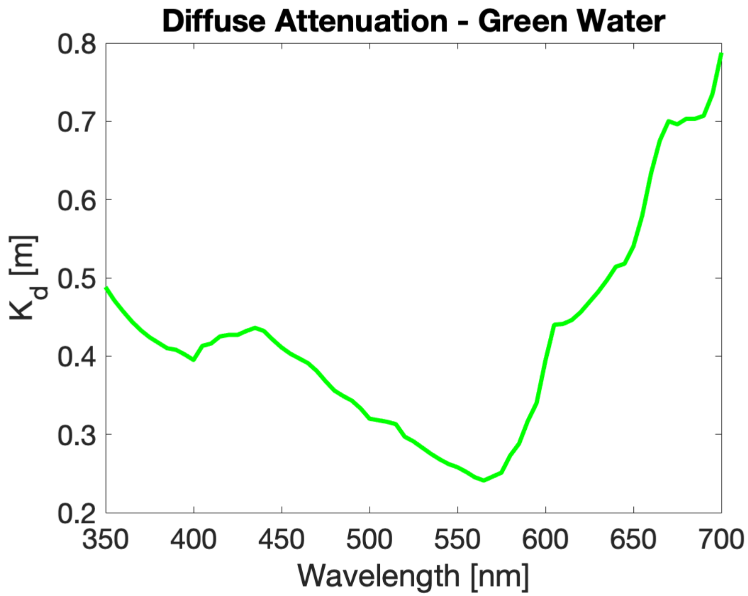

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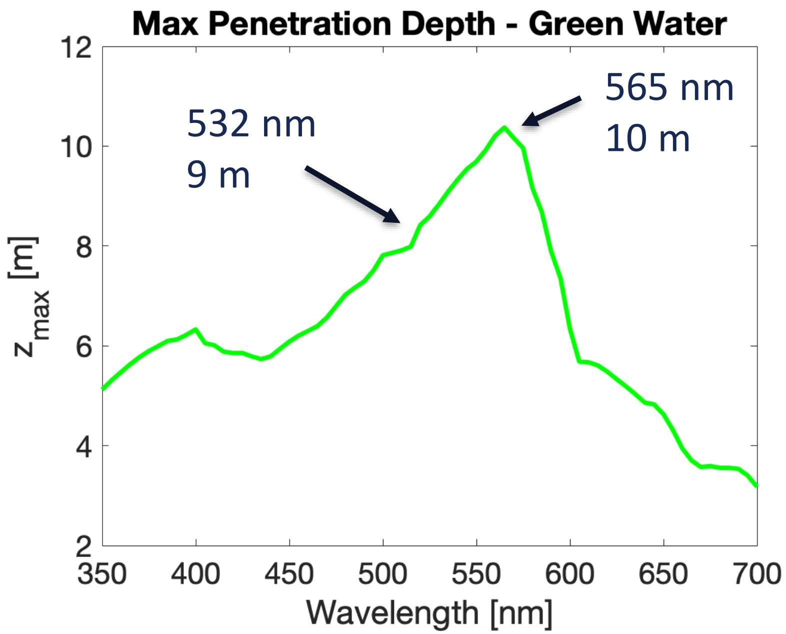

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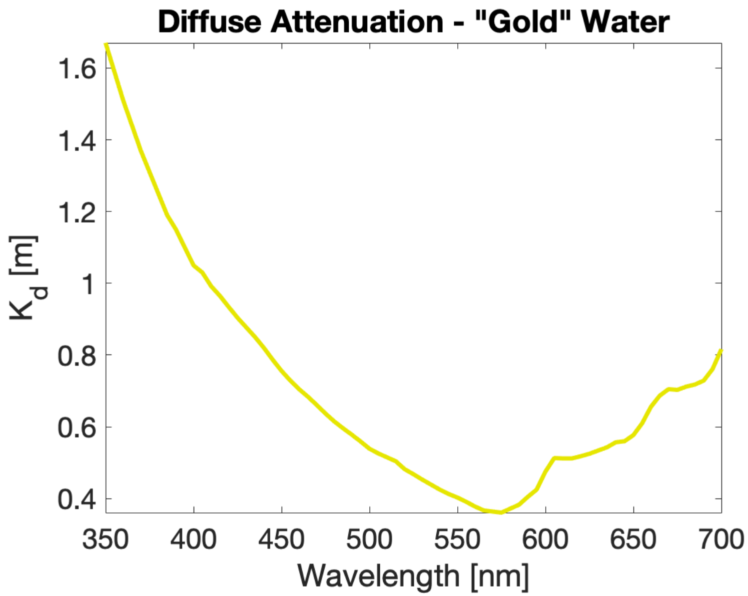

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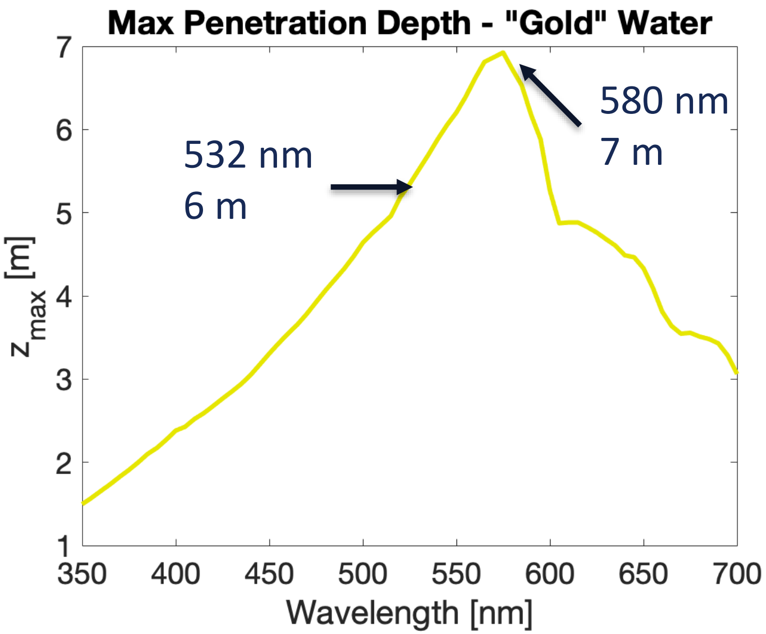

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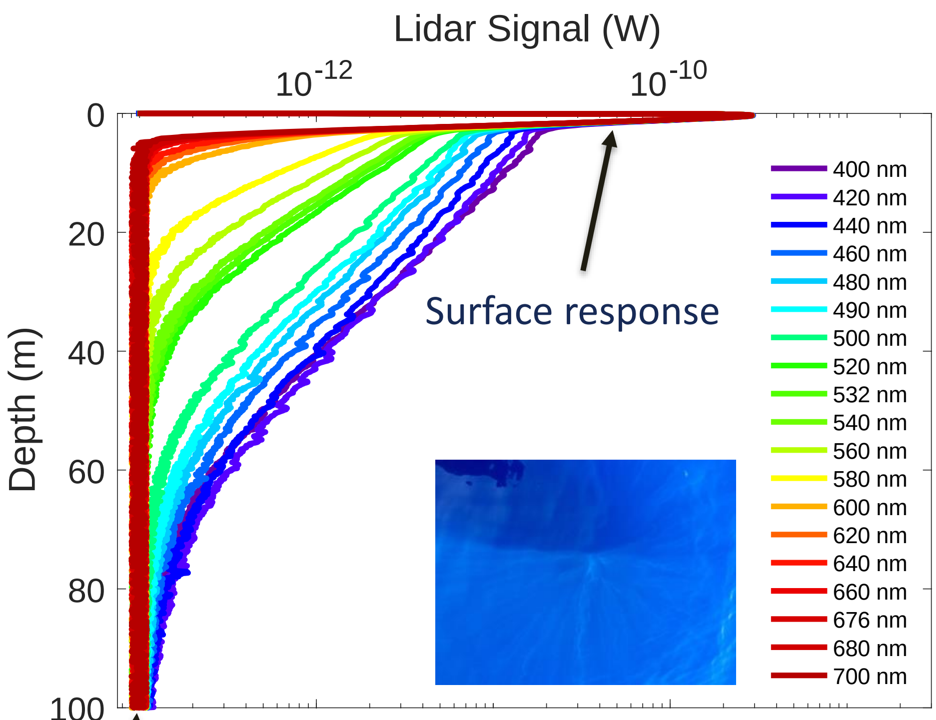
Optimum Wavelength for Different Water Types

532 nm is the best single wavelength, except in deep blue water, where 420-440 nm is optimal

But what about the lidar signal?

What about the lidar signal as a function of wavelength?

Lidar Signal for Different Wavelengths



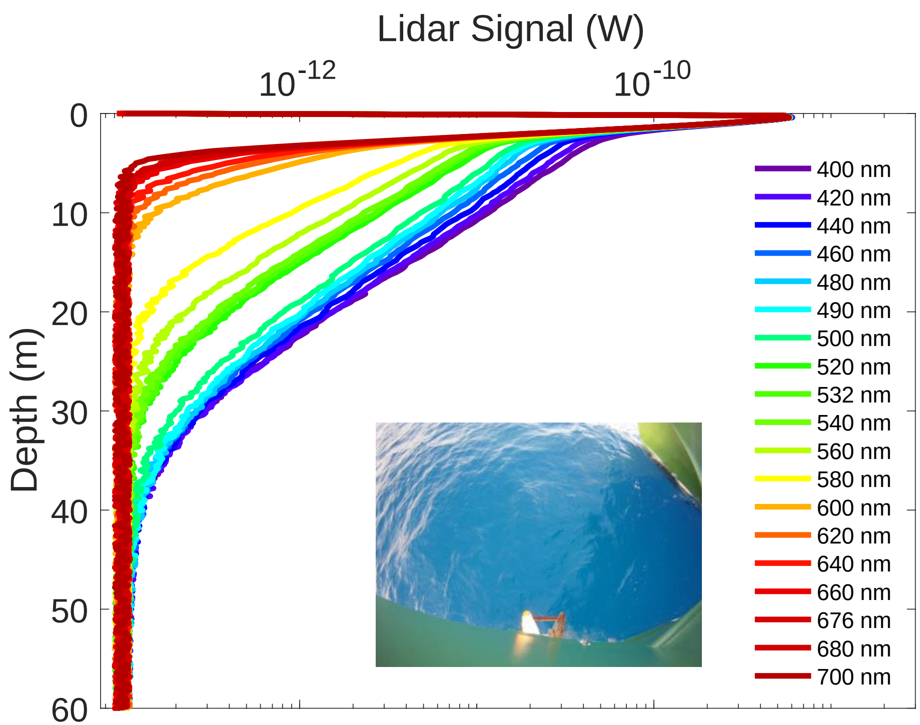
Modeled lidar return for Deep Blue Water

Background/electronic noise floor

Modeled airborne lidar signals showing spectral returns as a function of depth

- Generally agrees with K_d prediction of optimal wavelength
- Background and electronic noise floor determine depth limit

Lidar Signal for Different Wavelengths



Modeled lidar return for Blue Water

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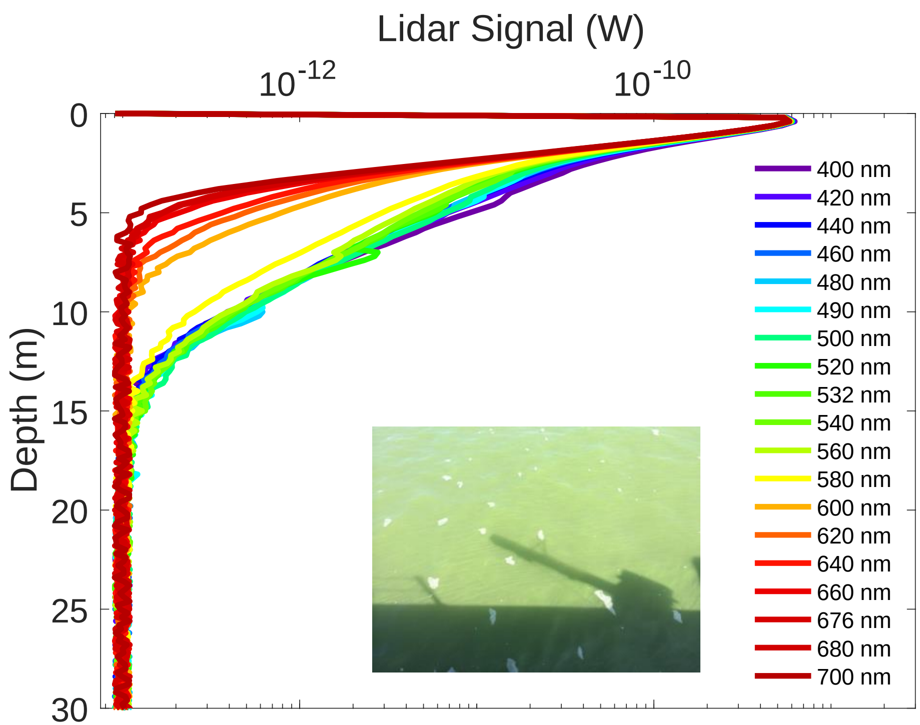
Lidar Signal for Different Wavelengths



Modeled lidar return for Green Water

Modeled airborne lidar signals showing spectral returns as a function of depth

- Generally agrees with K_d prediction of optimal wavelength
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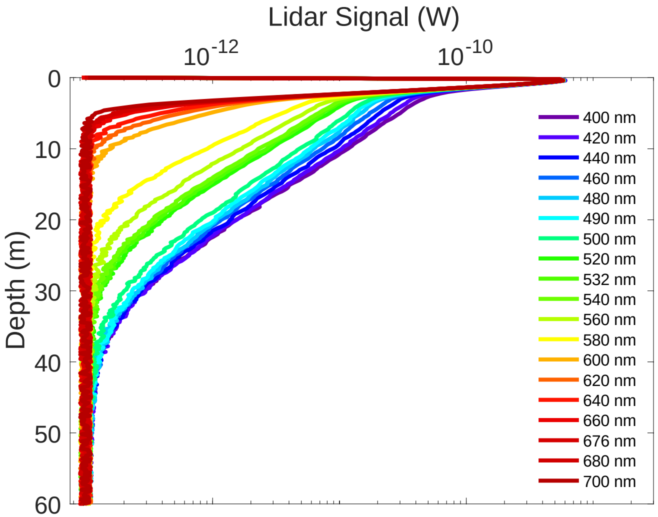
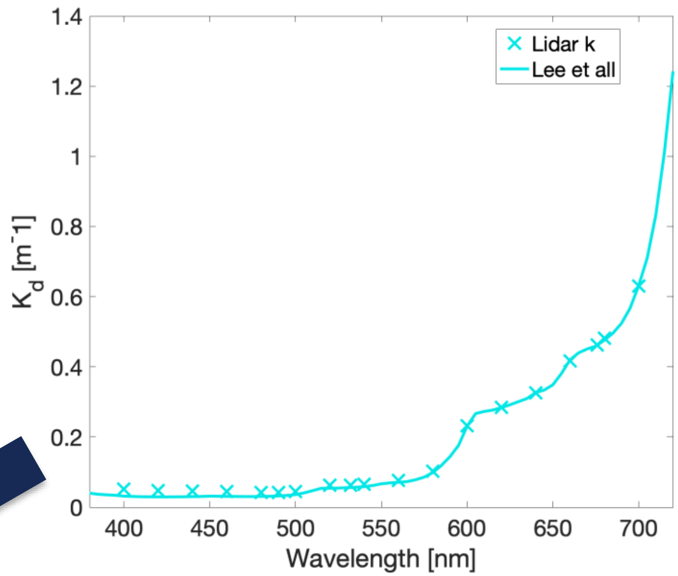
Retrieval of Spectral Diffuse Attenuation

Above-Surface Lidar equation in the ocean:

$$S(z,\lambda) = C\frac{\beta(\pi,z,\lambda)}{(nH+z)^2}\exp\left(-2\int_0^z k_{sys}(\lambda,z')dz'\right) \qquad k_{sys} \approx K_d$$

We can derive the lidar k_{sys} from the waveforms and compare to calculated or measured K_d





From $K_d(\lambda)$ we can derive Chlorophyll, CDOM, SPM, etc

What else can be retrieved?

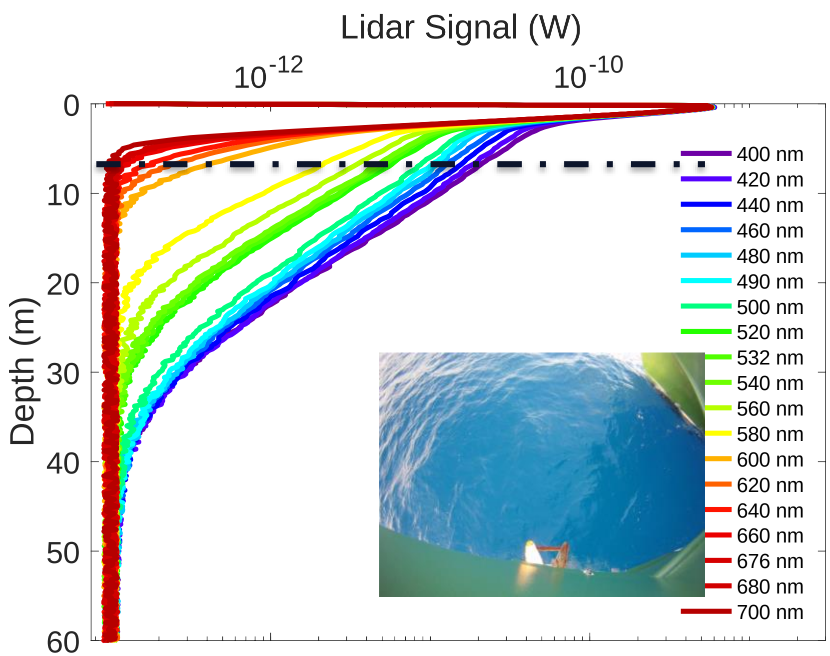
Above-surface Lidar equation in the ocean:

$$S(z,\lambda) = C\frac{\beta(\pi,z,\lambda)}{(nH+z)^2}\exp\left(-2\int_0^z k_{sys}(\lambda,z')dz'\right)$$

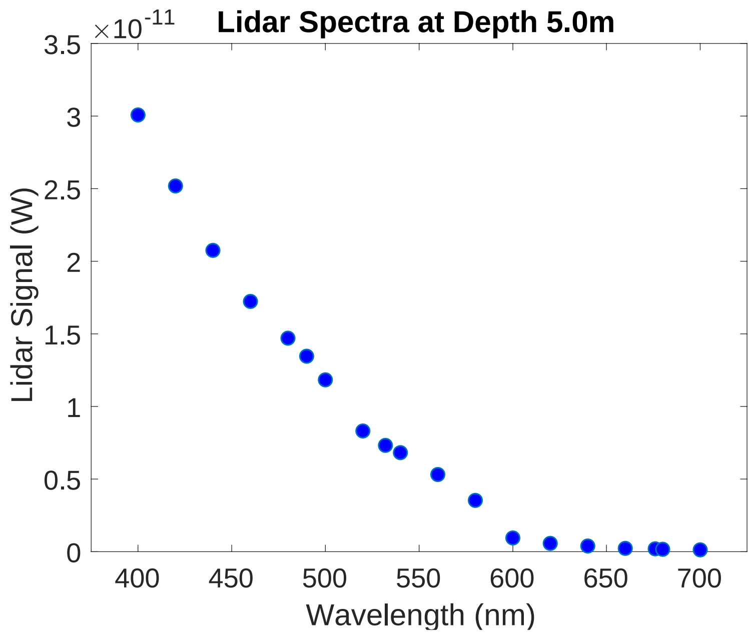
- Near the surface, the spectral lidar signal is determined mostly by $\beta(\lambda)$
- At depth increases, the spectral signal is dominated by $K_d(\lambda)$

3-D Spectral View?

If we can use multiple laser wavelengths* on the same water mass, we can create a 3-D spectral view under the water surface



Modeled lidar return for Blue Water



* A well-calibrated system

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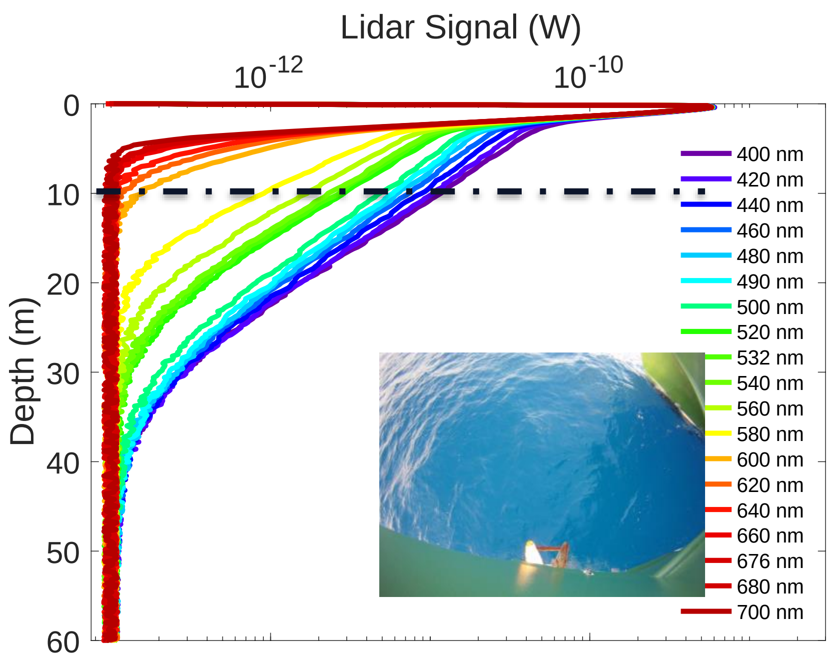

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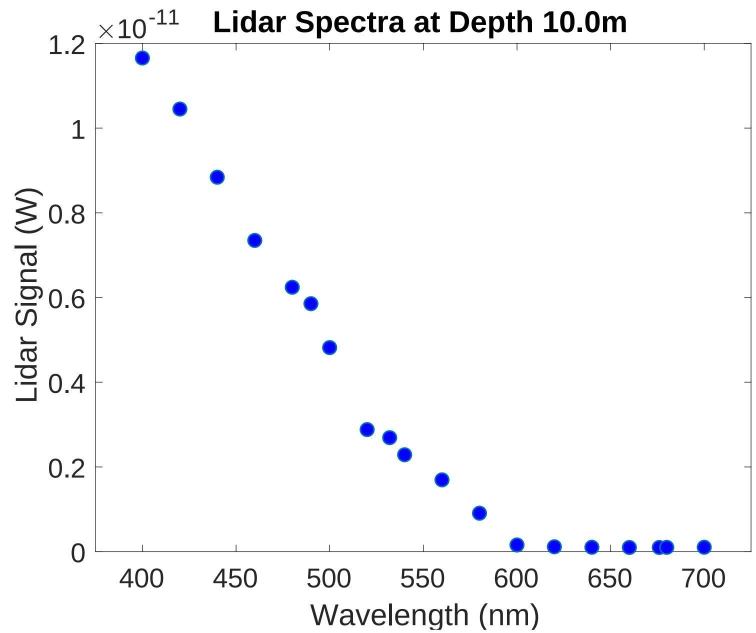

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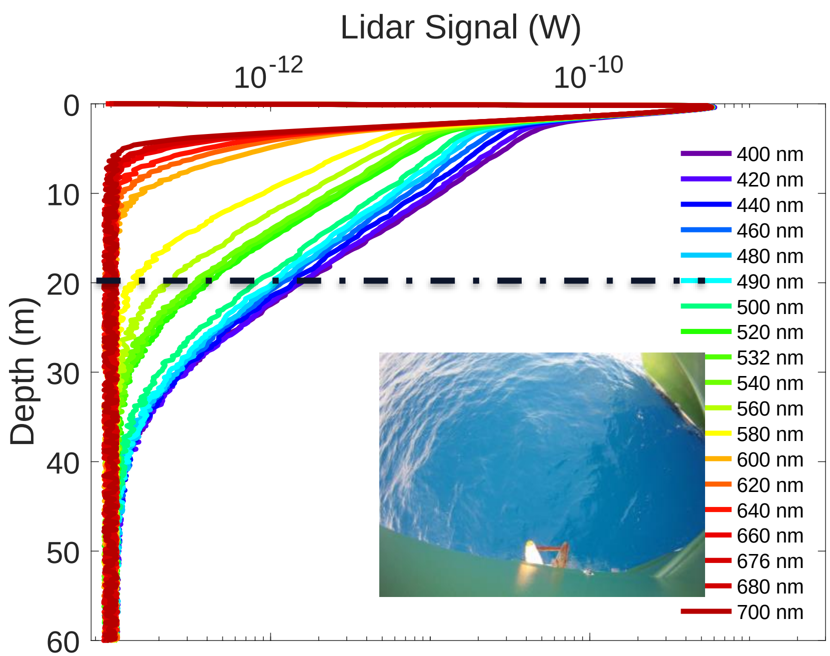

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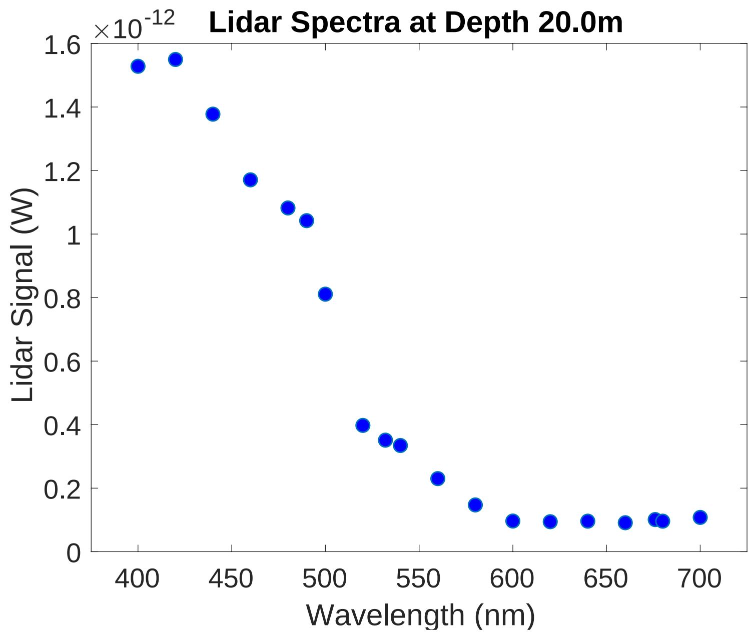

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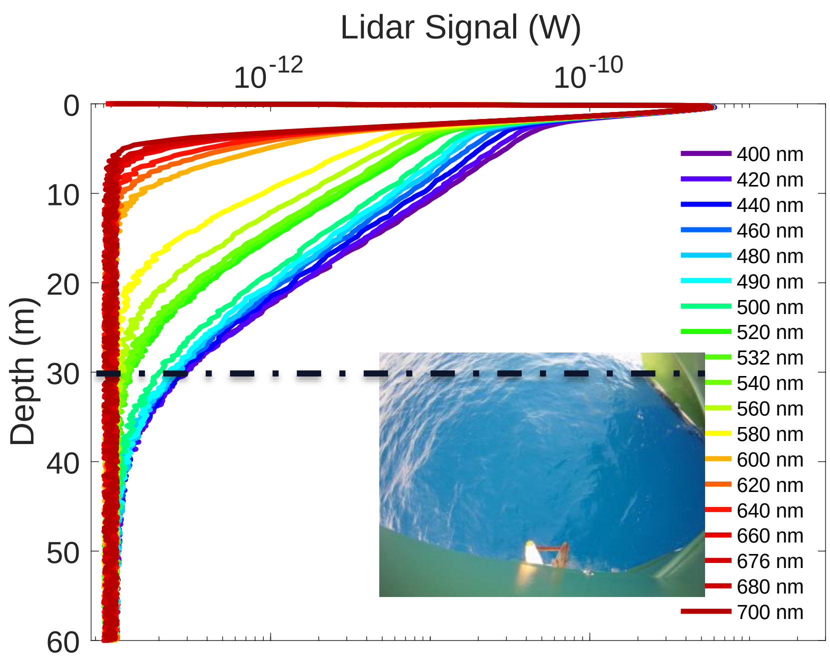

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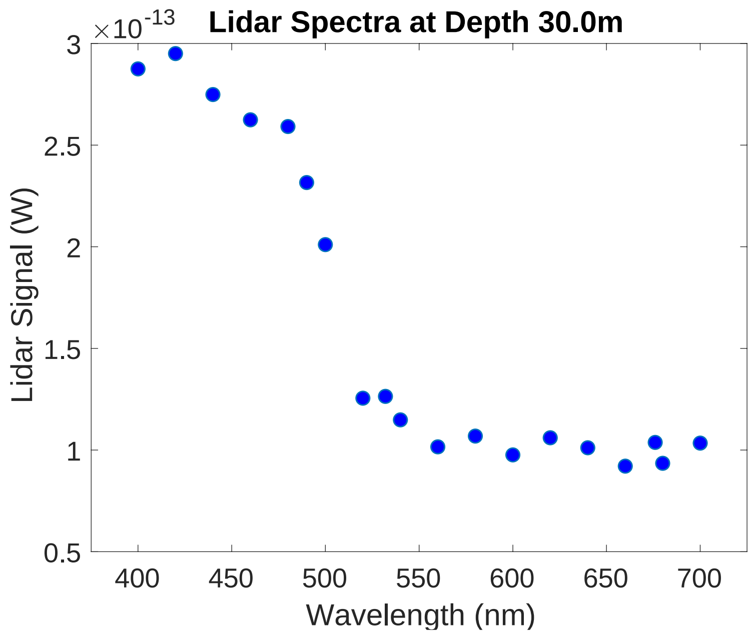

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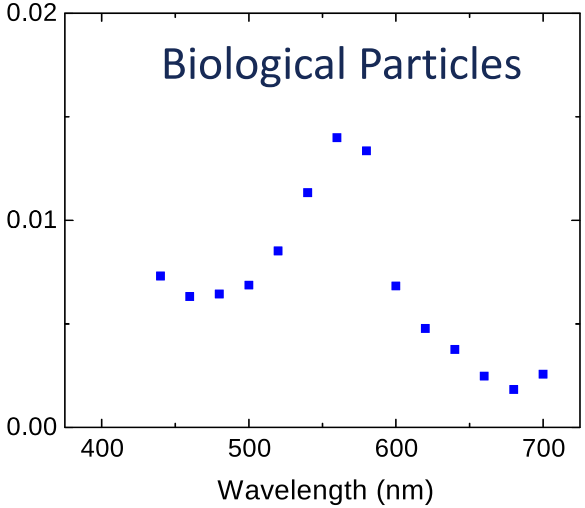
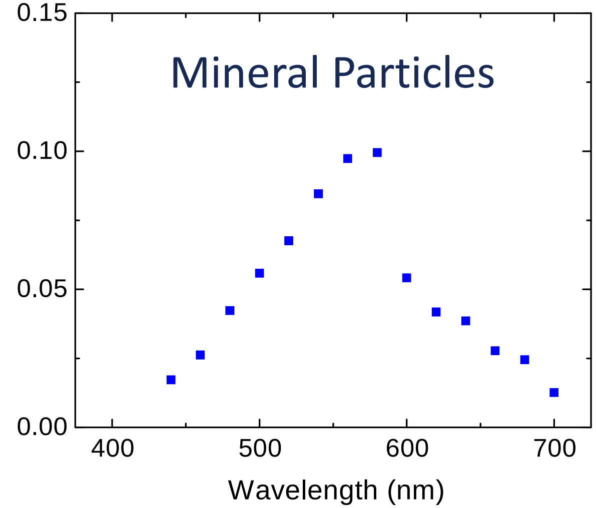
Particle Discrimination

Laboratory Experiments show that the lidar spectra can be used to characterize particle types





A lot of work remains to be done, but the lidar spectra could

- be a means to determining the spectral backscatter
- discriminate between particle types

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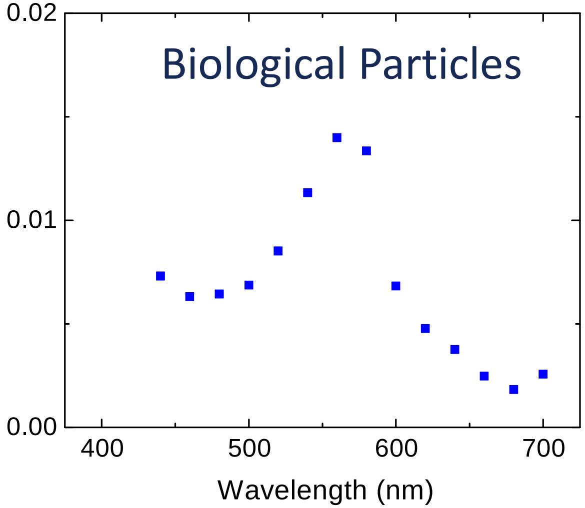

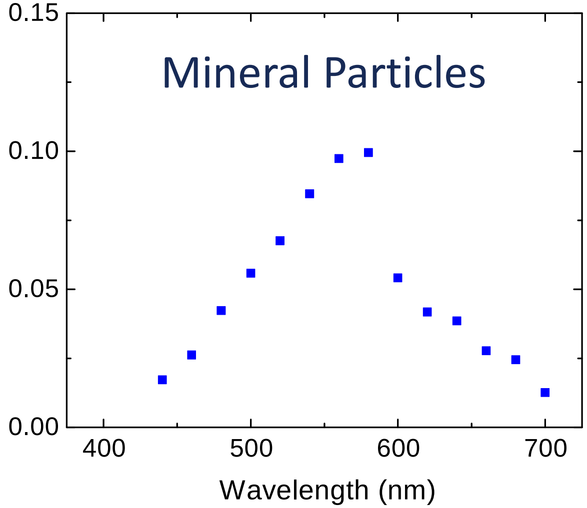

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- be a means to determining the spectral backscatter
- discriminate between particle types

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Prototype Multi-wavelength lidar

Lidar

OPOTek OPO laser

- Continuously tunable from 410 – 2200 nm
- 0.1 nm increments
- 0.2 nm FWHM
- 0.5 – 2.5 mJ/pulse
- 7 ns pulse length
- 20 Hz repetition rate
- Can change wavelengths in seconds

Receivers

- 6 channels - 440, 490, 532, 580, 625, 685 (FL) nm

Instruments – Passive Imagers and Navigation

ITRES
CASI-1500
Visible/Near-IR
hyperspectral
~375 – 1050nm

µSHINE
Visible/Near-IR
hyperspectral
~330 – 970nm

Applanix POS
GPS/INS
200 Hz

FLIR SC6000
Midwave-IR
3-5mm,
broadband

Sofradir Atom 1024
Longwave-IR
8-14mm, broadband

Systron CMIGITS III
GPS/INS
10 Hz

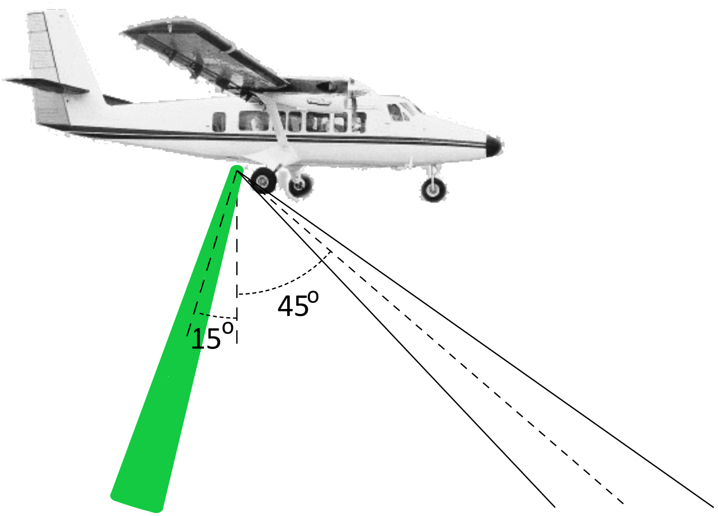
Surface Optics
Shortwave-IR
hyperspectral
~900-1700nm

Jai CM-200MCL
Panchromatic
1620x880, 24 Hz
~400-700nm

First Tests of the airborne lidar

Goals:

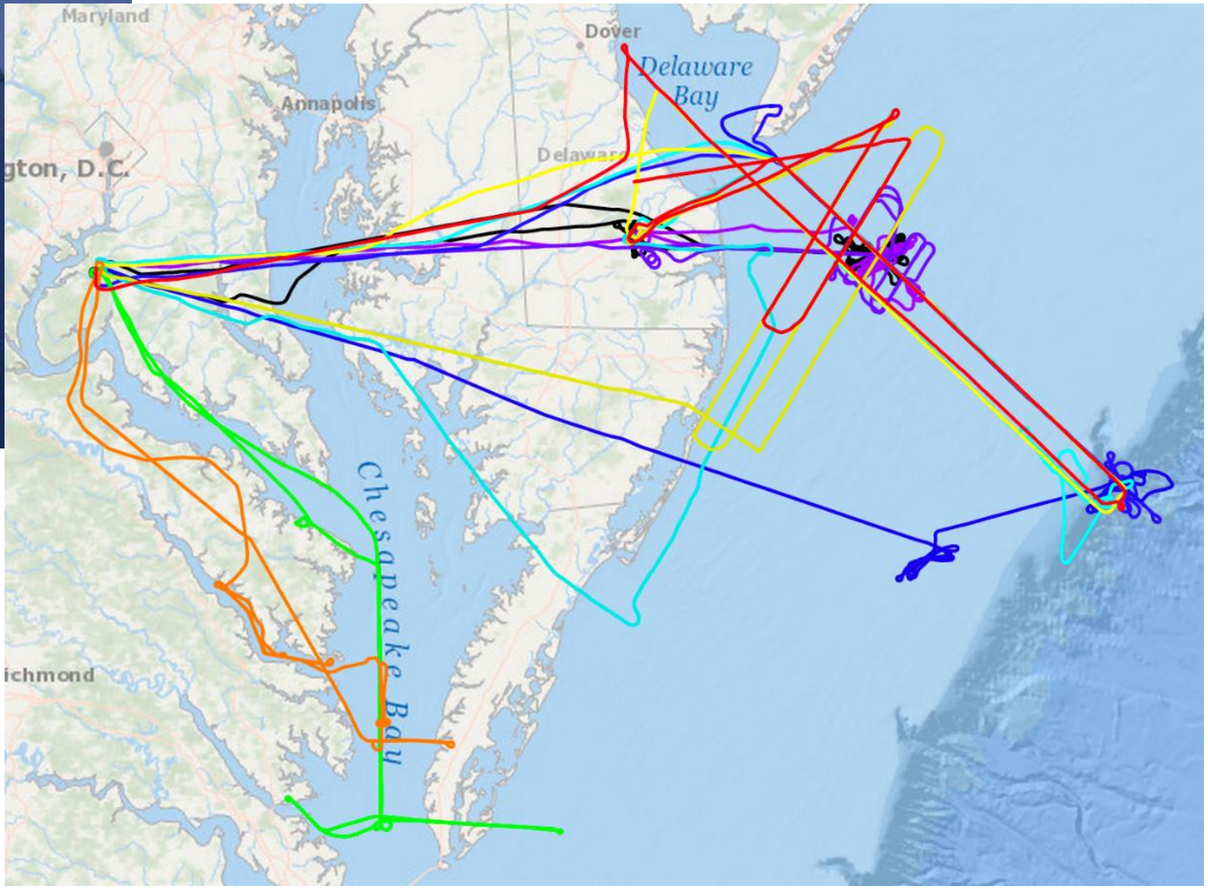
- Instrument:
  - Test performance in different Condition
  - Find optimal wavelengths in different water types and conditions
- Environmental
  - Bathymetry
  - Spectral diffuse attenuation



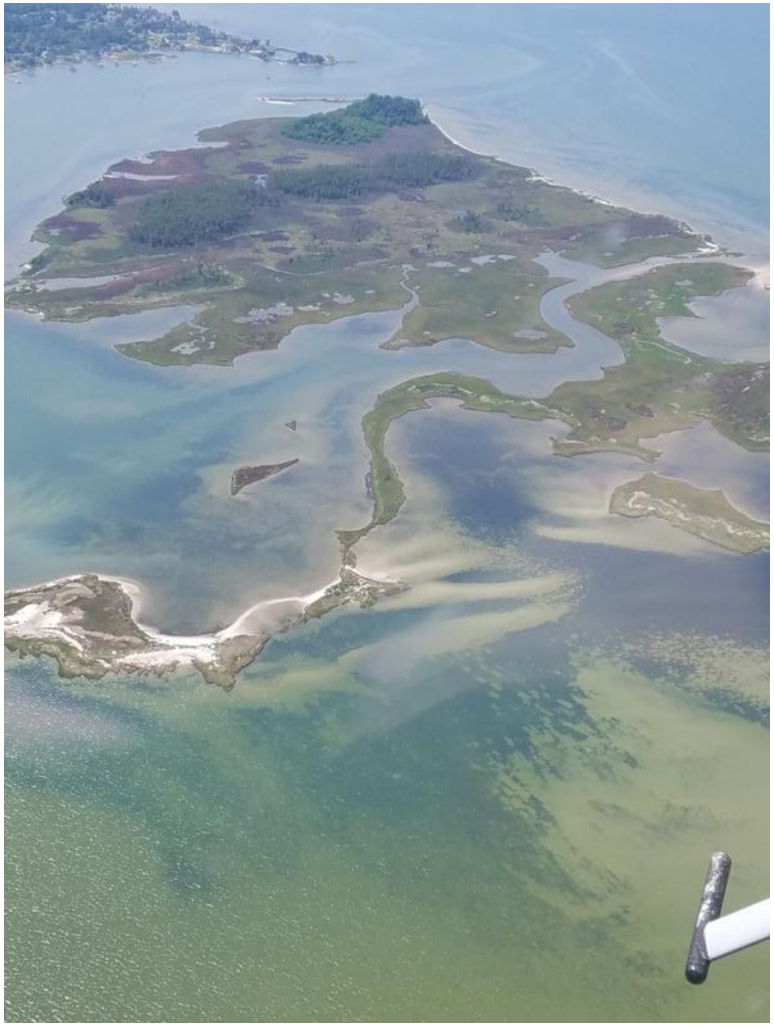
Flight Parameters

- Usually around 400-500m altitude
- Lidar transceiver oriented at 15° angle aft from the vertical

Flights Tracks

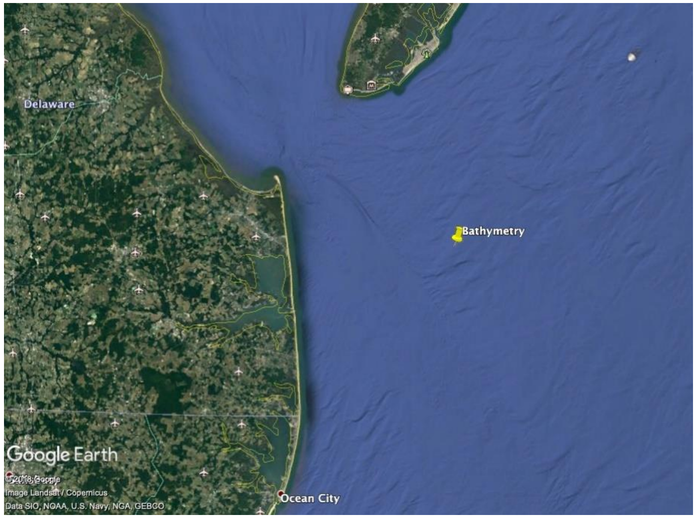


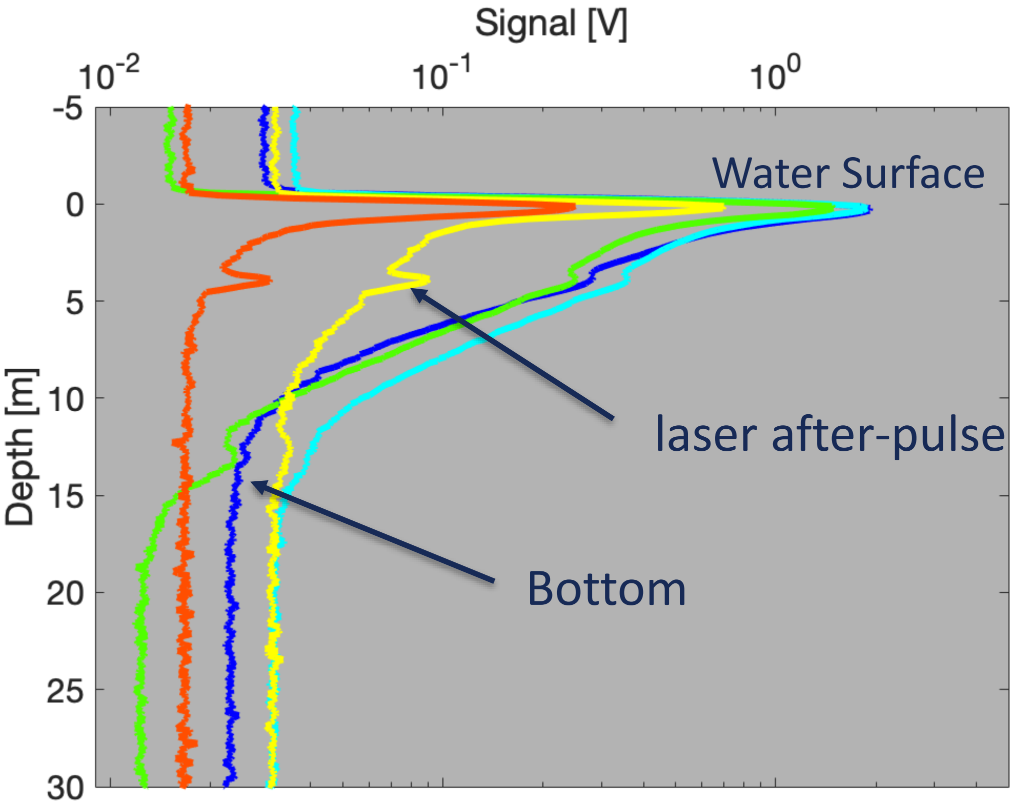
Test Flight in the Delaware Bay\Chesapeake Bay region



Preliminary Lidar Profiles

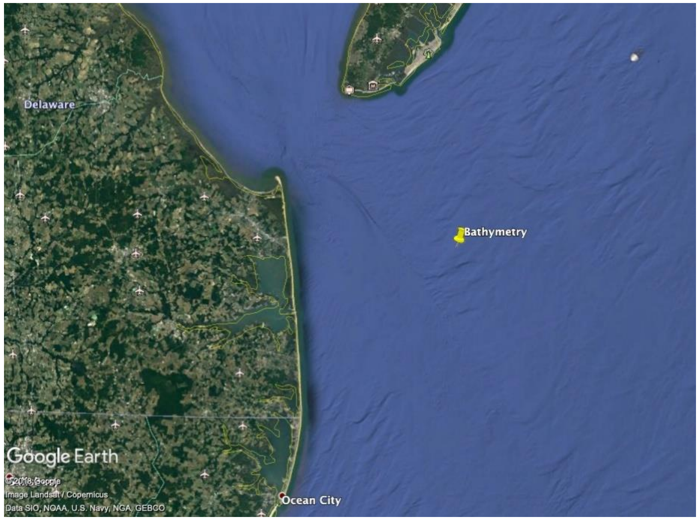
Example of an ocean profile

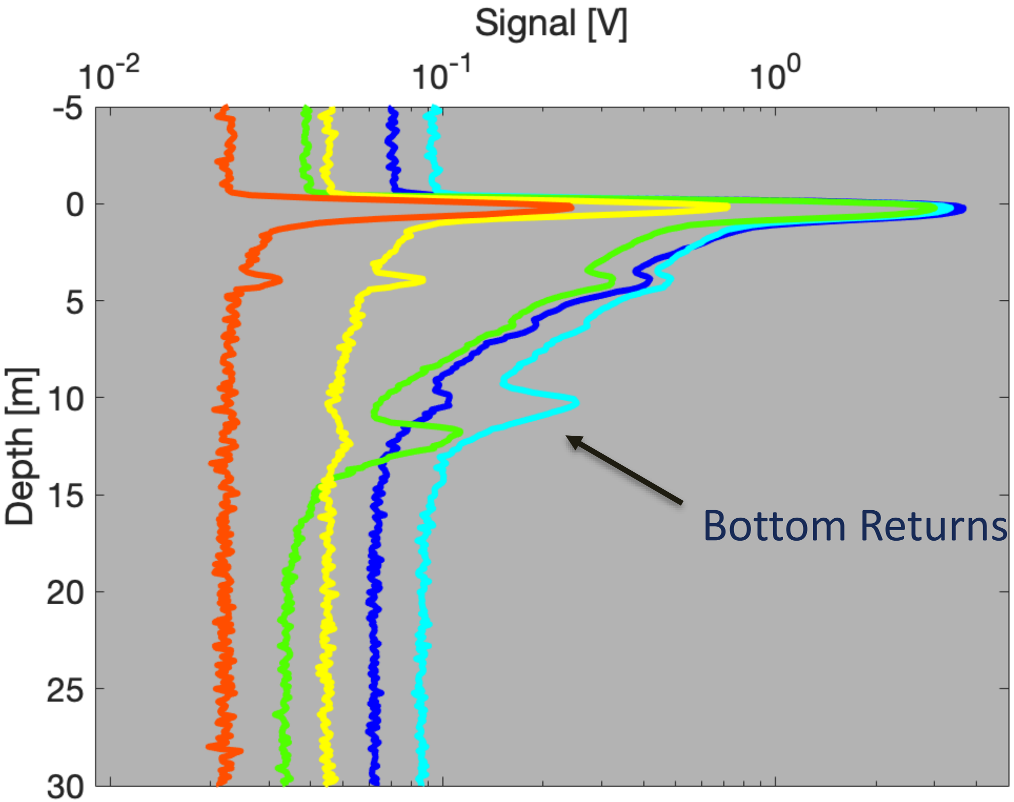




Lidar Profiles

Bathymetry retrieval to around 15 m at multiple wavelengths

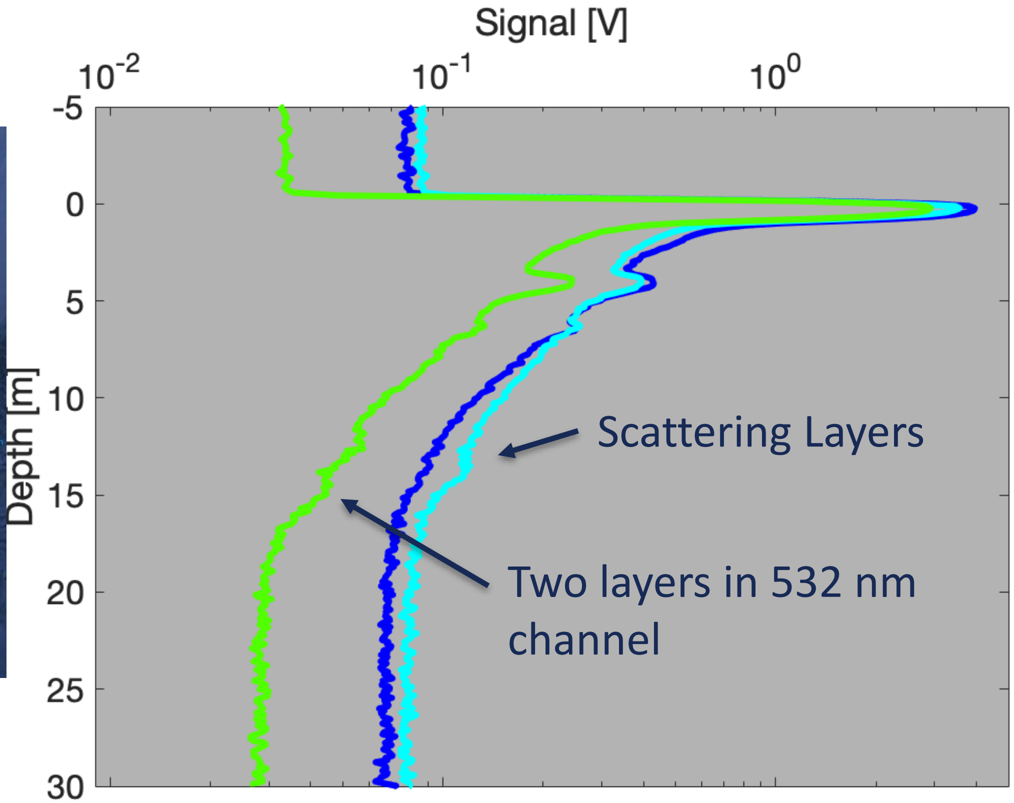




Lidar Profiles

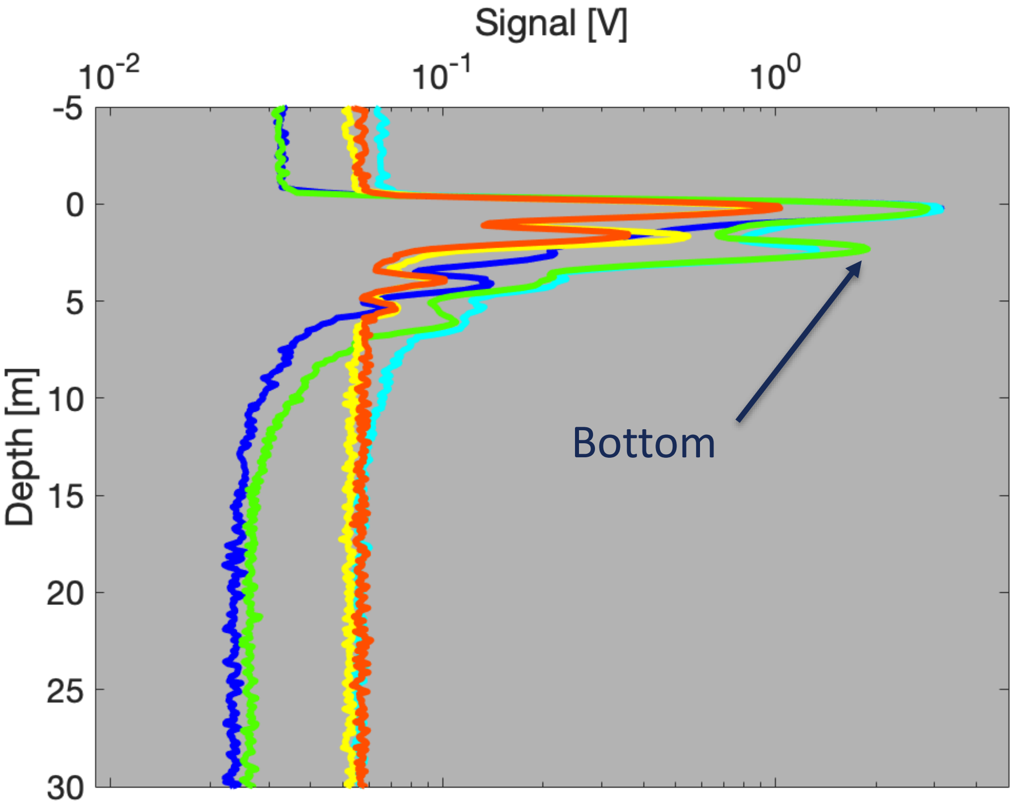
We found consistent scattering layers around 15-20 m near the shelf break

- Gliders in area observed similar layers



Lidar Profiles

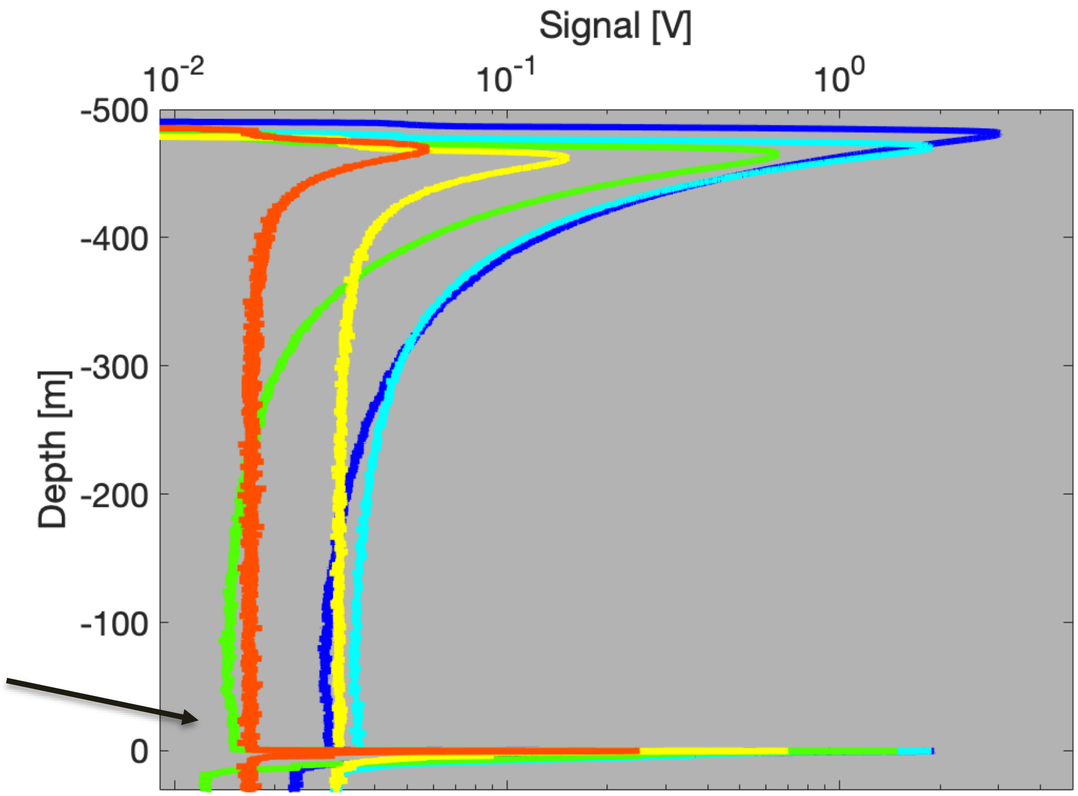
Shallow Water Bathymetry in the Rhappahannock River ~ 2m



Lidar Profiles - Atmosphere

The atmospheric returns can be as large or larger than the ocean surface

- The spectral decay is providing information on the optical depth
- In many cases, we see an increase in lidar signal about 50m above the ocean surface



Conclusions

Multi-wavelength lidar can be a valuable tool in remote sensing of the oceans and complex waters

- Operate in more challenging environments
- Better bathymetry, bottom type identification/classification
- Potential to detect and identify subsurface layers
- Coupling lidar measurements with ocean color

Challenges Remain

- Standardized systems and calibration protocols
- Atmospheric correction

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Naval Research Laboratory

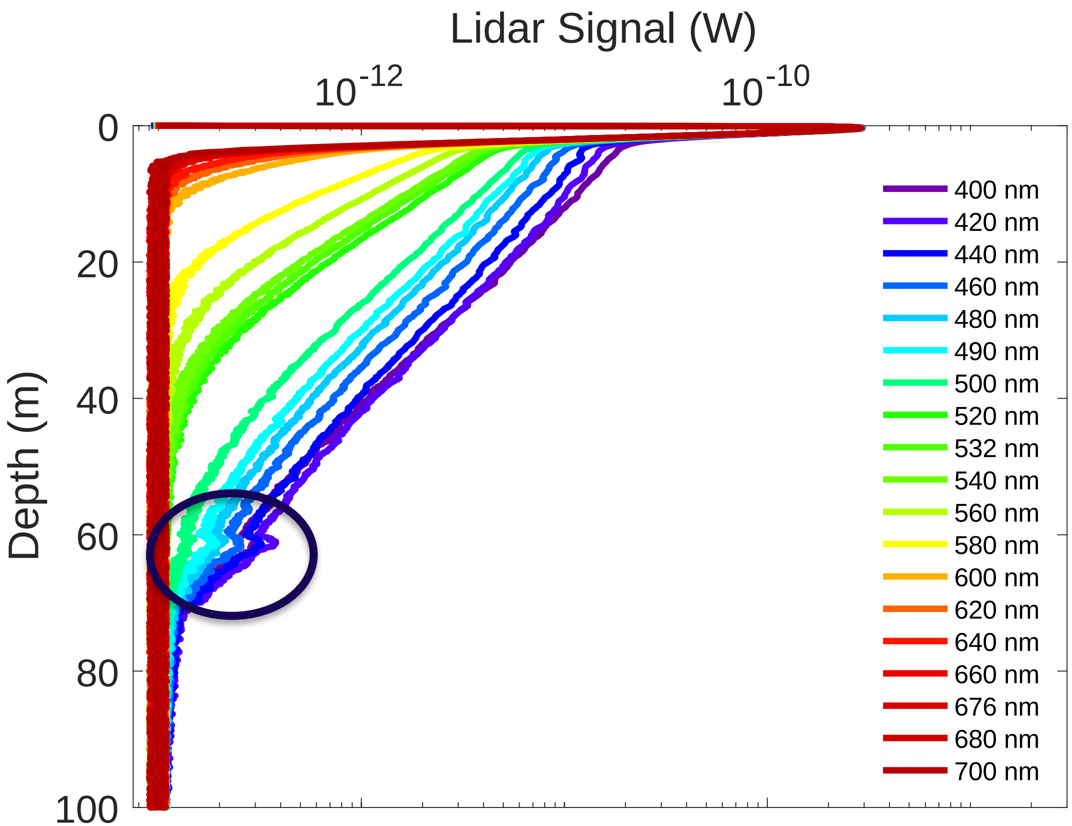
John Anderson, Jean Nelson, Jarrod Edwards
Engineer Research and Development Center
Army Corps of Engineers

Zhongping Lee
University of Massachusetts Boston

Thank You!

Backup

Can lidar get to the Deep Chlorophyll Maximum?

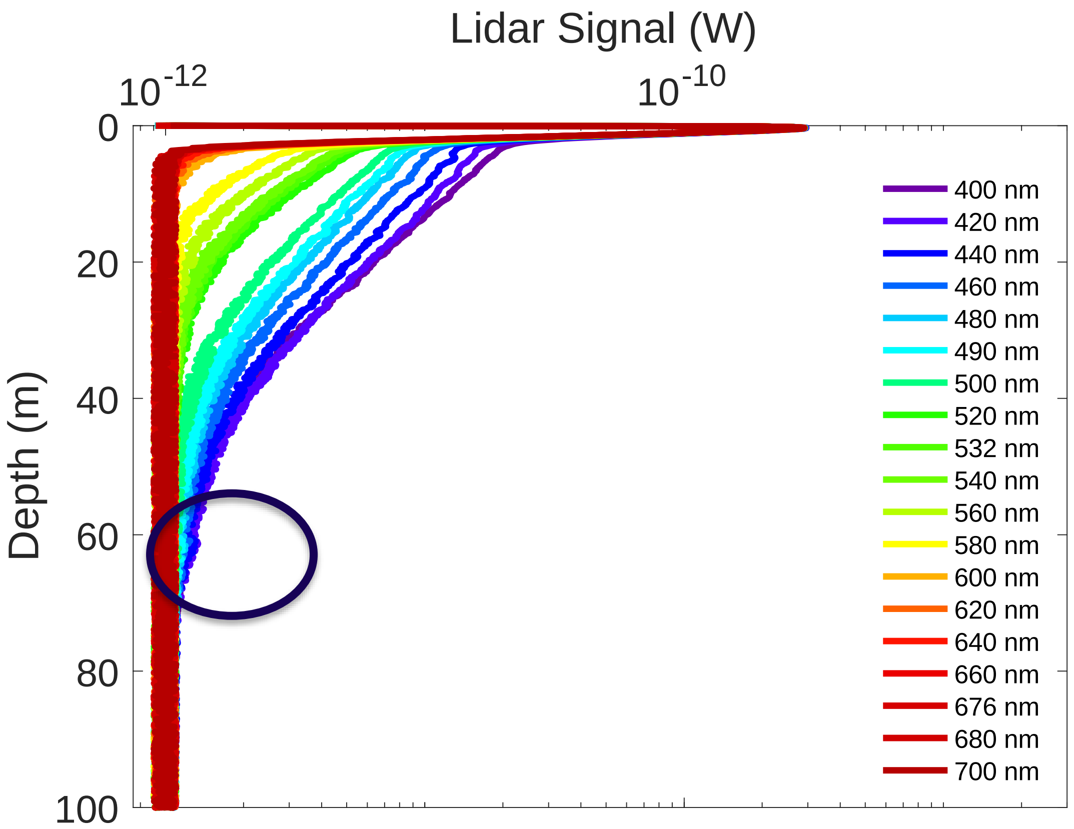


Modeled lidar return for Deep Blue Water but with a 5m thick DCM at 60m

Maybe!

- Depends on how "deep"
- Most wavelengths below 500 nm cam reach the deep chlorophyll maximum at 60 m
- But it strongly depends on the background noise level

Can lidar get to the Deep Chlorophyll Maximum?



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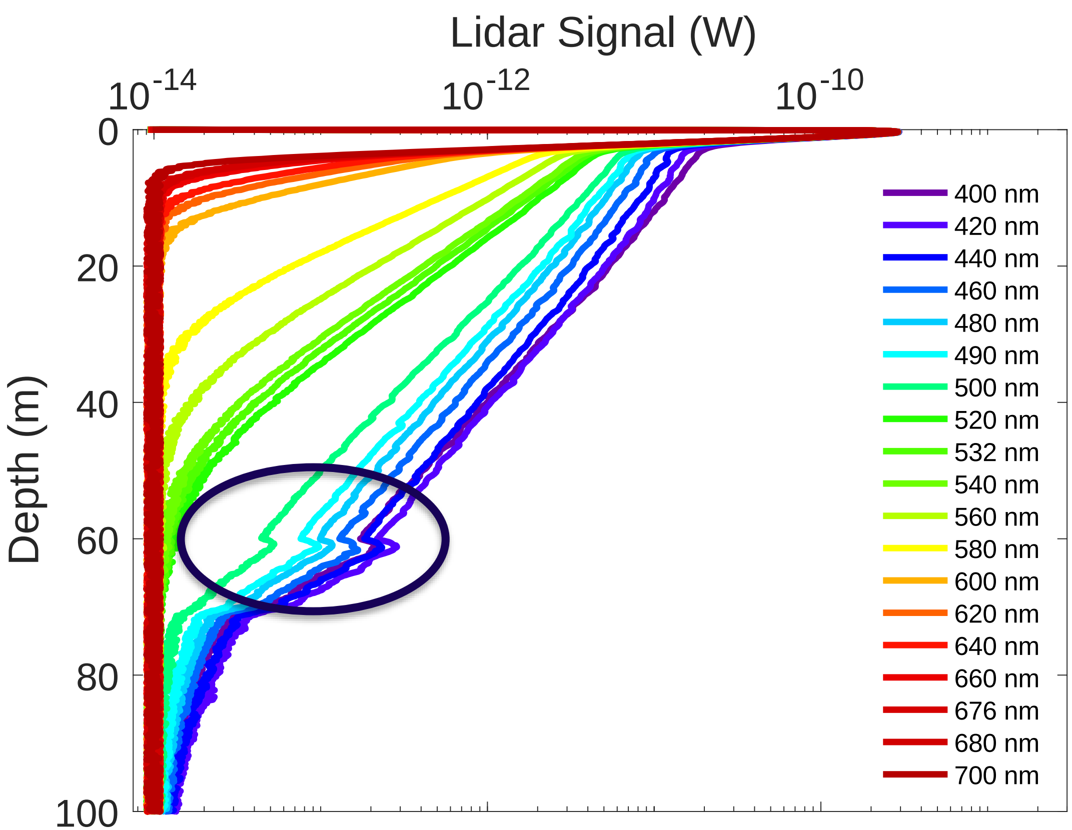

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