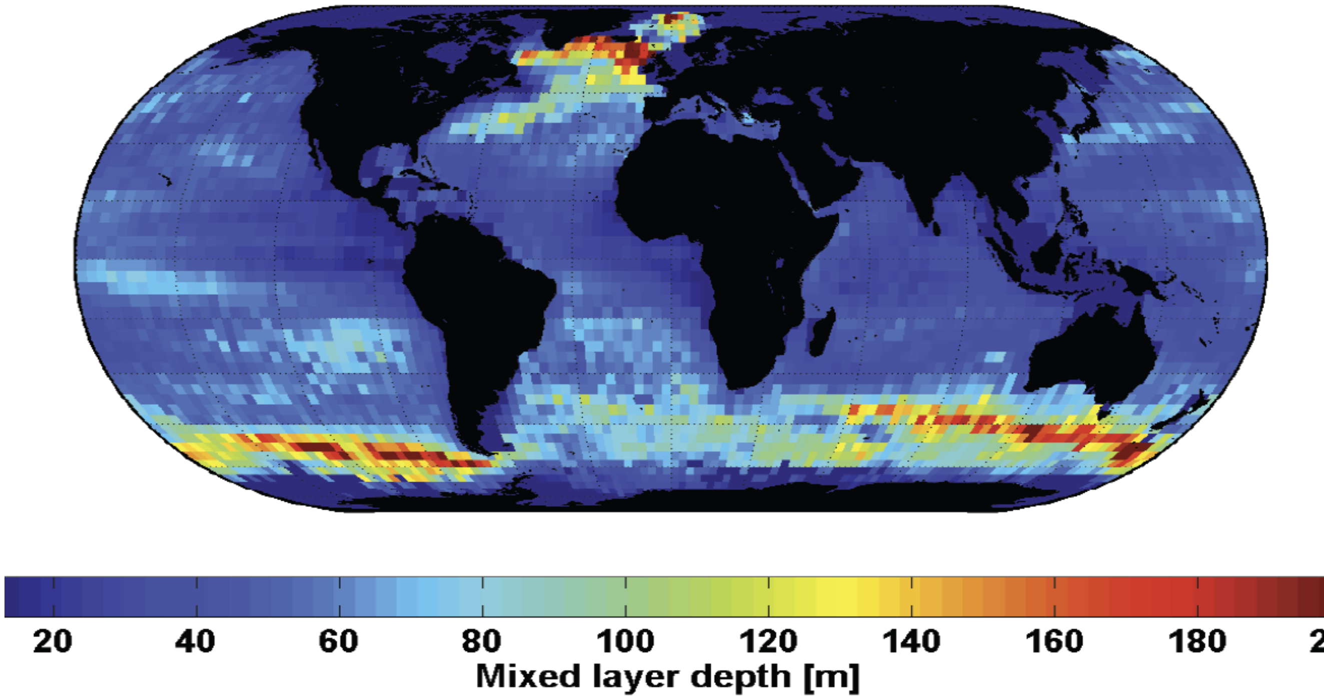
Direct Remote Measurement of Mixed Layer Using Lidar

Gary Spiers -JPL,
Paul von Allmen – JPL
Dimitris Menemenlis- JPL
Julian A. Domaradzki – USC
Tyler Schlenker- SpaceX

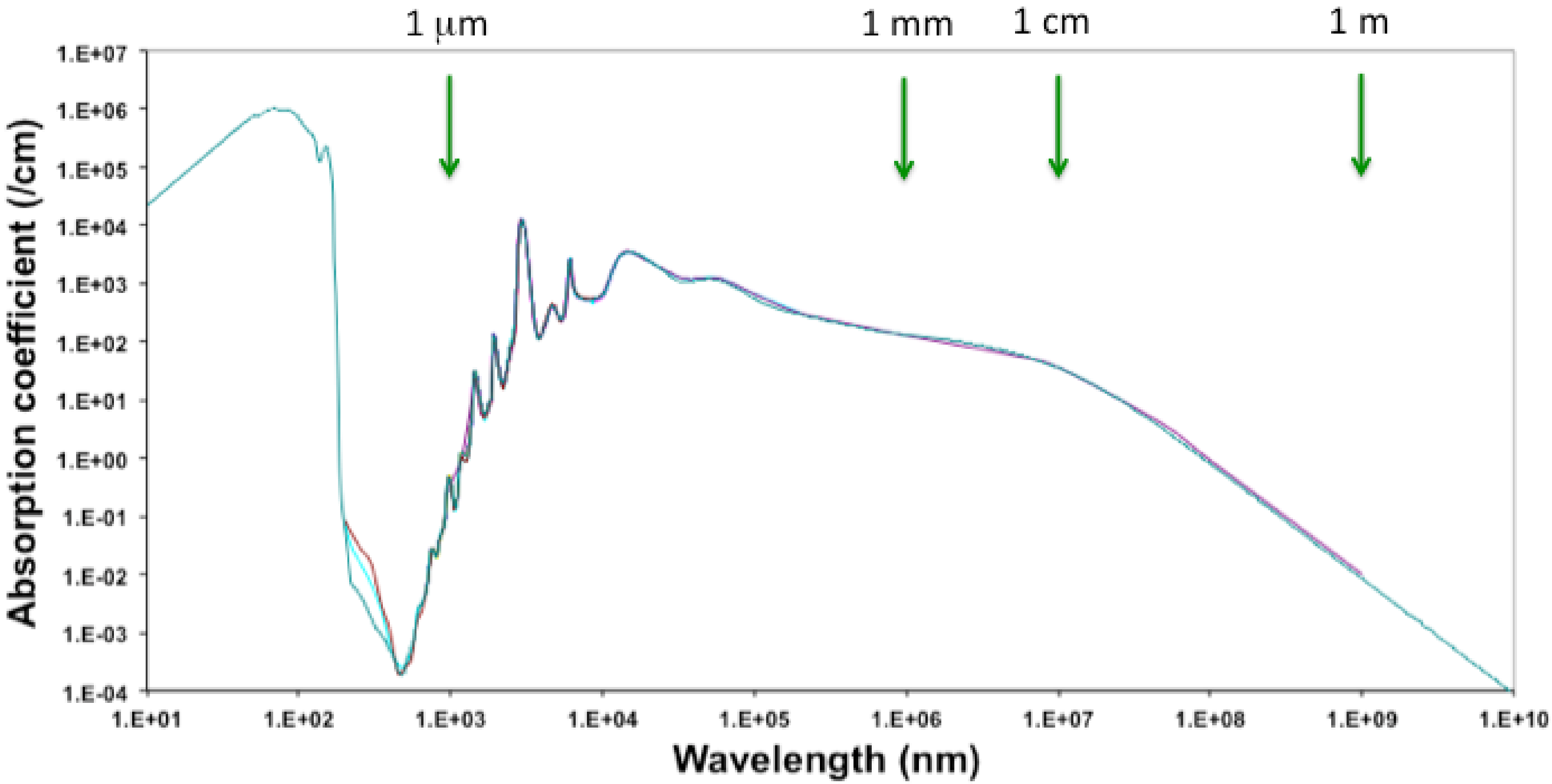


Darek Bogucki
Department of Physical & Environmental Sciences
Texas A&M University-Corpus Christi
Darek.Bogucki@tamucc.edu

MLD measurements obtained by global array of Argo floats January 2003 - January 2013 Bogucki and Spiers 2013. MLD following approach J. Holte and L. Talley, 2009.

Why Lidar? Water Absorption Coefficient:

Pure water - Compilation from multiple sources



Minimum absorption occurs for a wavelength in the range 450-500 nm

Outline:

- How deep can Lidar sense?
- The ML turbulent structure
- Remote methods to sense the MLD
- Our concept – polarimetric Lidar
- Verification of polarimetric Lidar MLD vs in situ observations

How deep can marine lidar sense?

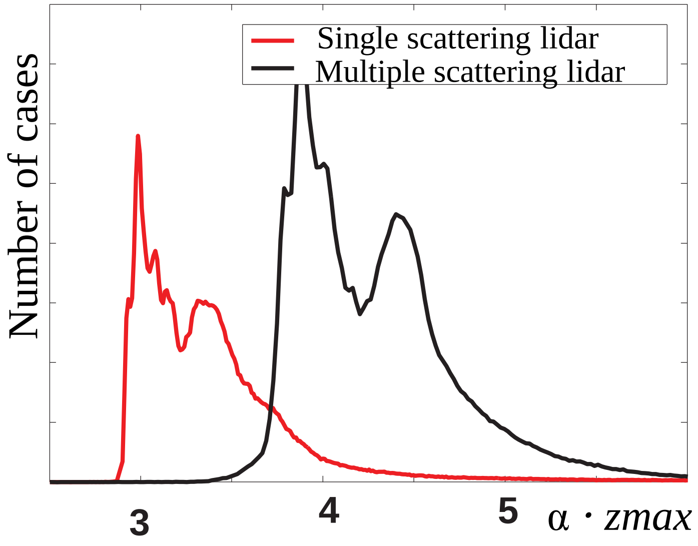
(Bogucki and Spiers 2013)

- Start with the Lidar equation:

$$S(z) = B_{lidar}\beta'(z,\pi)\frac{\exp(-2\tau(z))}{z^2}$$

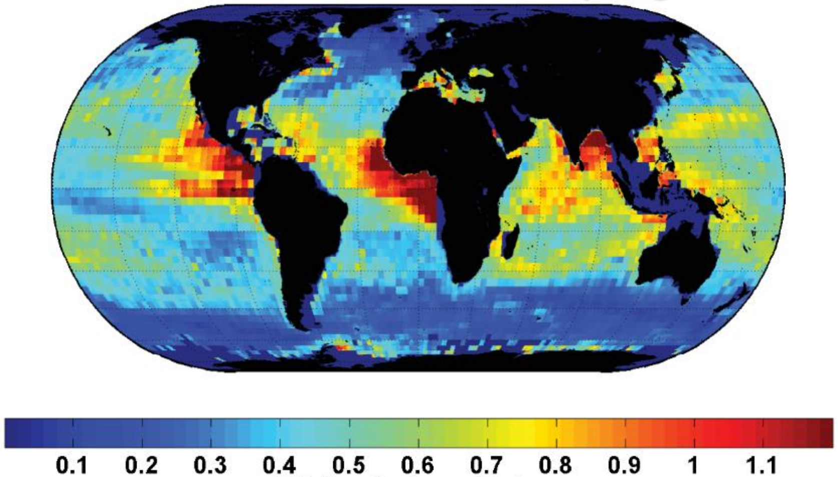
- Simplify: $1 = 6.8 \cdot 10^8 b_{bp} \frac{\exp(-2\alpha \cdot z_{max})}{z_{max}^2}$

- Examine *two limits* for marine Lidar: single or multiple scattering with $\alpha=c=a+b$ or $\alpha=a+b_b$ (Receiver footprint *R: R<1/c* or *R>1/c* respectively*)*
- Assemble temporally averaged maps of the relevant parameters entering Lidar Eq: *a* (absorption), *b* (scattering), b_b(backscattering) and $\beta(\pi)$ (backscattering at backward direction) averaged for the analyzed period**:** *January 2003 - January 2013.*
- Get the MLD measurements obtained by global array of Argo floats. Argo is an array of 3,000 free-drifting profiling floats that measure the temperature and salinity in the upper 2000 m of the ocean
- Expected Lidar observation depth: note the large deviation from the mean optical depth

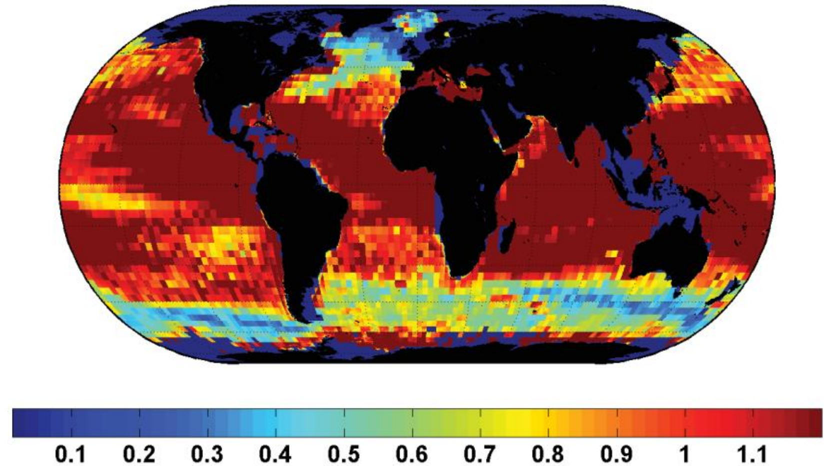


What percentage of the oceanic mixed layer is accessible to marine lidar?

(Bogucki and Spiers 2013)



FPLD - single scattering
(>1 means Lidar penetrates below the MLD)



FPLD - quasi-single scattering
(>1 means Lidar penetrates below the MLD)

- Fraction Lidar penetration depth: *FLPD = zmax/MLD.*

- On average, we have found that at least 50% of the global oceanic mixed layer depth is accessible to the Lidar observations.

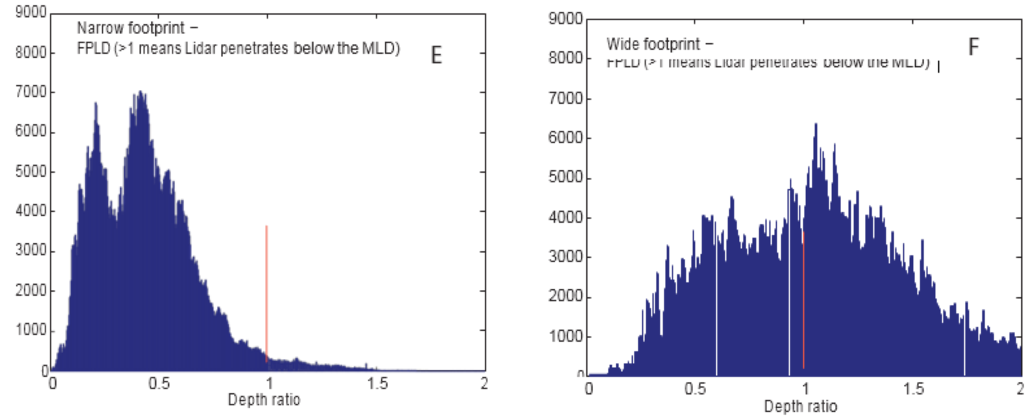
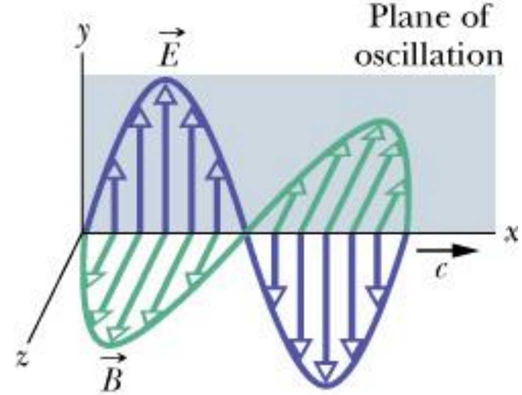


Fig. 6. Histograms for the maps in Fig. 2, Fig. 4 and the Fig. 5. A- Histogram of the Lidar receiver radius $R = 1/c$. B-Mixed layer depth. C-Single scattering Lidar penetration depth. D-quasi-single scattering Lidar penetration depth. E- FPLD - Single scattering Lidar. F- FPLD - D-quasi-single scattering Lidar. The red line denotes FPLD of 1.

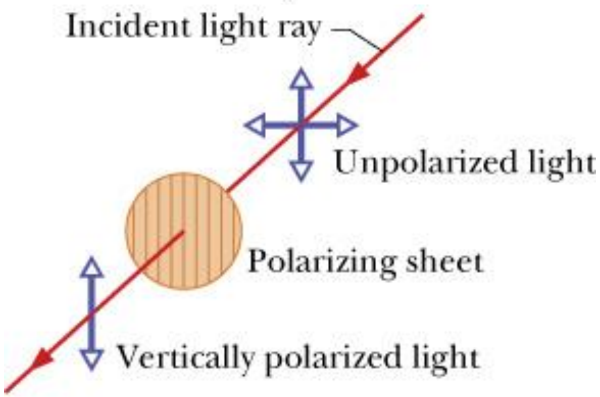
Polarized light:

- Light is an **electromagnetic wave**, where the electric field E (blue) and the magnetic field B (green) are orthogonal (perpendicular) to each other, and also orthogonal to the direction of propagation. These 2 fields change with time and space in a sinusoid fashion.



(a)

- In general, to represent light, we show the electric field because it is with the **electric field that detectors** (eye, photographic film, CCD, etc.) interact.



- **“ordinary'' light**, or natural light, is in general non-polarized: the electric field is on average oriented in an arbitrary direction, and has a very precise orientation for too short a time to be measured by instruments.

- If light is **linearly polarized**, the electric vector has a fixed orientation in space.

Light beam depolarization by a turbulent flow- results

•Experimentally measured mean pure water *forward depolarization rate*: ***γ*** depends on the turbulent flow parameters (depolarization over number of small turbulent eddies) :

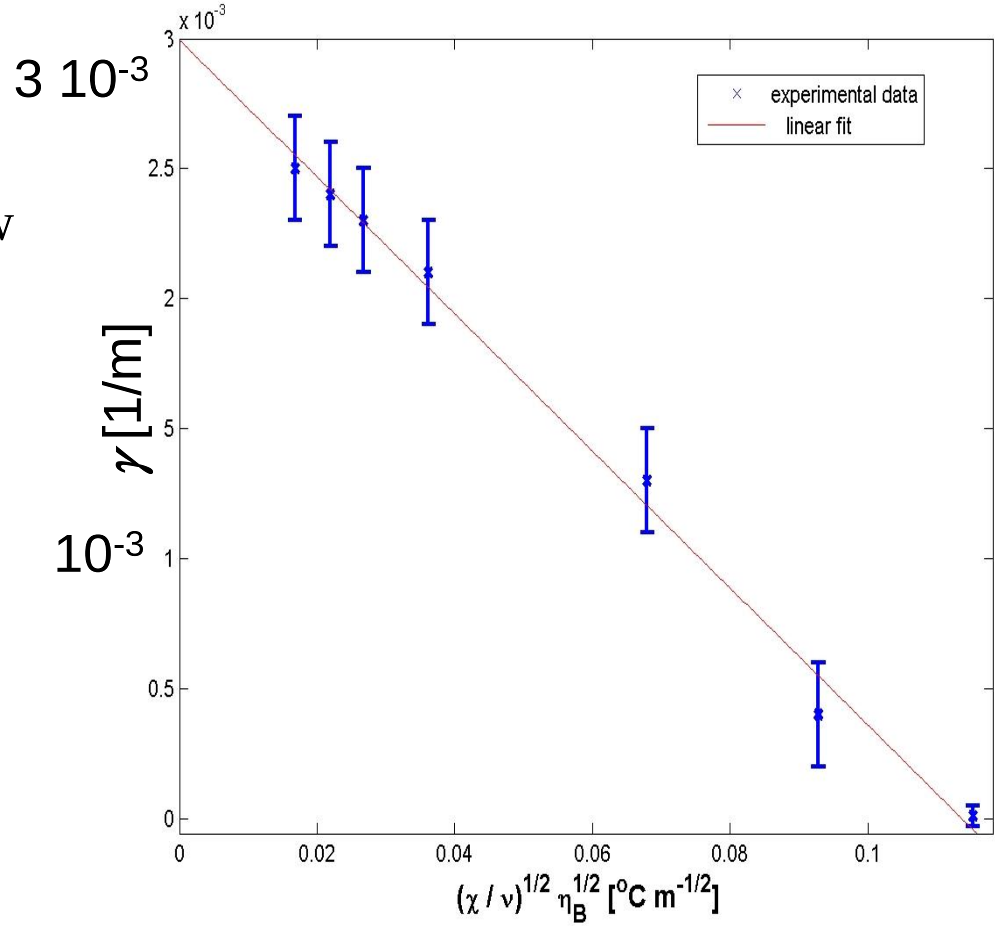
$\gamma \sim (\chi/\varepsilon)^{1/2} \ \eta_B^{1/2}$

where:

$$\eta_B \propto \left(\nu D^2 / \varepsilon \right)^{1/4}$$

or: $\gamma \propto \chi^{1/2} \varepsilon^{-3/8}$

(In the presence of particles this dependence is preserved)



Woods and Bogucki, Applied Optics 2010

Polarimetric Lidar:

•The polarized laser sends short light pulse of *co-polarized* light: $\mathbf{S}_{c0}$

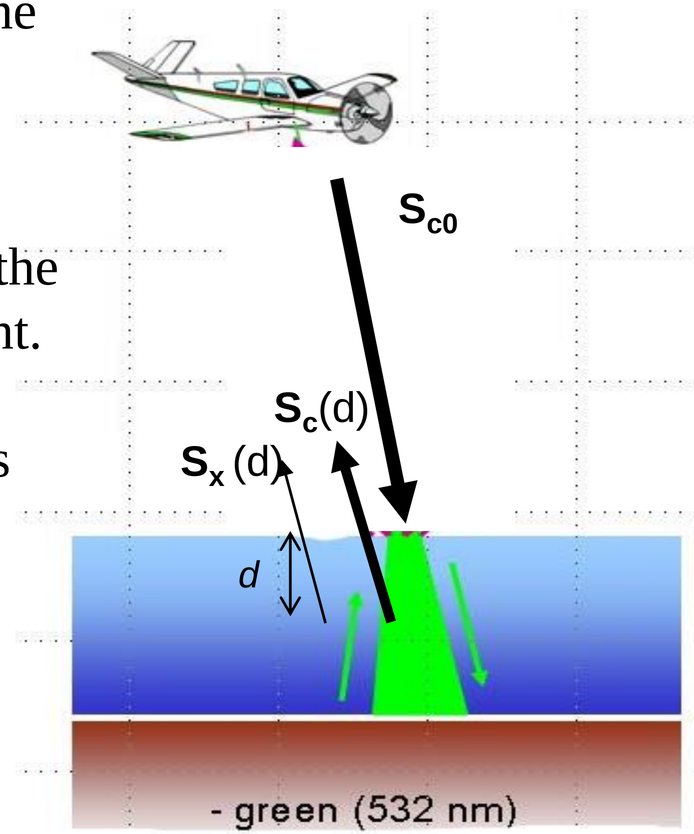
•In general - the Lidar return (signal) originates from a single particle backscattering event in the water column at depth *d*.

•Receiver measures gated arrival time/strength (depth ~time) of the *co-polarized* –$\mathbf{S}_c(z)$ and the *cross-polarized* – $\mathbf{S}_x(z)$ (orthogonal) component.

•In the LIDAR measured total depolarization is calculated as:

$$D(z) = \frac{S_x(z)}{S_c(z)}$$

•*The **total depolarization** D(z)* depends on the media properties. (Typically: $S_x(z) << S_c(z)$)

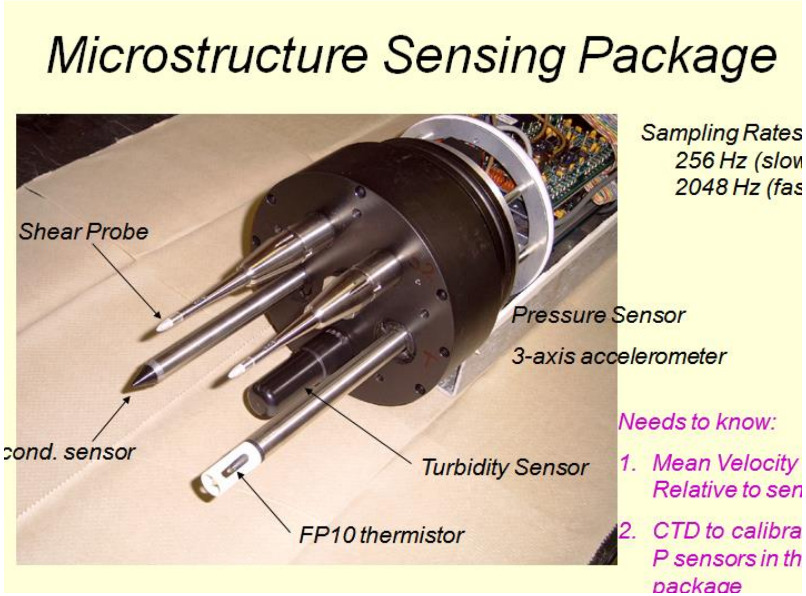


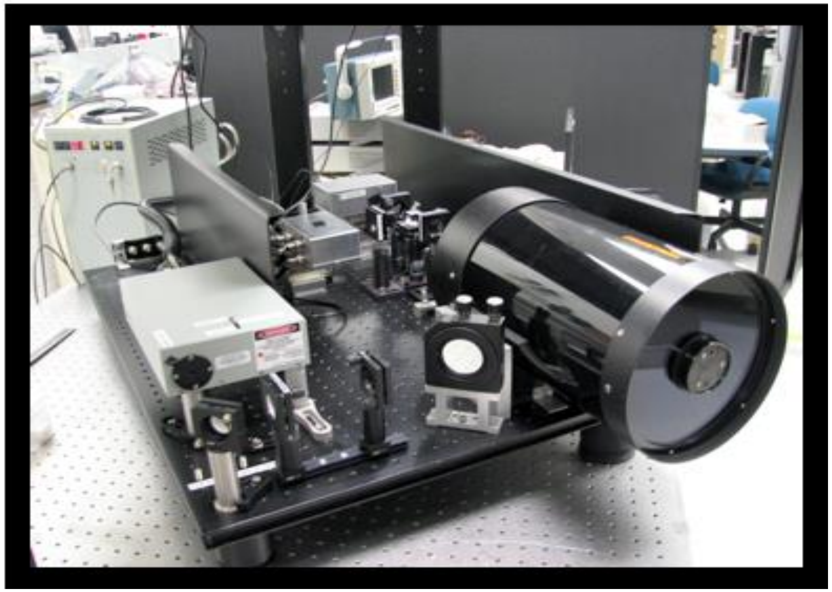
Lidar experiment instrumentation:

- The flume with grid generated turbulence, heater and controlled energy and temperature dissipation rate: $\varepsilon, \chi.$

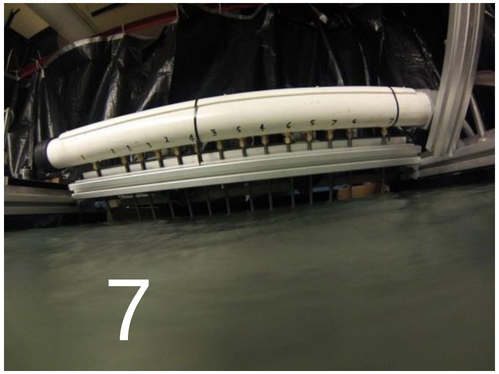
- The turbulent microstructure system (VMP200) to measure: $\varepsilon, \chi.$

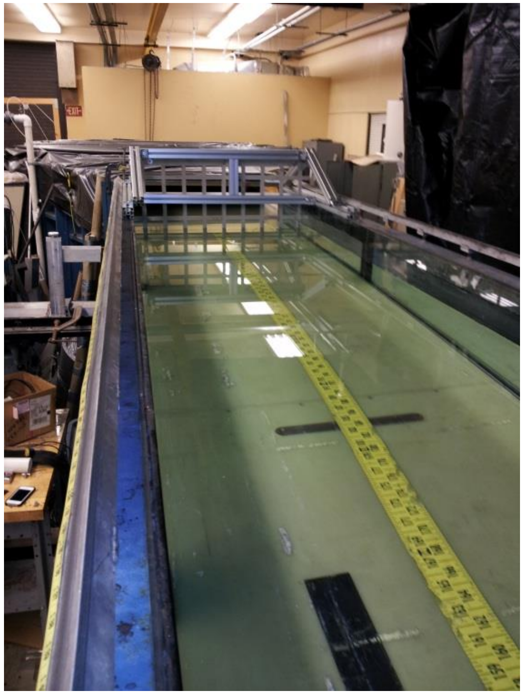
- The Lidar system to measure: $\alpha(z)$ $\gamma(z)$

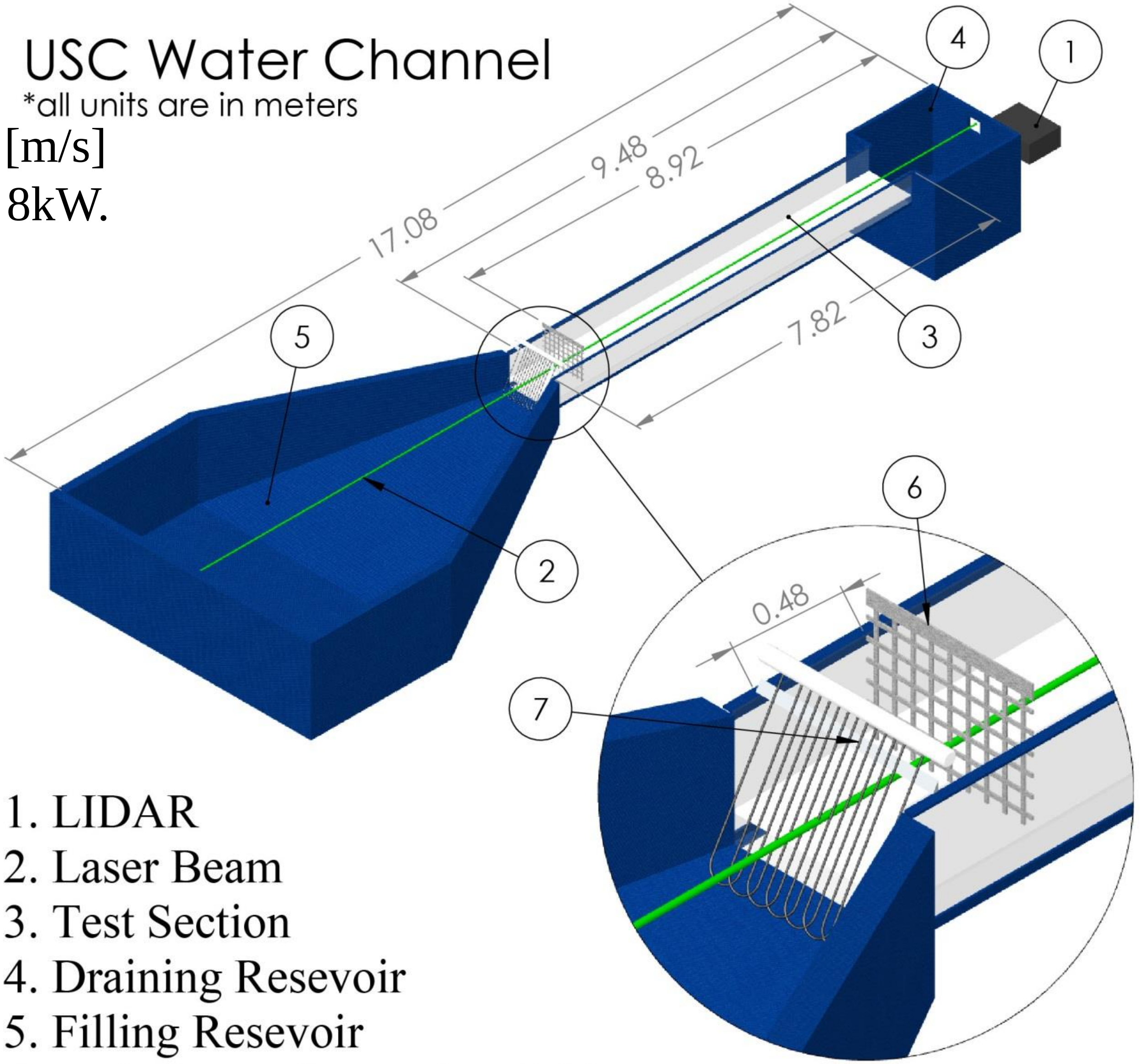




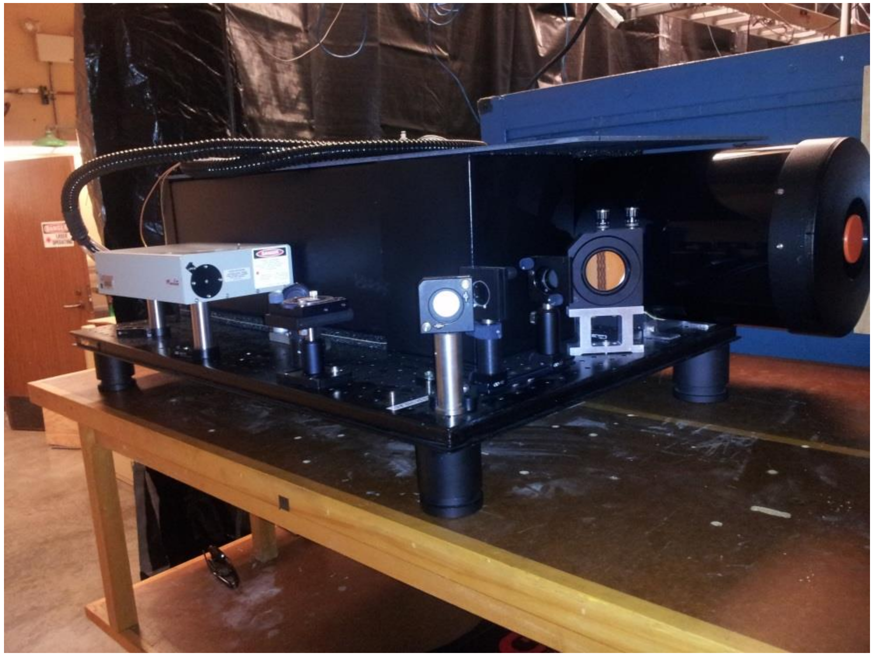
- Flow speed – up to 0.5 [m/s]
- Dissipated heat – up to 8kW.

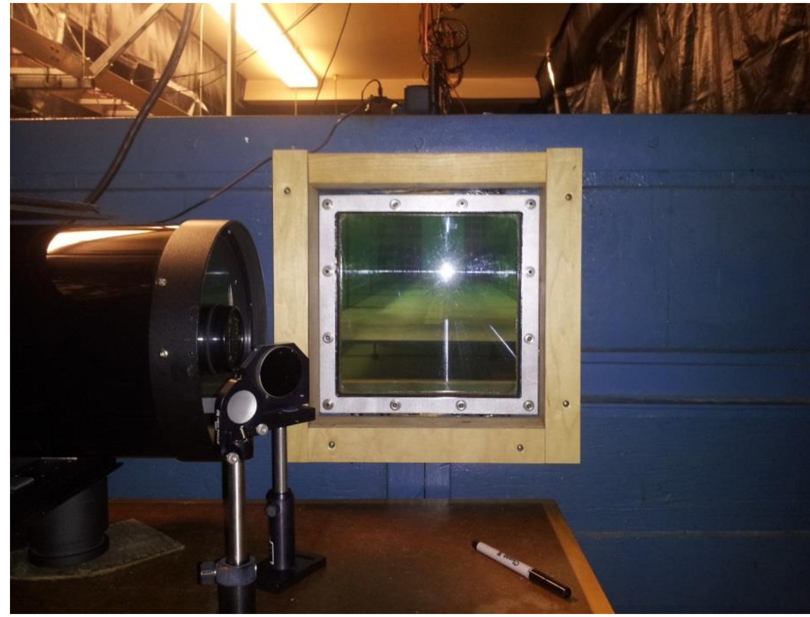






1. LIDAR
2. Laser Beam
3. Test Section
4. Draining Resevoir
5. Filling Resevoir
6. Turbulence Generating Grid
7. Heater Grid

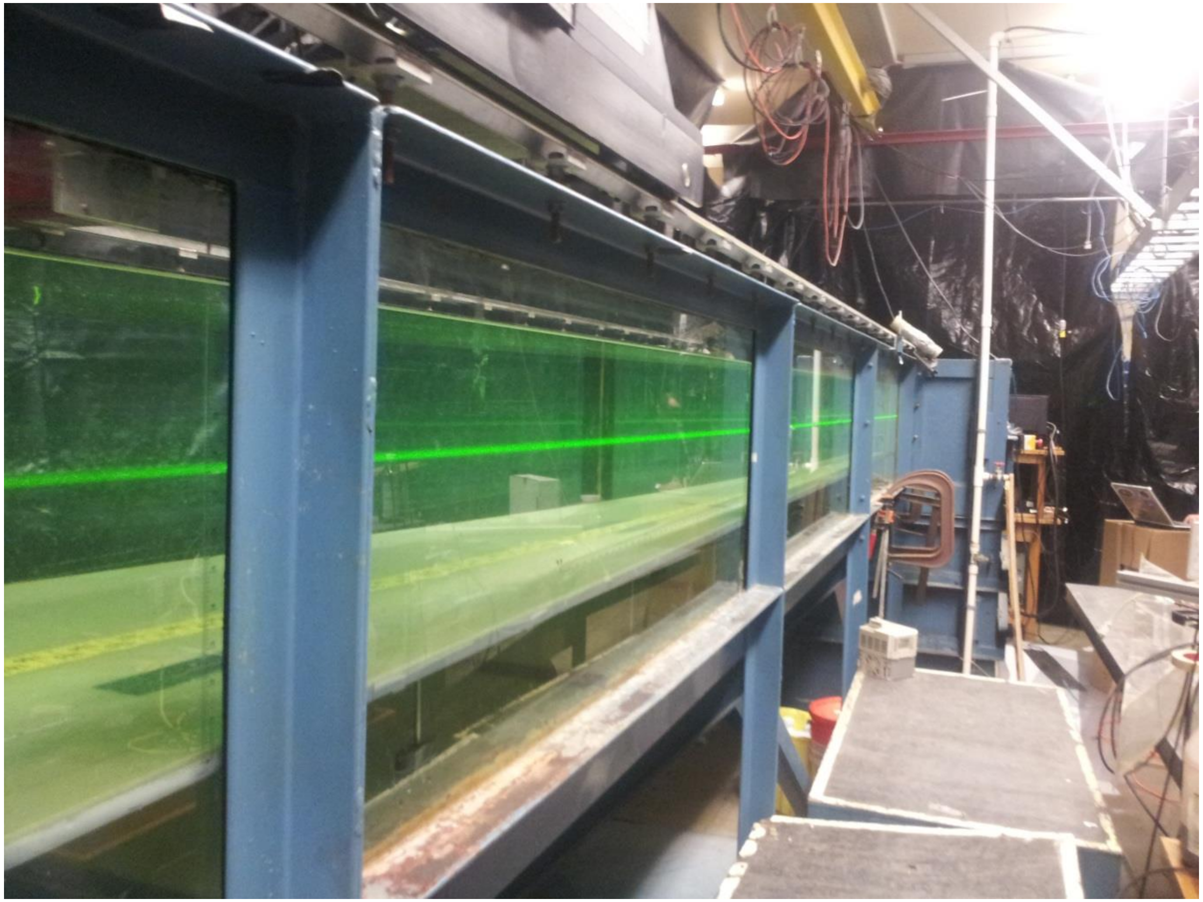




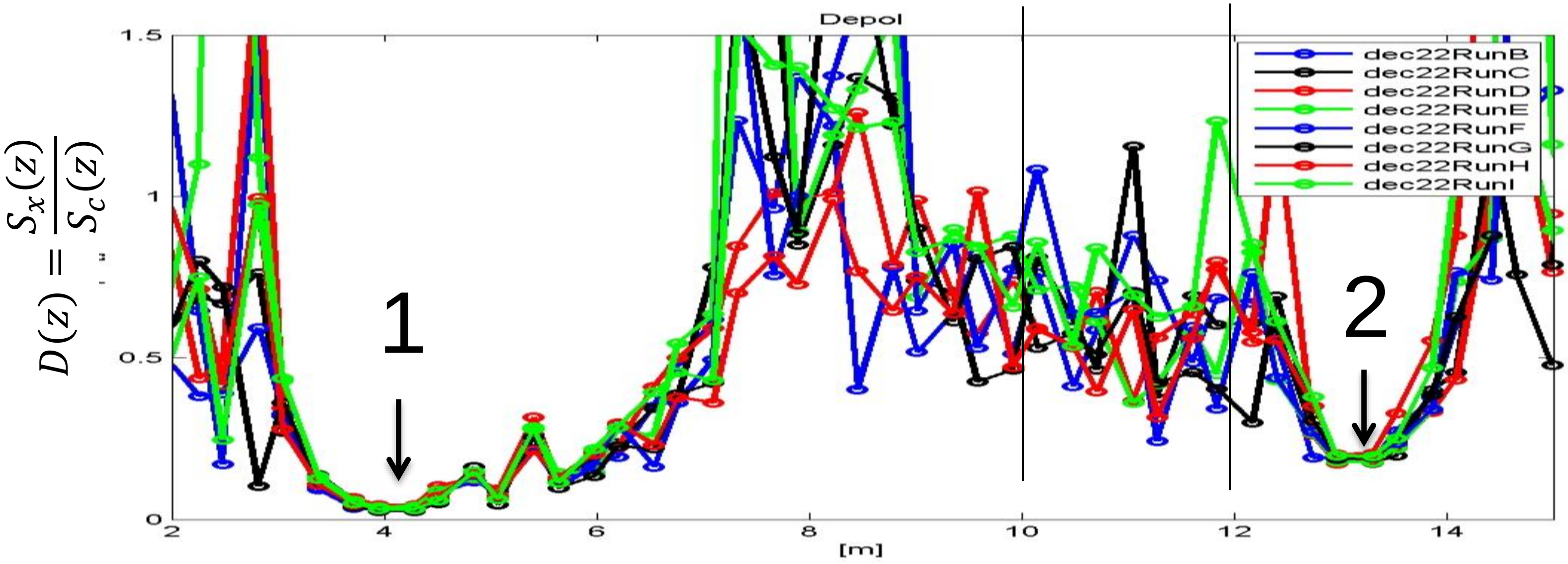
The transmitter setup

Laser parameters:

- Wavelength: 532 nm (green)
- Power: 375 mW Average
- Pulse energy: 0.025 J/pulse,
- Duration: 3-5 nS
- **Pulse length in water: 0.67m to 1.12 m**
- Pulse repetition: 15 Hz

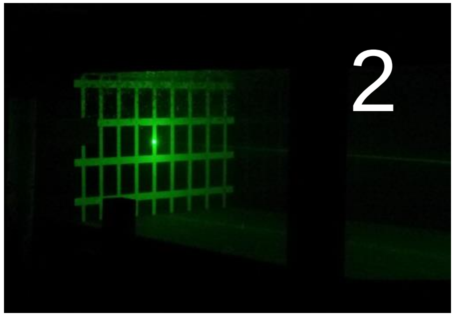


The effects of finite pulse length, digitizer speed and optical echo



- Total depolarization on the exit window, transmitter optics optical reverberations on the transmitter optics/exit window- **(1)**

- Depolarization on the tank grid at the tank end- **(2)**



- The cleanest data set collected *from 10 to 12 meter* of the tank.