Remote Sensing of Optical Characteristics and Particle Distributions of the Upper Ocean Using Shipboard Lidar

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Introduction: Passive ocean color remote sensing has revolutionized our ability to quantify horizontal patterns of algal distributions across the ocean surface. It does not however provide subsurface information on the vertical distribution of particles, which can contribute significantly to total carbon biomass. Active Light Detection and Ranging (LIDAR) sensors, which use pulsed lasers (~1 ns) at 532 nm to vertically resolve scattering layers, can provide measurements of suspended sediments, absorbing layers, bathymetry, suspended objects, and under water visibility.

Objective: This project will evaluate the utility of using a LIDAR instrument at 532 nm for determining the vertical distribution and composition of particulate material within the oceanic water column.

**Fig. 1:** The lidar was deployed at 4 stations along a cruise track from Cape Henry to ~75 km off the coast of Virginia (a) in the vicinity of the lidar on the M/V Nova Star transit line (green) through a fairlead at the bow of the ship about 10 m above the water surface. (c,d) allowed for continuous sampling without disruption of the passenger ferry operations. A 13 day glider crossing (red) provided vertical profiles of various water column properties along the ferry transit line.

**Fig. 2:** Lidar system attenuation coefficient (Ksys) is determined from the slope of the ln corrected signal (solid line).
- Multiple Ksys calculated when slope varies with depth (red).
- At some shallow stations, subsurface peaks representing the seafloor were present (arrow).

**Fig. 3:** Profiles of Ksys showed good correlation with in situ profiles of optical properties:
- Ksys increased from the furthest offshore station (a) to the furthest inshore station (d).
- Where there exist Ksys captures vertical gradients in the non-water absorption coefficient (ns).

**Fig. 4:** Two detectors are used, one detecting the signal returning with the emission polarization state (co), and one detecting the cross-polarized signal (cross) and gives the depolarization ratio (r).
- | 0.1 | 0.15 | 0.2 | 0.25 | 0.3 | 0.35 |
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<td>Backscattering Ratio (β(λ))</td>
<td>0.005</td>
<td>0.01</td>
<td>0.015</td>
<td>0.02</td>
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- r is well correlated with the backscattering ratio.
- May serve as a method for measuring bulk particle composition.

**Fig. 5:** Spatial patterns in Ksys and peak return power (Pp-max) (a,b) consistent with satellite imagery (c,d).
- Increase in Ksys associated with increase in Pp-max (c).
- Ksys east of 68.75° with exception of some small patches of high depolarization.

**Fig. 6:** Increased depolarization on western margin.
- Increased depolarization east of 68.75° with exception of some small patches of high depolarization.

**Fig. 7:** Patterns in glider measurements consistent with lidar measurements:
- Water column unstratified within range of lidar (a)(red line; ~40 m); consistent with lack of vertical structure in Ksys.
- Backscatter(bb) co-varies with [Chl] along eastern portion of the glider section (bc); patches of high bbb low [Chl] west of 68°; consistent with region of increased depolarization (b,c)(cf. Fig.6).

**Fig. 8:**
- Ksys was well correlated with chlorophyll concentration derived from the SAS shipboard radiometer ([Chl]SAS) (a,b).
- [Chl]SAS suggests the utility of lidar to study phytoplankton distribution.
- The ratio of the cross-polarized signal to the total return signal (r-max) (a,b).
- Decreased depolarization on eastern margin.
- Increase again on eastern margin consistent with satellite bathymetry, sediment, and peak return power (Pp-max) (c).

**Fig. 9:**
- The relationship between Ksys and [Chl]SAS suggests the utility of lidar to study phytoplankton distribution.
- By relating Ksys to both [Chl] and the single scattering albedo (ωn), much of the variability between the two sampling regimes was explained.

**Conclusions**
1. Vertical and horizontal variability in surface ocean properties can be measured remotely using shipboard lidar.
2. Lidar depolarization may provide a method for retrieving estimates of bulk particle composition.
3. Correlation between Ksys and [Chl]SAS suggests the utility of lidar for mapping upper ocean phytoplankton distribution.
4. Complex dependence of Ksys on system parameters (field of view (FOV), beam width) and water column optical properties.

**Future Work**
1. How does multiple scattering affect the behavior of Ksys in regards to water column IOPs (pulse stretching effects)?
2. What role does multiple scattering play in signal depolarization? Can this effect be minimized by the inclusion of a variable aperture?
3. Can volume scattering function (VSF) and particle size distribution (PSD) information be derived from the lidar by varying the FOV? Using Monte Carlo radiative transfer model and multiple-FOV lidar to address above questions.