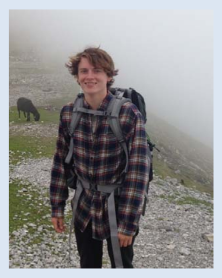
Remote Sensing of Optical Characteristics and Particle Distributions of the Upper Ocean Using Shipboard Lidar





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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 (green) for determining the vertical distribution and composition of particulate material within the oceanic water column.***

Deployments and Configurations

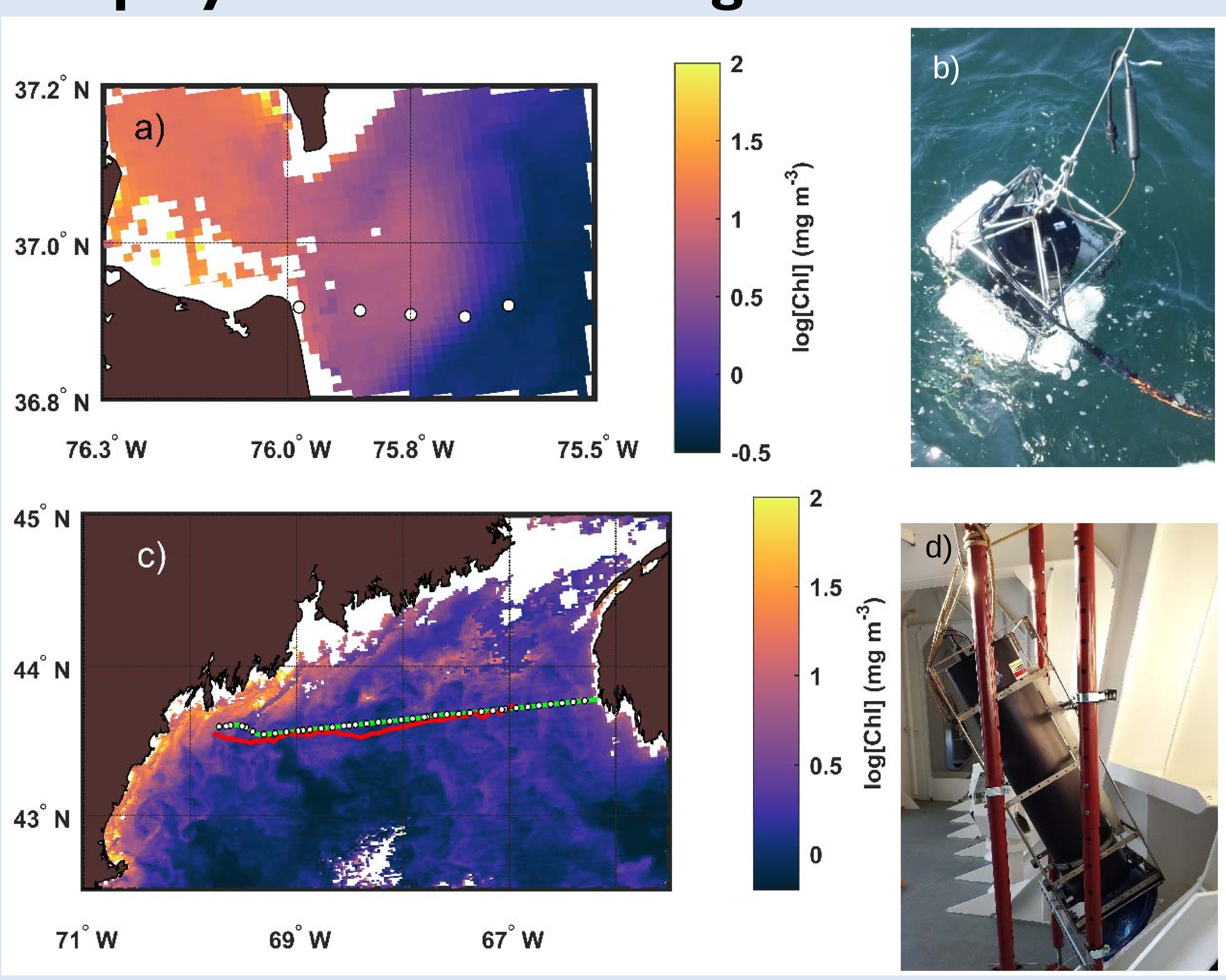

Fig. 1: The lidar was deployed at 4 stations along a cruise track from Cape Henry to ~75 km off the coast of Virginia (a) in the *in situ* configuration (b). Deployment of the lidar on the M/V *Nova Star* ferry along a crossing of the Gulf of Maine (green) through a fairlead at the bow of the ship about 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

Lidar Signal

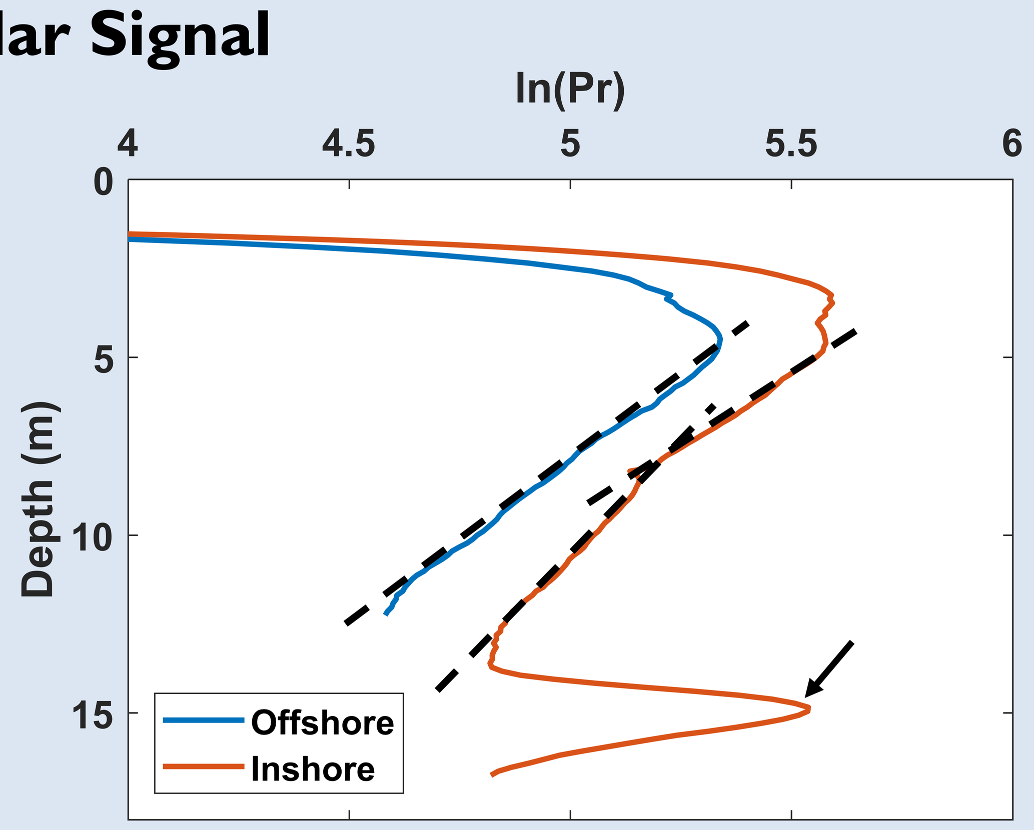

Fig. 2

- Lidar system attenuation coefficient (K_{sys}) is determined from the slope of the ln corrected signal (dotted line)
- Multiple K_{sys} calculated when slope varies with depth (red)
- At some shallow stations, subsurface peaks representing the seafloor were present (arrow)

Mid-Atlantic Bight (in situ)

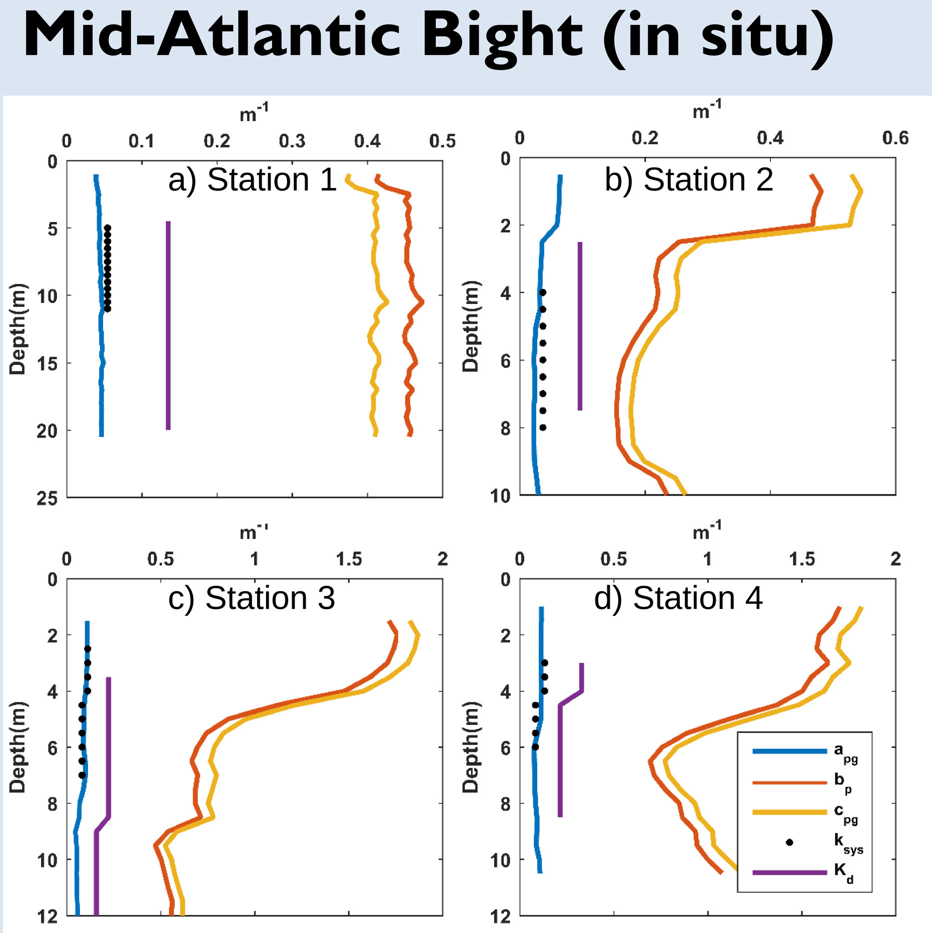

Fig. 3

- Profiles of Ksys showed good **correlation with in situ profiles of optical properties**
- K_{sys} increased from the furthest offshore station (a) to the furthest inshore station (d)
- *Where they exist,* K_{sys} **captures vertical gradients** in the non-water absorption coefficient (a_{pg}) (c,d)

Mid-Atlantic Bight (in situ) cont…

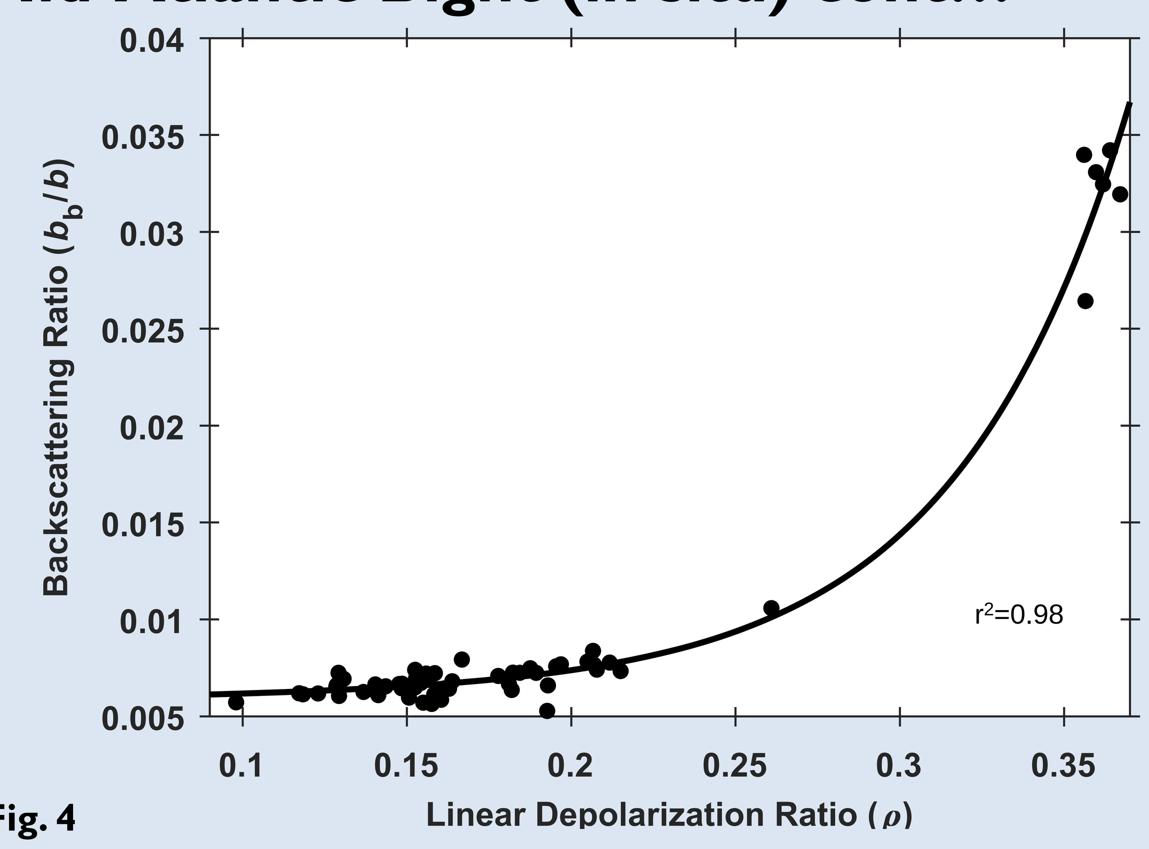

Fig. 4

- Two detectors are used, one detecting the signal returning with the emission polarization state (co), and one detecting the cross-polarized signal (cross)
- The ratio of the cross-polarized signal to the total return signal (cross/co+cross) gives the depolarization ratio (ρ)
- ρ is well correlated with the backscattering ratio
- May serve as a method for measuring **bulk particle composition**

Gulf of Maine (above water)

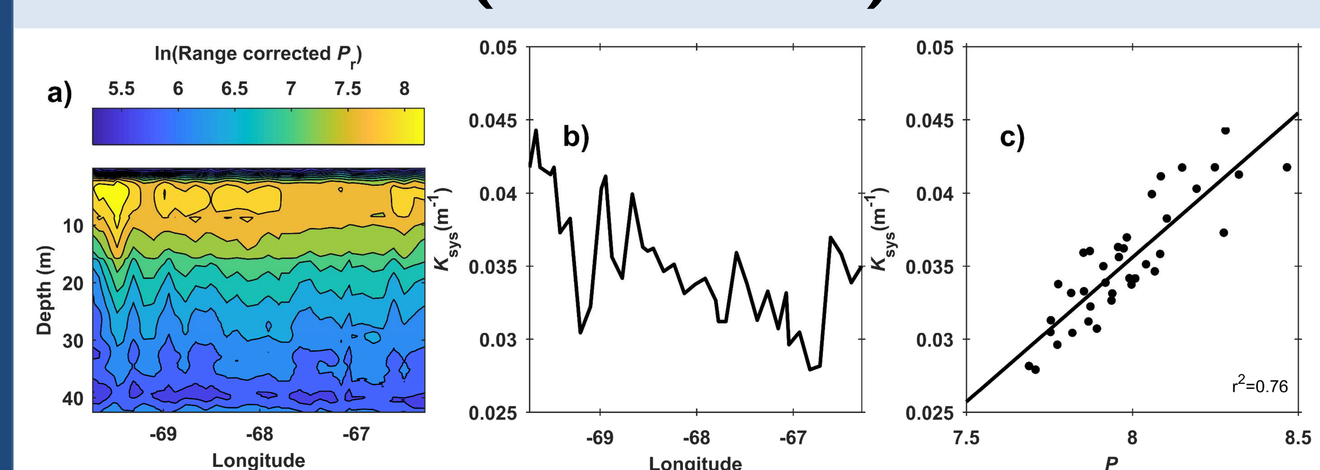

Fig. 5

- Spatial **patterns in K_{sys} and peak return power ($P_{r\text{-}max}$) (a,b) consistent with satellite** imagery (cf. Fig1c); high on western margin; decrease eastward; increase again on eastern margin
- Increase in K_{sys} associated with increase in $P_{r\text{-}max}$ (c);

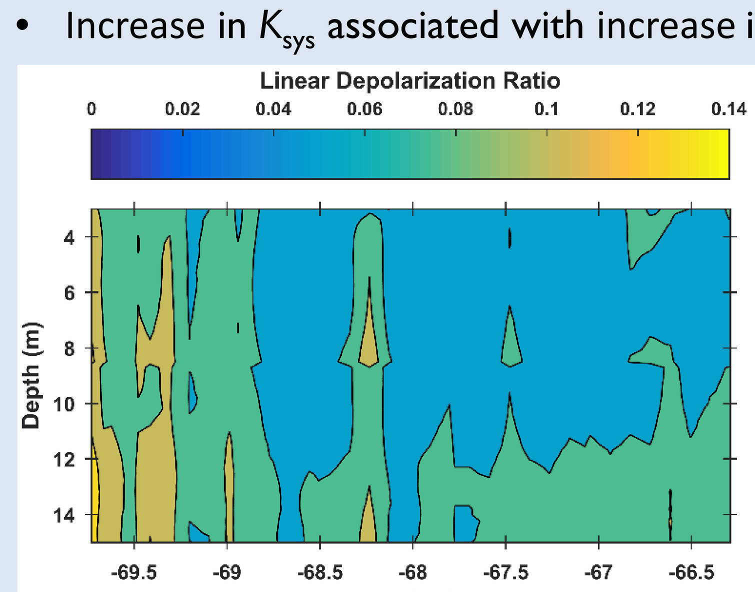

Fig. 6

- Increased depolarization on western margin
- Decreased depolarization east of -68.75° with exception of some small patches of high depolarization

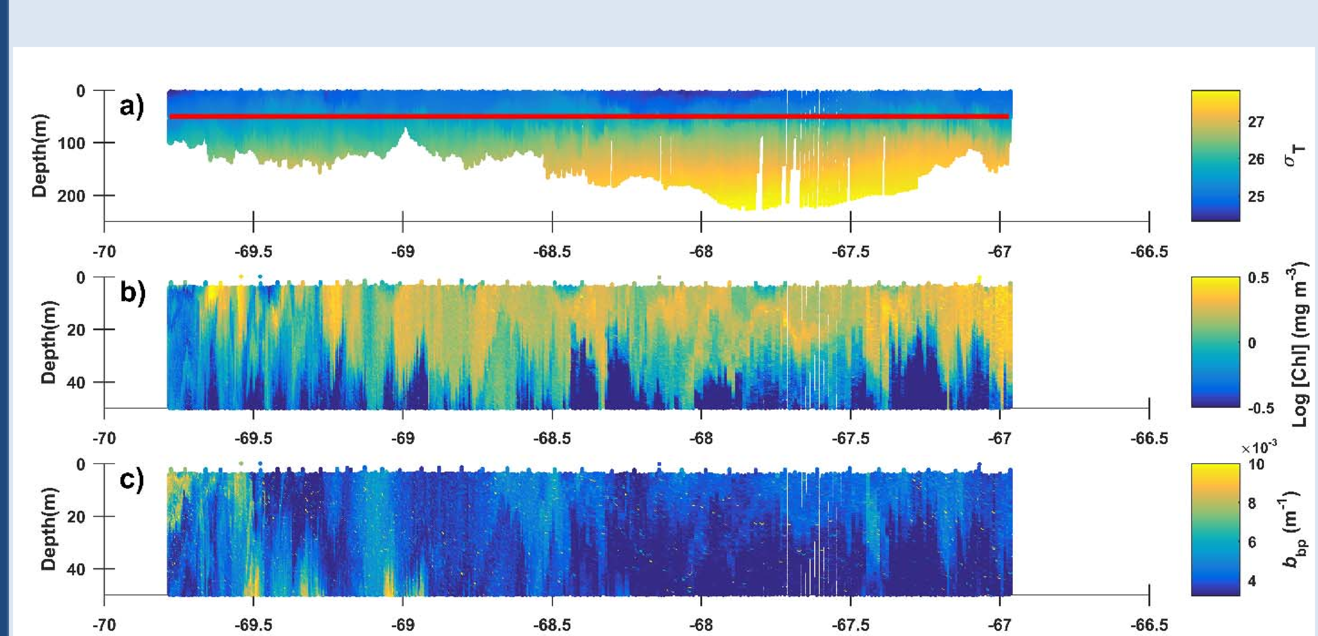

Fig. 7

- Patterns in glider measurements consistent with lidar measurements
- Water column unstratified within range of lidar (a)(red line; ~40m); consistent with **lack of vertical structure in K_{sys}**
- Backscatter(b_b) co-varies with [Chl] along eastern portion of the glider section (b,c); patches **of high b_b / low [Chl]** west of -69°; **consistent with region of increased depolarization (b,c)(cf. Fig.6)**

Gulf of Maine (above water) cont…

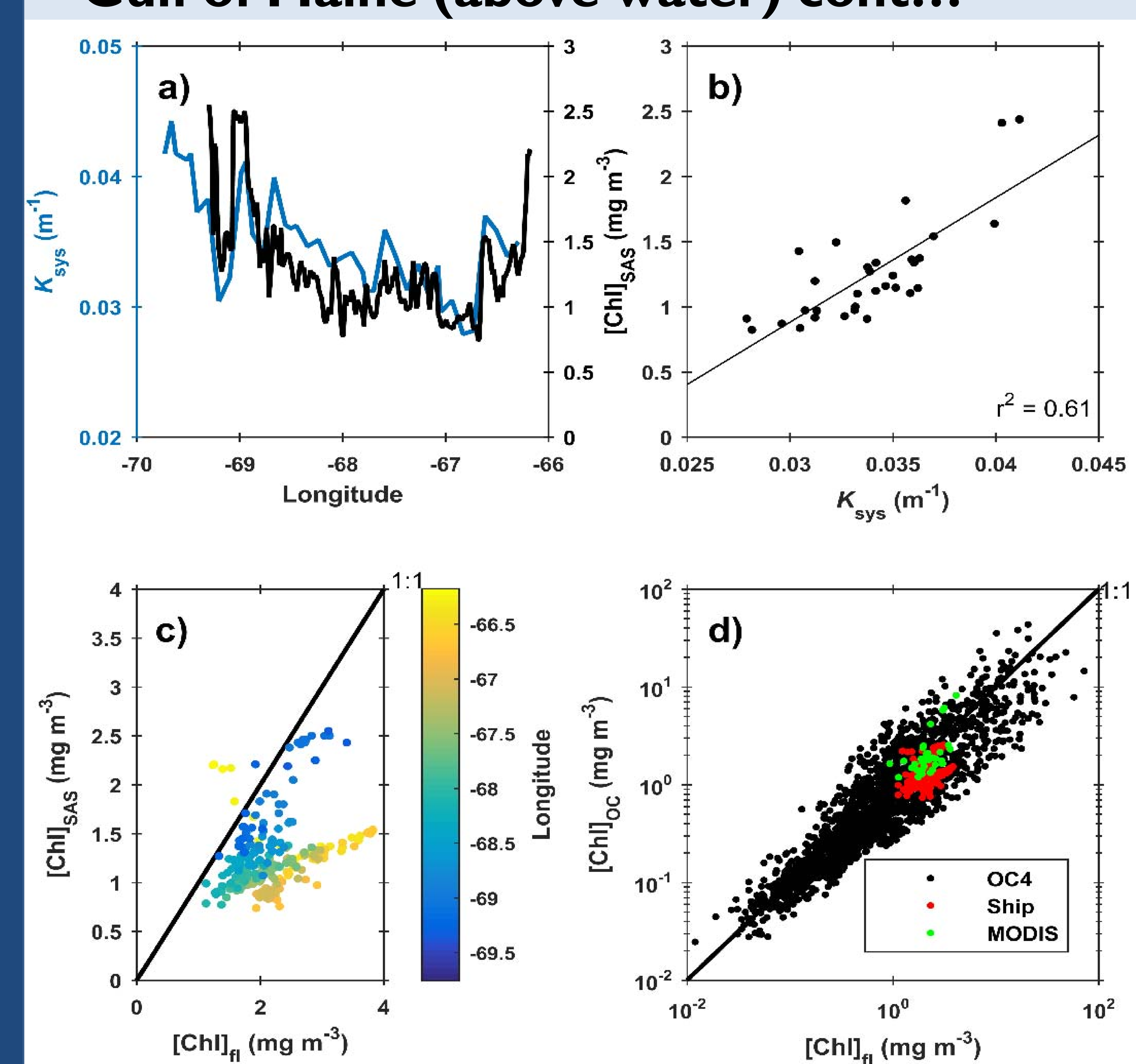

Fig. 8

- **K_{sys} was well correlated with chlorophyll concentration** derived from the SAS shipboard radiometer ($[Chl]_{SAS}$) (a,b)
- $[Chl]_{SAS}$ was poorly correlated with fluorometry derived chlorophyll ($[Chl]_{fl}$); K_{sys} was even worse (c)
- However, over the small range of observed [Chl] these relationships were **well within the error of the OC4 algorithm** (d)

Comparison

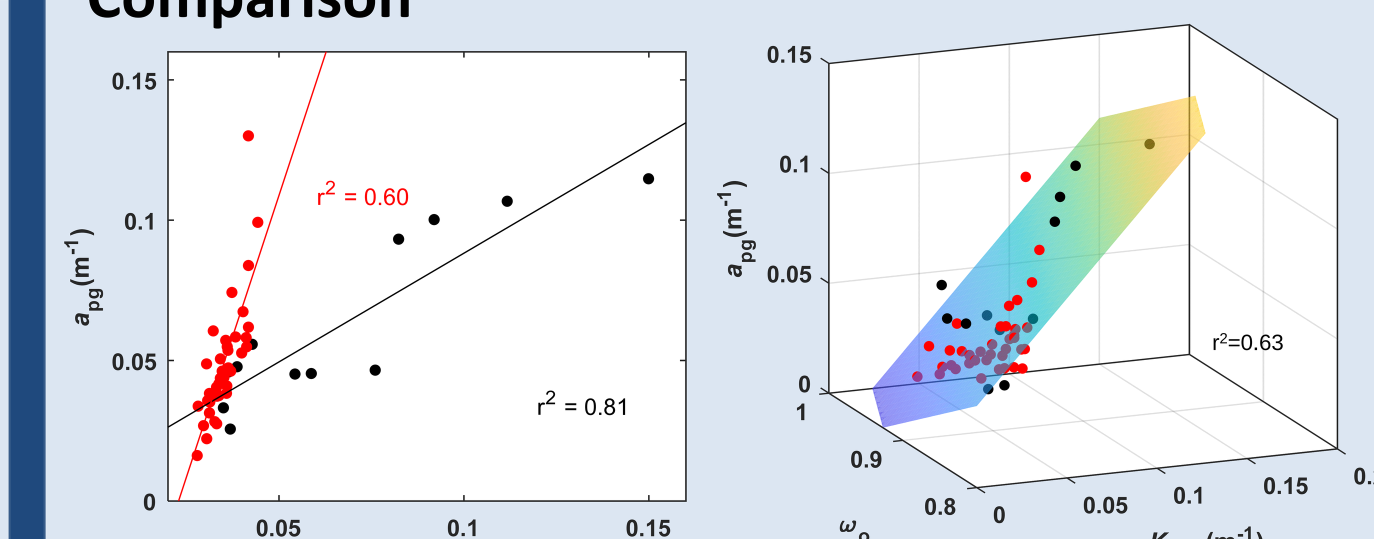

Fig.9

- *The relationship between* K_{sys} *and* a_{pg} *(a) measured in the MAB (black) differed from the same relationship in the GOM* (ANCOVA, p<0.0005)
- By relating a_{pg} to both K_{sys} and the single scattering albedo (ω_o) (b), 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* K_{sys} *and* $[Chl]_{SAS}$ *suggests the utility of lidar for* ***mapping upper ocean phytoplankton distribution***
4. *Complex dependence of* K_{sys} *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 K_{sys} in regards to water column IOPs (pulse stretching effect)?
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?
4. Develop Monte Carlo radiative transfer model and multiple-FOV lidar to address above questions