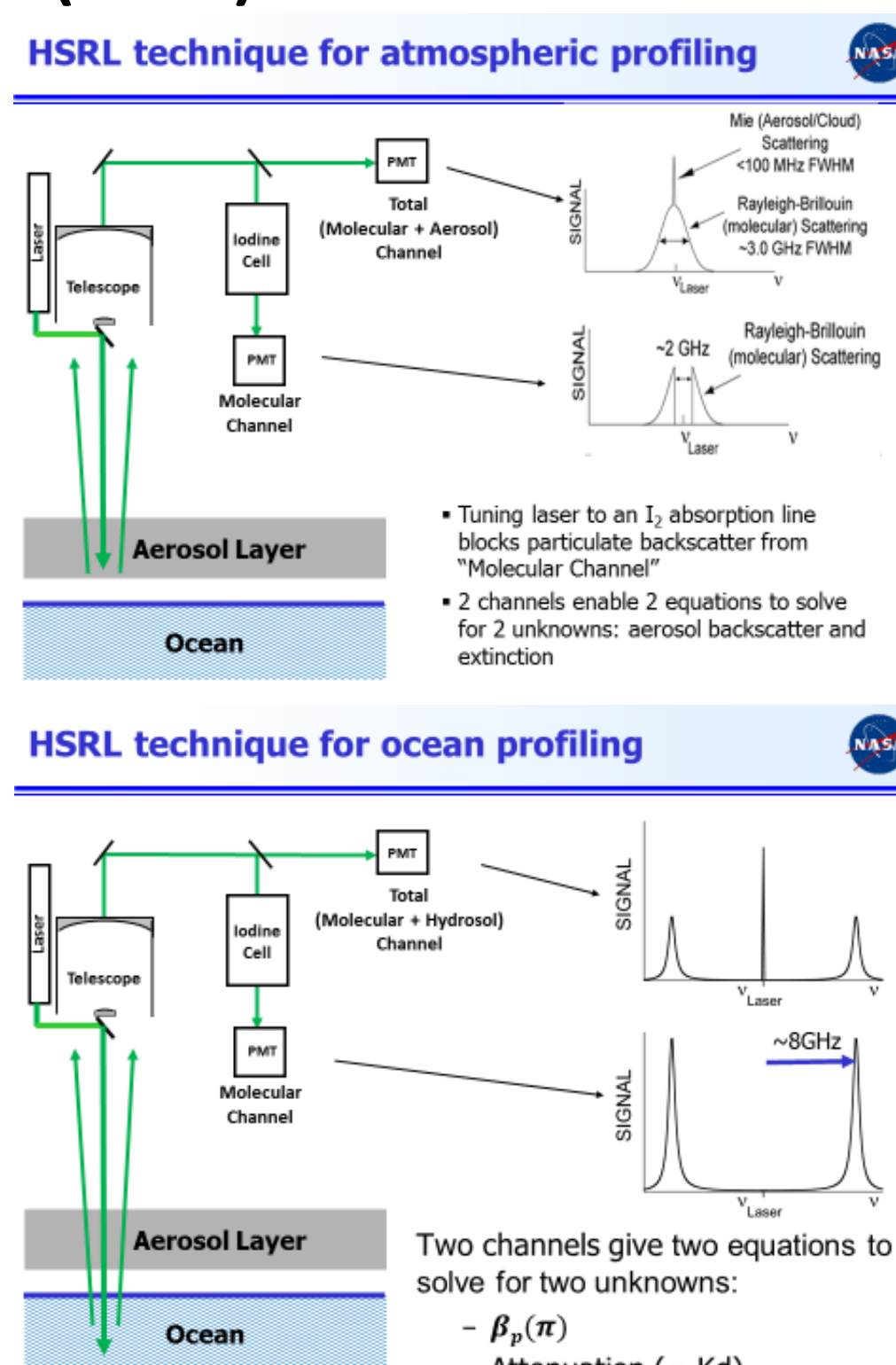


# Vertical Profiles of Ocean Optical Properties and Cloud Top Droplet Number Concentration from Airborne High Spectral Resolution Lidar (HSRL) and the Research Scanning Polarimeter (RSP) Measurements

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## Lidar Methodology & Measurement Parameters High Spectral Resolution Lidar (HSRL) Measurements

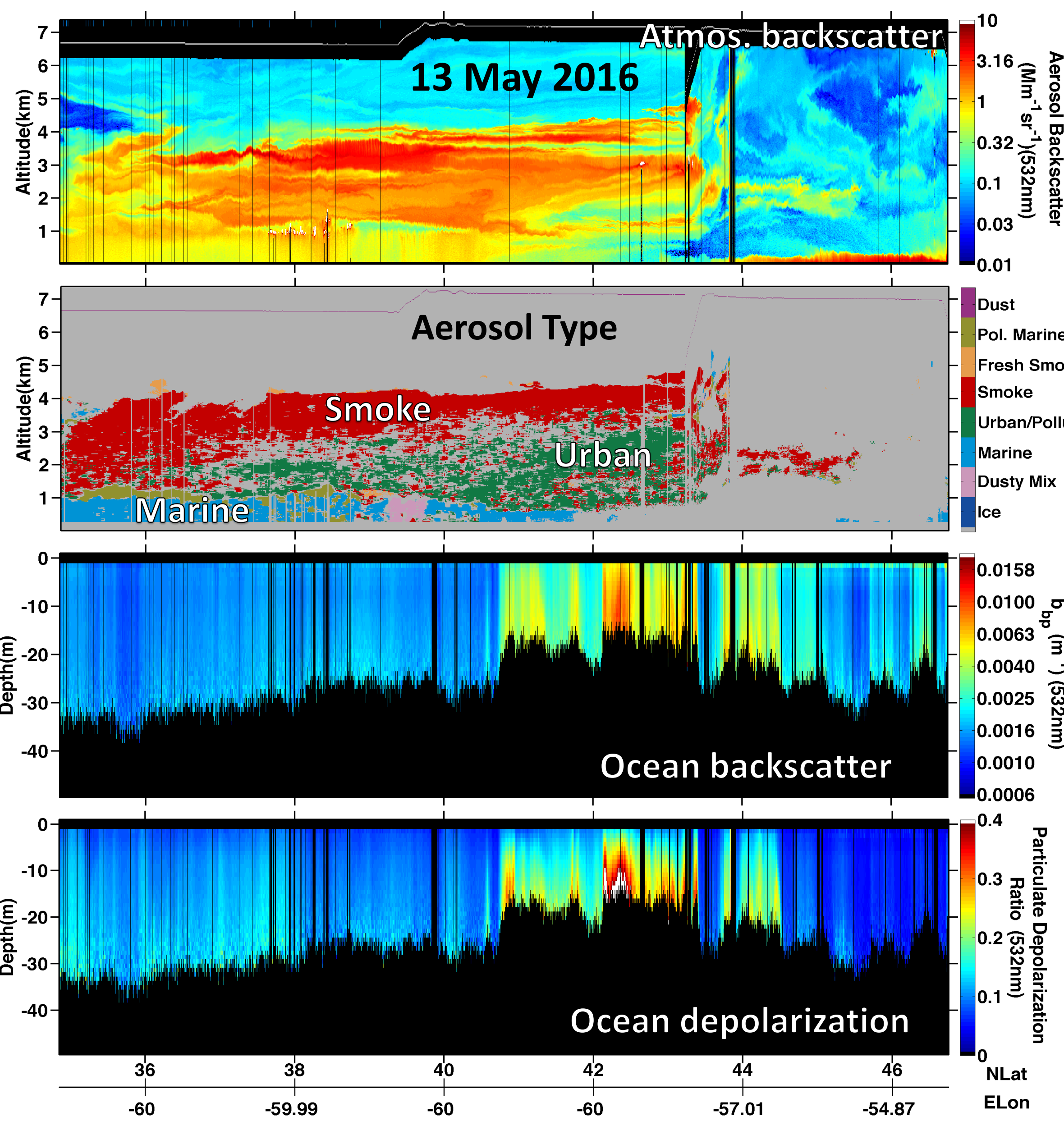


Fundamental Resolution: 0.5 seconds (~100m) horizontal  
1.25m atmosphere, 0.93m ocean vertical

| Instrument and Relation to Objectives               | Geophysical Products                           |
|-----------------------------------------------------|------------------------------------------------|
| HSRL-1                                              | Aerosol backscatter (532/1064nm)               |
| • Aerosol and cloud properties                      | Aerosol extinction (532nm)                     |
| • Ocean properties                                  | Aerosol & cloud depolarization (532/1064nm)    |
| • Relate ship-scale to satellite-scale measurements | Boundary Layer Height                          |
| • ACE prototype satellite instrument                | Aerosol Type (e.g. dust, marine)               |
|                                                     | Ocean diffuse attenuation coeff. (532nm)       |
|                                                     | Ocean particulate backscatter coeff. (532nm)   |
|                                                     | Ocean particulate depolarization ratio (532nm) |

## Example and Advantages for HSRL Ocean Retrievals

- Provides depth-resolved profiles
- Internally calibrated and direct measurement of particulate backscatter at 180 degrees
- Independent measurement of lidar attenuation (diffuse attenuation coefficient,  $K_d$ )
- Provides accurate ocean retrievals even when aerosol loading is high, including the absorbing aerosols (i.e., smoke)
- Lidar depolarization provides information content on hydrosol shape



## Comments and Next Steps Ocean Profiling

- Evaluation of existing airborne datasets
  - Continue comparisons with ship based measurements and other remote sensing measurements from NAAMES datasets
  - Evaluation and interpretation of the depolarization measurements and comparisons with in situ data still required
  - Continue evaluating synergies with active and passive retrievals
- Ocean retrievals from space
  - Detailed simulations have been performed showing the precision from spaceborne lidars for some cases, additional cases and depolarization measurements could be included
  - Development of retrievals using interferometric receivers still needs optimization along with assessment of precision and accuracy

## Cloud Droplet Number Concentration and Liquid Water Content Combined HSRL and RSP measurements during NAAMES Field Campaigns

$$N_d = \frac{\text{Extinction}}{\text{Scattering Cross Section}}$$

From lidar (HSRL) extinction retrieval with multiple scattering correction  
From polarimeter (RSP) size distributions

### How do we get droplet cross section from RSP?

RSP uses the shape (angle) of polarized reflectance in the rainbow region to derive the droplet size parameters at cloud top: **effective radius and variance of size distribution**

- Polarized reflectance angular variation is dominated by single cloud scattering
- Using relative angular variation is less sensitive to the 3D effects, overlying cirrus, and aerosol scattering

These size parameters provide accurate estimates of the scattering cross section from Mie theory.

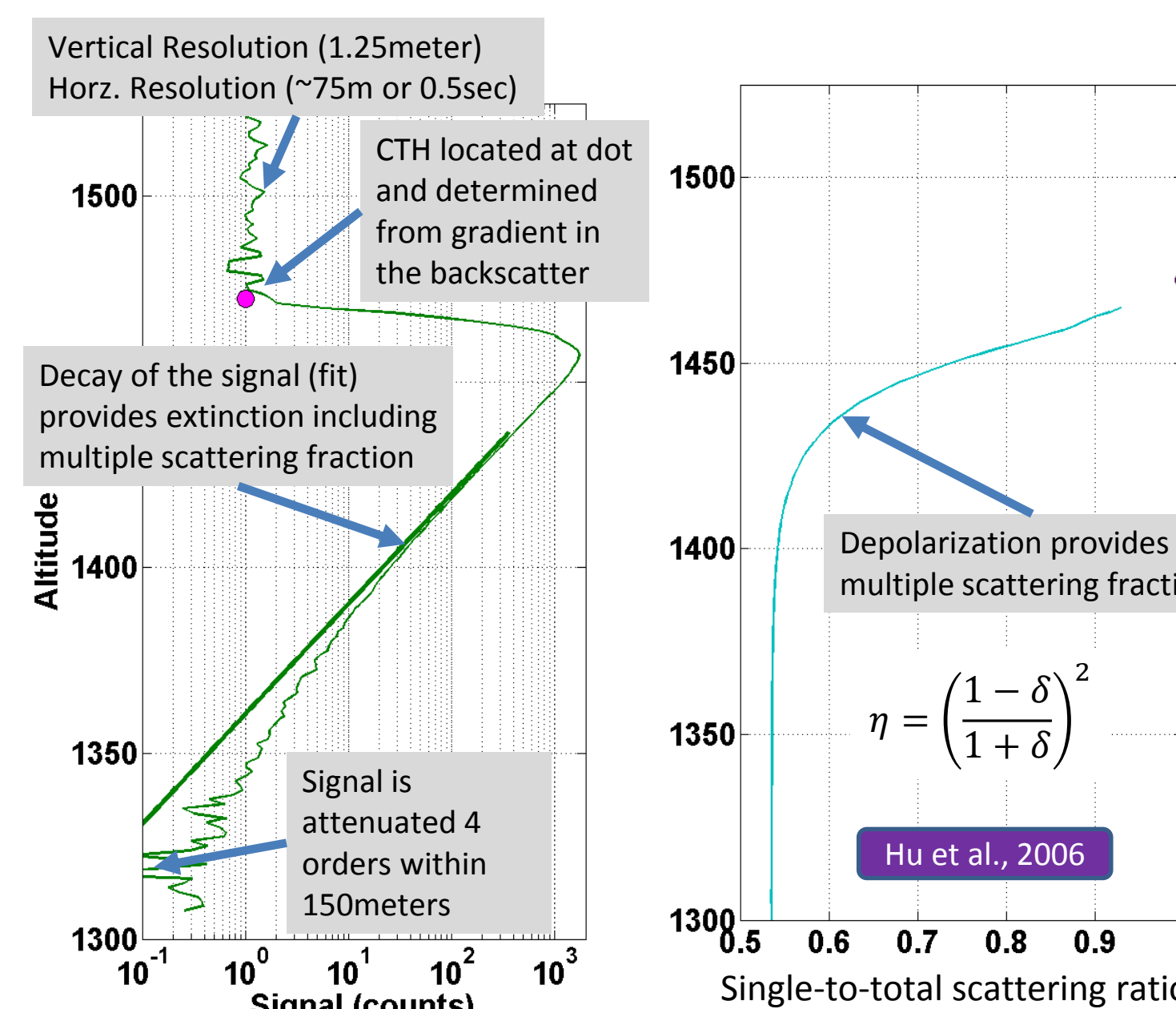
Alexandrov, Mikhail D., et al. 2012

Alexandrov, Mikhail D., et al. 2018 (Remote Sensing of the Environment)

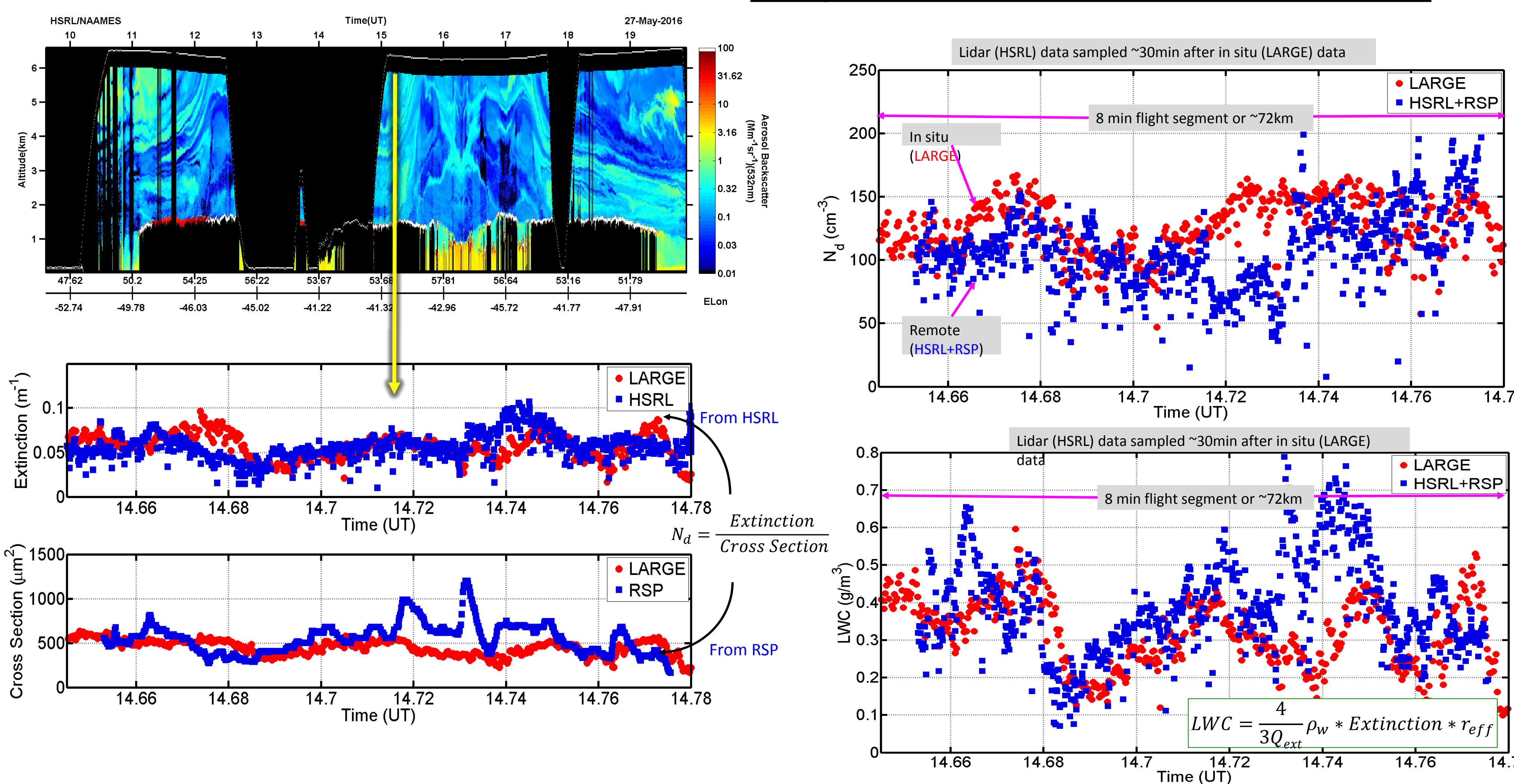
Accuracy assessments of cloud droplet size retrievals from polarized reflectance measurements by the research scanning polarimeter.

Retrievals of cloud droplet size from the research scanning polarimeter data: Validation using in situ measurements

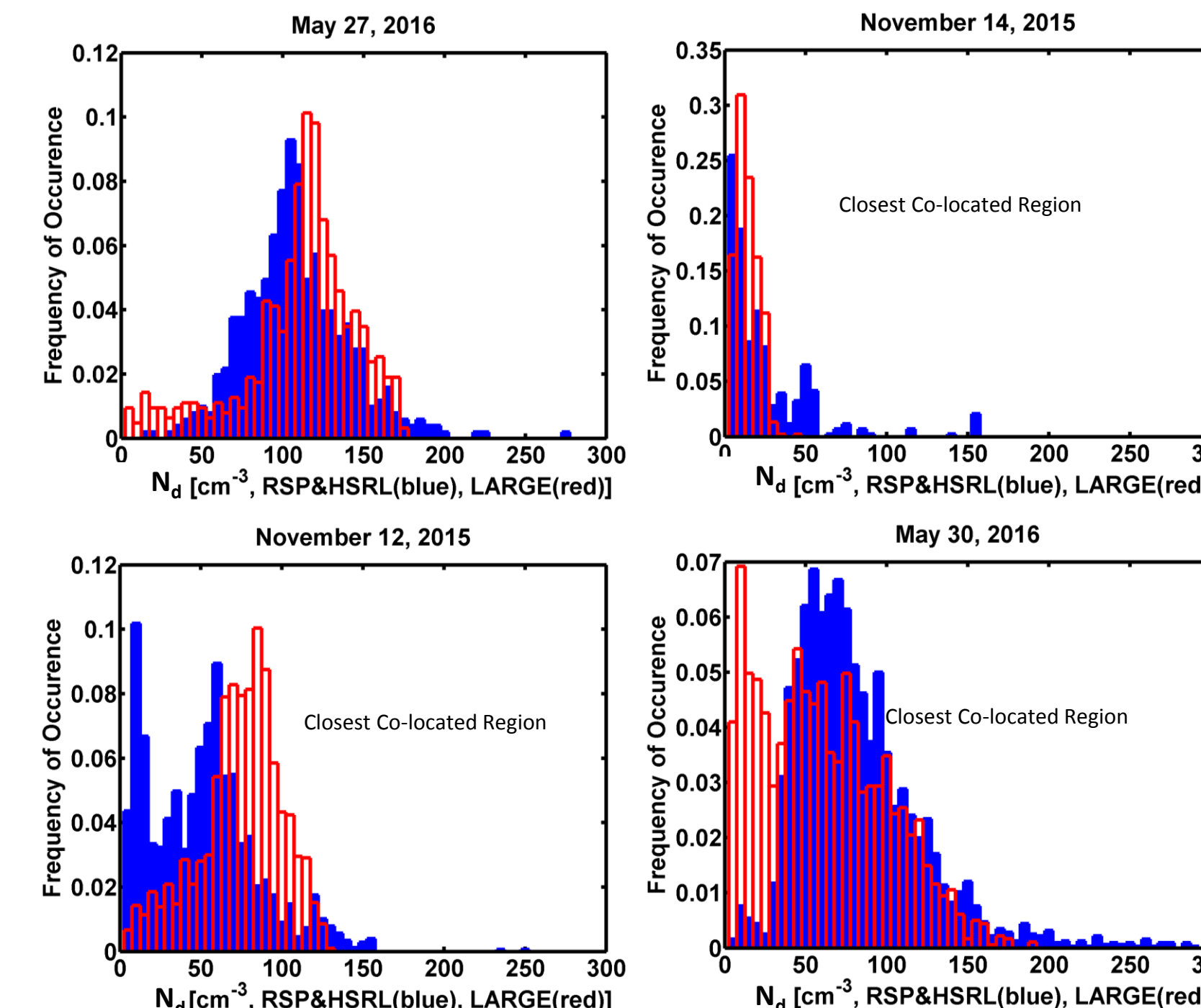
### How do we get cloud extinction coefficient?



## Example of Combined HSRL and RSP measurements



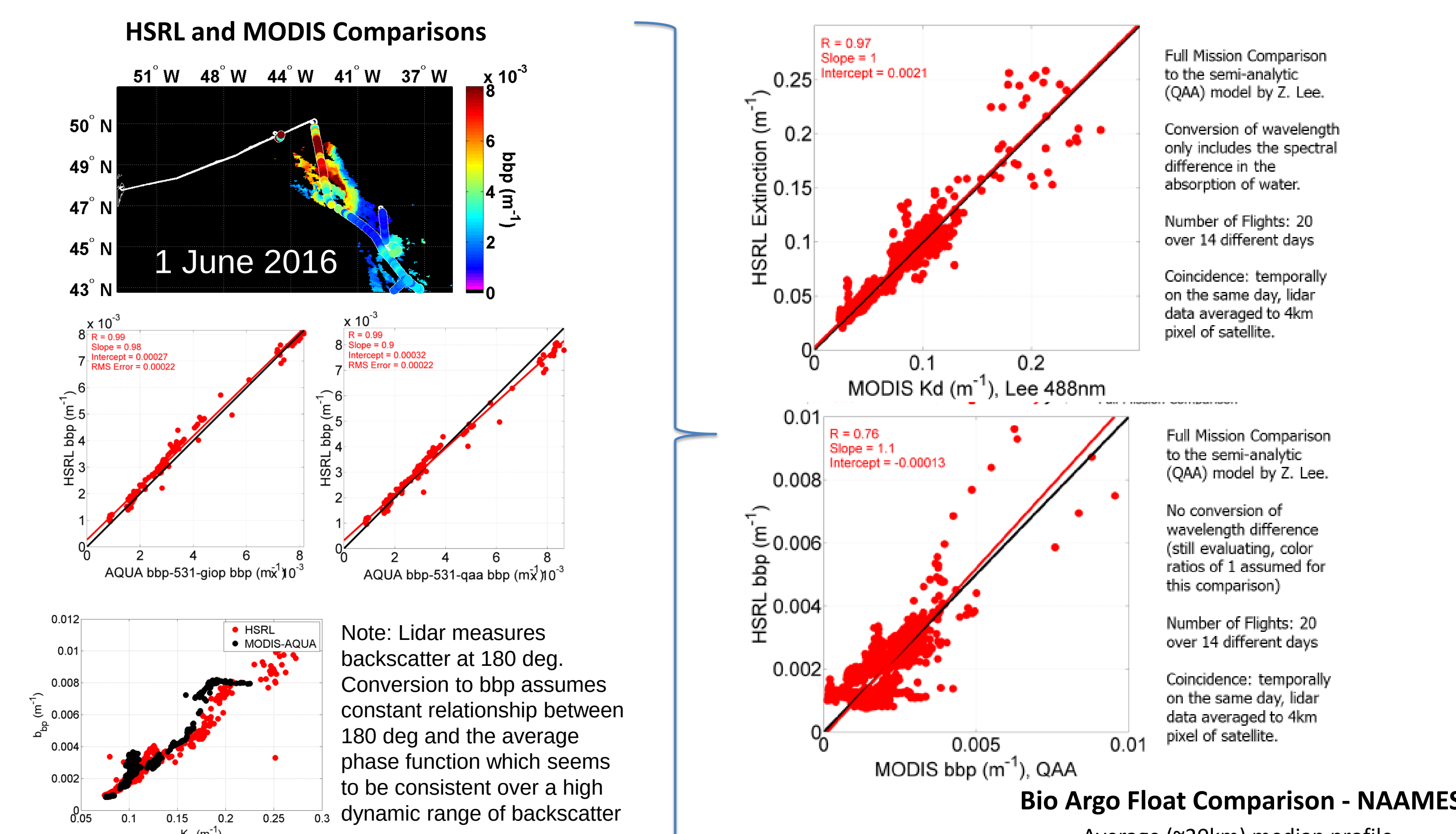
In situ, Mean = 126 cm<sup>-3</sup>, Median = 127 cm<sup>-3</sup>, Std dev = 22 cm<sup>-3</sup>. Lidar+Polarimeter Mean = 108 cm<sup>-3</sup>, Median = 107 cm<sup>-3</sup>, Std dev = 31 cm<sup>-3</sup>.



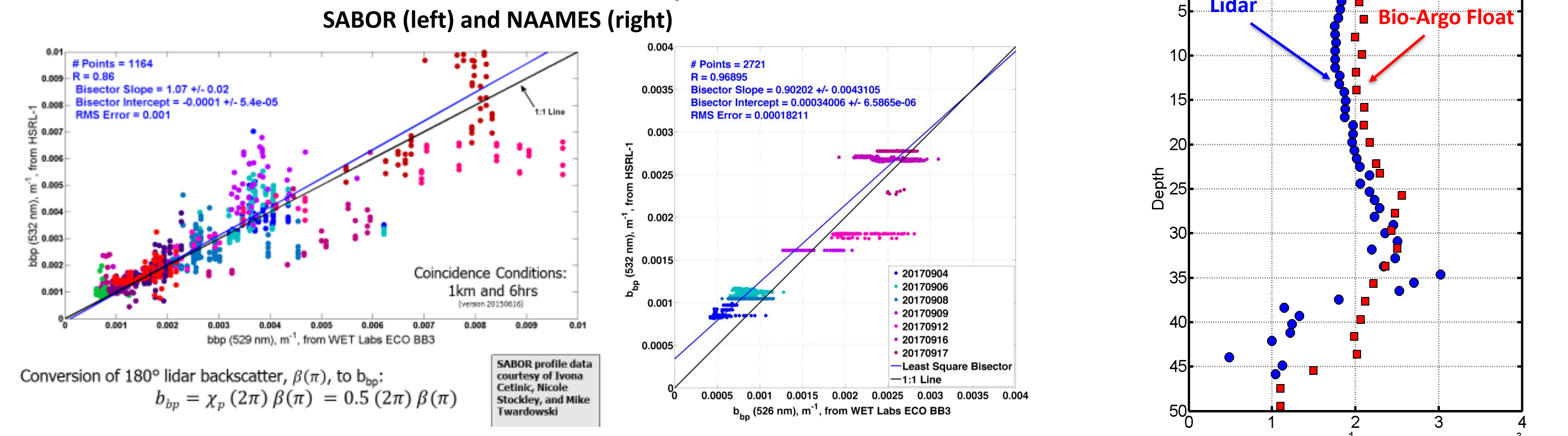
Contrast 12 and 14 November 2015: Note lower number concentration on 14<sup>th</sup> November 2015. Remote measurements have lower concentrations compared to in situ on 12<sup>th</sup> November, however the two sets of data were not in exactly the same location.

30 May 2016: Overall distributions match well, however LARGE shows lower mode (<25 cm<sup>-3</sup>)

## HSRL Ocean Profile Comparisons



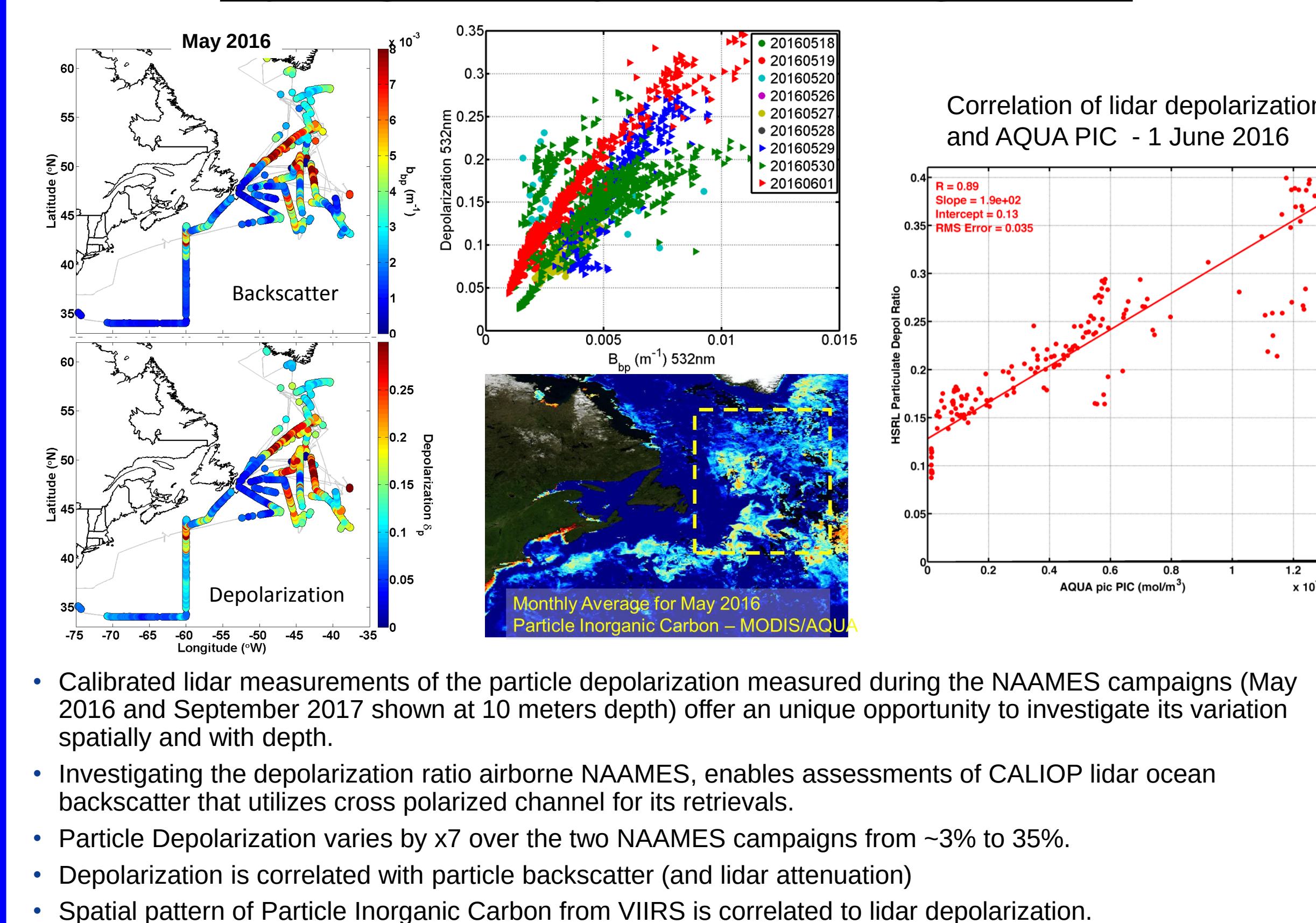
## Inline in situ measurement Comparisons



## Comments and Next Steps – Cloud Retrievals

- Evaluation of existing airborne measurements
  - For example, SEAC4RS, NAAMES, ORACLES campaigns have combined lidar and polarimeter data with focus on sampling clouds
  - Sensitivity studies, retrieval error assessments, and in situ comparisons for different clouds are in progress
  - Spatial sampling assessments to address broken cloud scenes are needed
- Future airborne campaigns – lidar, polarimeter, microwave radiometer, in situ sampling of warm clouds
  - Assess biases and precisions - requires statistical sampling (many cases) to compare in situ and remote measurements.
  - Assess retrievals of additional parameters (i.e. cloud thickness, clouds condensate rate)
- Assessment of instrument requirements for cloud retrievals from space
  - Resolutions (both horizontal and vertical) requirements
  - SNR requirements (single shot versus averaging)

## Exploring Ocean Depolarization during NAAMES



- Calibrated lidar measurements of the particle depolarization measured during the NAAMES campaigns (May 2016 and September 2017 shown at 10 meters depth) offer an unique opportunity to investigate its variation spatially and with depth.
- Investigating the depolarization ratio airborne NAAMES, enables assessments of CALIOP lidar ocean backscatter that utilizes cross polarized channel for its retrievals.
- Particle Depolarization varies by x7 over the two NAAMES campaigns from ~3% to 35%.
- Depolarization is correlated with particle backscatter (and lidar attenuation)
- Spatial pattern of Particle Inorganic Carbon from VIIRS is correlated to lidar depolarization.