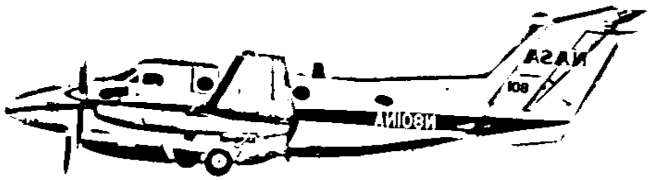
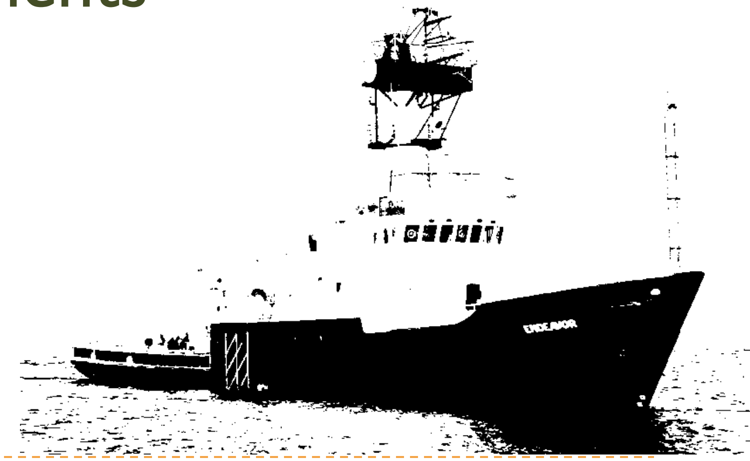
SABOR: Ship-Aircraft Bio-Optical Research Campaign

Outline

- SABOR
  - Genesis & objectives
- Components
  - Ship based measurements
  - Aircraft based measurements
- Deployment concept
  - Where, when & how





SABOR: Genesis

- Three independent proposals funded under the OBB A.3 had related objectives and complementary methodologies
  - Cetinić et al.: Multi-sensor, ecosystem-based approaches for estimation of particulate organic carbon
  - Gilerson et al.: Development of a Methodology for the Retrieval of Characteristics of Water Constituents from Satellite Polarimetric Observations
  - Hostetler et al.: Advanced Ocean Retrievals Using Lidar and Polarimeter Measurements
- With Paula's encouragement, the teams joined forces for a combined effort
- Collaboration between NRL and NASA LaRC led to ONR funding for NRL's participation

SABOR: Objectives

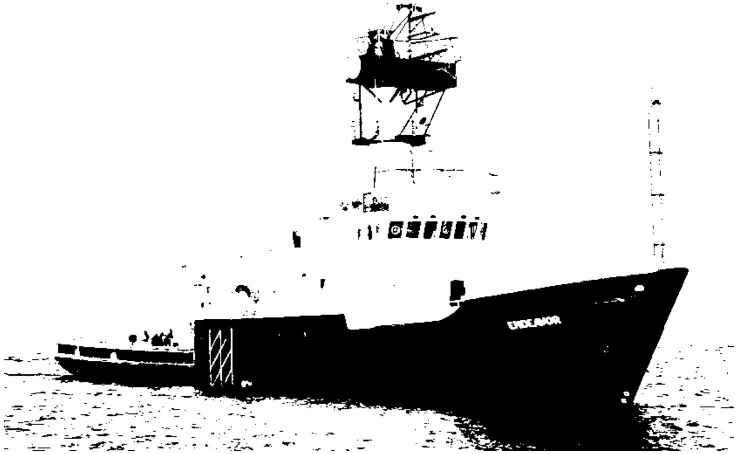
Can we use polarization measurements to do biogeochemistry?

Synergistic approach:

- In situ IOPs and biogeochemical measurements
- In situ polarimetric (above and in water) measurements for retrieval of IOPs
- Airborne lidar + polarimeter measurements

Redundancy and Cross-Validation

Ship based measurements

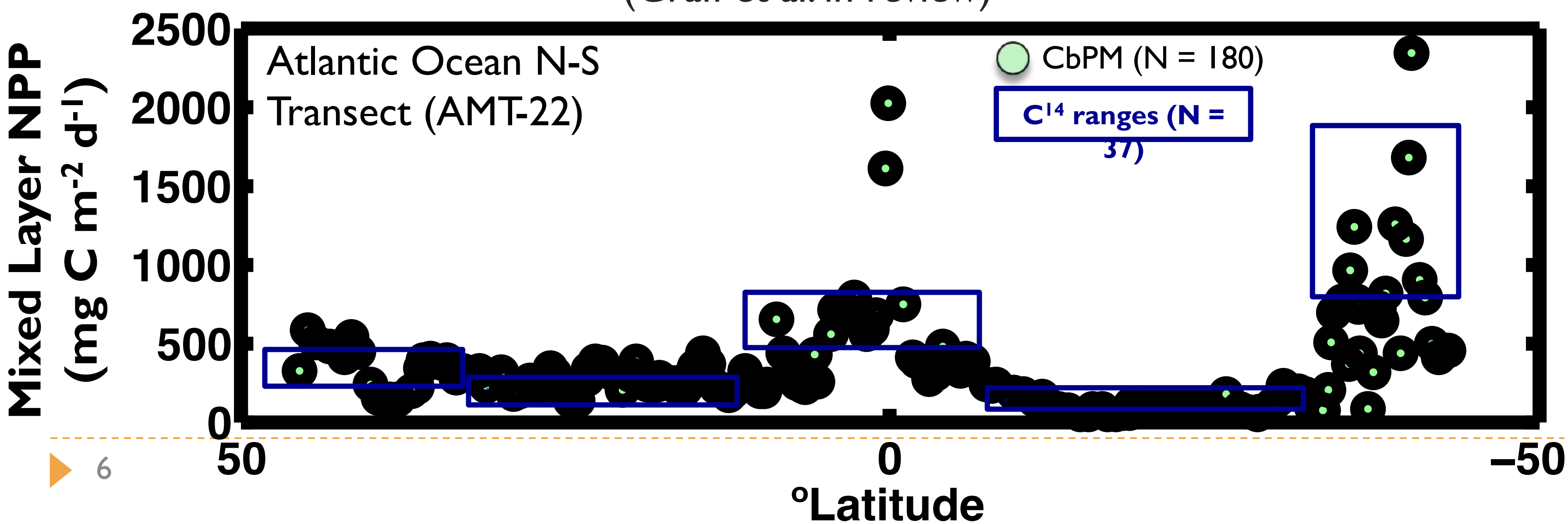


Phytoplankton Carbon, Growth Rates, and Primary Production

1) Behrenfeld, Graff, Westberry & Milligan
2) Halsey & Fisher

Phytoplankton Carbon	Growth Rate (μ)	Primary Production (C x μ)	Supporting Measurements
Direct measurement	Carbon-based Productivity Model (CbPM)	C^{14} – multiple incubation durations (Gross & Net PP)	HPLC PIgments
b_{bp} – C_{phyto} proxy	Dilution Experiments	CbPM (Net PP)	Total POC
Flow-cytometry	Species-specific μ (sequence-based)		Community Composition

Example of the CbPM applied in-situ vs ranges in depth integrated C^{14} NPP (Graff et al. in review)



Ecosystem based POC retrieval

Cetinić, Perry, Poulton & Slade

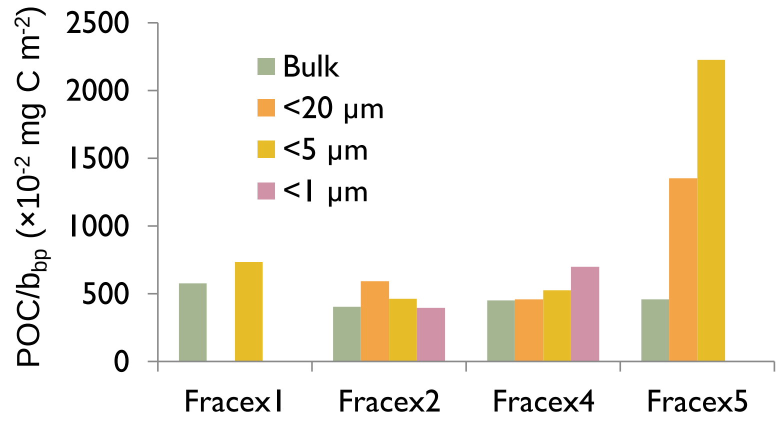
Flow-through, size fractionated IOPs

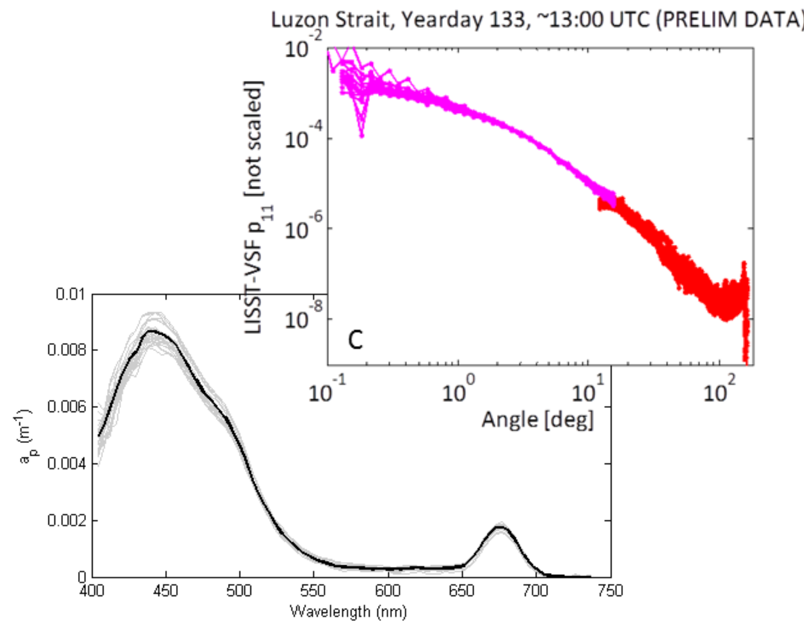
sensor	measurement
Flow control	(0.2, 1/5 and 20 μm @ hourly)
LISST-vsf	$\beta(515\ \text{nm}, \psi), \psi = 0.08\text{–}150°$ and $DoP = S12/S11, \psi = 10\text{–}150°$
BB3	$\beta(\lambda, 117°),\ \lambda = 400, 532, 660$ nm
ac-s	$a_t, c_t, a_{pg}, c_{pg}, a_g, a_p, c_p$ (multi λ)
C-star	$c_{pg}(657)$ closed path
Wetstar	*chl fluorescence*

& discrete samples (size fractionated)

POC, SPM, HPLC pigments,

C_{phyto}, Phytoplankton composition + PSD

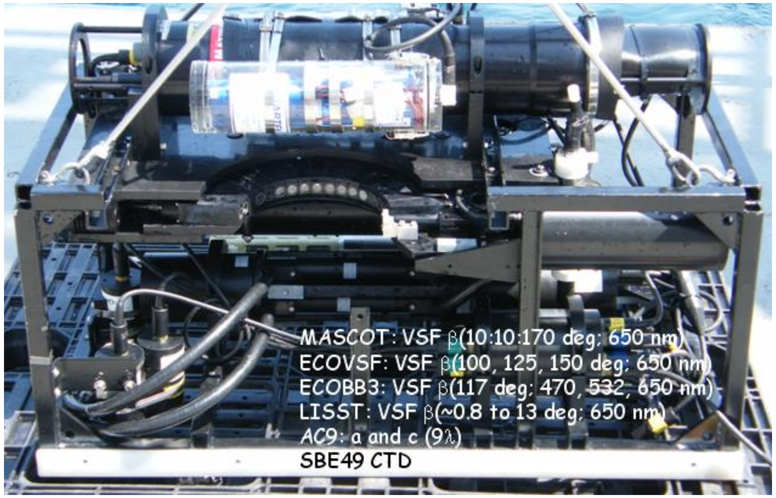




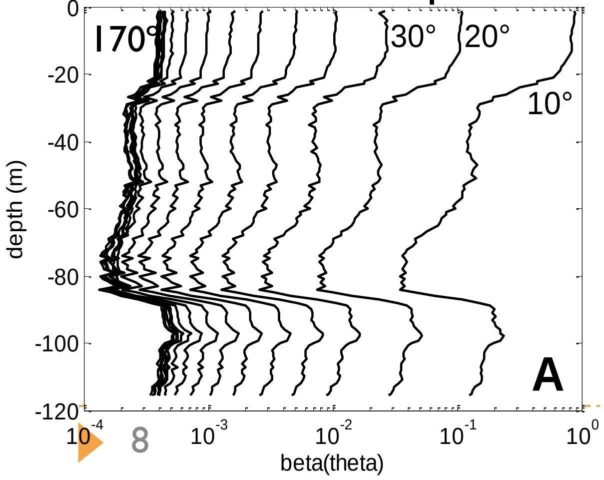
In situ polarized VSF and other IOPs

Twardowski & Stockley

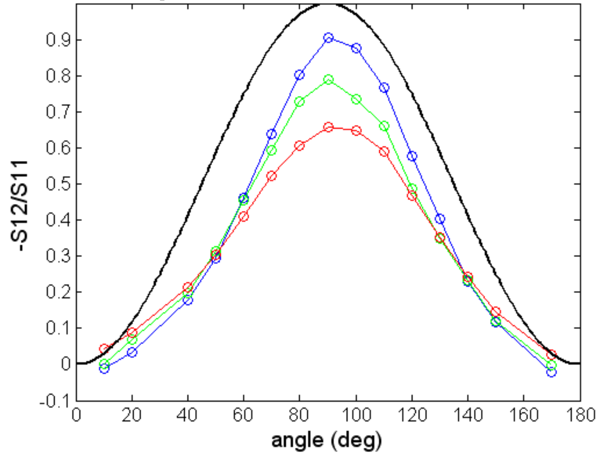
sensor	measurement
MASCOT + POLMOD	$\beta(10{:}10{:}170°)$, $i_{\perp}(10{:}10{:}170°)$, $i_{\parallel}(10{:}10{:}170°)$ at 658 nm
LISST-B	$\beta(0.8 - 13°)$ at 650 nm
ac-9s	a_t, c_t, a_{pg}, c_{pg}, a_g, a_p, c_p (9 λ)
ECOs	β(412 - 700 nm, 104 - 151°)
C-star	$c_{pg}(657)$ open path
CTD	z, T, S



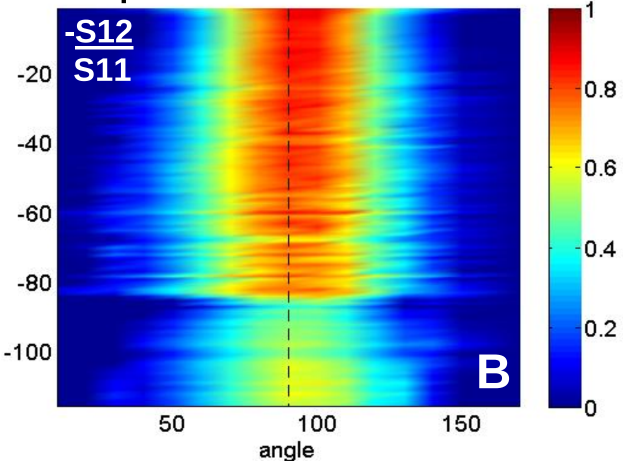
MASCOT VSF profile



depolarization ratio, θ



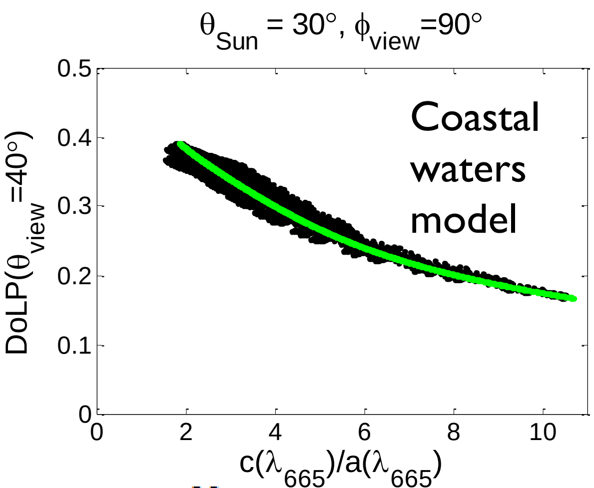
depolarization ratio, z

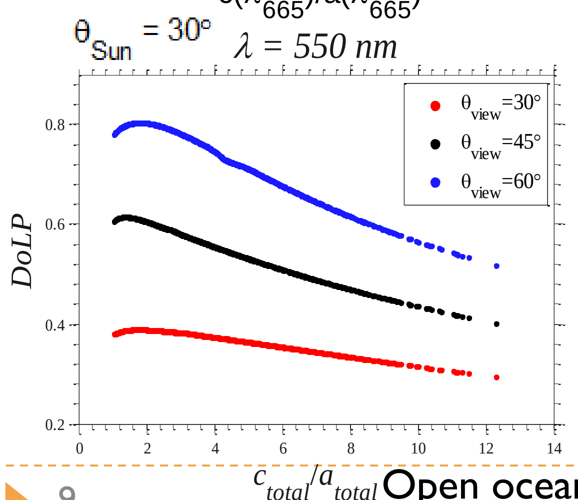


Polarization light fields

Gilerson, Ahmed, Gross, Moshary, Puschell, Cairns and Chowdhary

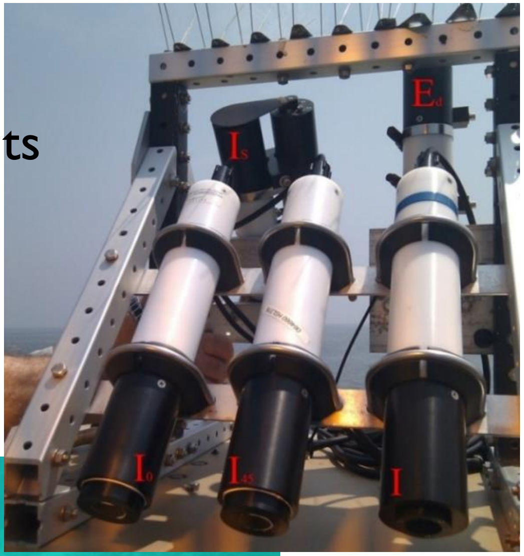
Expected DoLP vs c/a relationships based on extensive RT simulations



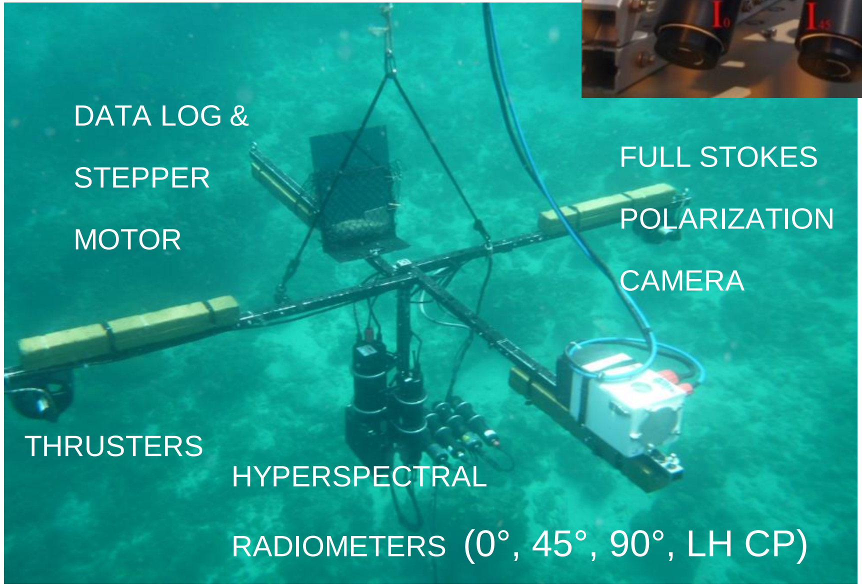


Open ocean model

HyperSAS-POL for underway measurements



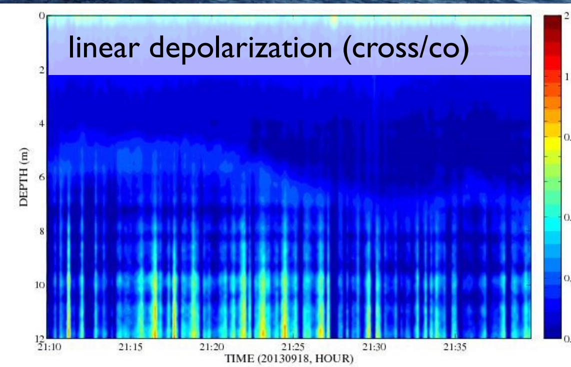
Underwater polarimeter–camera system

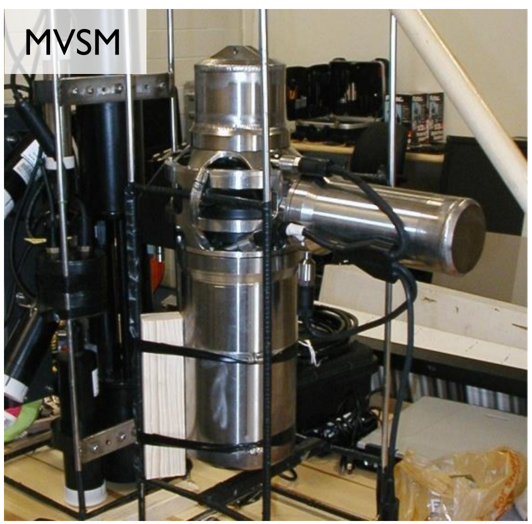


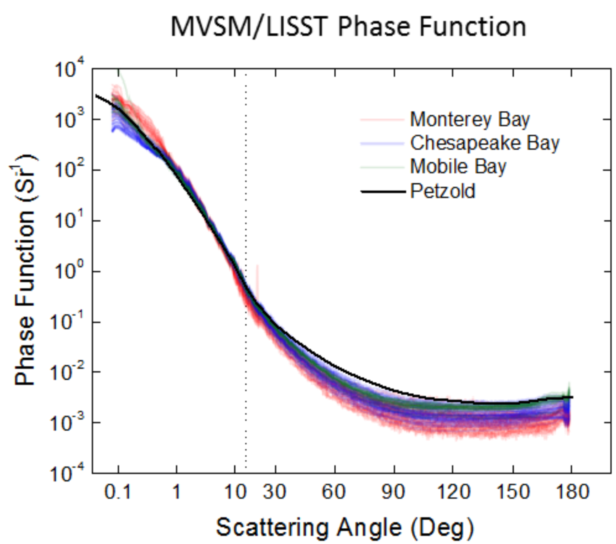
In situ VSF
& ship-based Polarimetric Lidar

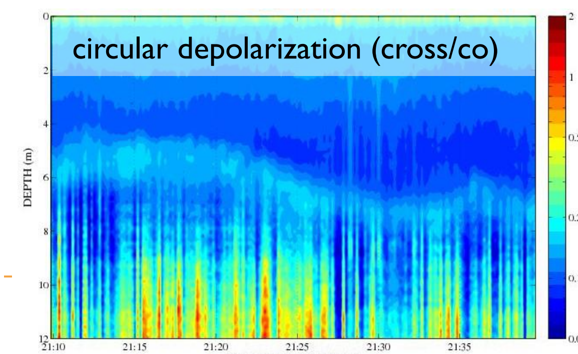
Gray, Kearney & Gould

Sensor	Measurement
MVSM	β (0.5-179°) at 443, 490, 510, 532, 555, 565, 590, 620 nm
LISST-100X	β (0.08-13°) at 532 nm
Polarimetric lidar	532 nm laser and four receiver channels

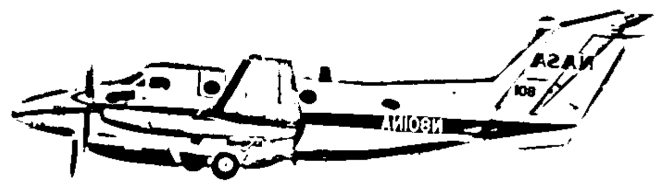








MVSM = Multi-spectral Volume Scattering Meter



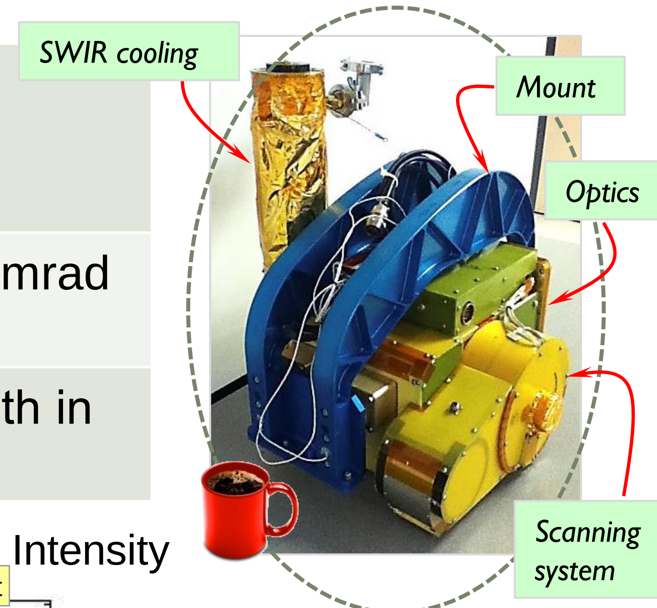
Aircraft based measurements

Research Scanning Polarimeter (*RSP*)

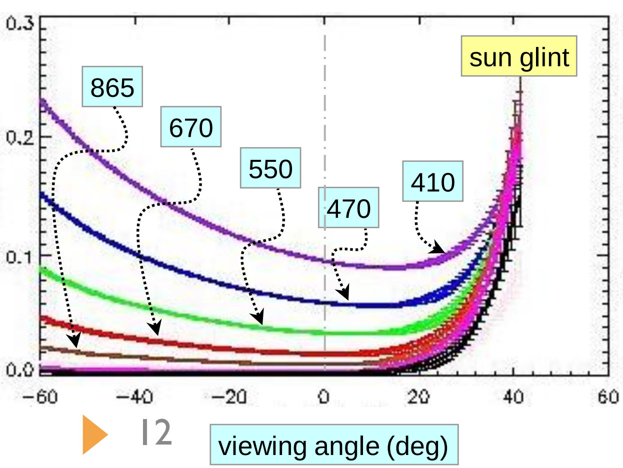
Chowdhary and Cairns

RSP obtains multiangle and multispectral measurements of intensity and of linear polarization for each pixel along the ground track

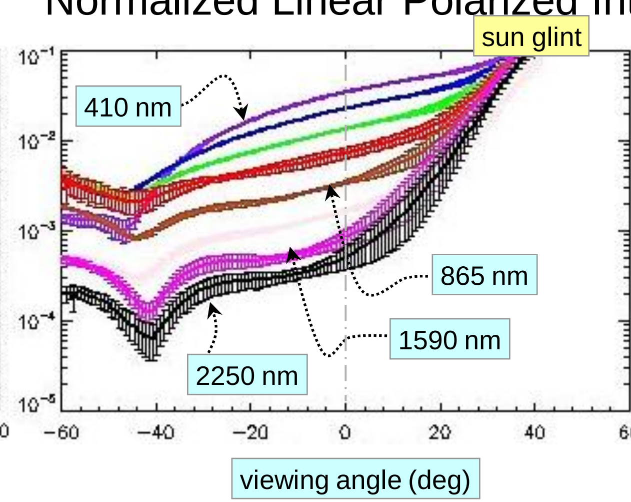
Radiances	Stokes parameter *I* (Intensity) Stokes parameters *Q* & *U* (Linear Polarization)
views	152 viewing angles, ±60° from nadir, 14 mrad IFOV
wavelengths	9 bands, 410 –2250 nm, 20 nm bandwidth in VIS

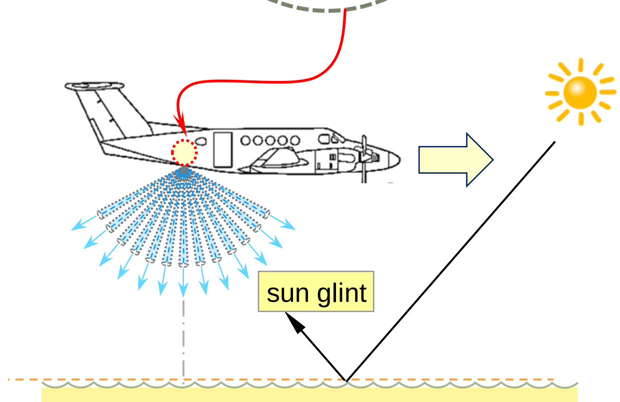


Normalized Intensity



Normalized Linear Polarized Intensity

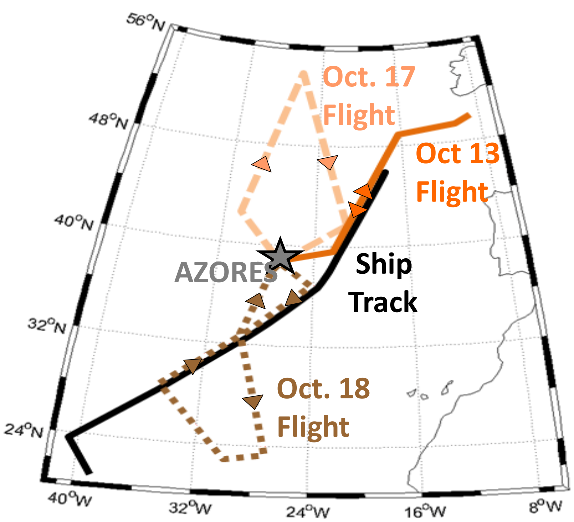


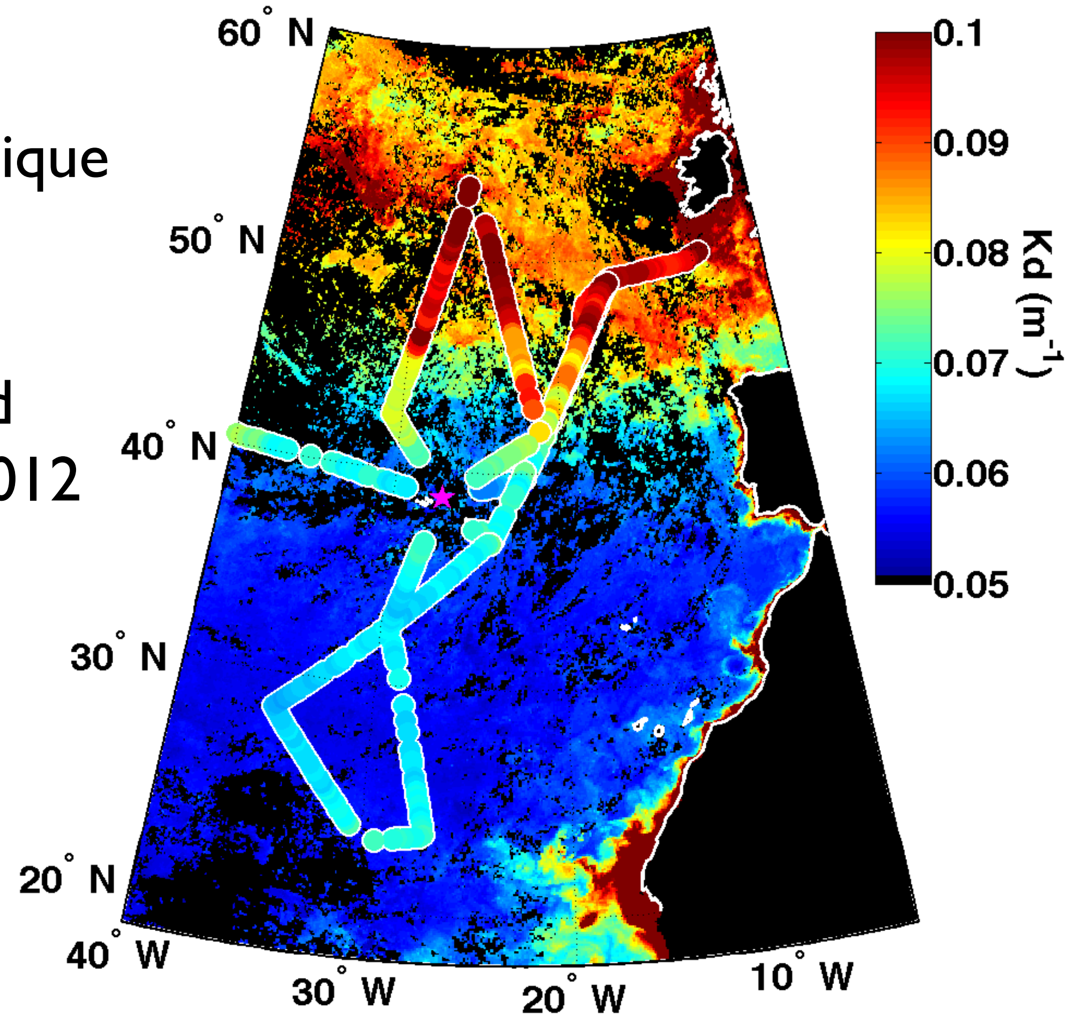


Improving and validating lidar retrievals

Hostetler, Hu, Hair, & Behrenfeld

- Employing the High Spectral Resolution Lidar (HSRL) technique to make quantitative profile retrievals of b_{bp} and K_d
- Preliminary data were acquired from the Azores in October 2012

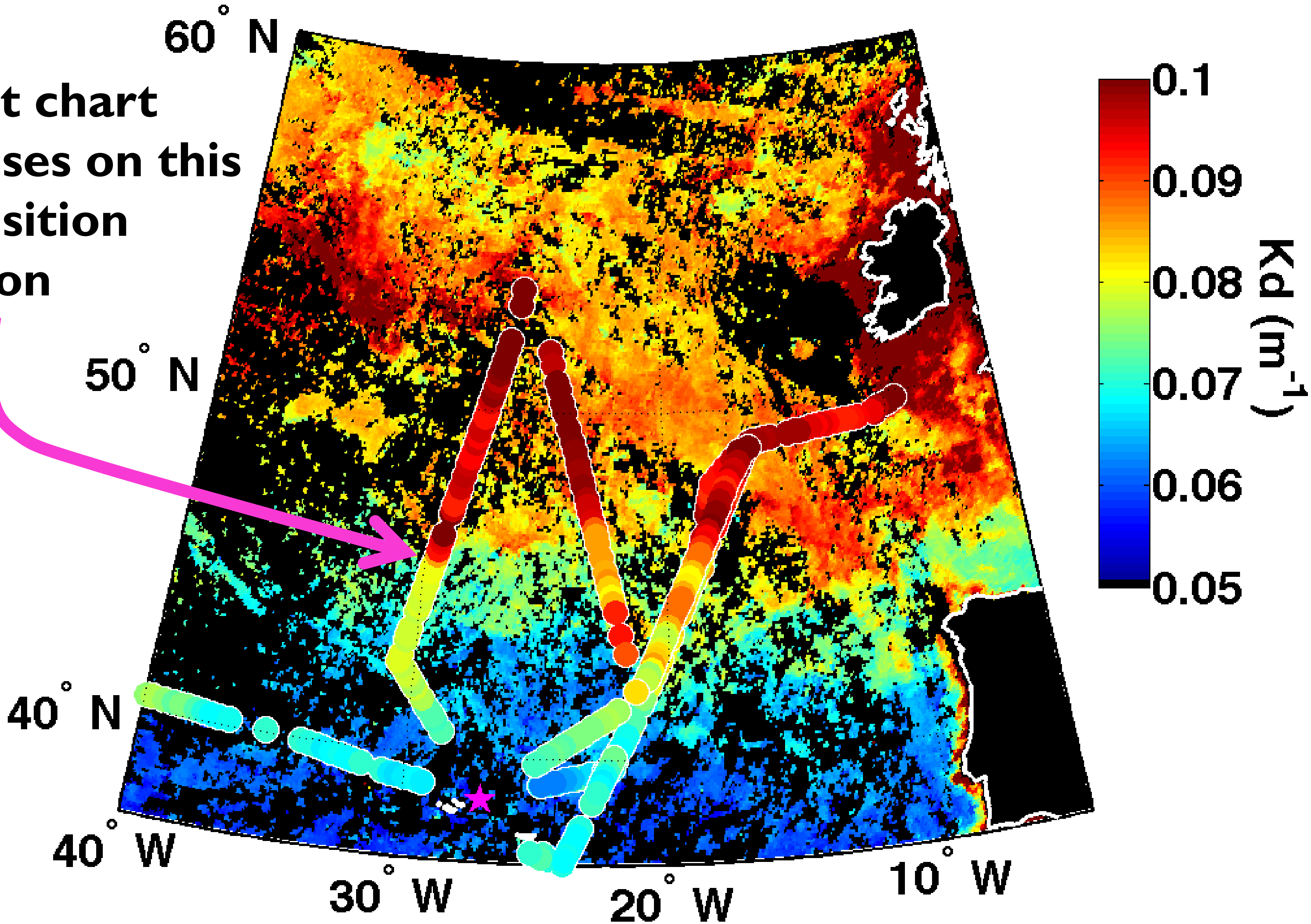




LIdar retrieval of Kd (532 nm) along flight tracks. Background is MODIS Kd scaled to 532 nm

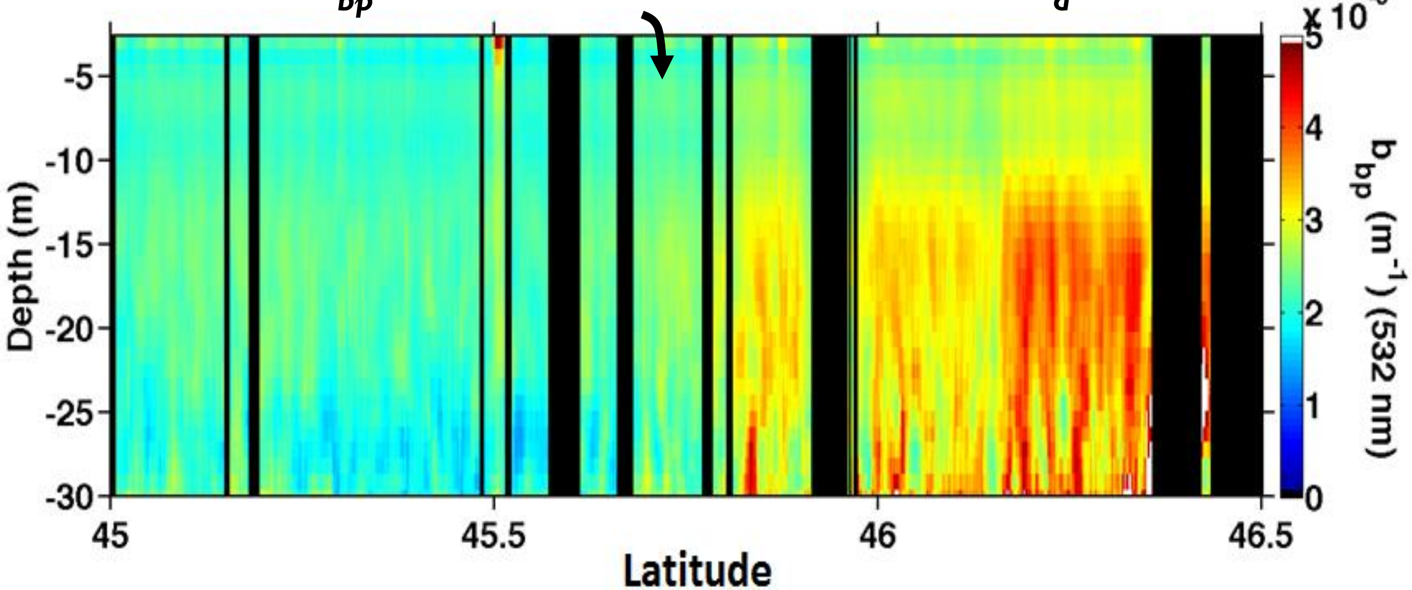
Lidar Kd Retrieval at 532 nm

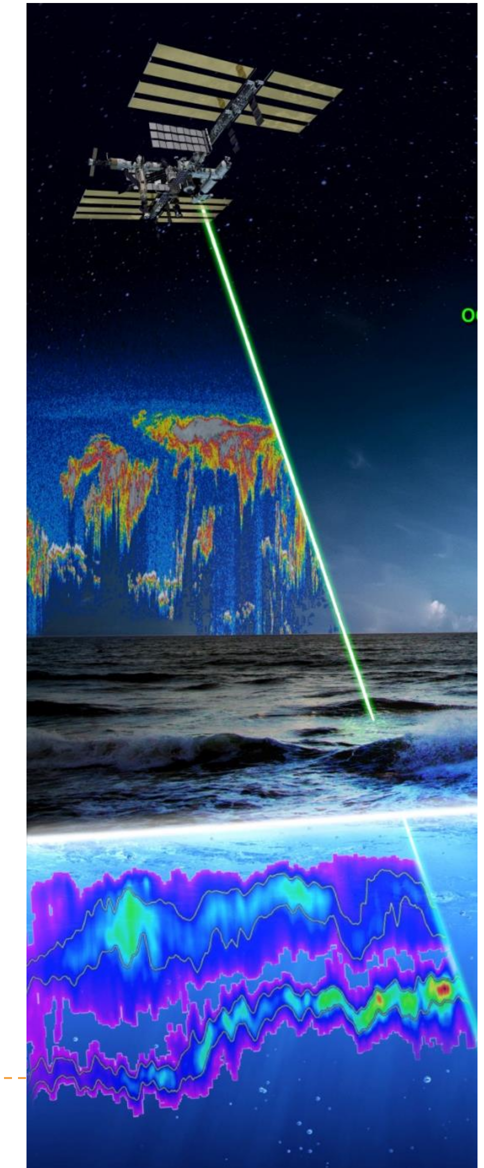
Next chart focuses on this transition region



b_{bp} retrieved from HSRL-1 lidar in the transition region

Transition in b_{bp} consistent with transition in K_d





- Azores mission provided first-ever independent profiles of K_d and b_{bp} from lidar via the HSRL technique
- The lidar has since been modified to improve the retrievals
- SABOR will vet the techniques planned a space version of the lidar: OPAL – Ocean Profiling and Atmospheric Lidar

SABOR Deployment

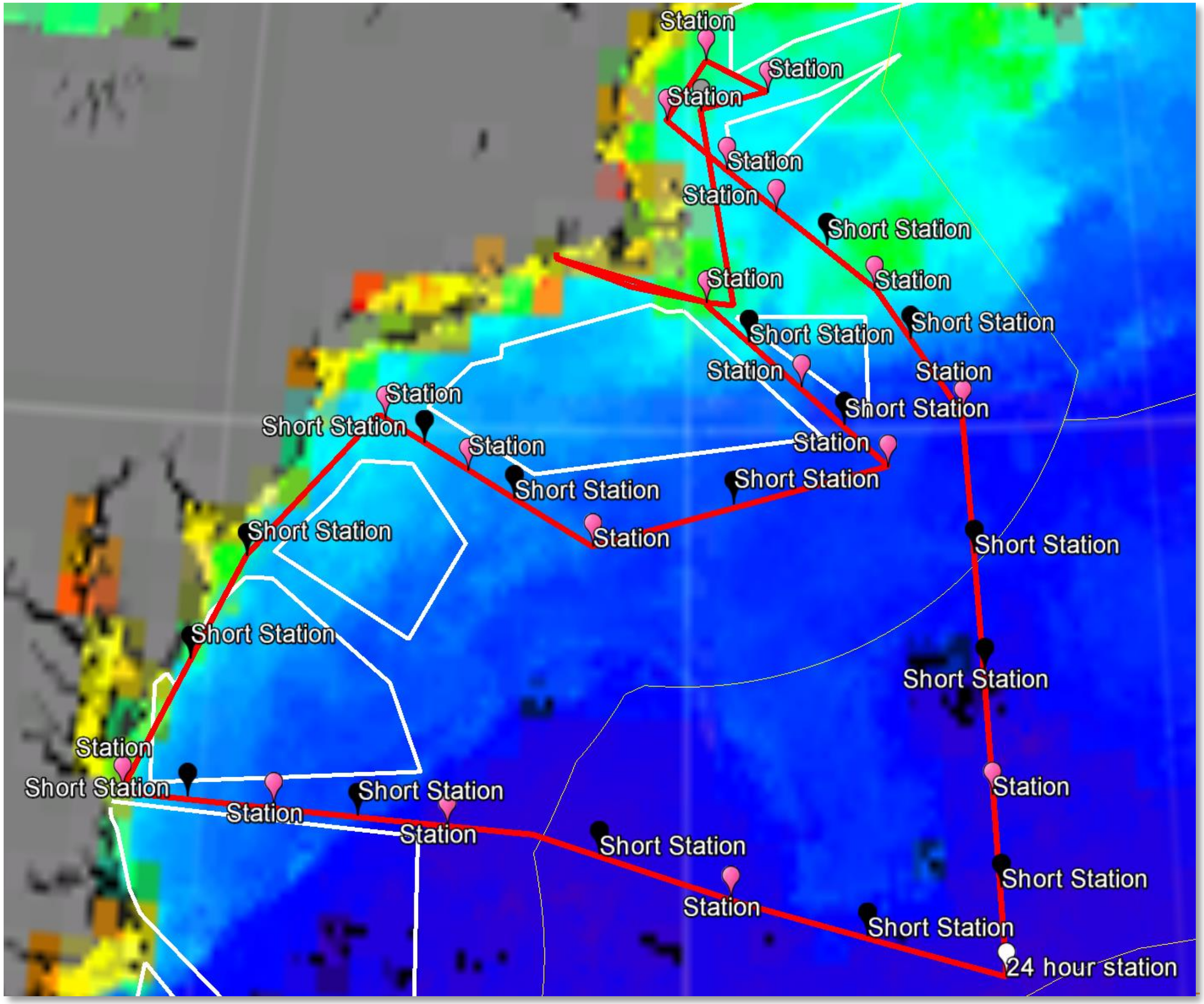
SABOR: Deployment

- 19 July – 5 Aug 2014, 20-day cruise
- Project management and support by Earth Science Project Office at NASA Ames (Allison and Tolley)

Platforms:

- R/V Endeavor - outfitted with optical and constituent measurements
- NASA's UC-12 Aircraft - deploying lidar and polarimeter

SABOR: Deployment



SHIP

- 24/7 flowthrough optics + pol-radiometry
- LIDAR before/after stations
- 18 long stations
- 16 short stations
  - 4 cross-shelf transects
- 2 – 24 hour stations

AIRCRAFT

- Transect flights
- Polarization overflights

SABOR: Summary

- Ship + Aircraft experiment
- Across-fields collaboration = Synergistic results
- Showcase for future of polarization measurements in field of oceanic biogeochemistry
- Airborne demonstration of potential future spaceborne ocean-profiling lidar
- Look for our posters/talks on future conferences (Ocean Optics and 2015 OCRT)

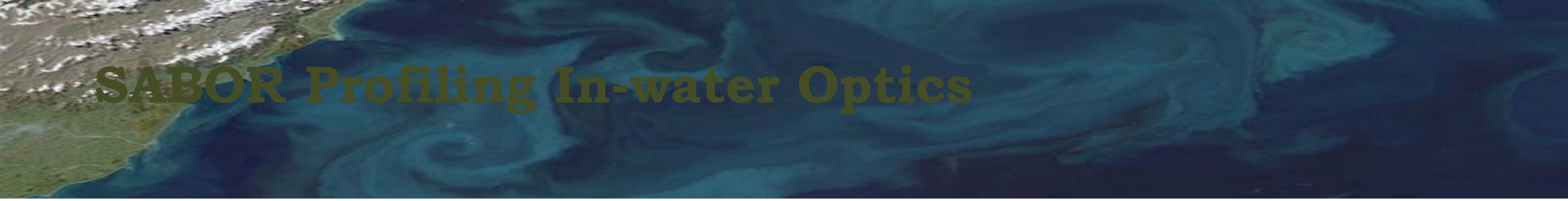

Ocean Optics XXII
October 26–31, 2014 • Portland, Maine
www.oceanopticsconference.org
Register now to attend this conference for international scientific professionals and students. Virtually every facet of ocean color remote sensing and optical oceanography will be presented, including basic research, technological development, environmental management, and policy.
Abstract deadline: May 15, 2014

Thank you


2014
NASA
ENDEAVOR
SABOR
Ship-Aircraft Bio-Optical Research

SABOR Underway Optics

Property Measured, Wavelengths	Instrument / Method	Precision / Accuracy	Provider	Comment
Automated periodic filtered seawater measurement	FlowControl (Lab)		Slade	Allows for calibration-independent particulate IOP by difference
Total absorption coefficient, $a(\lambda)$, $\lambda = 400–730$, 4 nm resolution	WET Labs ac-s	± 0.001 m^{-1} / 0.01 m^{-1}	Perry / Cetinic	Limited characterization of measurement uncertainty in absorption correction due to scattering correction. Note "total" measurements do not include optical properties of seawater.
Total attenuation coefficient, $c(\lambda)$, $\lambda = 400–730$, 4 nm resolution		± 0.001 m^{-1} / 0.01 m^{-1}	Perry / Cetinic	
Volume scattering function $\beta(\lambda, 117°)$, $\lambda = 400, 532, 660$ nm	WET Labs BB-3	~3×10^{-6} m^{-1} sr^{-1} resolution	Cetinic	Using flowthrough chamber as in [Dall'Olmo et al., 2009]
Angular volume scattering function and degree of linear polarization: $\beta(515\ \text{nm}, \psi)$, $\psi = 0.08–150°$ and $DoP = S12/S11$, $\psi = 10–150°$	Sequoia LISST-VSF	TBD	Slade	Also possible estimate of $S22$
Chlorophyll fluorescence, 470 nm excitation, 700 nm emission	WET Labs WETStar or WET Labs FLNTU		Perry / Cetinic	
Total and polarized radiance, downwelling irradiance and	Hyperspectral polarimeter CCNY		Gilerson	Tonizzo et al, 2009
Polarized images	Full Stokes vector imaging camera Bossa Nova Technology		Gilerson	Vedel et al, 2011



SABOR Profiling In-water Optics

Property Measured, Wavelengths	Instrument / Method	Provider	Comment
Allows filtered up-cast for ac-s	FlowControl (Submersible)	Slade	
Total absorption coefficient, $a(\lambda)$	WET Labs ac-s	Behrenfeld	CTD is needed on package for TS correction
Total attenuation coefficient, $c(\lambda)$			
Volume scattering function $\beta(\lambda, 117°)$, $\lambda = 400, 532, 660$ nm	WET Labs BB-3	Behrenfeld	Possibility of borrowing BB-9 from E. Boss
Angular volume scattering function and degree of linear polarization: $\beta(515\text{ nm}, \psi)$, $\psi = 0.08–150°$ and $DoP = S12/S11$, $\psi = 10–150°$	Sequoia LISST-VSF	Slade	Also possible estimate of $S22$ Included only for select casts
Chlorophyll fluorescence, 470 nm excitation, 700 nm emission	WET Labs WETStar / FLNTU	TBD	
Upwelling radiance, $L_u(\lambda)$, $\lambda = 350–800$ nm, 10 nm resolution	Satlantic HyperOCRs	Boss (borrowed)	
Downwelling irradiance, $E_d(\lambda)$, $\lambda = 350–800$ nm, 10 nm resolution			
In water total and polarized radiance at various viewing and azimuth angles	Polarimeter, camera	Gilerson	

Rosette

Property Measured, Wavelengths	Instrument / Method	Provider	Comment
Volume scattering function $\beta(700\text{ nm}, 140°)$	WET Labs FLNTU	Perry / Cetinic	
Chlorophyll fluorescence, 470 nm excitation, 700 nm emission			
Total attenuation coefficient, $c(\lambda)$, $\lambda = 660$ nm	WET Labs C-Star	Perry / Cetinic	

SABOR Underway Optics

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Chlorophyll fluorescence, 470 nm excitation, 700 nm emission	WET Labs WETStar or WET Labs FLNTU		Perry / Cetinic	
Total and polarized radiance, downwelling irradiance and	Hyperspectral polarimeter CCNY		Gilerson	Tonizzo et al, 2009
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Angular volume scattering function and degree of linear polarization: $\beta(515\ \text{nm}, \psi)$, $\psi = 0.08–150°$ and $DoP = S12/S11$, $\psi = 10–150°$	Sequoia LISST-VSF	Slade	Also possible estimate of $S22$ Included only for select casts
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Rosette

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Volume scattering function $\beta(700\ \text{nm}, 140°)$	WET Labs FLNTU	Perry / Cetinic	
Chlorophyll fluorescence, 470 nm excitation, 700 nm emission			
Total attenuation coefficient, $c(\lambda)$, $\lambda = 660$ nm	WET Labs C-Star	Perry / Cetinic	

Hyperspectral Imager for the Coastal Ocean (HICO)

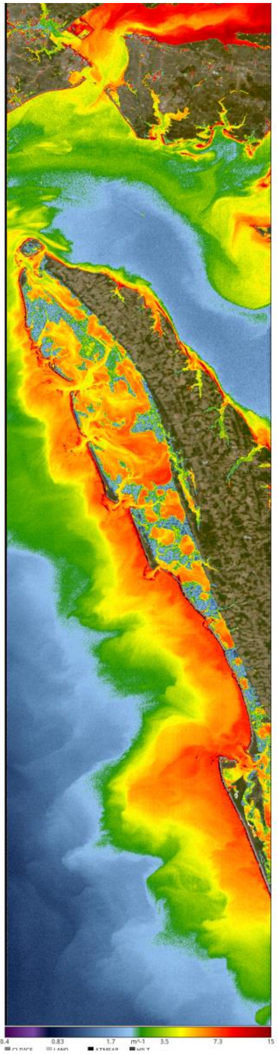
- Built by NRL and installed on the International Space Station (ISS) in October 2009
- Currently operated by NASA and NRL
- NASA OC standard and NRL specific IOP and AOP products available

Number of Spectral Bands	128
Spectral Wavelength Range	350-1080 nm
Spectral Wavelength Bandwidth	5.7 nm
Ground Sample Distance (at Nadir)	100 m
Signal to Noise Ratio (water-penetrating wavelengths)	> 200 to 1
Polarization Sensitivity	< 5%
Scene Size (varies according to ISS height)	50 x 200 km
Cross-track pointing	45 to -30 degrees
Maximum scenes per orbit	1
Maximum number of orbits (scenes) per day	15

Chesapeake Bay 26 January 2010

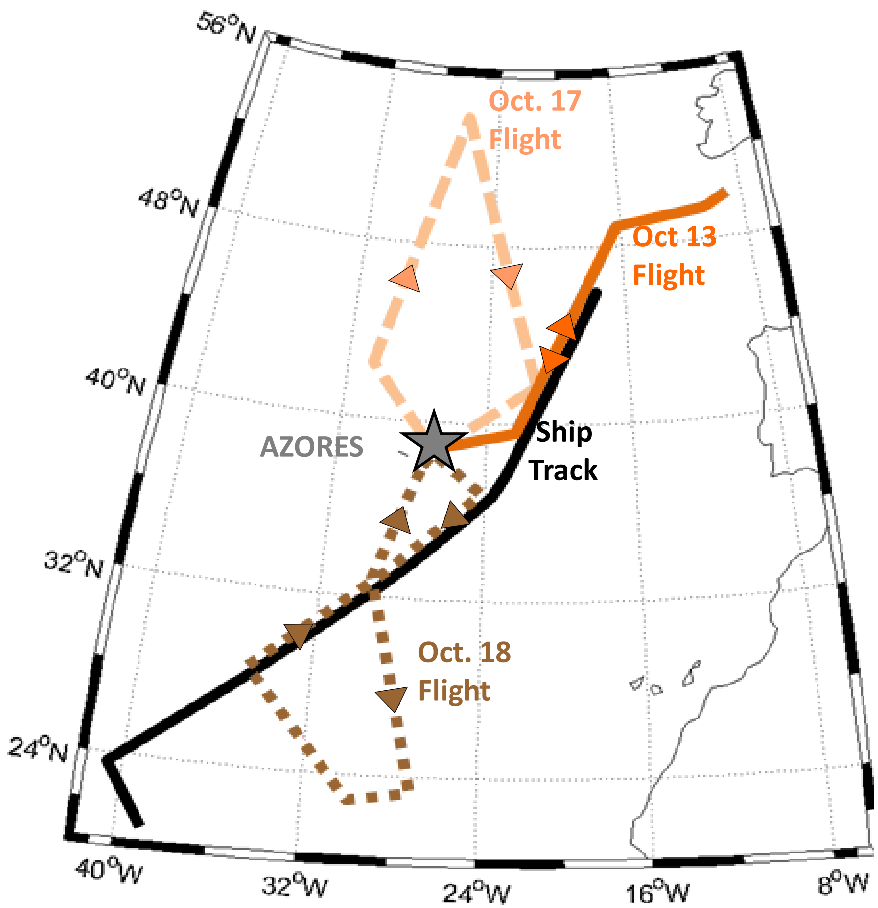
TCC

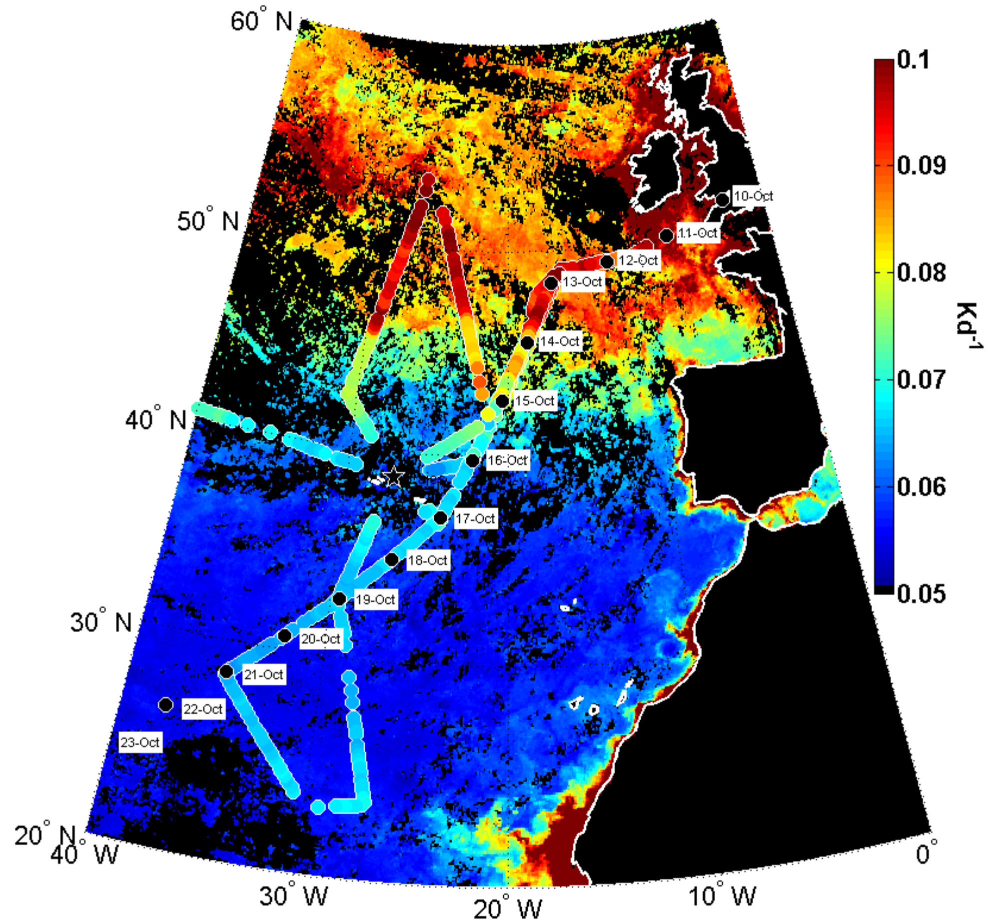
Code 7330/Ocean Sciences
Naval Research Laboratory
Stennis Space Center, MS



Beam c 667 nm

Azores 2012 Deployment, October 2012

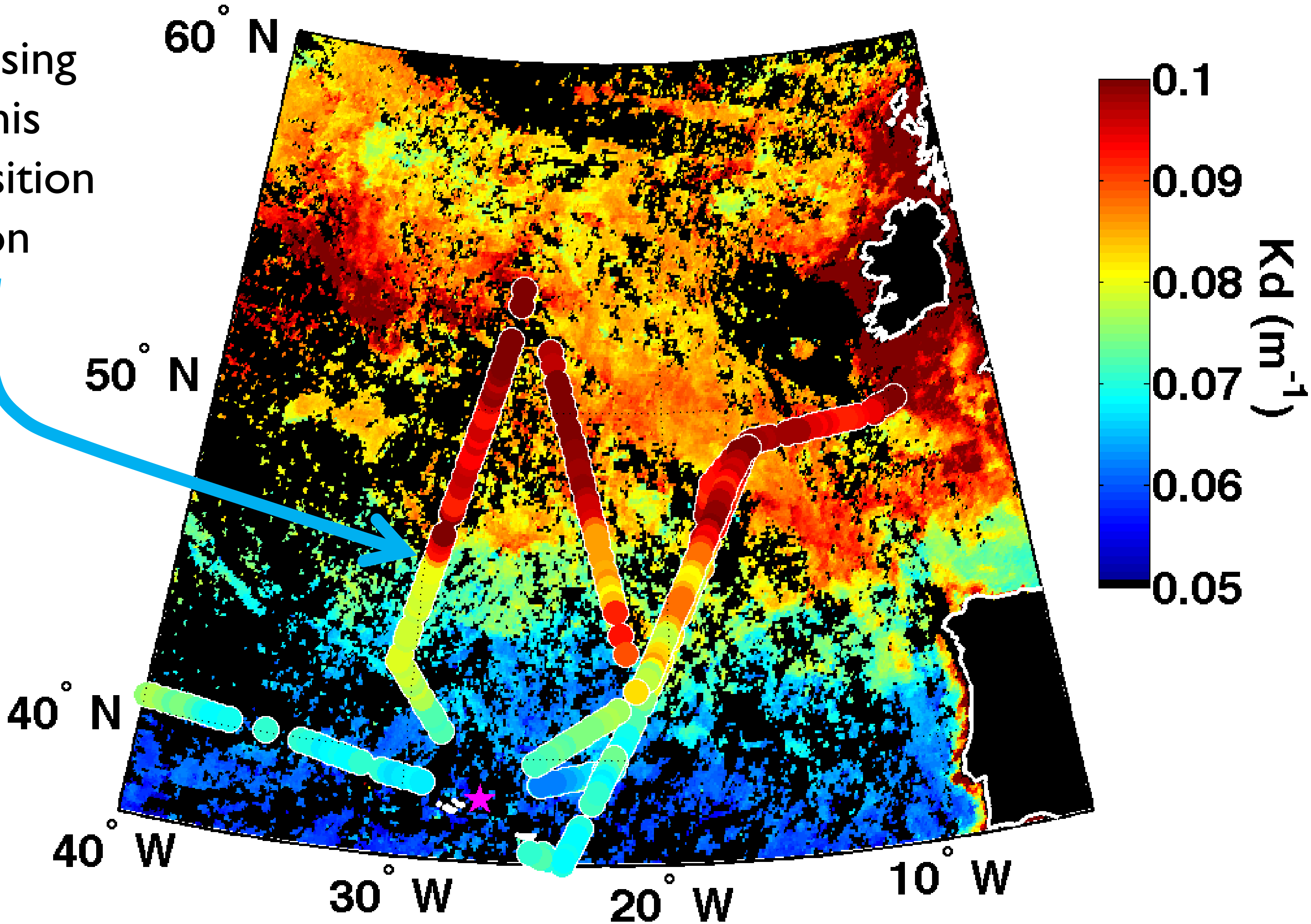




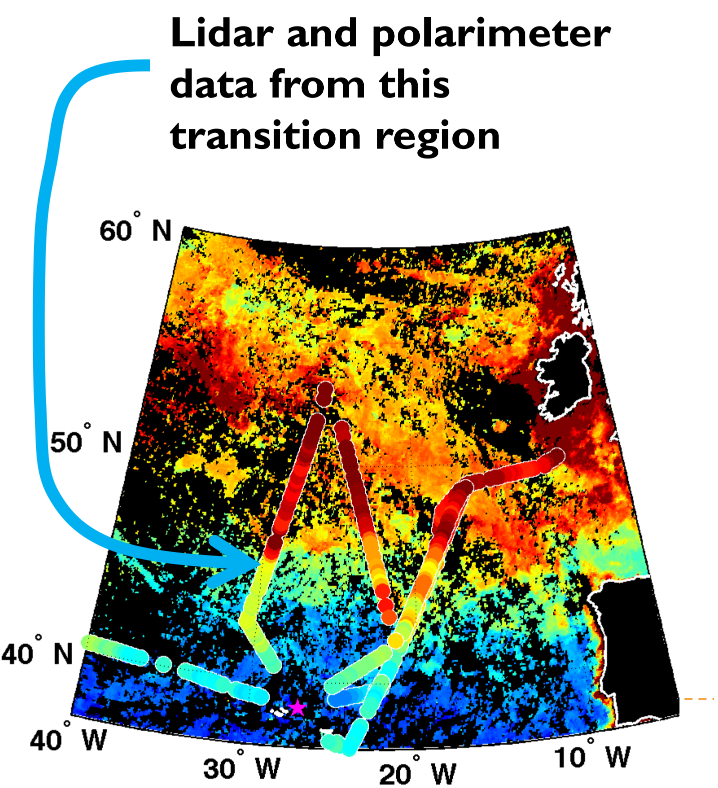
HSRL-1 retrieval of Kd (532 nm) along flight t
Background is MODIS Kd scaled to 532 nm

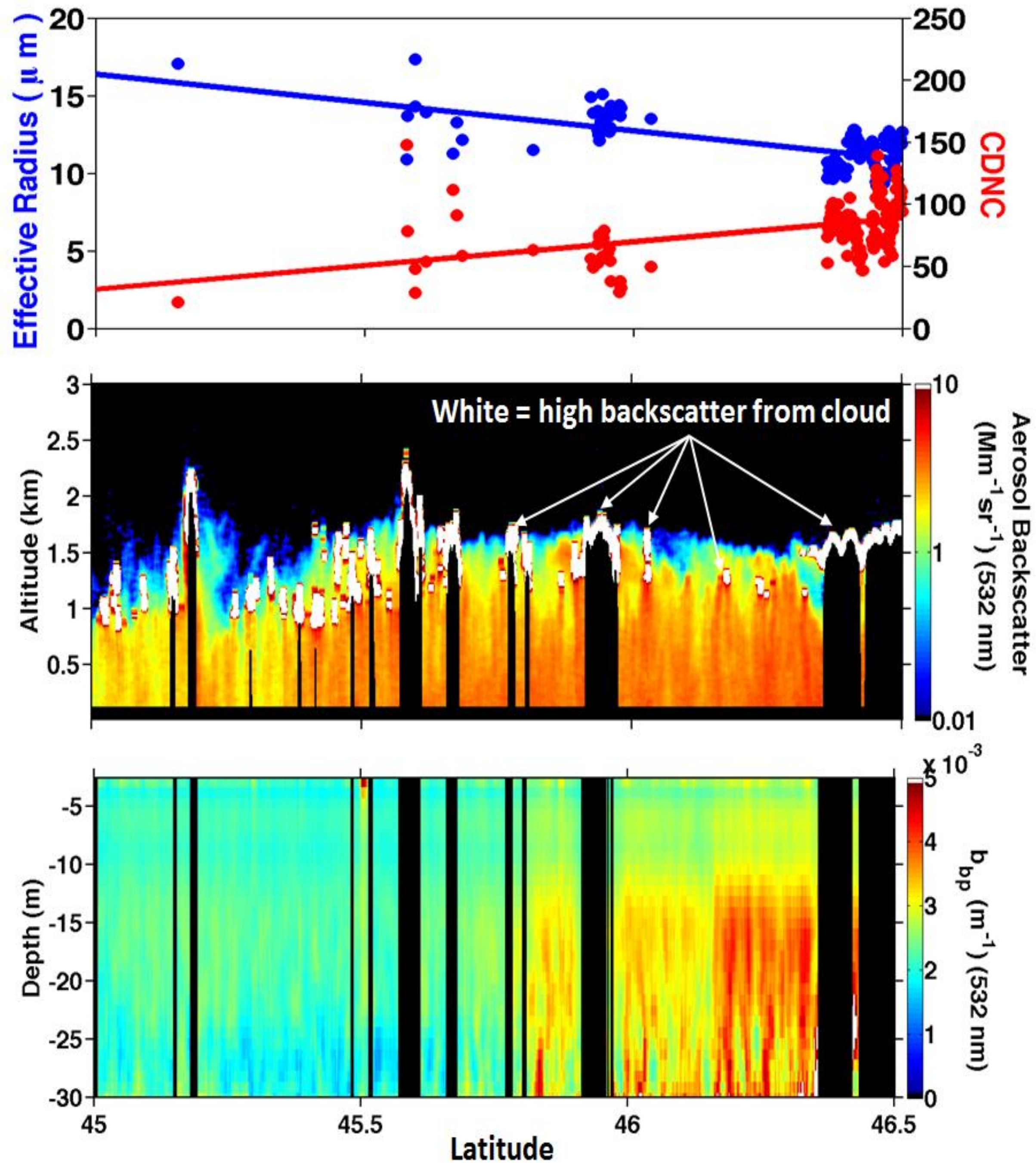
HSRL Kd ~10% larger than MODIS with high correlation

Focusing on this transition region



understanding marine biogenic aerosols and their impact on the radiation budget. Airborne lidar and polarimeter observations provide coincident data on plankton abundance and aerosol and cloud properties.





Retrievals possible in broken cloud conditions