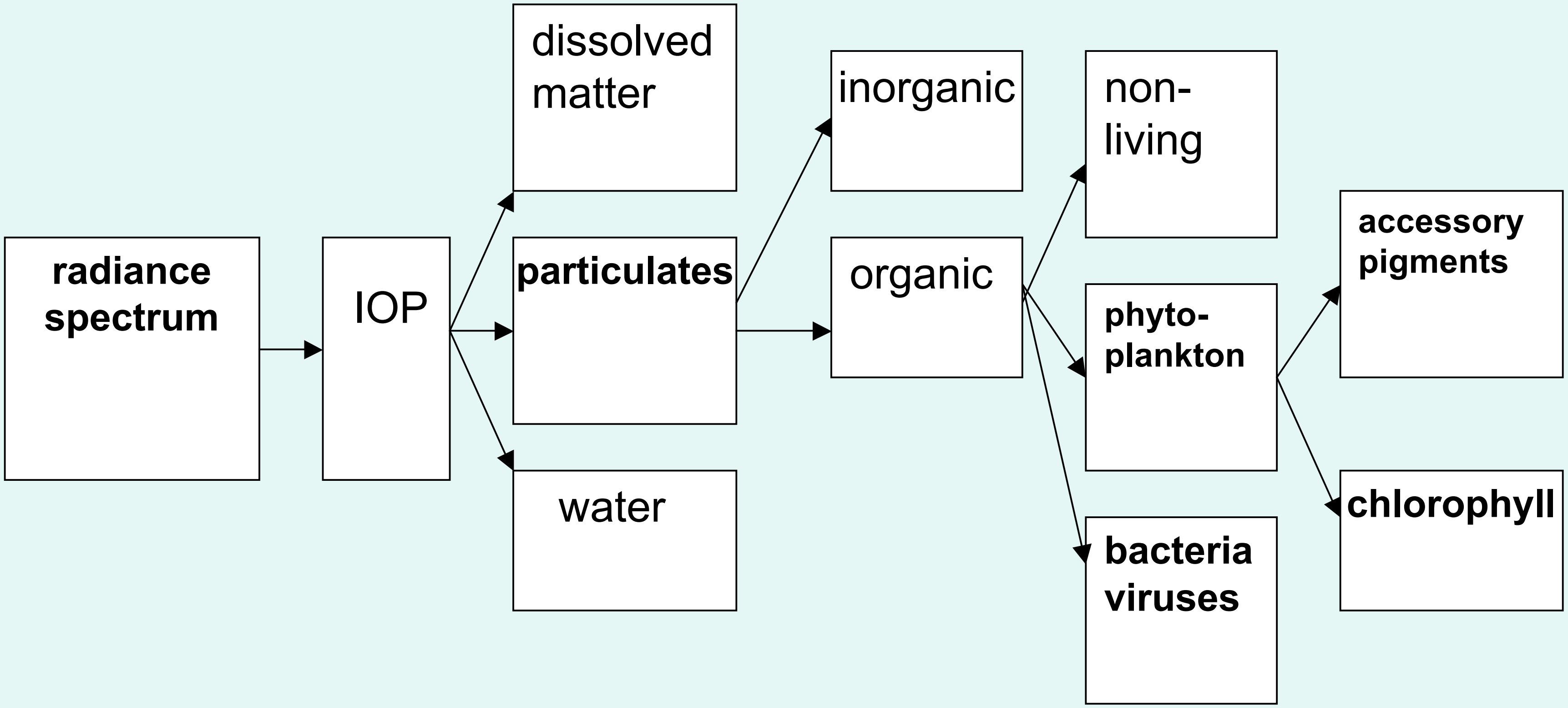
Perspectives on Observational Frontiers

Ron Zaneveld

Thanks to: Emmanuel Boss, Mike Behrenfeld, Mike Twardowski



radiance spectrum

IOP

dissolved matter

particulates

water

inorganic

organic

non-living

phyto-plankton

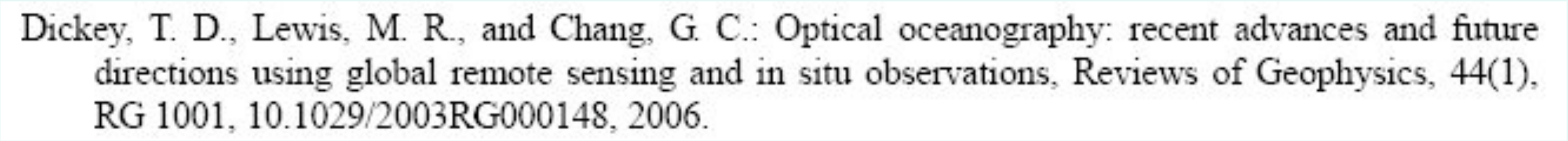
bacteria viruses

accessory pigments

chlorophyll

Carbon, ecosystem and near-shore issues all require the inversion of radiometric data to obtain particulate and dissolved material properties via the IOP (either explicitly or implicitly)

See Lee, Ed. IOCCG report 2006



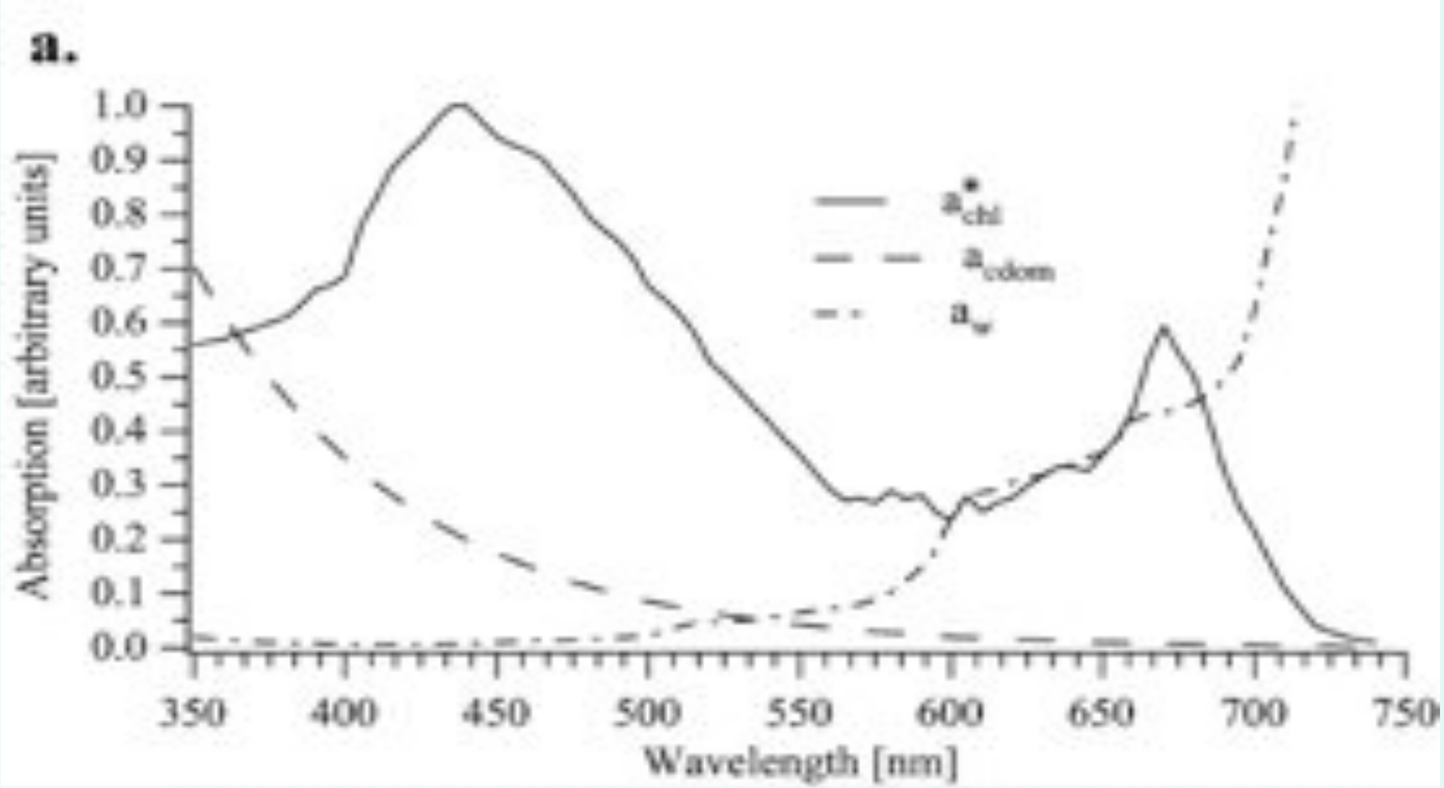
Dickey, T. D., Lewis, M. R., and Chang, G. C.: Optical oceanography: recent advances and future directions using global remote sensing and in situ observations, Reviews of Geophysics, 44(1), RG 1001, 10.1029/2003RG000148, 2006.

PASSIVE REMOTE SENSING

Parameters we can vary :

- **Increase number of bands- hyperspectral**
- **Increase wavelength domain- UV and NIR measurements**
- **Polarization**
- **Increase spatial and temporal resolution: Geostationary sensors**

All these have been proposed for future satellite missions



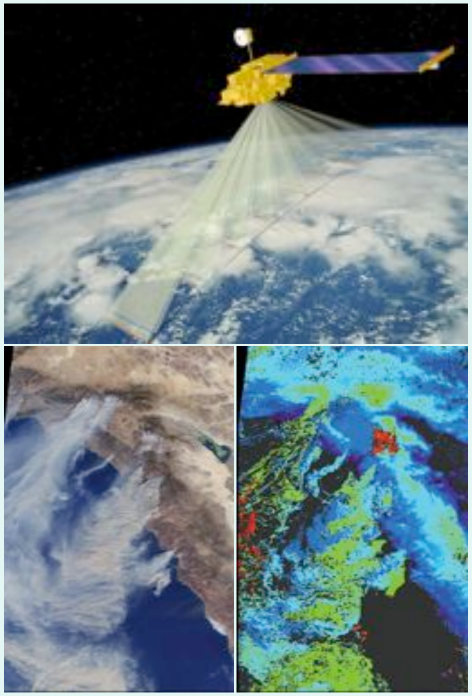
In order to determine particulate properties CDOM must be separated. Measurements in the UV would help a great deal as that is where CDOM predominates. Many pigments absorb in the UV-improved component separation.

Requires extensive in situ work to establish and validate spectra. UV-absorption and backscattering devices need to be developed.

Similarly increased spectral resolution including NIR allows better atmospheric correction, water need not be “black” in the IR.

Increased spectral resolution allows better component separation.

Observational Strategies: Aerosols



MISR (image from David Diner)

Multi-Angle or Scanning Aerosol Spectropolarimeter

(a) Column-average optical, microphysical, & macrophysical aerosol properties

(AOD, particle sizes & shape, SSA, size-resolved real RI…)

(b) Tropospheric ozone to determine short- & long-term changes

(c) Aerosol heights for ocean color correction

(d) NO_2, HCHO, O_3 and SO_2

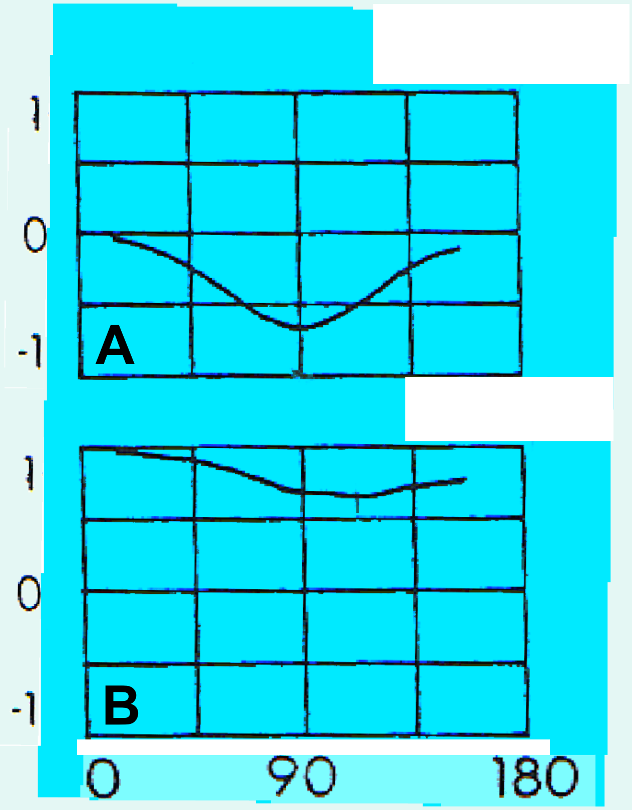
Behrenfeld

Voss and Fry (1984) measured the Mueller matrix for various ocean waters

.

For spheres, S22=S11 and so the normalization should be 1.

The greater the deviation from 1, the more significant the "nonsphericity" of the population.



S12/S11top, S22/S11 bottom

Polarization can provide information on size, shape, and index of refraction of particles. It is a weak signal that can be derived only after correction for the atmosphere

See also Kattawar, Loisel, Chami, Chowdary, and others

LOISEL et al., 2006 used POLDER data to study water–leaving polarization

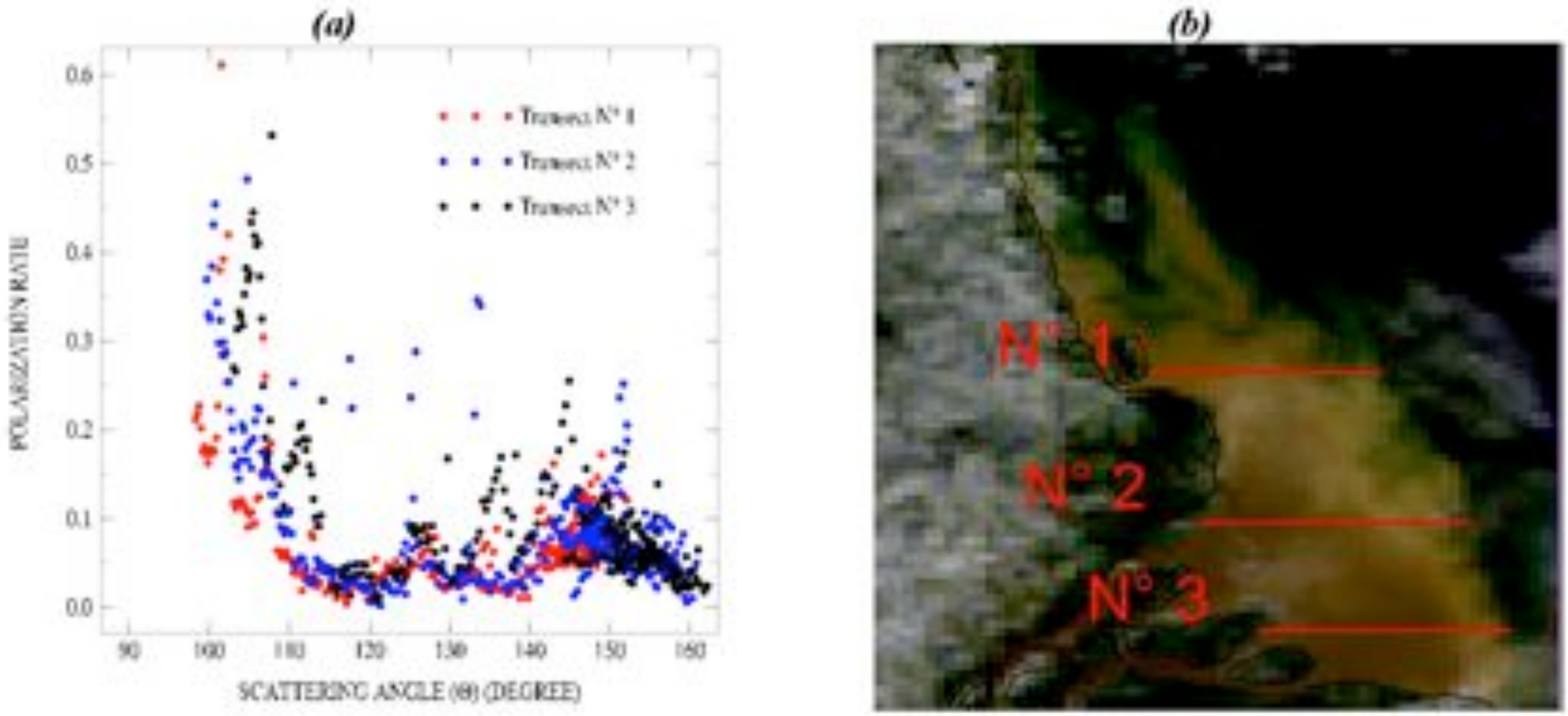


Figure 6: (a) Variations of the degree of polarization, P, as a function of the scattering angle, θ, estimated using POLDER2 data collected over3 different transects (b) of the Amazon plume.

Only near 90° scattering angle is there a strong polarization signal.

Loisel et al., 2006

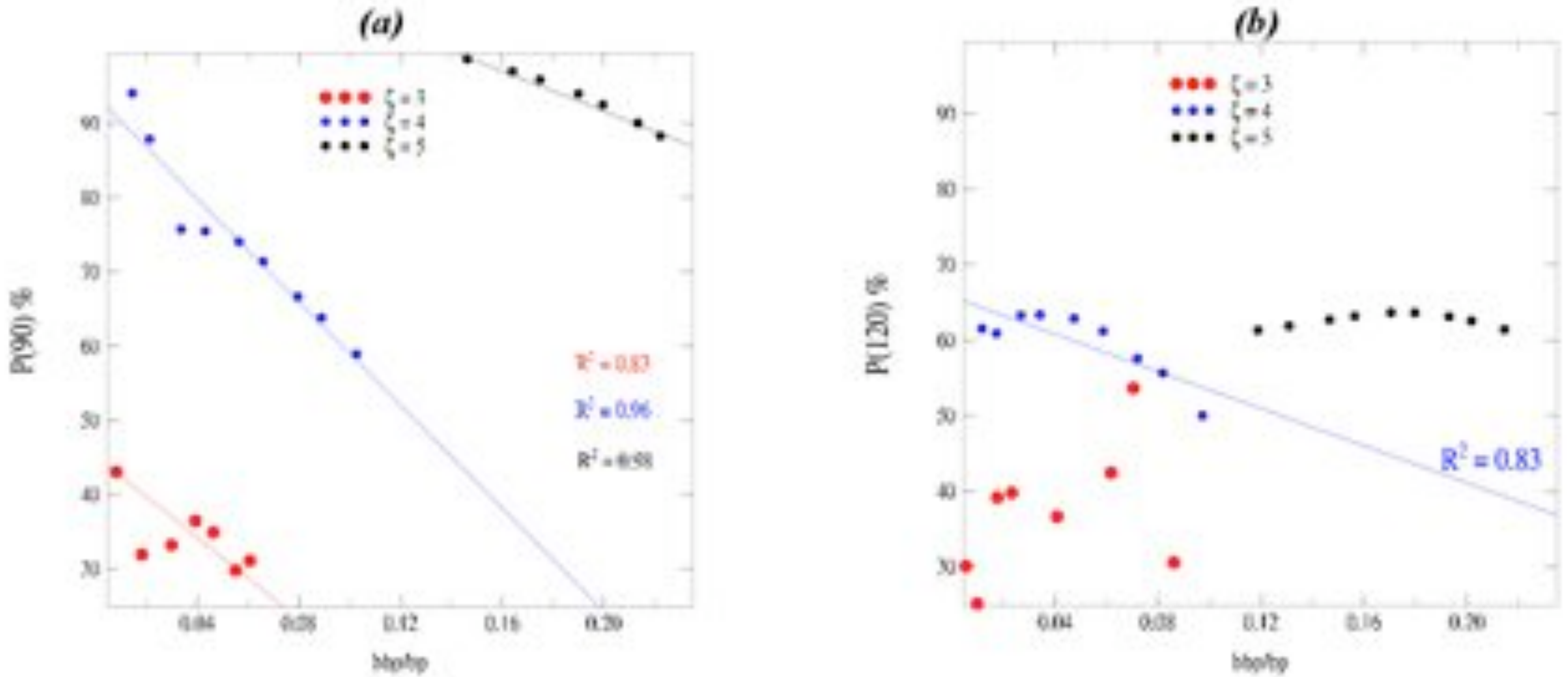


Figure 5: (a) P(90) as a function of b_{bp}/b_p from Mie computations. Each color corresponds to a fixed ξ value as indicated. For a given ξ value, each point corresponds to a given n value. (b) idem as (a) but for P(120).

Near 90° scattering angle, polarization is a strong function of b_b/b and ξ , past 120° it is not.

Polarization measurements can provide additional information on particulate properties

Loisel et al., 2006

ACTIVE REMOTE SENSING

LIDAR

- Coincident with passive
- Different wavelengths
- Scanning, same coverage as passive
- Femto-second pulses

- Improved atmospheric correction
- Water leaving signal proportional to b_b / K_{sys}
- Reduce uncertainty in b_b
- Vertical profiles of b_b / K_{sys}
- Fluorescence

Observational Strategies: Aerosols

GLAS (image from Jim Spinhirne)

Aerosol

(a) Vertical aerosol backscatter & extinction profiles

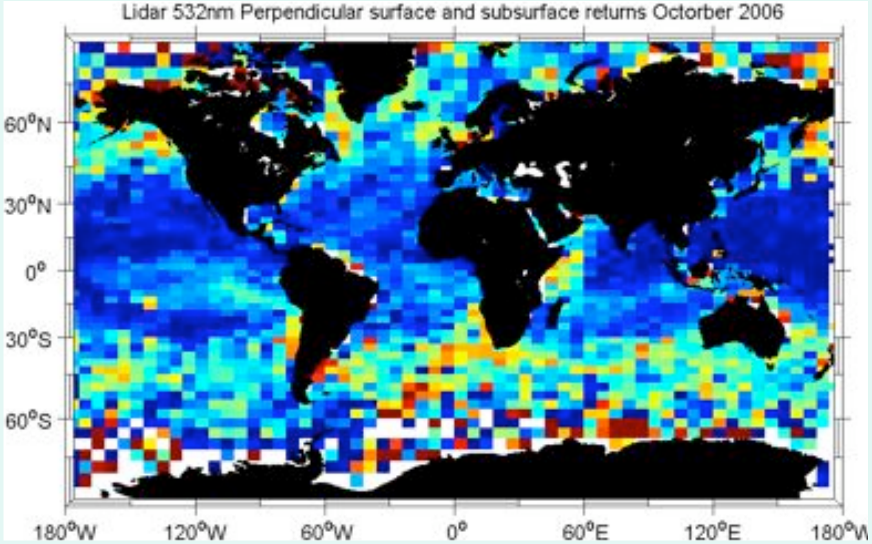
(b) Layer-wise optical, microphysical, & macrophysical properties

(#/surf./vol. concentrations, eff. radius, complex index of refr., SSA)

(c) Aerosol particle shape and cloud liquid/ice phase

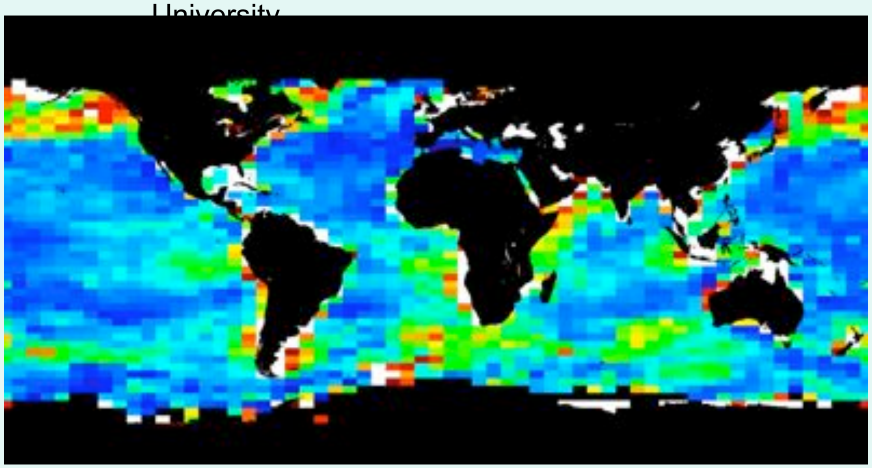
Is there a usable signal emanating from the ocean?

Behrenfeld



CALIOP LIDAR b_b

Backscatter from SEAWIFS By Oregon State University



SeaWIFS b_b

1. The proof-of-concept: first ocean sub-surface study using space-based lidar
2. Value-added: no extra cost to the mission
3. New science: leading to improved understanding of ocean primary productivity with unambiguous separation between particulate backscatter and chlorophyll

There is enough signal from the ocean to get useful information using LIDAR

Hu and Behrenfeld

Decreased attenuation of Femto-second (10^{-14} sec) laser pulses in water

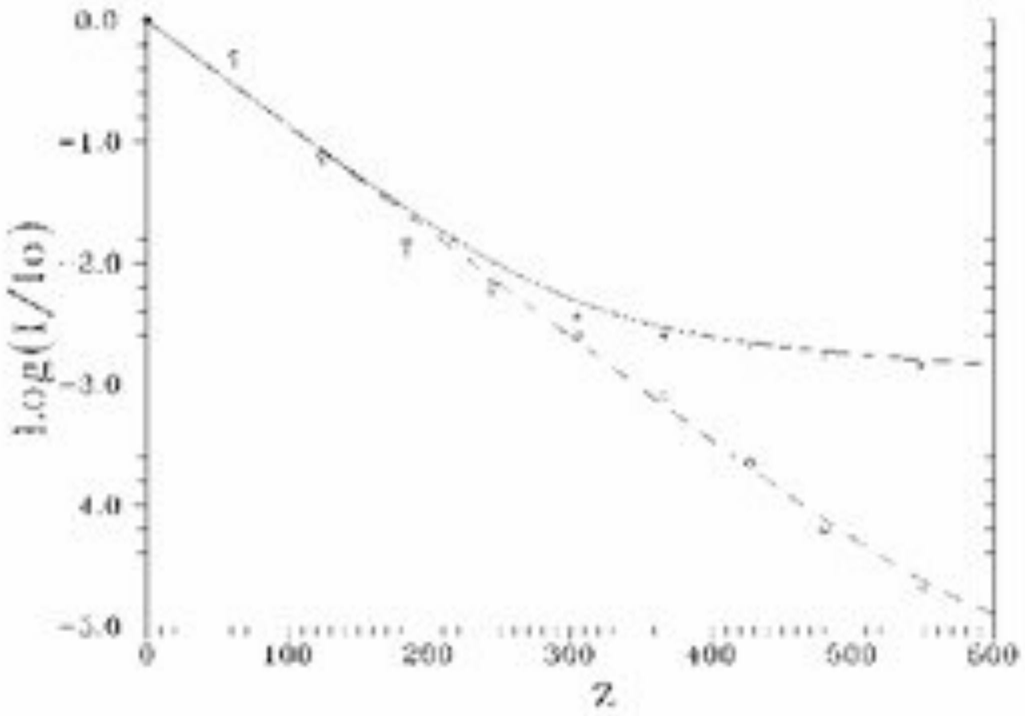


Figure 1 : Plot of the relative intensity decay as a function of distance in centimeters of a 6 x 10^{-14} sec laser pulse (the experimental points are denoted by +; the model fit with δ=15 is given by the solid line). The experimental results of Fox and Osterberg [7] for 90 x 10^{-14} sec laser pulses are denoted by the circles ° and the corresponding model fit is represented by the dashed line. δ is the ratio of the laser pulse width T_L divided by the water response time T_W. Both laser were centered at 800 nm. with a controlled spectral width of 50 nm. The absorption spectrum of pure water in that region is a relatively flat plateau with an average absorption coefficient of 0.02 cm^{-1}. The non-exponential behavior of the decay is clearly visible for the 6 x 10^{-14} sec laser pulse. The light in fact decays asymptotically as 1/z both experimentally and theoretically.

The effect of femto-second pulses on aerolsols and hydrosols is not known.

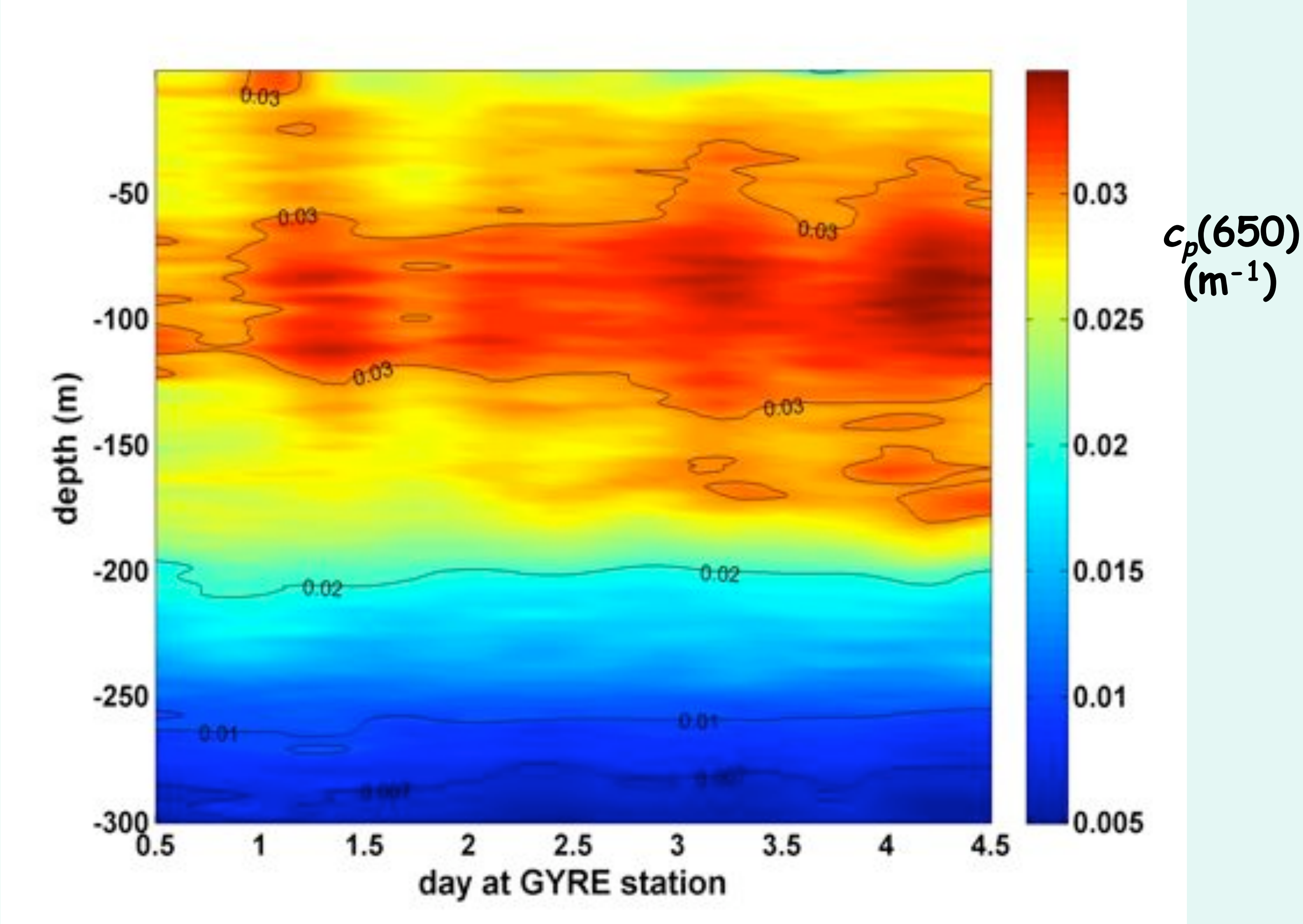
Fournier, 2006

Measurements in the UV, polarization, increased spatial and temporal resolution and LIDAR can all help to increase understanding of particulate and dissolved property distributions.

Further studies of these parameters is encouraged. Associated AOP and IOP instruments need to be developed.

Exclusively space –based algorithms can only contain vertical structure statistically, i.e. we can't measure or deduce everything from space.

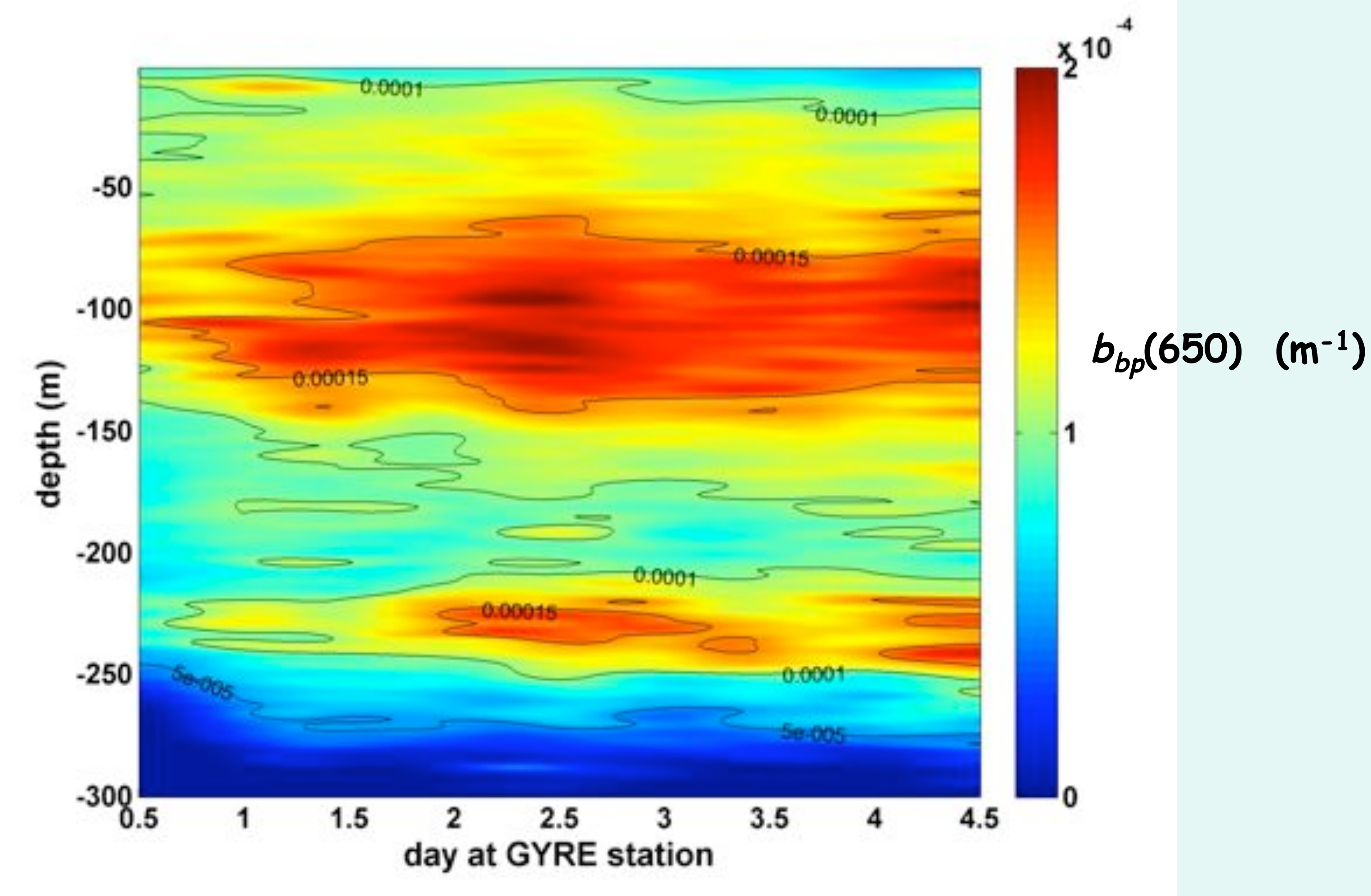
In the next 5- 7 years we face the following problem: How do we decrease uncertainty of global biogeochemical parameters if rather than increasing the number and resolution of measured parameters, they are decreased (VIIRS)?



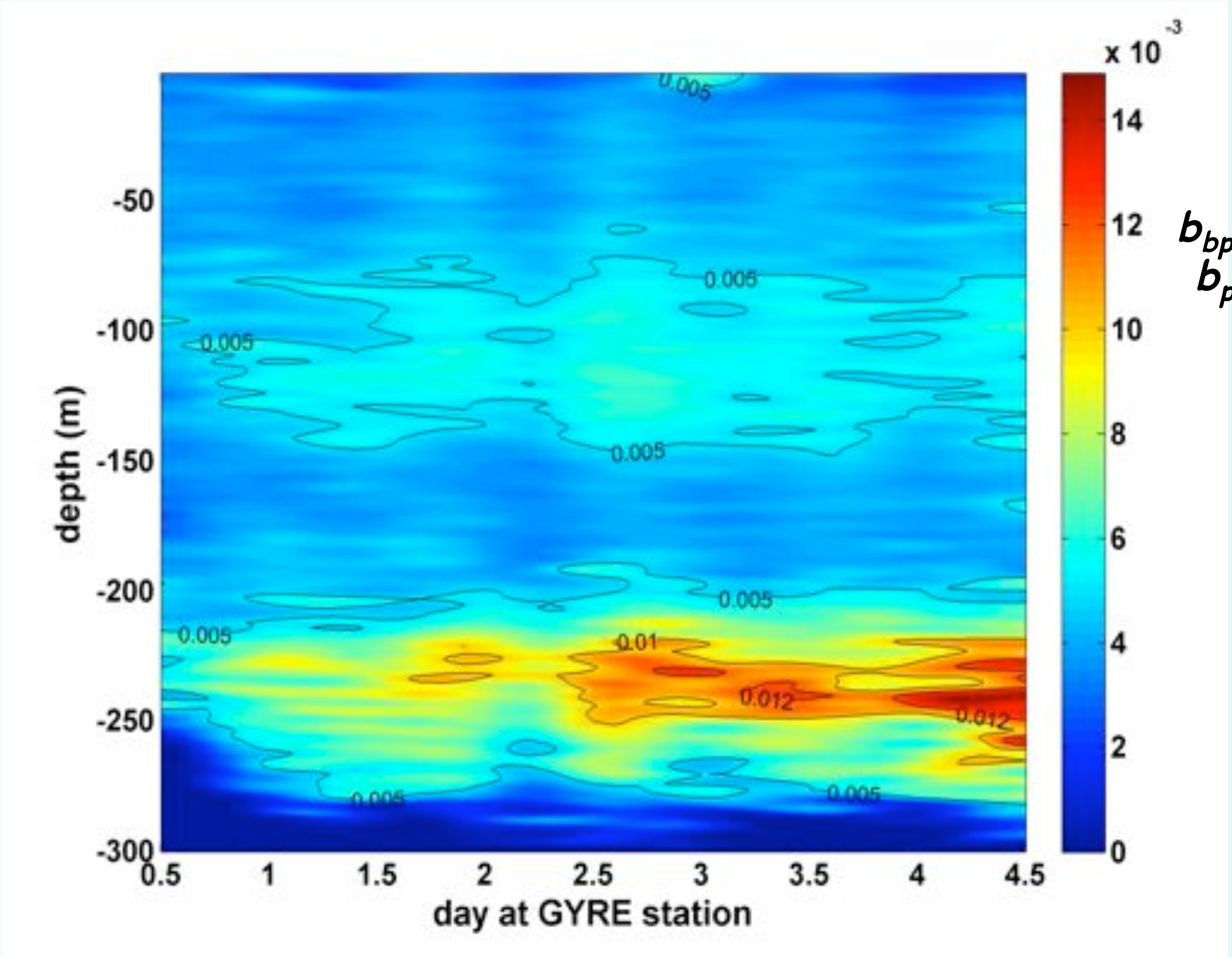
Central Eastern Pacific

Twardowski, Claustre, and Freeman

Vertical distribution of different particle types cannot be seen by remote sensing



Twardowski, Claustre, and Freeman



$b_{bp}(650)/$
$b_p(650)$

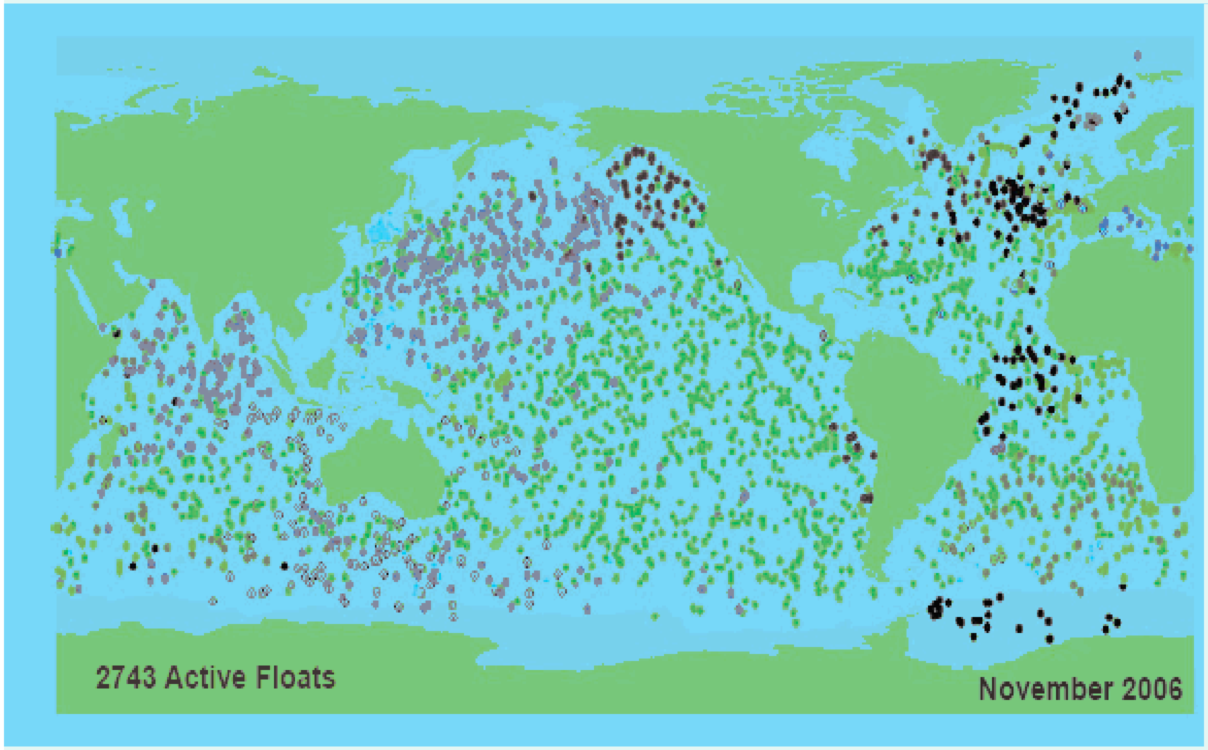
Twardowski, Claustre, and Freeman

…. data acquisition in the ocean is sufficiently difficult and costly so as to make field estimates by direct measurements, …. essentially prohibitive. However, data acquisition for field and parameter estimates via data assimilation is feasible, even though substantial resources must still be applied to obtain enough observations.

Robinson,2000

Meteorologists and dynamicists routinely measure, model, and forecast complex systems

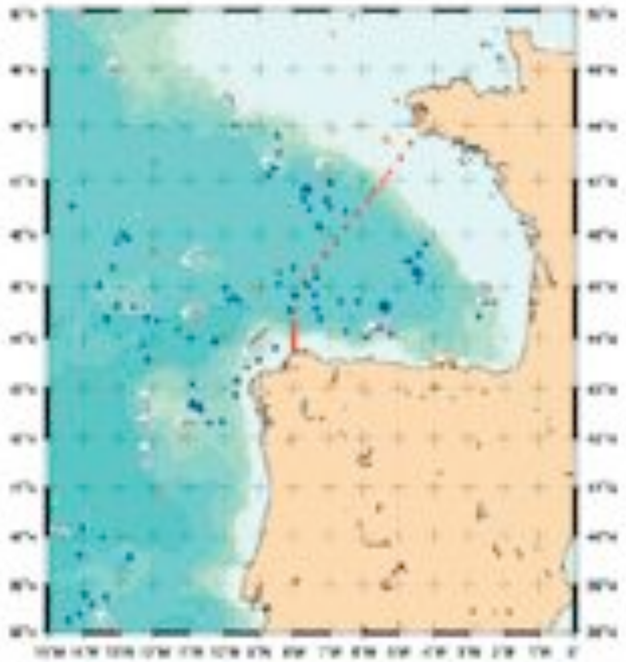
Active ARGO floats as of November 2006.



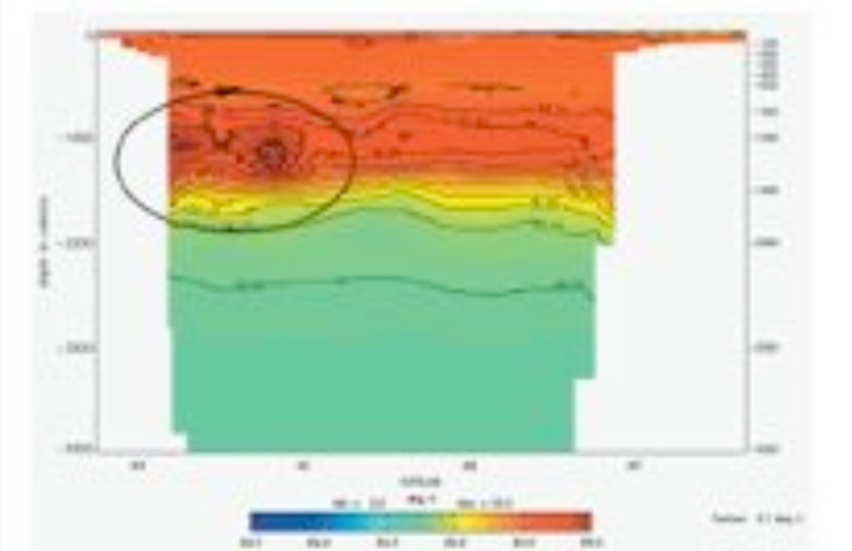
Argonautics #8, December 2006.

ARGO fleet takes approx.103,000 profiles per year.
WOCE (1990-1996) gathered 20,000 CTD stations.
Target is 200 profiles/float over 5 years

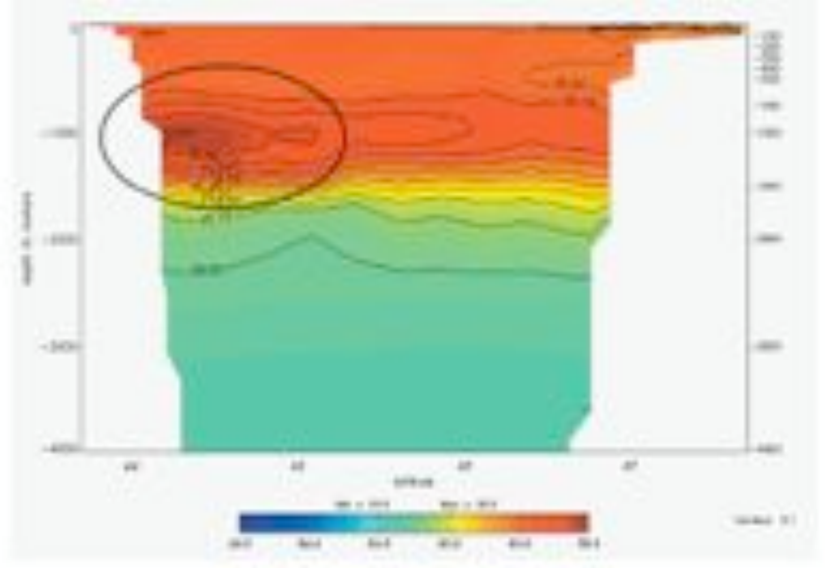
Figure 1 : Positions of the Argo floats (blue dots) and also of CTD measurements



(red dots) and XBT measurements (orange dots) obtained by the Thalassa research ship on a cruise funded by the Spanish Institute of Oceanography (IEO). These measurements are assimilated into the PSY2v2 prototype.

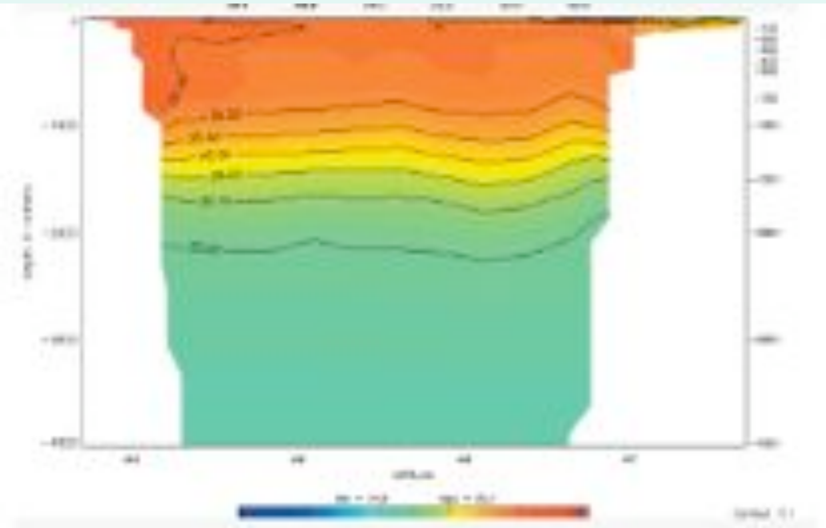


Measured salinity section



Modeled salinity section with assimilated in situ data,

Note Mediterranean water.



Modeled salinity section without assimilated in situ data

Lellouche et al., Argonautics #7

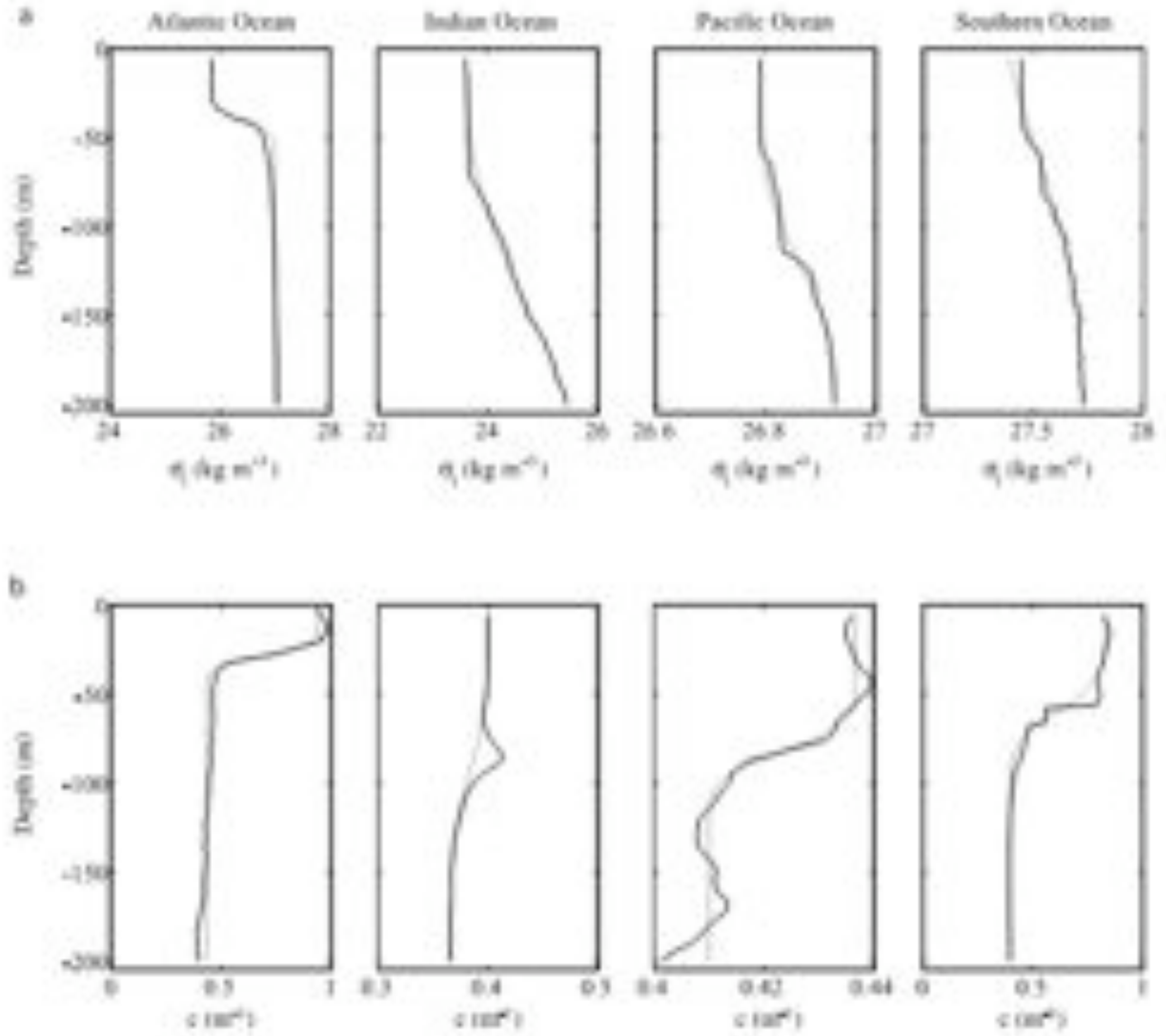


Figure 5. Comparison of idealized and observed profiles. Sample profiles corresponding to (a) density and (b) beam attenuation are depicted for each major ocean basin. Black lines are the WOCE data, and gray lines represent the optimal fit of the idealized profiles.

Zawada et al., 2005

FINDING TRENDS IN HIGHLY VARIABLE GLOBAL PARAMETERS IS DIFFICULT BECAUSE WE ONLY KNOW THE BIOLOGICAL VERTICAL STRUCTURE STATISTICALLY AND/OR THEY CAN ONLY BE DERIVED APPROXIMATELY FROM DYNAMICS AND SURFACE VALUES

SIMULTANEOUS *in situ* OBSERVATIONS OF VERTICAL STRUCTURE WOULD ALLOW VIA DATA ASSIMILATION:

- **Improved vertically integrated models as vertical bio-optical structure can be assimilated**
- **Improved IOP inversions**
- **Improved atmospheric corrections**

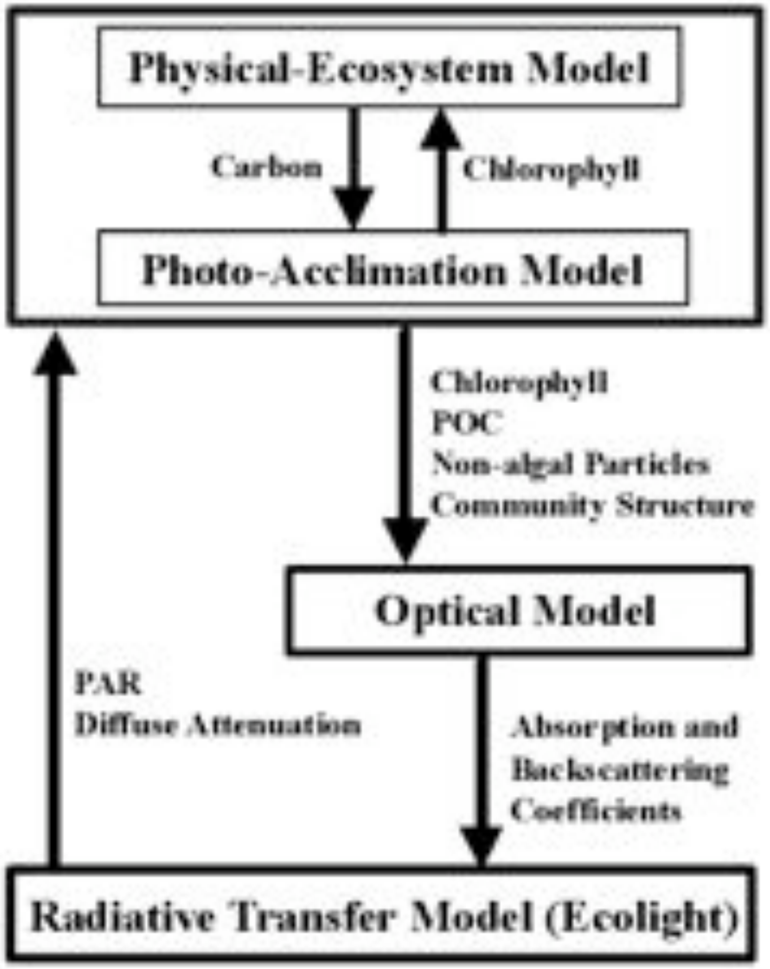
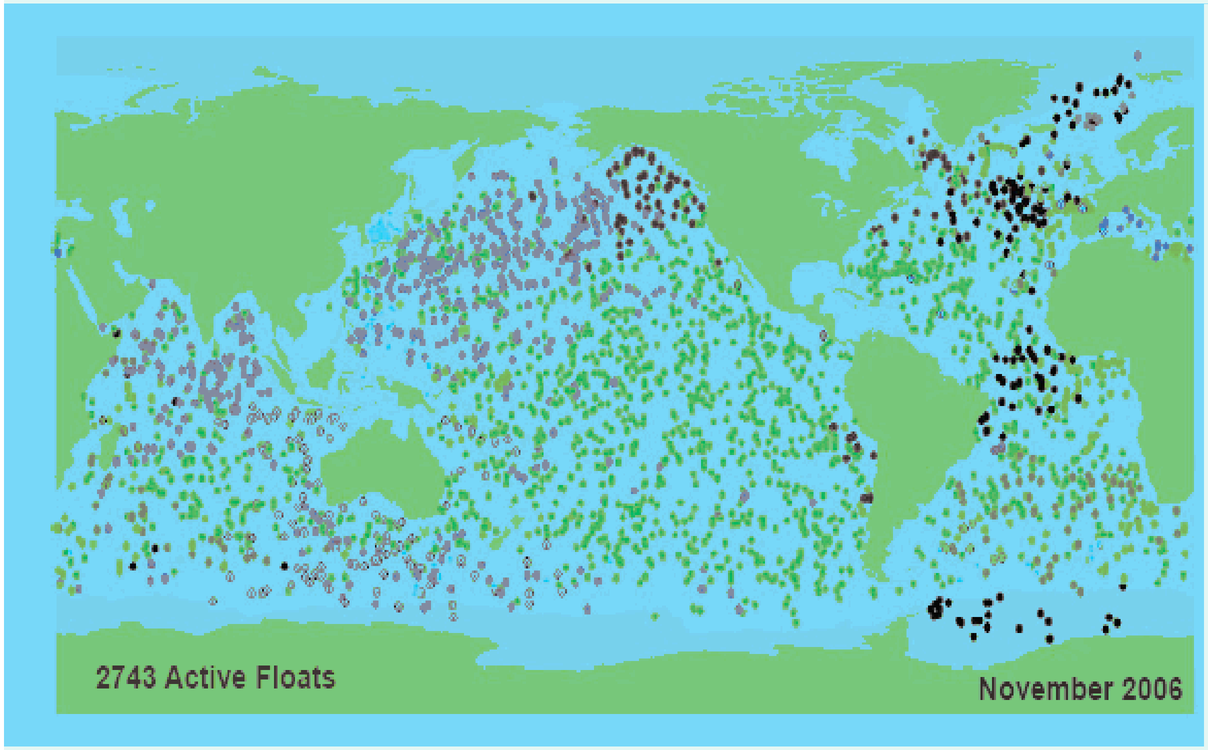


Fig. 1 (Fujii et al.)

Model that allows bio-optical parameters to be assimilated

See also Arnone, Siegel, McGillicuddy, Friedrichs (ECoS) and others

Active ARGO floats as of November 2006.



Argonautics #8, December 2006.

ARGO fleet takes approx.103,000 profiles per year. These could, at the minimum, include b_b and chl. fluorescence with off-the-shelf technology.

Cost/profile could approximate that of CTDs.

Existing profiling float instrumentation

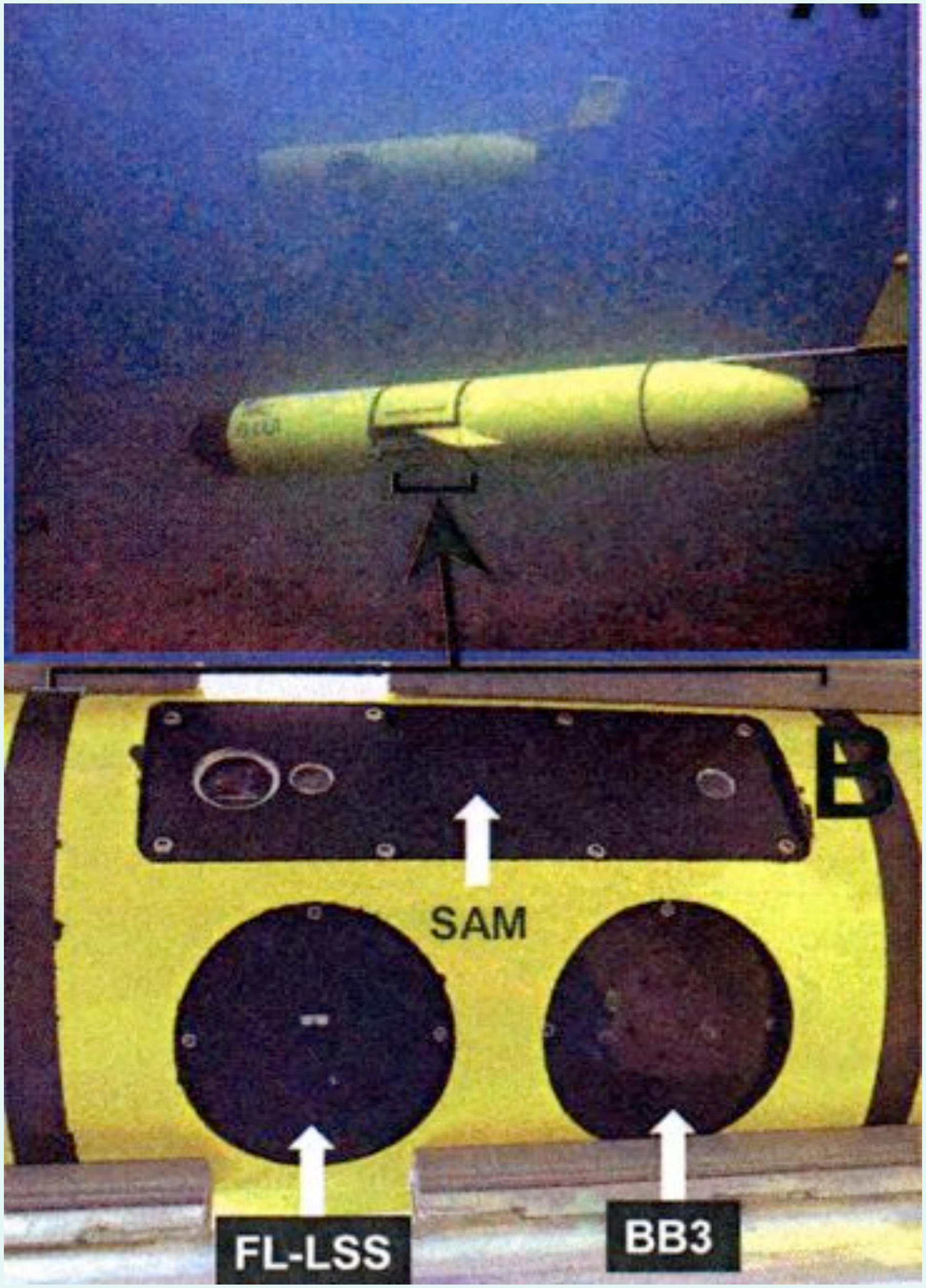
Downwelling irradiance (3 wavelengths),

Beam attenuation

Backscattering

Chl. Fluorescence

WET Labs, Satlantic

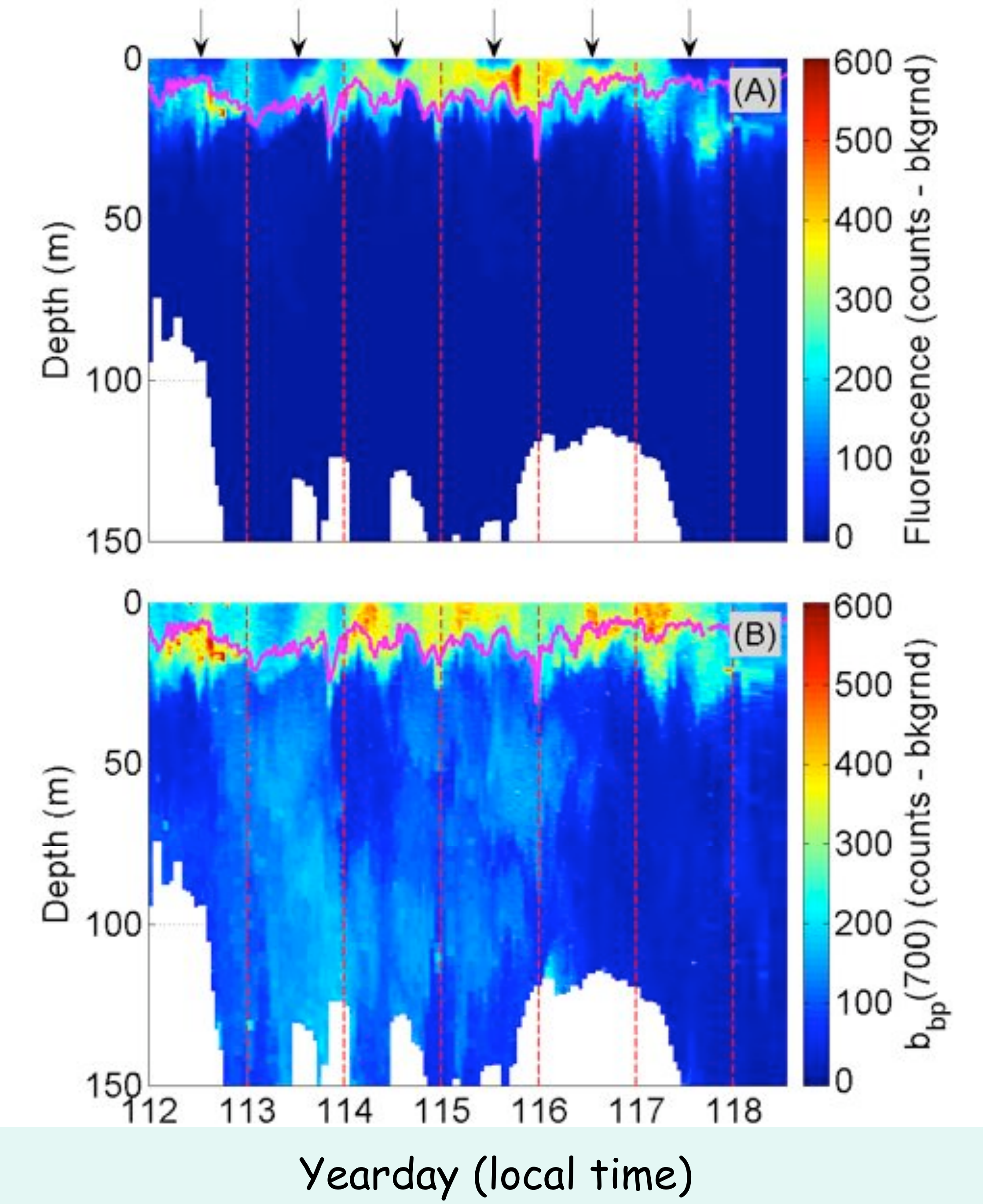


Slocum glider with beam attenuation, backscattering and chl fluorescence meters

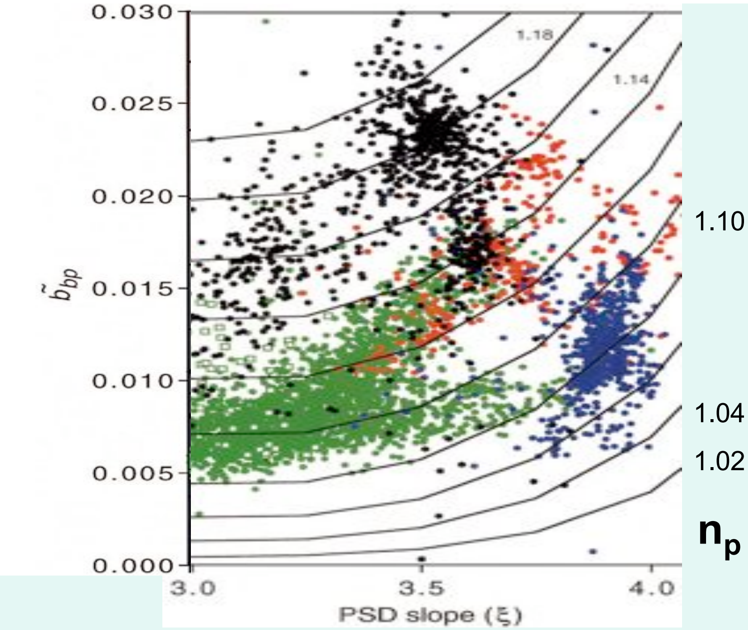
Fluorescence may suggest trophic dynamics associated with visual predators.

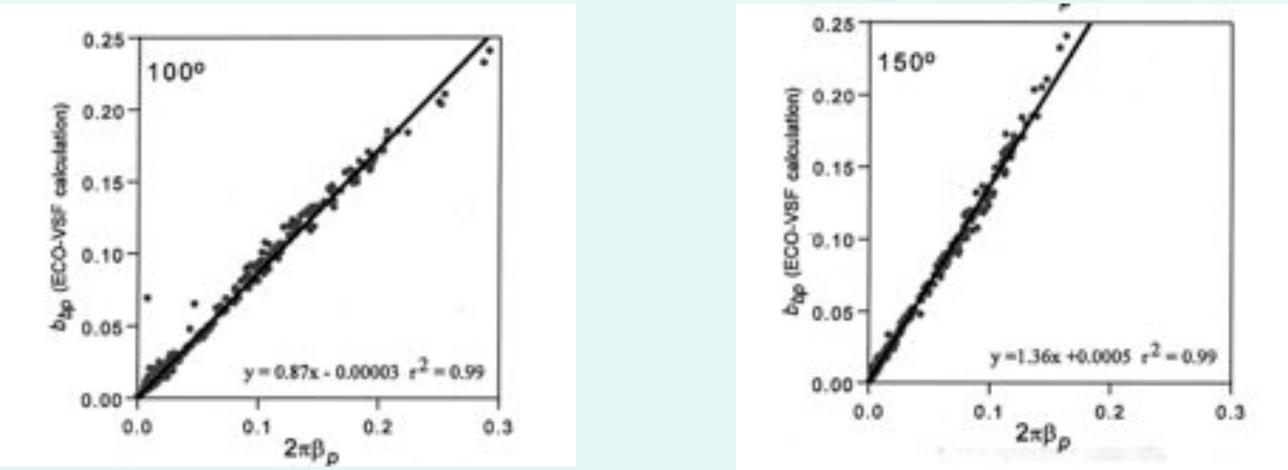
Scattering pattern is insensitive to light.

Sackman, 2006,
Data from C. Eriksen's glider



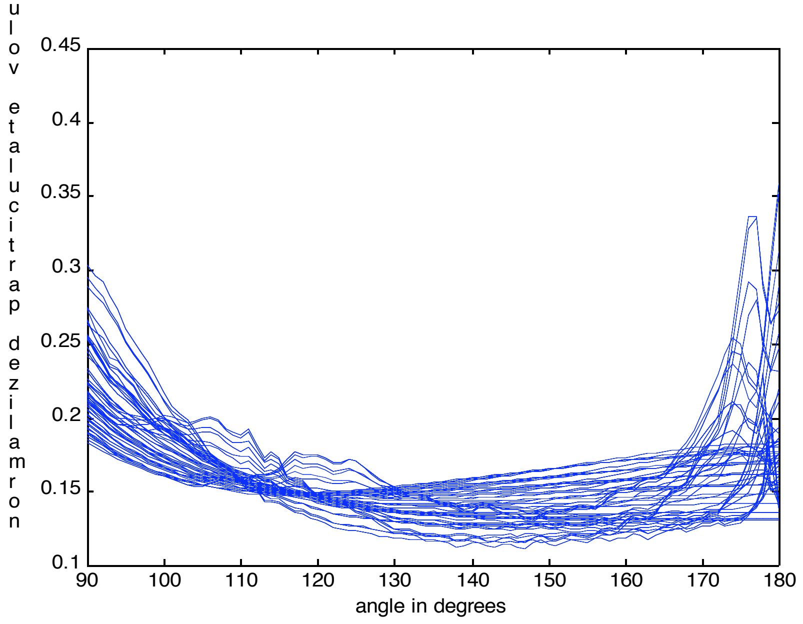
What are the effects of particle size distribution and index of refraction on the measurement of b_b?

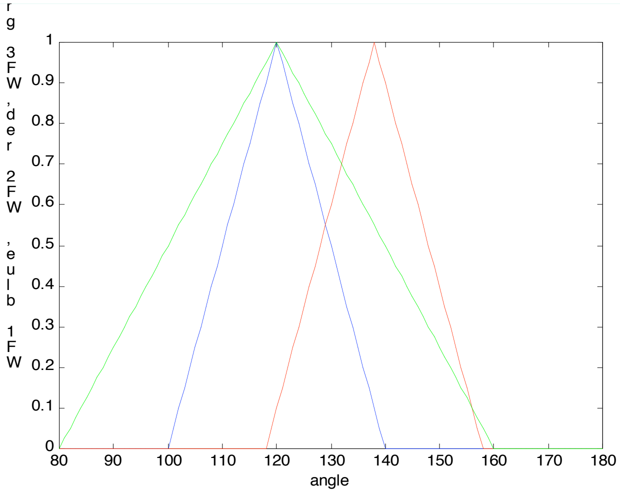


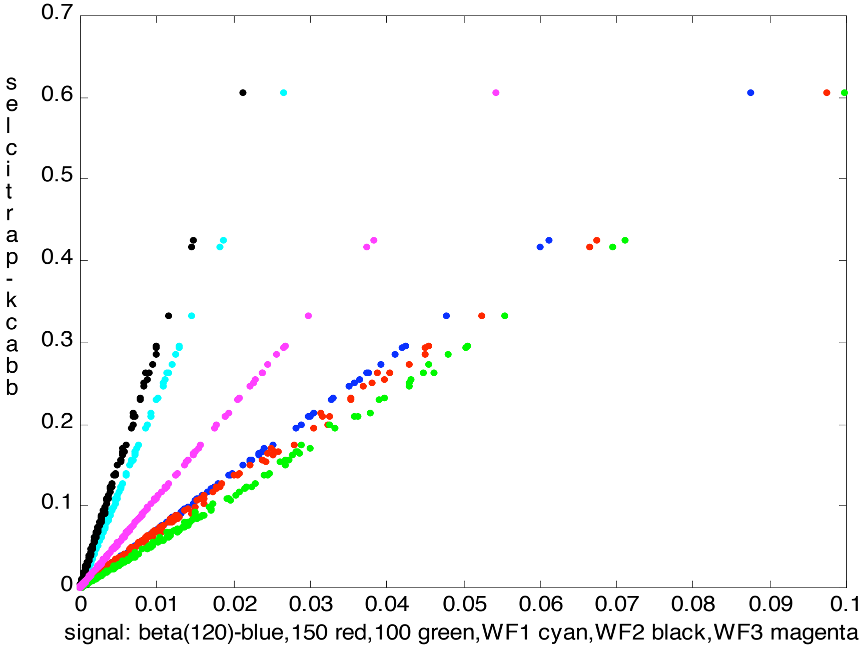


The particulate backscattering as a function of scattering at an angle for some of the data points in the top figure.

(from Sullivan et al., 2005).







Using random PSD slope, index of refraction and b, the calculated relationship between b_{bp} and the VSF at several angles and simulated instruments is nearly linear.

The particle concentration overwhelms the influence of particle nature.

The backscattering coefficient is not difficult to measure for oceanic particle assemblages

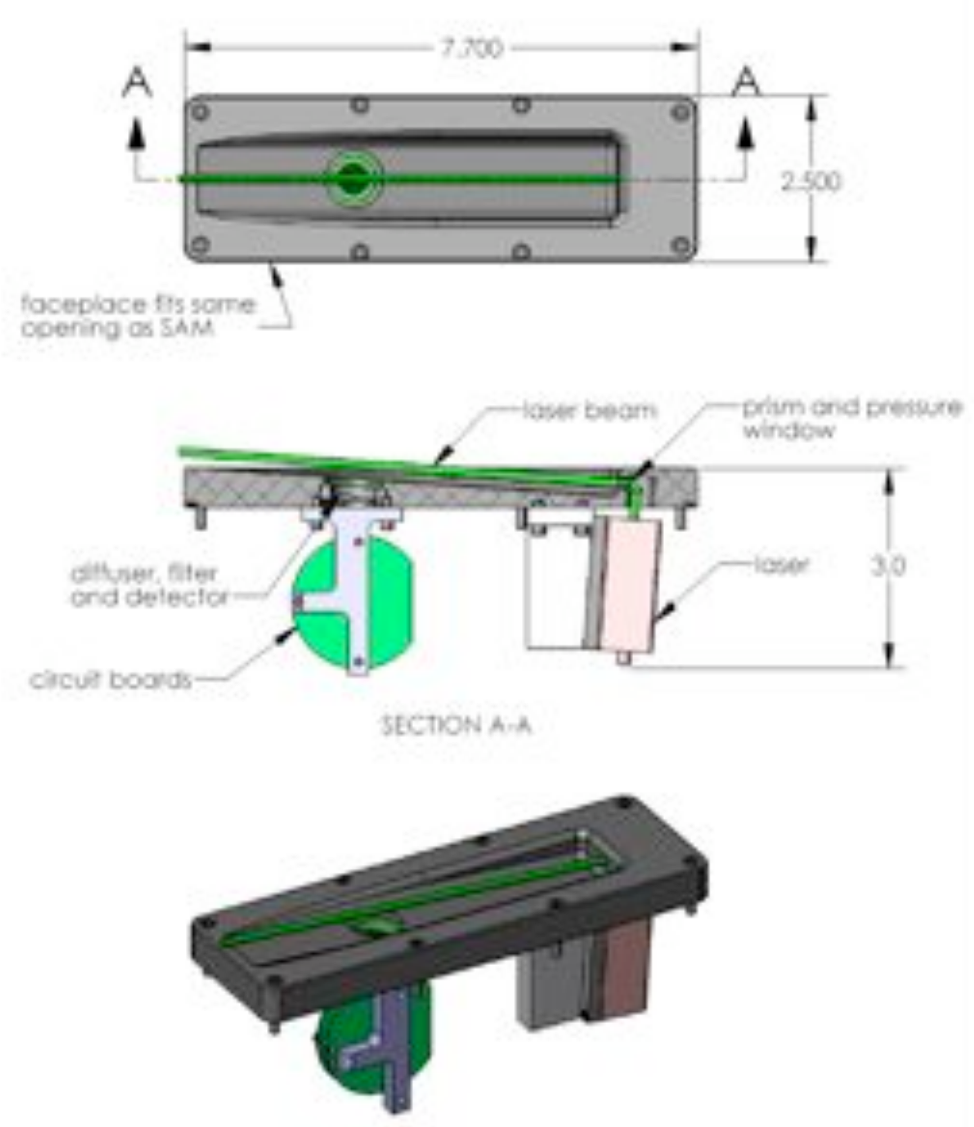
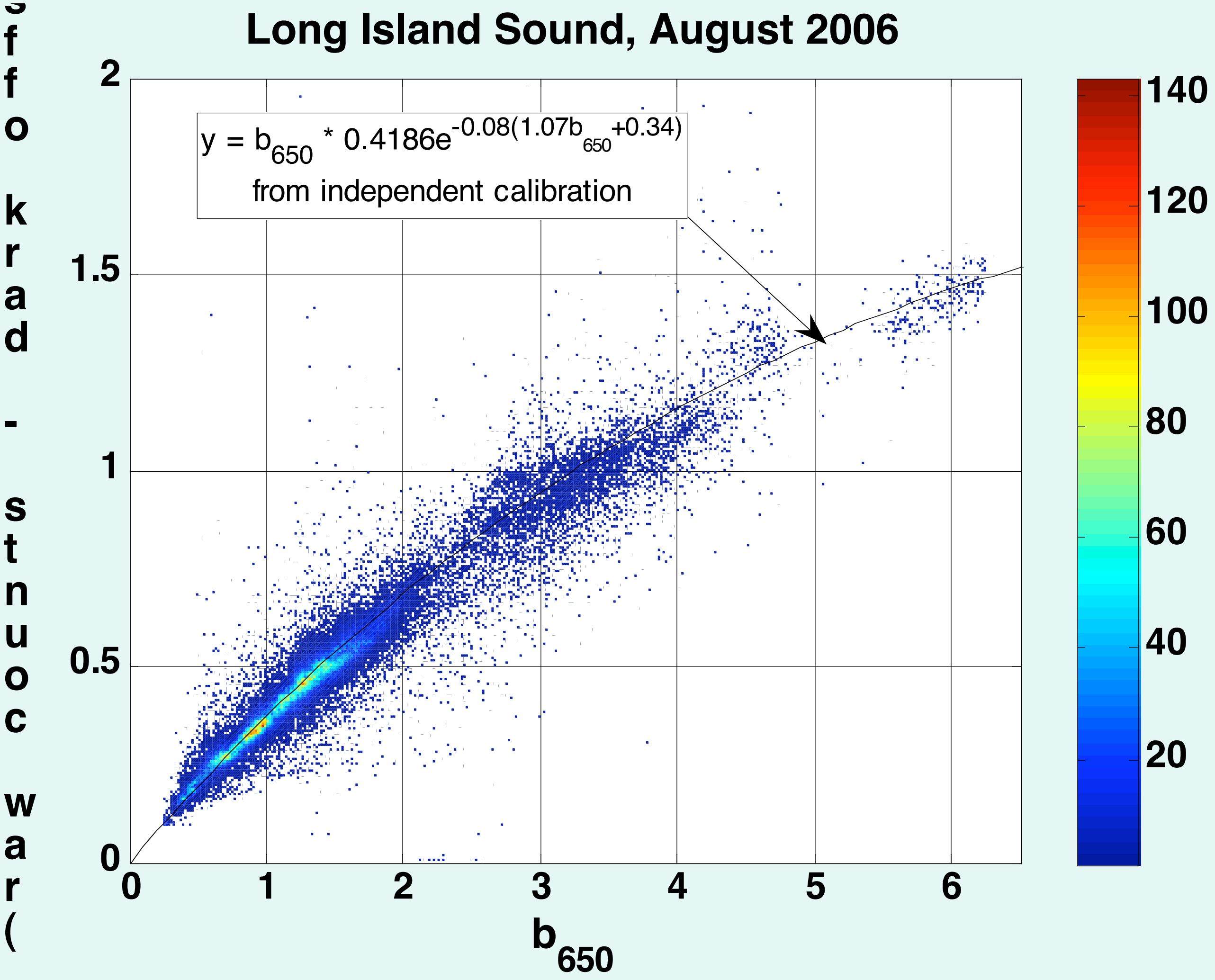


Figure 1. **Concept illustration for the AUV-b total scattering meter. Based on an inverse Beutell and Brewer (1949) arrangement.**

WET Labs



AUV-b meter raw counts versus ac-9 b at 650 nm

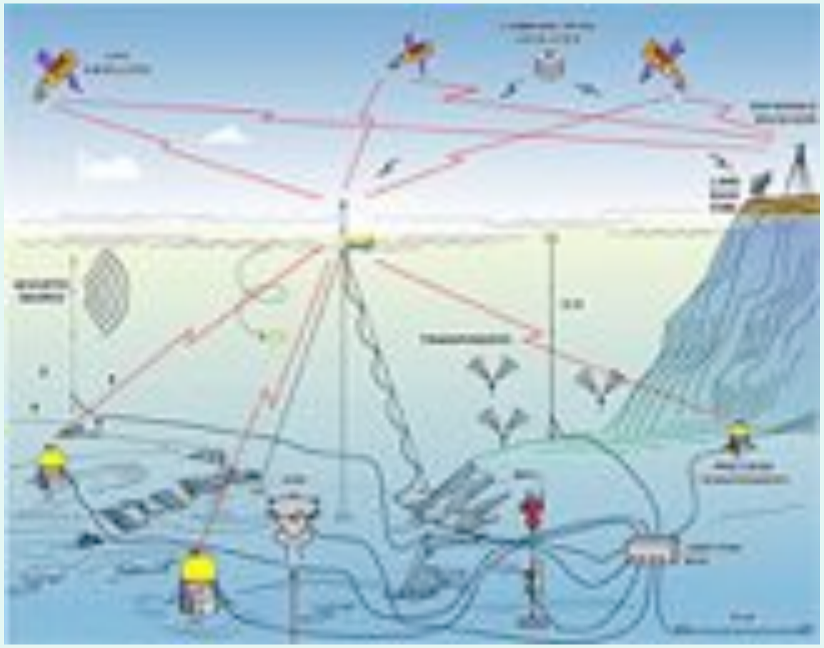
Twardowski, Zaneveld, Moore, and Freeman

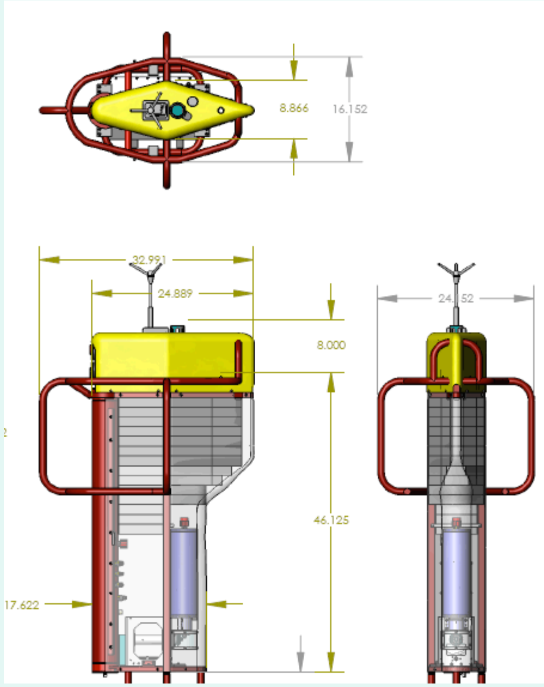
When a significant number of in situ and remotely sensed data (paying proper attention to their uncertainties) are assimilated into a combined biological-dynamical-radiative transfer model , we can obtain vastly improved global parameters and can improve prediction parameter evolution in time and space.

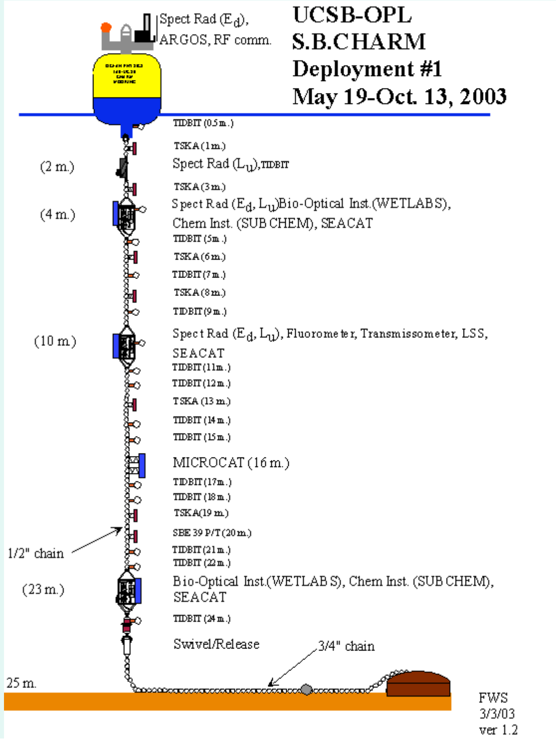
The more we know about the ocean the more useful remotely sensed parameters become.

Ease of measurement, calibration, and miniaturization of IOP instruments are important.

The combination of ADV and optics allows (turbulent) particle fluxes to be measured directly

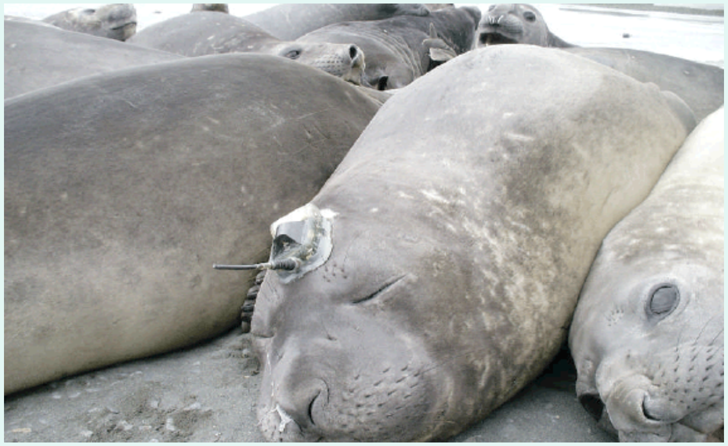


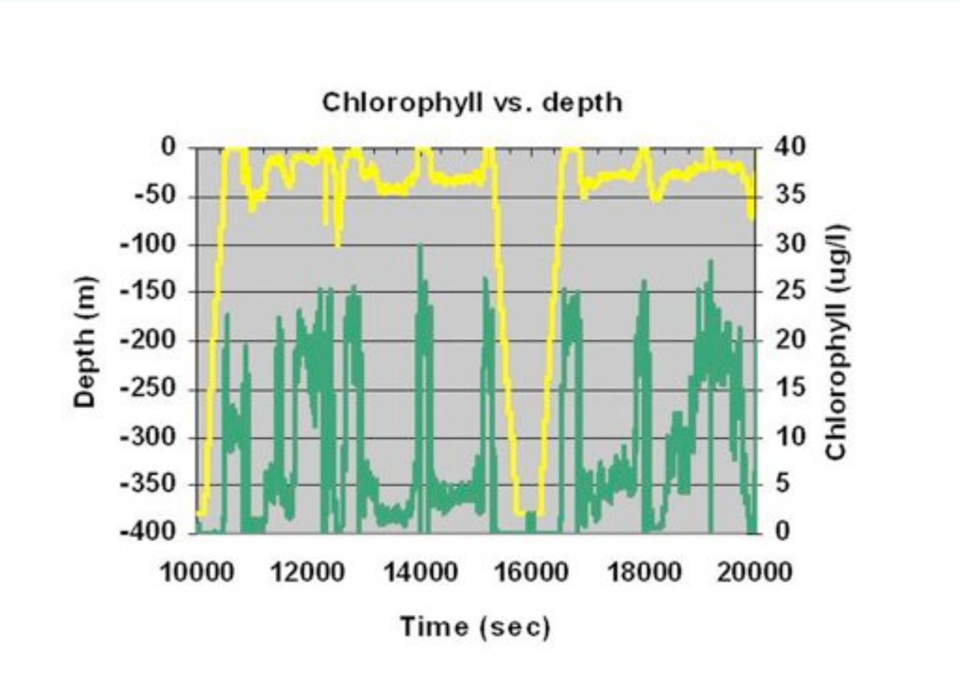

8.866
16.152
32.991
24.889
8.000
46.125
17.622
24. 52


Spect Rad (E_d),
ARGOS, RF comm.
UCSB-OPL
S.B.CHARM
Deployment #1
May 19-Oct. 13, 2003
TIDBIT (0.5 m.)
TSKA (1 m.)
(2 m.)
Spect Rad (L_u), TIDBIT
TSKA (3 m.)
(4 m.)
Spect Rad (E_d, L_u)Bio-Optical Inst.(WETLABS),
Chem Inst. (SUB CHEM), SEACAT
TIDBIT (5m.)
TSKA (6 m.)
TIDBIT (7 m.)
TSKA (8 m.)
TIDBIT (9 m.)
(10 m.)
Spect Rad (E_d, L_u), Fluorometer, Transmissometer, LSS,
SEACAT
TIDBIT (11m.)
TIDBIT (12 m.)
TSKA (13 m.)
TIDBIT (14 m.)
TIDBIT (15 m.)
MICROCAT (16 m.)
TIDBIT (17m.)
TIDBIT (18 m.)
TSKA(19 m.)
SBE 39 P/T (20 m.)
1/2" chain
TIDBIT (21 m.)
TIDBIT (22 m.)
(23 m.)
Bio-Optical Inst.(WETLABS), Chem Inst. (SUB CHEM),
SEACAT
TIDBIT (24 m.)
Swivel/Release
3/4" chain
25 m.
FWS
3/3/03
ver 1.2


HYDROID
REMUS

CHARISMATIC PLATFORMS

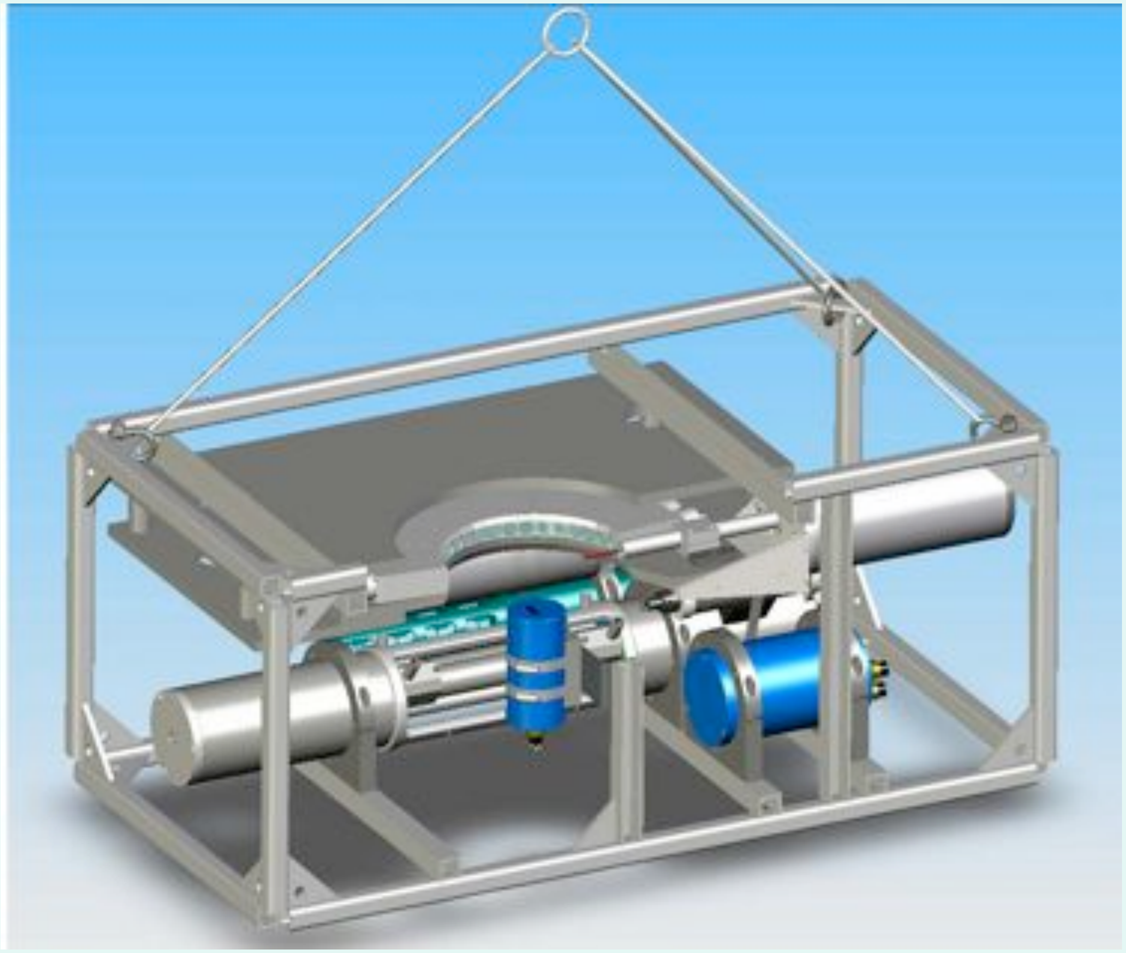




f/Q is a function of the shape of the VSF via radiative transfer.

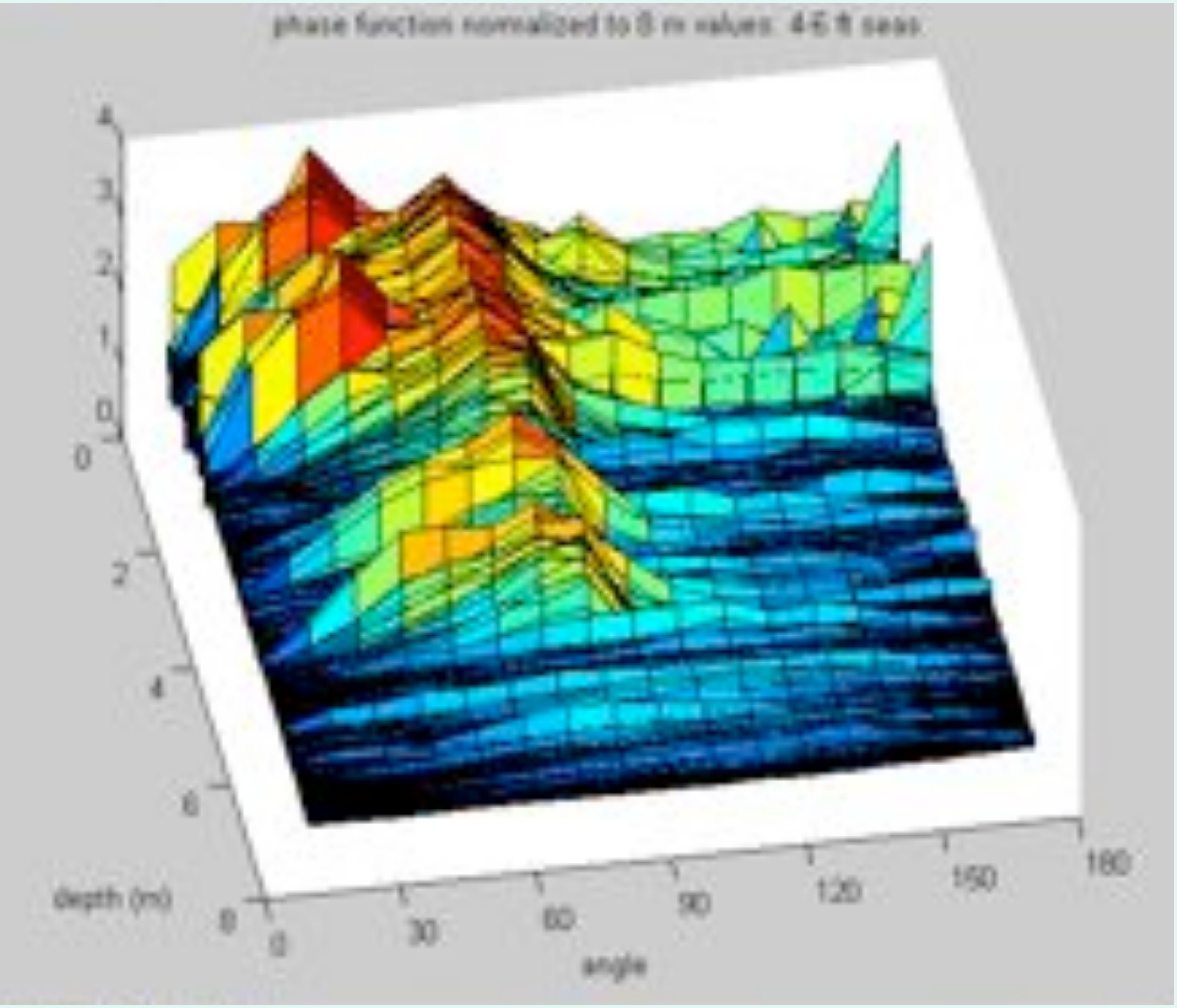
Shape of the VSF is determined by particle size, shape and index of refraction.

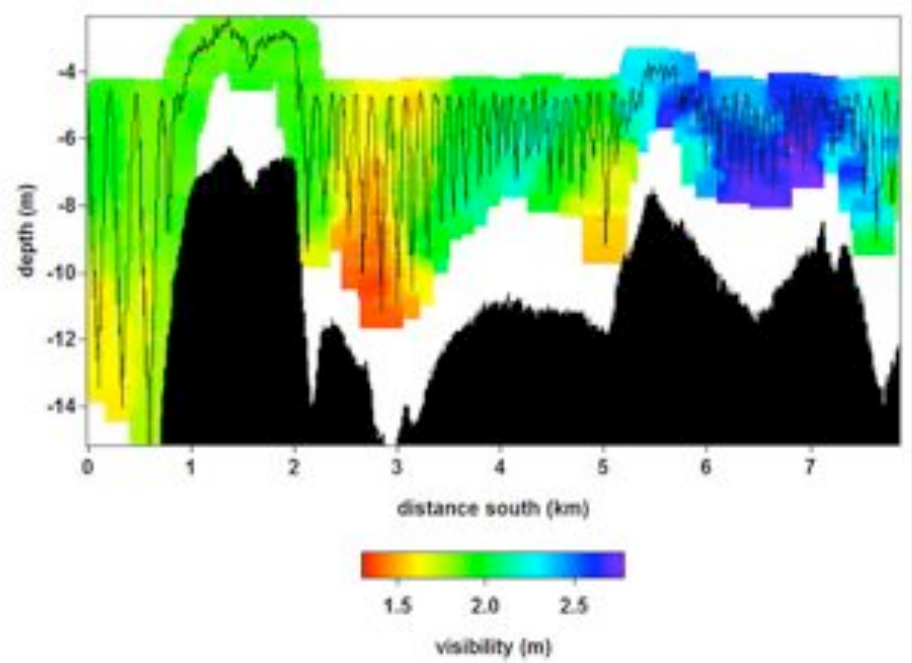
Accuracy of simple bb devices can be tested.



Instrument package with VSF sensor (20 Hz, 10-170°, every 10°, 1λ), a(80λ), c(80λ), b_b(1λ), chl. fluorescence

WET Labs


phase function normalized to 0 m values: 4-6 ft seas
4
3
2
1
0
0
2
4
6
8
depth (m)
0
30
60
90
120
150
180
angle



The scale problem- in situ observations are at one location, whereas satellite observations cover 1 km^2 . This issue can be resolved by use of tow-yo platforms.

Twardowski

Excitation –Emission Fluorometer (XMF)

Excitation 220 to 730 nm FWHM 10 nm

Emission 240–680 nm

Rated depth 500 m

Sample rate 6 Ex/Em samples/sec

WET Lab