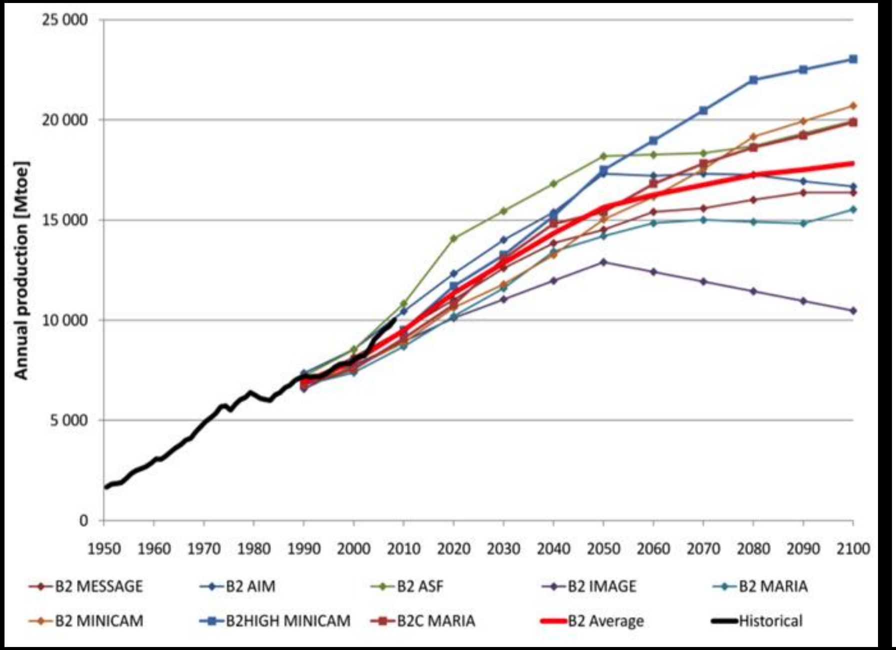
In Situ Observations Supporting Future Ocean Color Science

(What should our capabilities be a decade from now?)

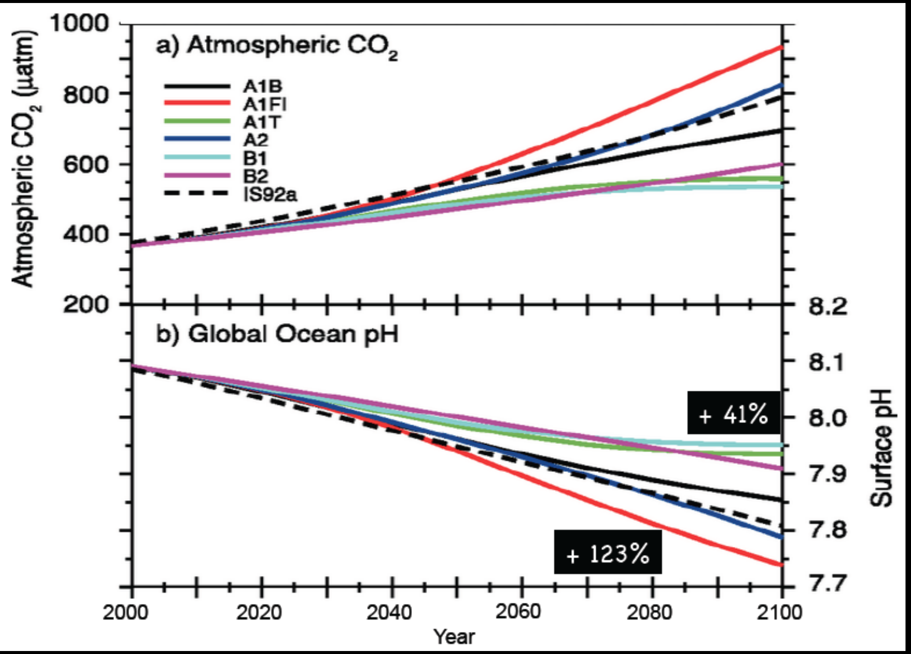
Steven G. Ackleson
SA Ocean Services, LLC
www.saoceans.com

Presented at
IOCCG International Ocean Color Science Meeting
Darmstadt, Germany
May 6-8, 2013

Science Increasingly Driven By Societal Concerns



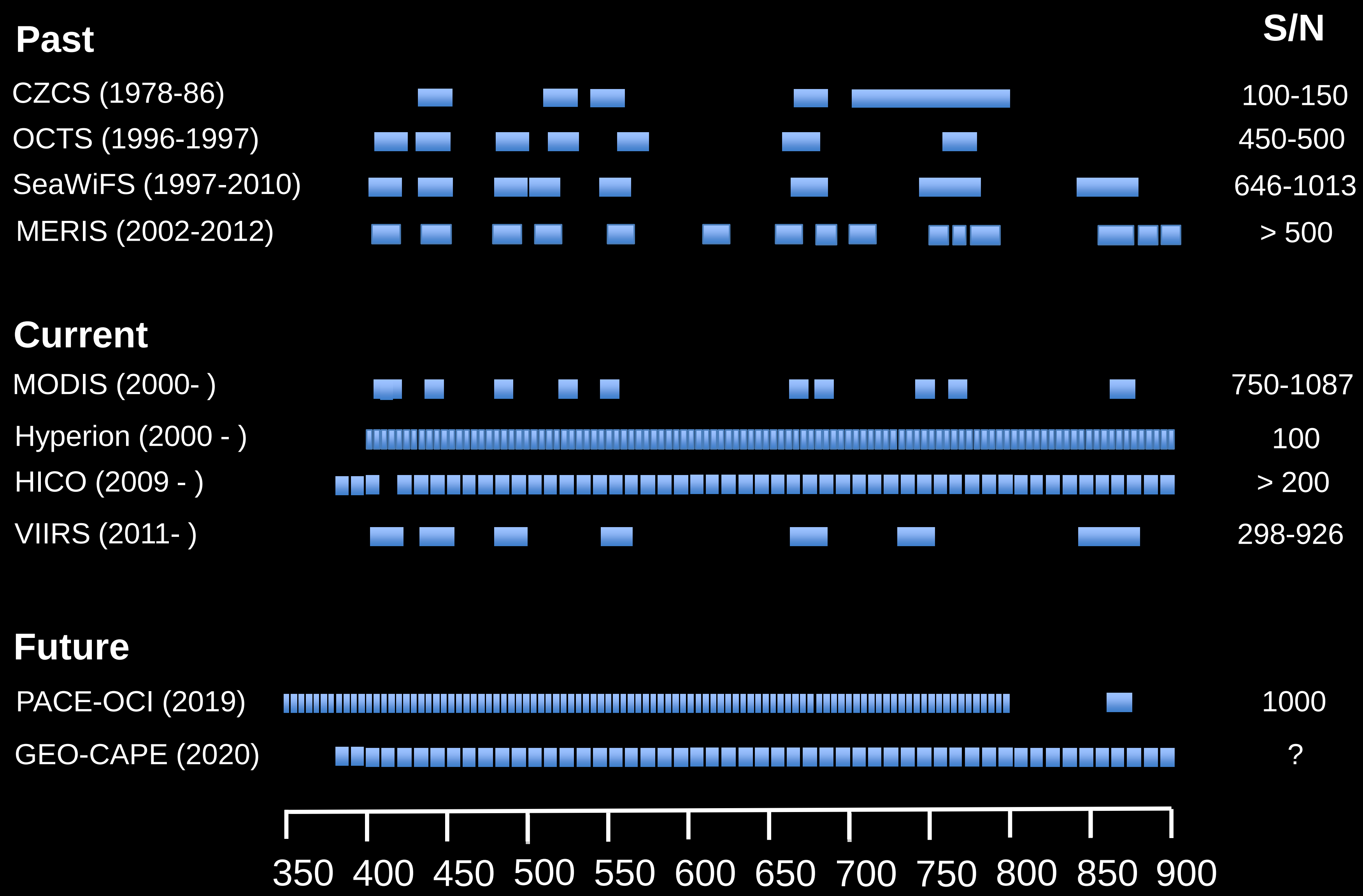
Climate Change Synthesis Report, IPCC , 2007



(Orr et al., 2005)

- 1 billion more people every 15 years
- 50% increase in fossil fuel consumption by 2050
- 50% of the the global population derives 15% of their daily intake of animal protein from the ocean

Past, Current, and Planned Ocean Color Sensors



PACE Ocean Color Science Drivers*

1. What are the standing stocks, compositions, and productivity of ocean ecosystems and how and why are they changing?
2. How and why are ocean biogeochemical cycles changing and how do they influence the Earth system?
3. What are the material exchanges between land and ocean; how do they influence coastal ecosystems and biogeochemistry; how are they changing?
4. How do aerosols influence ocean ecosystems and biogeochemical cycles; how do ocean biological and photochemical processes affect the atmosphere?
5. How do physical ocean processes affect ocean ecosystems and biogeochemistry; how do ocean biological processes influence ocean physics?
6. What is the distribution of both harmful and beneficial algal blooms; how is their appearance and demise related to environmental forcing; how are these events changing?
7. How do changes in critical ocean ecosystem services affect human health and welfare; how do human activities affect ocean ecosystems and the services they provide; what science-based management strategies need to be implemented to sustain our health and well-being?

* *Pre-Aerosol, Clouds, and ocean Ecosystem (PACE) Mission Science Definition Team Report, October 2012*

Climate Quality Data:

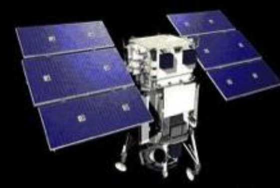
Time series of observations of sufficient length, consistency, continuity, and accuracy to reveal meaningful climate variability and change.

Recommended OCI Property/Process Retrievals

Measurement Class	Geophysical Parameters
Core Optical Variables	
radiometric quantities	$L_u(z,\lambda)$, $L_i(\lambda)$, $L_{sky}(\lambda)$, $E_d(z, \lambda)$, $E_s(\lambda)$, PAR(z)
apparent optical properties (AOPs)	$K_d(\lambda)$, K_{PAR}, Z_{eu}
inherent optical properties (IOPs)	$a(z,\lambda)$, $a_p(z,\lambda)$, $a_{ph}(z, \lambda)$, $a_d(z, \lambda)$, $a_{CDOM}(z, \lambda)$, $b_b(z, \lambda)$, $c(z, \lambda)$
Biogeochemical State Variables and Processes (Secondary Variables)	
phytoplankton pigment concentrations	Chl, accessory pigments, carotenoids, etc.
phytoplankton characteristics	C_{phyto}, taxonomic/functional groups, chlorophyll fluorescence
particle population characteristics	Suspended Particulate Matter (SPM), POC, PIC, PSDs, $\beta(z, \lambda)$
photobiochemical characteristics	DOC, CDOM fluorescence, MAAs, phycobili proteins
production	NPP, NCP, nutrients
Synthesis and Modeling Variables (Tertiary Variables)	
Fluxes and ecosystems	C export, air-sea CO_2 exchange, land-ocean material exchange

"Essential Ocean Variables"; A Framework for Ocean Observing (www.oceanobs09.net)

CAL/VAL SYSTEMS



L_t

Earth Radiance Received On-Orbit

Water-Leaving Radiance

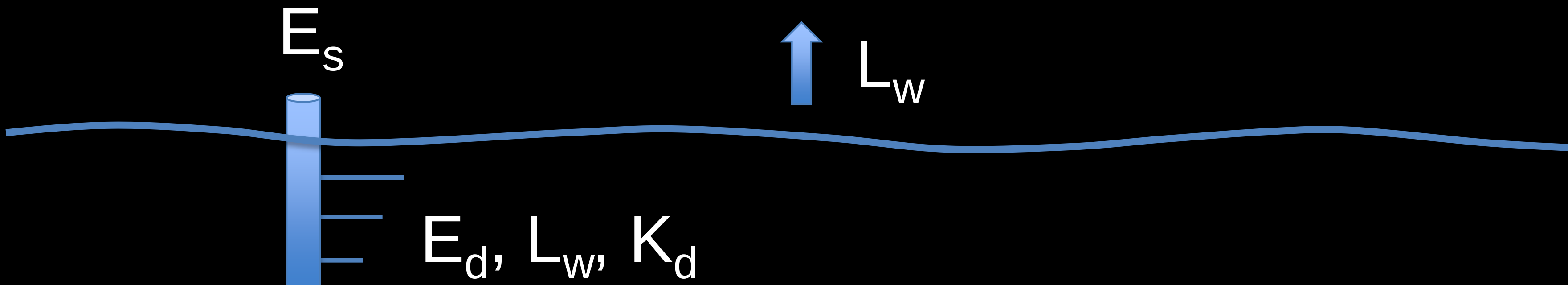
$$L_t = [L_r + L_a + t_{dv} L_f + t_{dv} L_w] \cdot t_{gv} \cdot t_{gs} \cdot f_p$$

Atmospheric Contributions

Water Surface Contributions

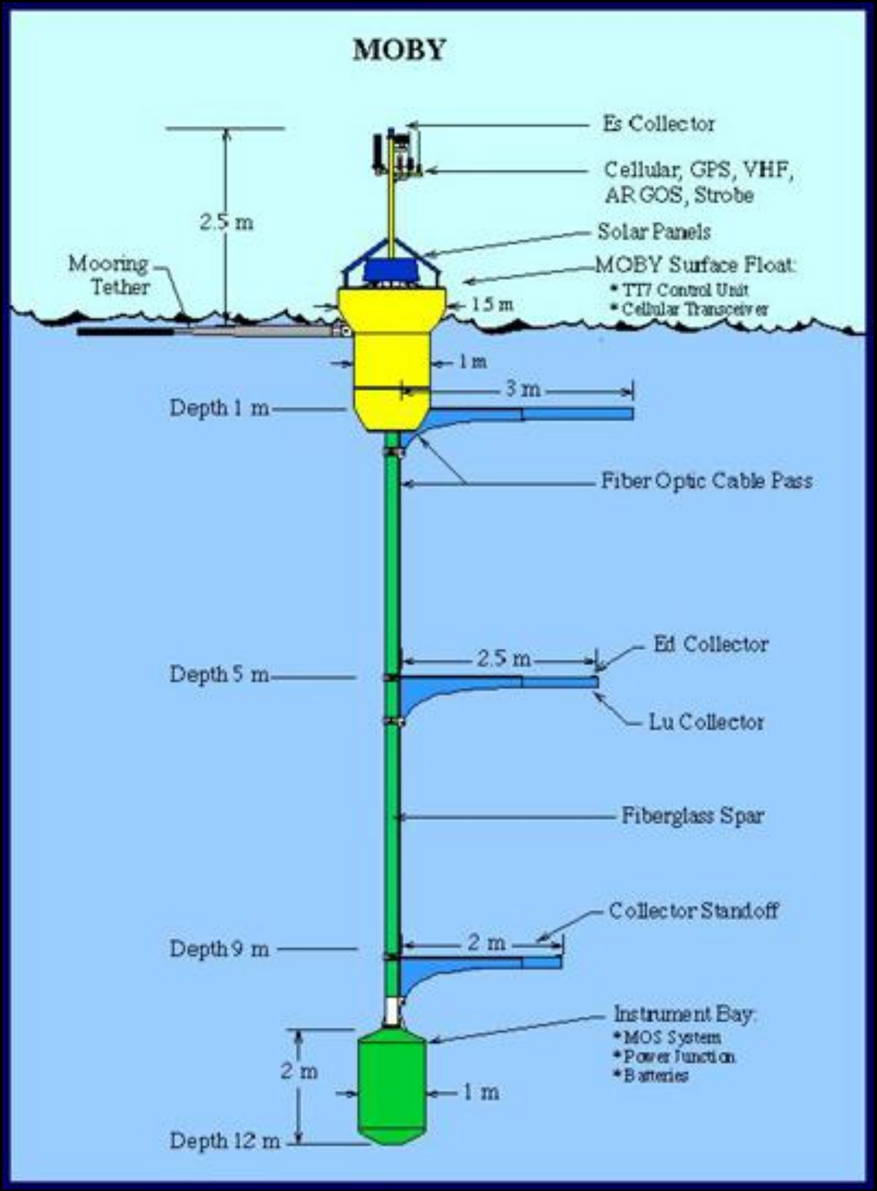
Atmospheric Absorption

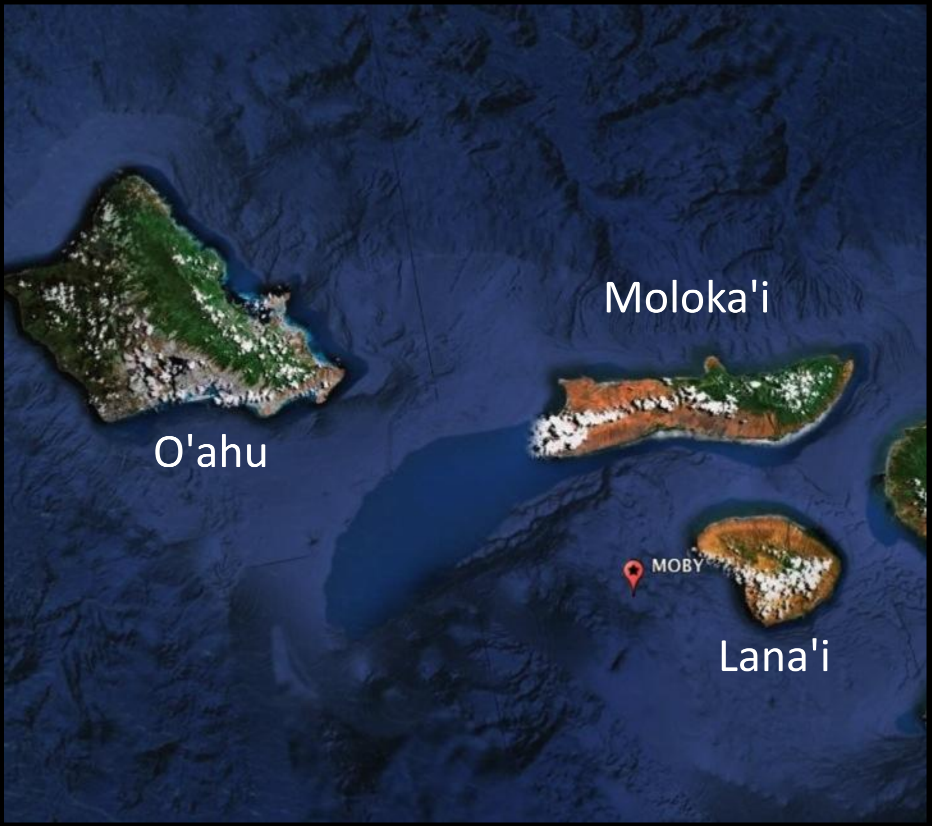
Instrument Response



Franz et al., Appl. Opt., 2007 (+ references cited)

Marine Optical Buoy Program (MOBY)





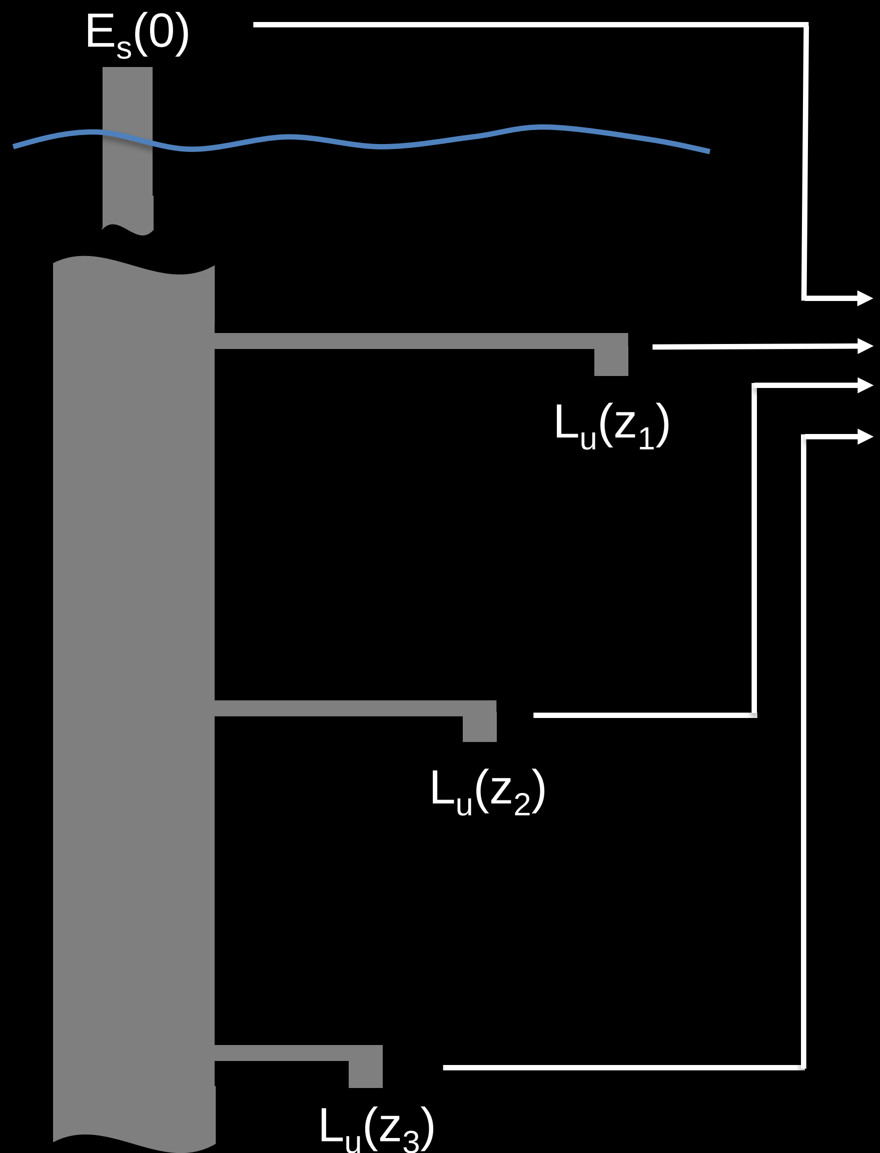
15 year time series (1997 - present)

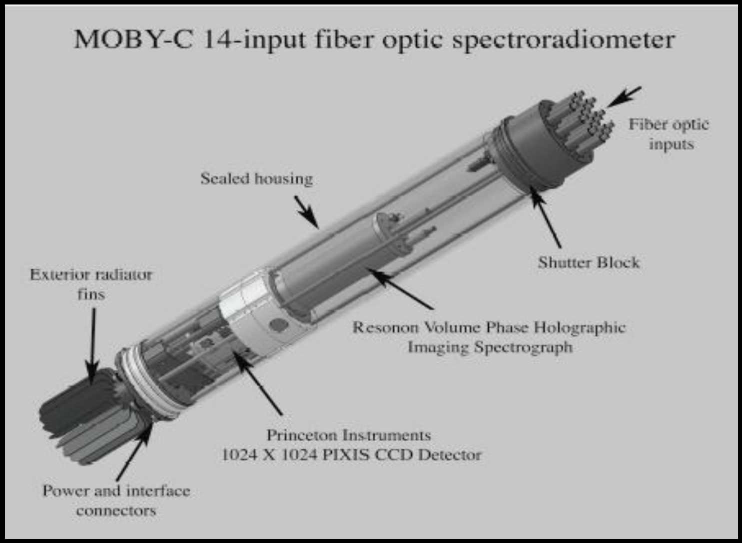
MOBY-C is hyperspectral (Dec, 2012)

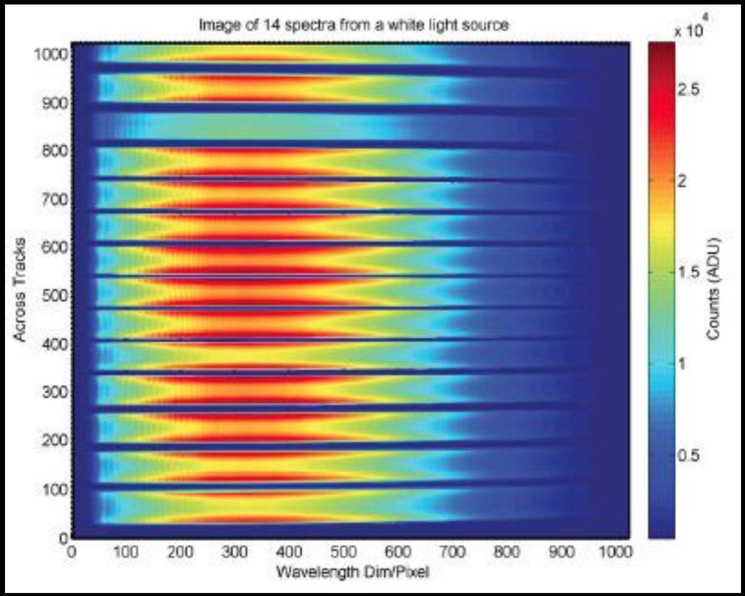
Annual O&M: $2M (25% data QA/QC)

Data: http://data.moby.mlml.calstate.edu

MOBY Refresh
(Voss, personal communication)

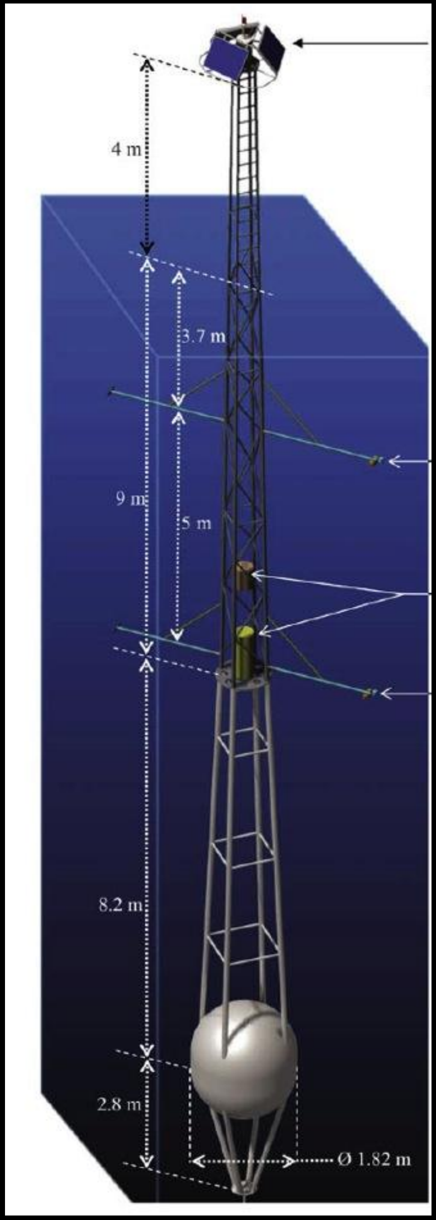


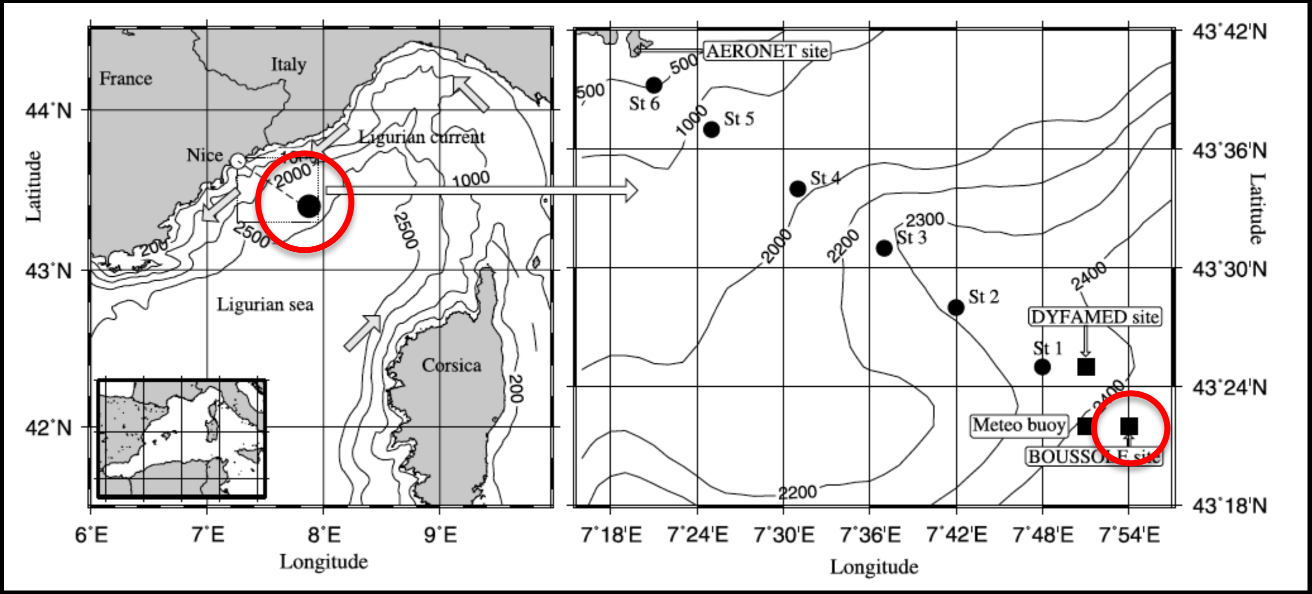




BOUSSOLE

(**BOU**ée pour l'acqui**S**ition d'une **S**érie **O**ptique à **L**ong term**E**)

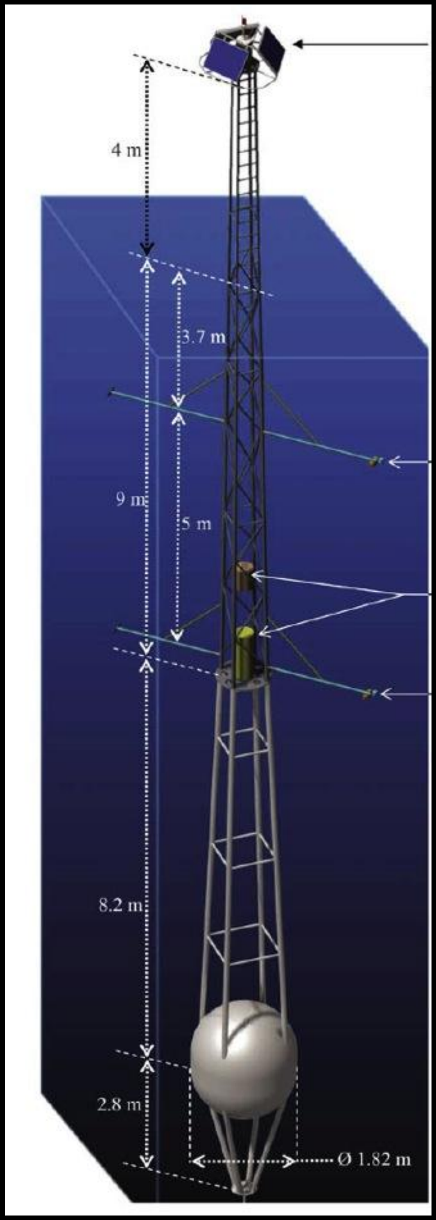


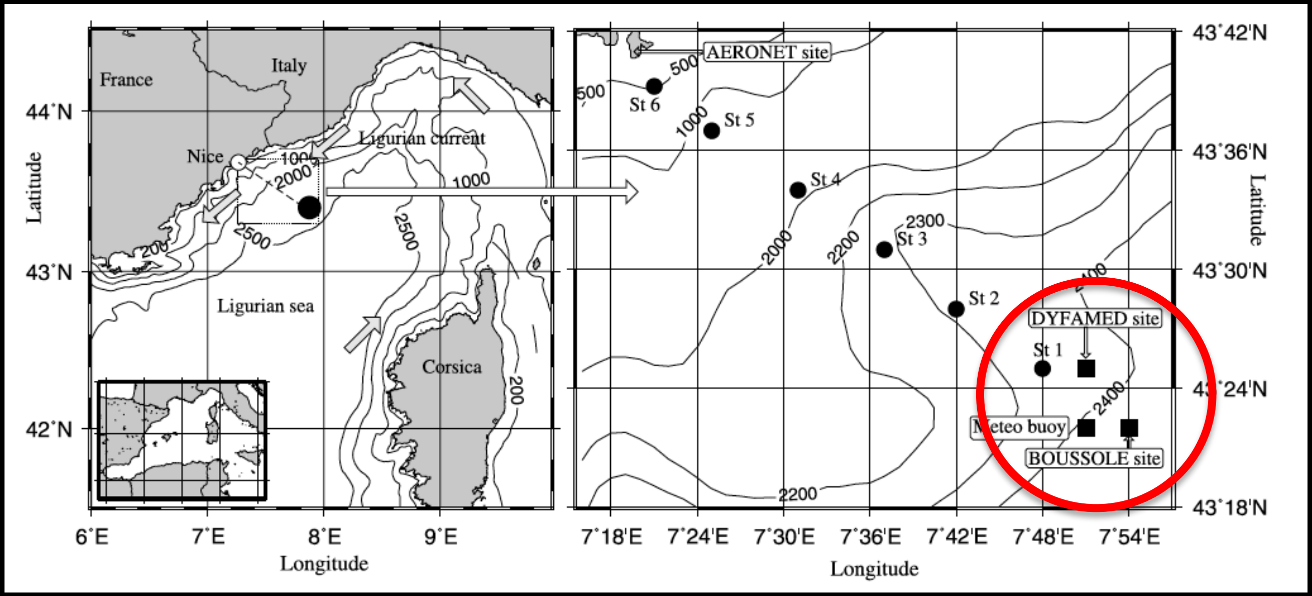


E_s	4.5 m (above surface)
E_d, E_u, and L_u (nadir)	4 and 9 m)
c	4 and 9 m
b_b (442 and 560nm)	9m
Two-axis tilt and compass	9 m
CTD	9 m
Chlorophyll fluorometer	4 and 9 m

Data: www.obs-vlfr.fr/Boussole/html/boussole_data/collected.php

BOUSSOLE Co-Sited with DYFAMED





DYFAMED Ocean Variables:

Meteorology	Pigment Concentration*
CTD	POC*
Dissolved Oxygen	PON*
Nutrients	Particle Flux*
pCO_2*	Primary Production*
TCO_2	Microbial Taxonomy*

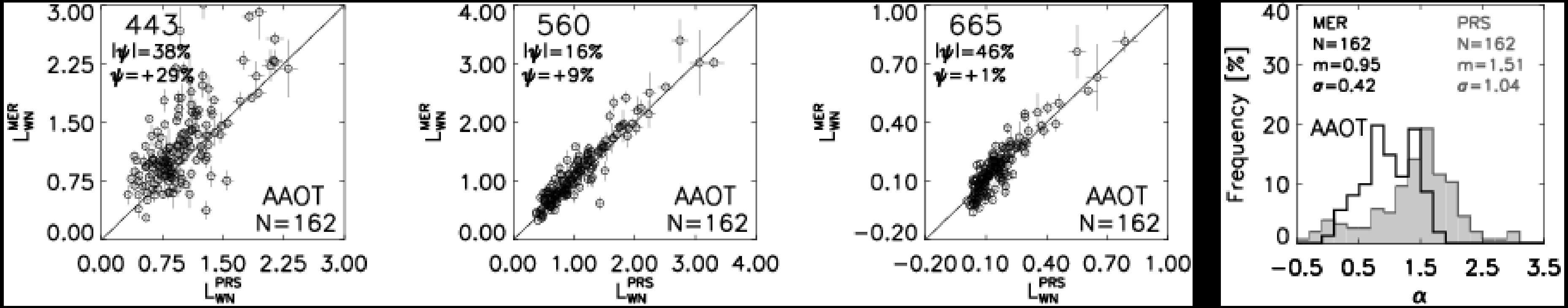
Data: www.obs-vlfr.fr/sodyf/

* 1991 – 2007 only

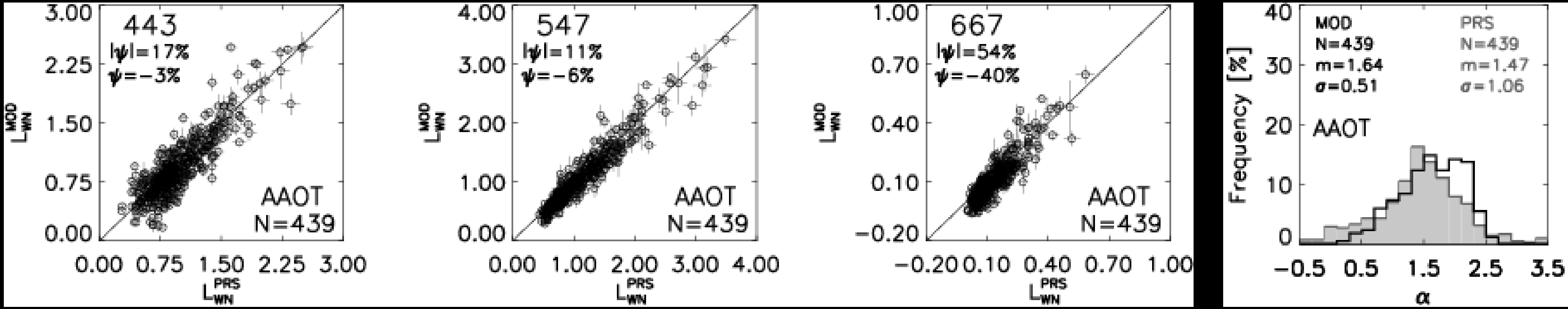
Ocean Station Aloha: A Better Location For MOBY?

AERONET-OC VALIDATION OF SATELLITE PRODUCTS

MERIS

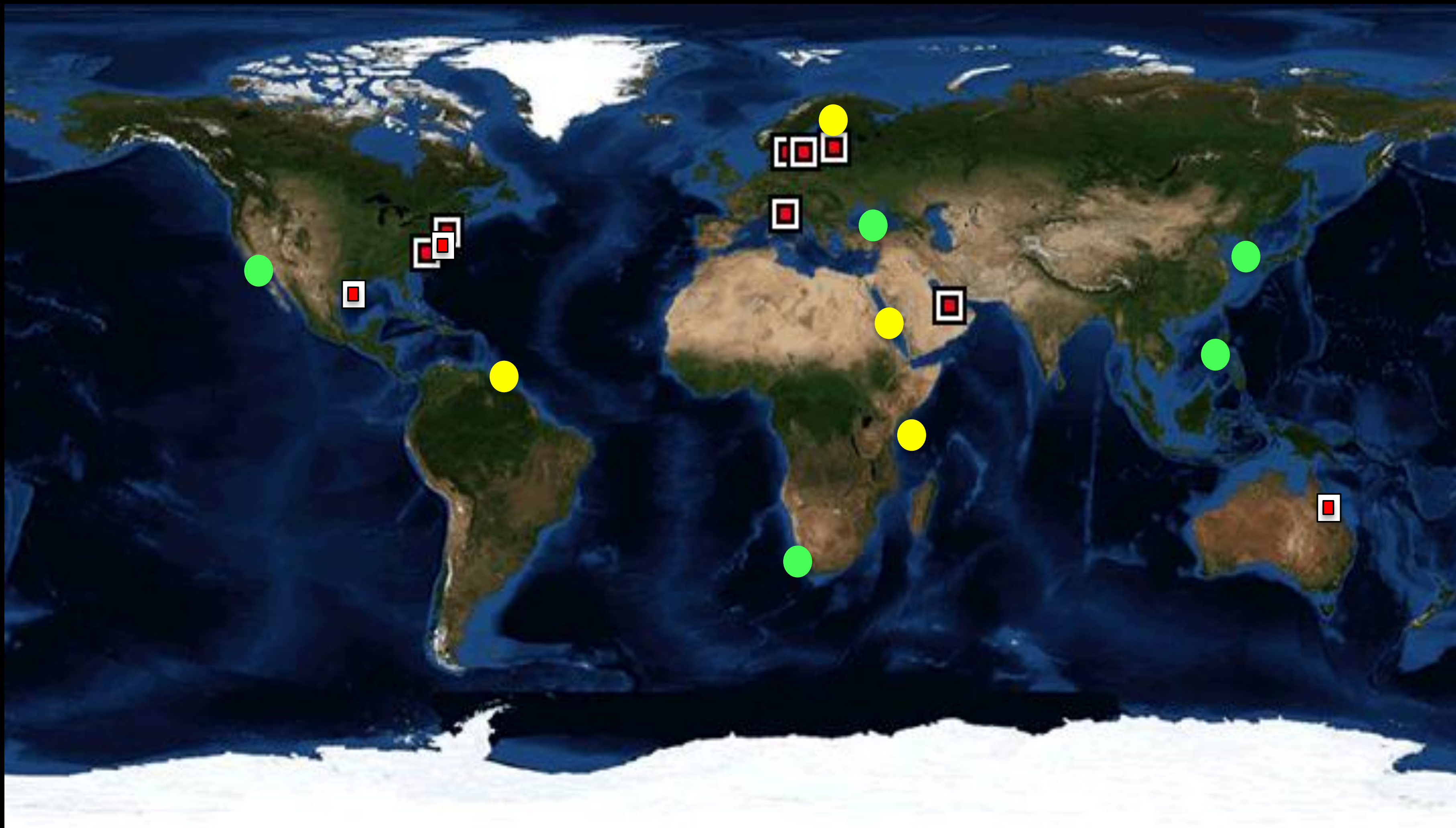


MODIS



Zibordi et al., Rem. Sens. Envir., 2009

Aeronet-OC Network

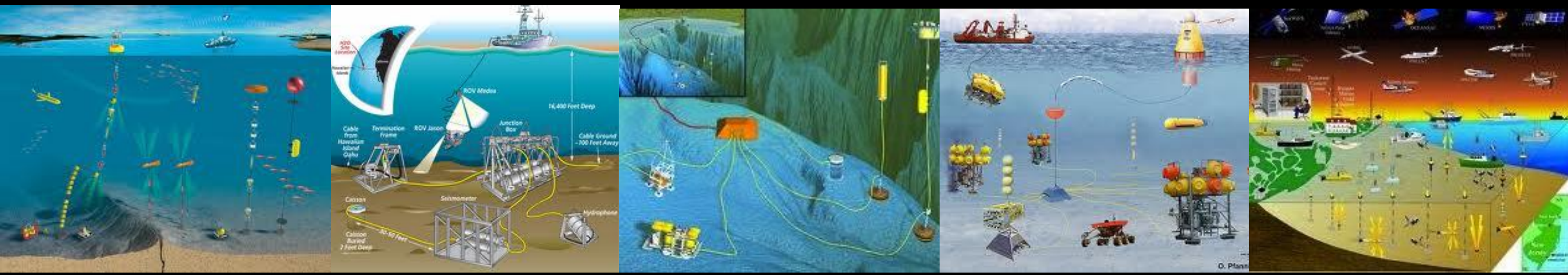


Current Sites
Planned Sites
Potential Sites

Zibordi et al., EOS Transactions, 2006

Ocean Observatories

O•cean Ob•serv•a•to•ry
(oh-sh*uh*'n *uh*'b-zur-v*uh*-tawr-ee)



EVOLUTIONARY TRENDS

Repeat Visits → Continuous Presence

Single Discipline → Interdisciplinary Observations

Single Location → Regional to Global Coverage

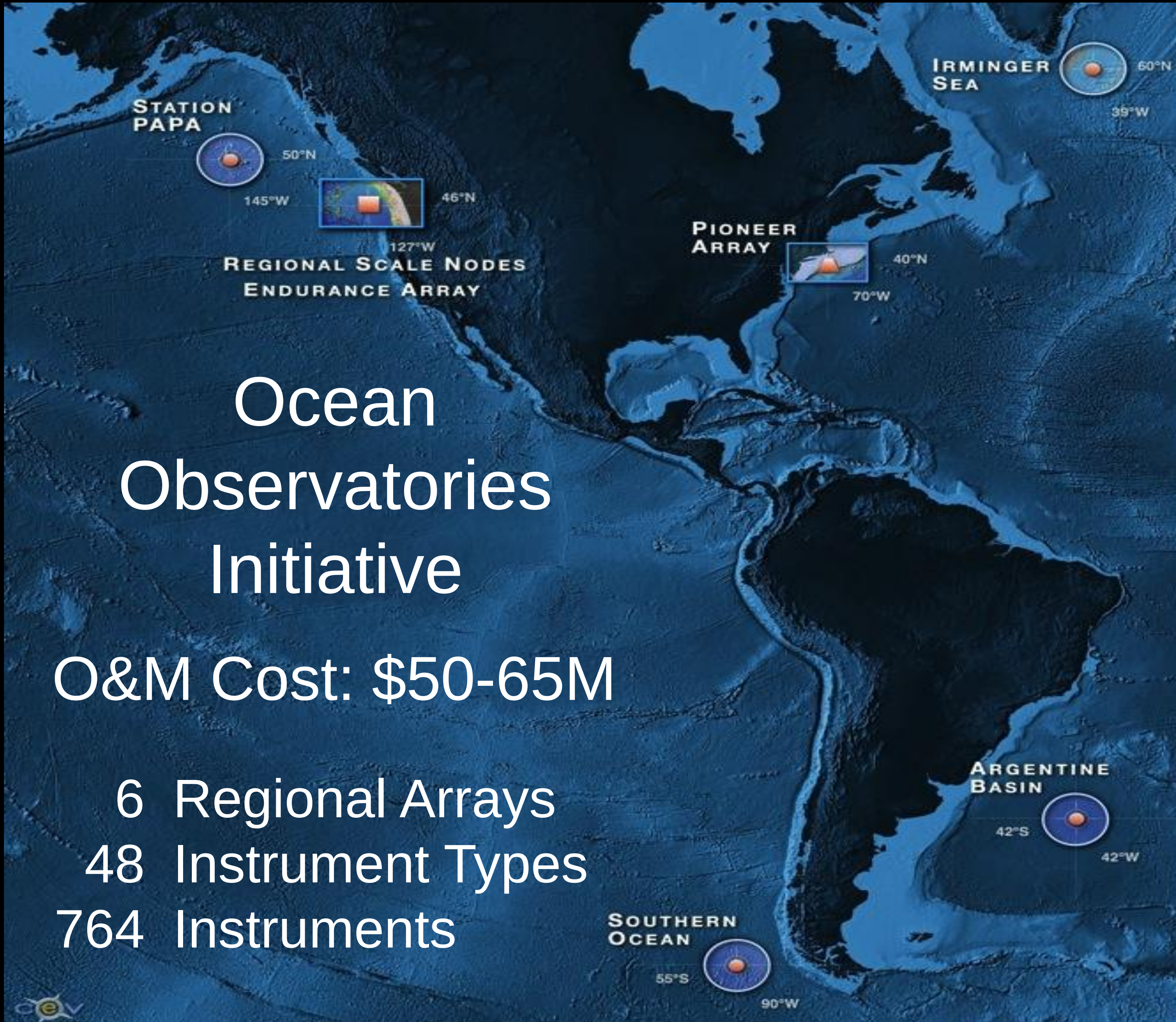
Project-Specific Data → Free & Timely Data Access

Curiosity-Driven → Societal Relevance

Ocean Observatories Initiative

O&M Cost: $50-65M

6 Regional Arrays
48 Instrument Types
764 Instruments



OOI Core Parameters

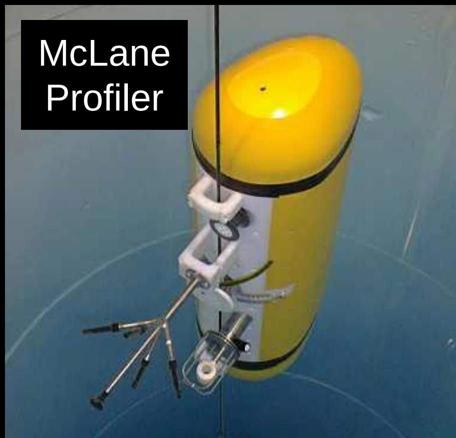
Optical:
- $a(\lambda)$
- $c(\lambda)$
- $b_b(\lambda)$
- PAR
- $E_d(\lambda)$
- $E_s(\lambda)$

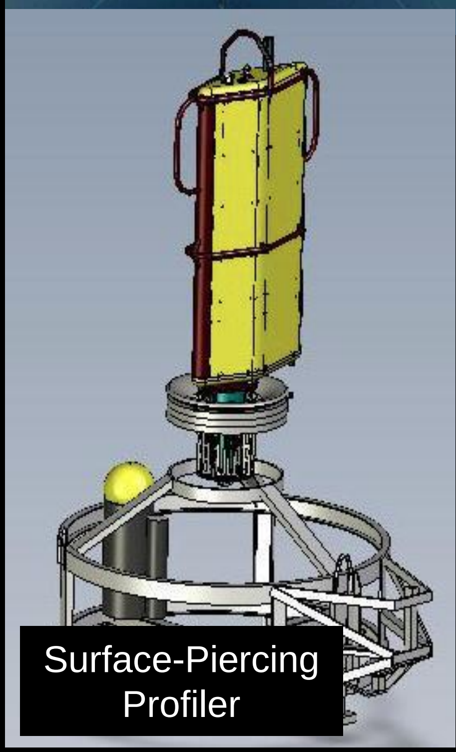
Biogeochemical:
- Chlorophyll (fluorescence)
- CDOM (fluorescence)
- Dissolved Oxygen
- pCO_2
- pH
- Nutrients (NO_2, NO_3, PO_4, SiO_4)

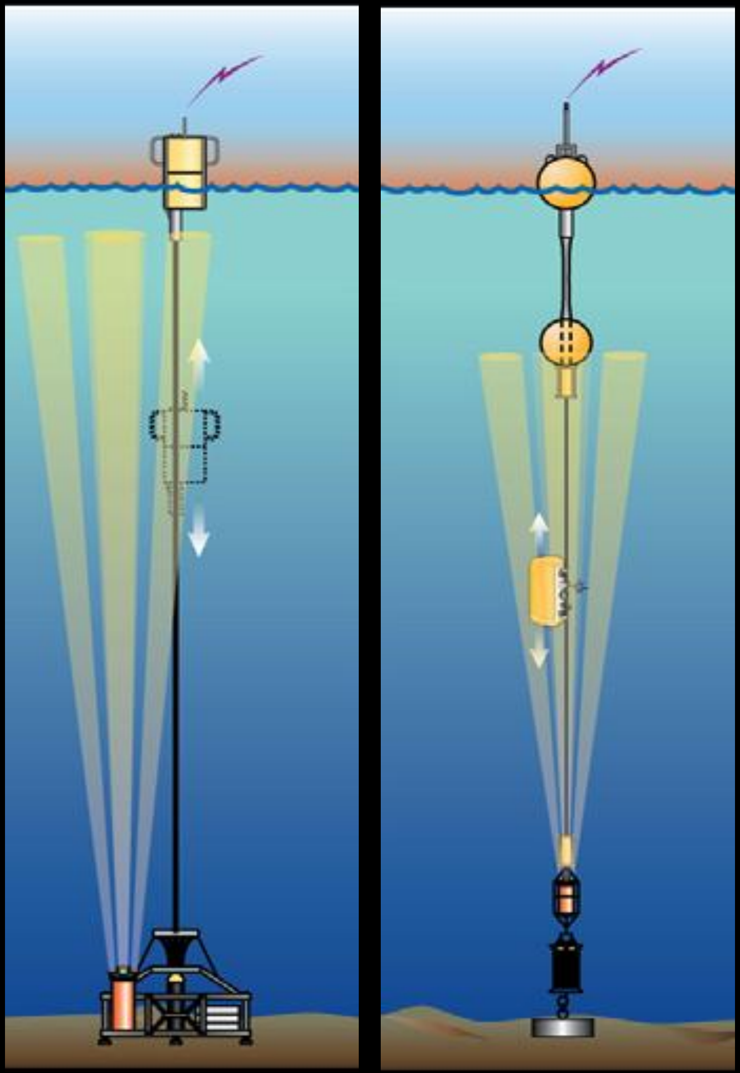
Physical:
- Temperature
- Salinity
- Current Velocity
- Turbulence
- Surface Waves

Meteorological:
- Surface Wind Velocity
- Long-wave Radiation
- CO_2

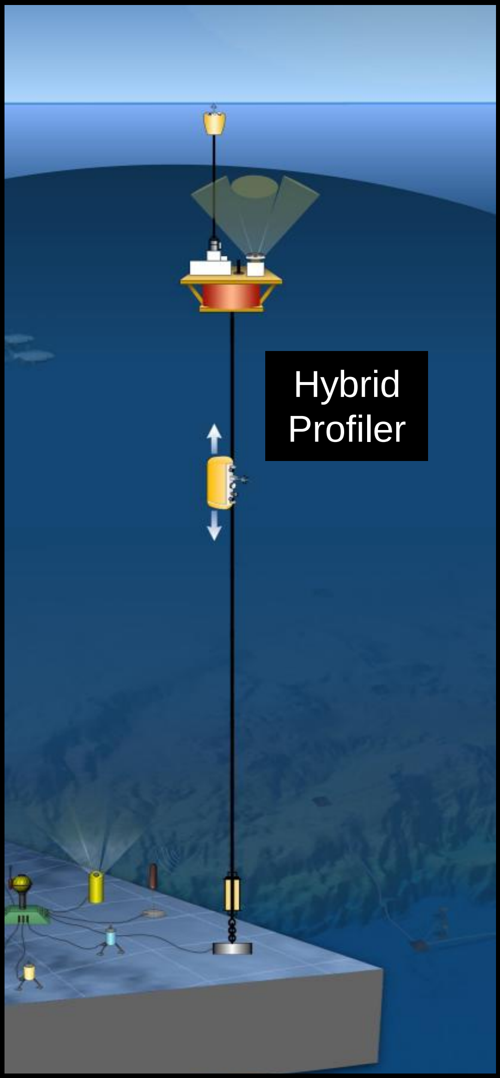
Autonomous Profiling Systems





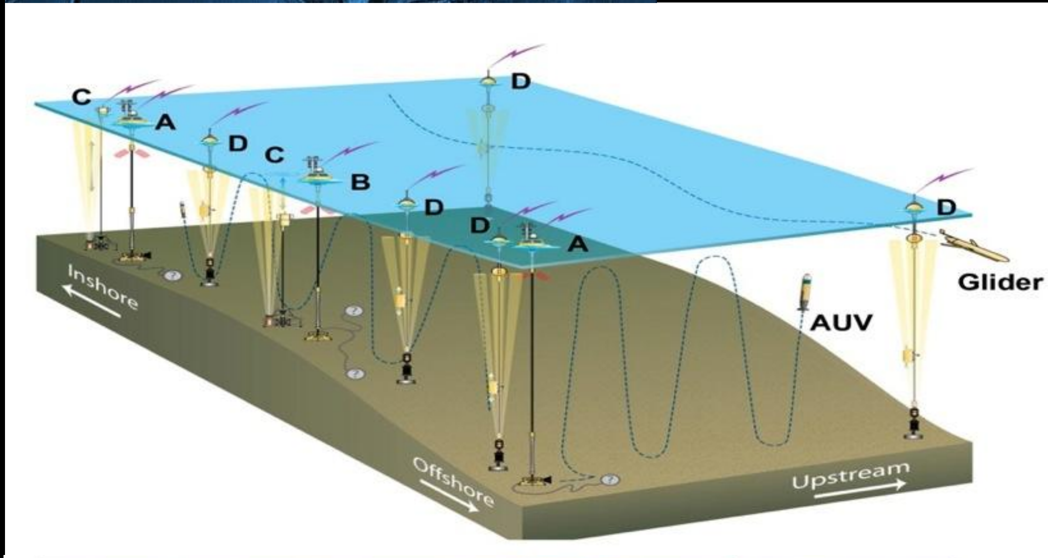


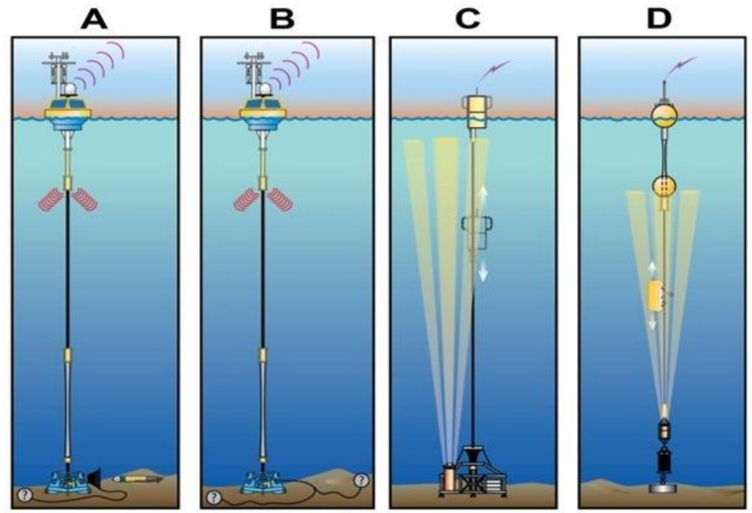
Profiling moorings planned for the Pioneer and Endurance Arrays

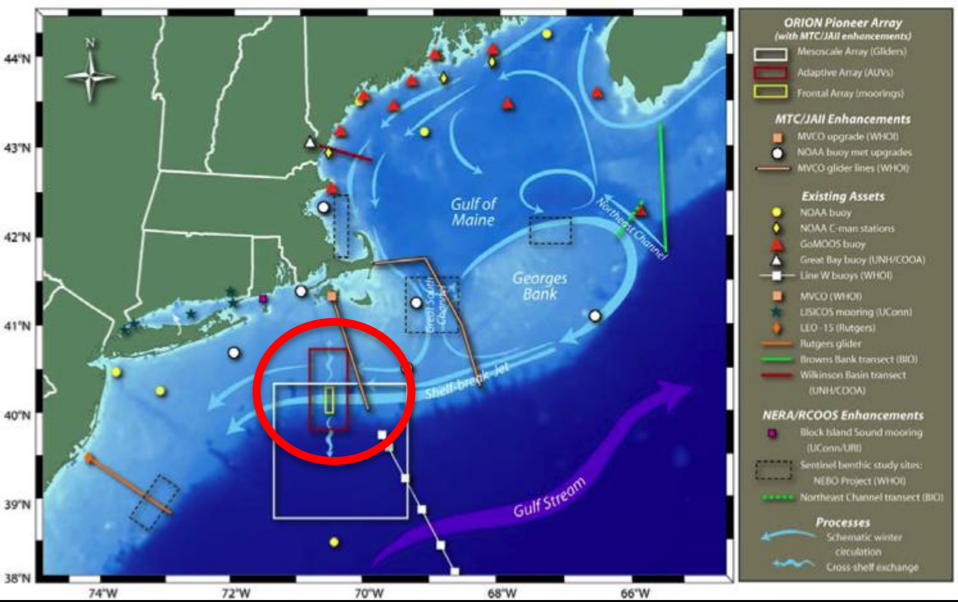


Global Array primary mooring

OOI Pioneer Array

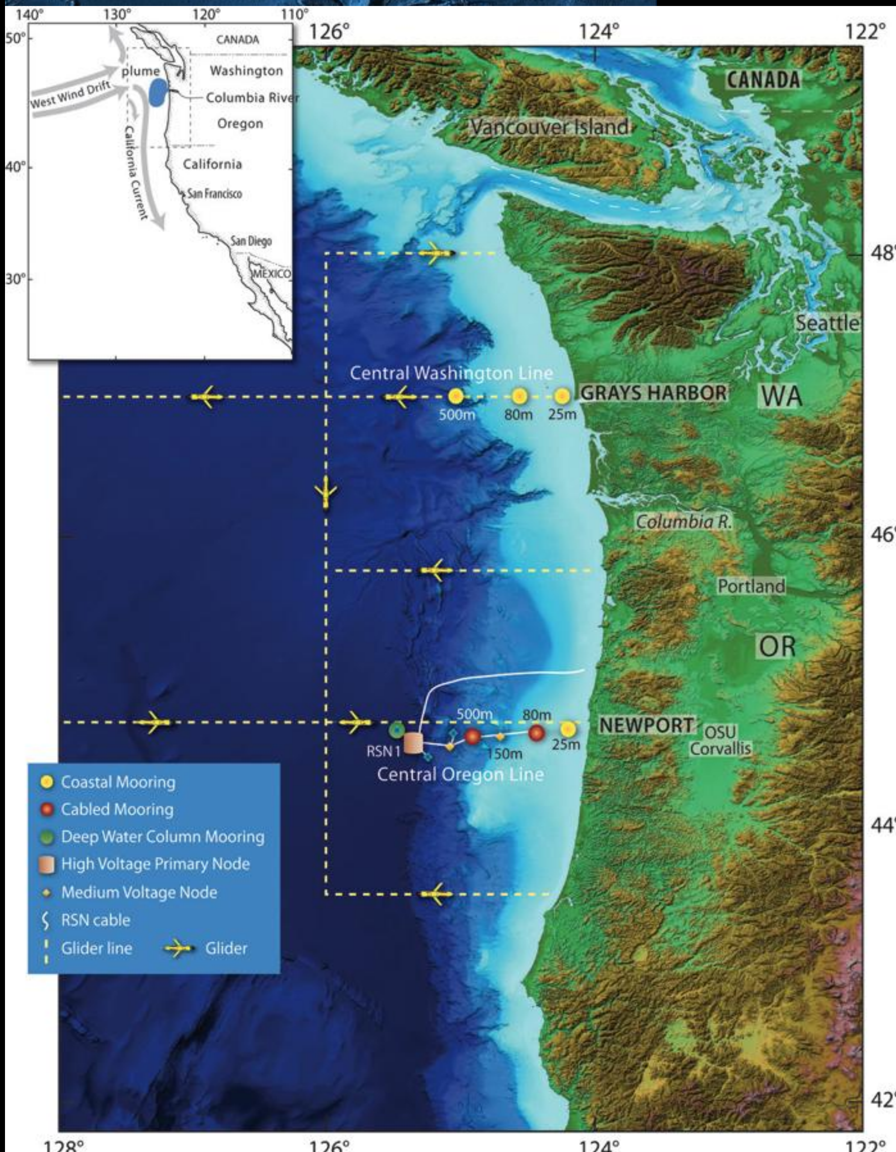


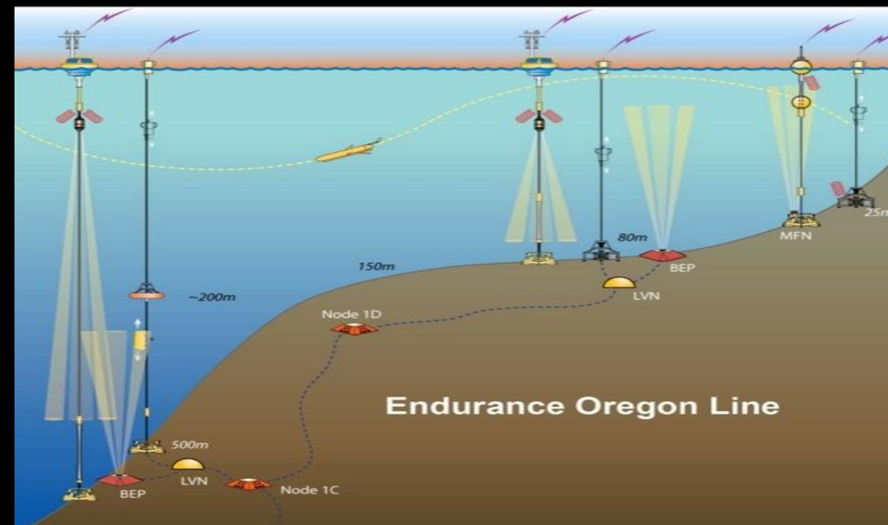




	Fixed Moorings	Moored Profilers	AUVs
PAR		4	9
$E_s(\lambda)$	3		
$E_d(\lambda)$	3	1	
$a(\lambda)$	3	1	
$c(\lambda)$	3	1	
$b_b(\lambda)$	3	4	9
Chl. Fluor.	3	4	9

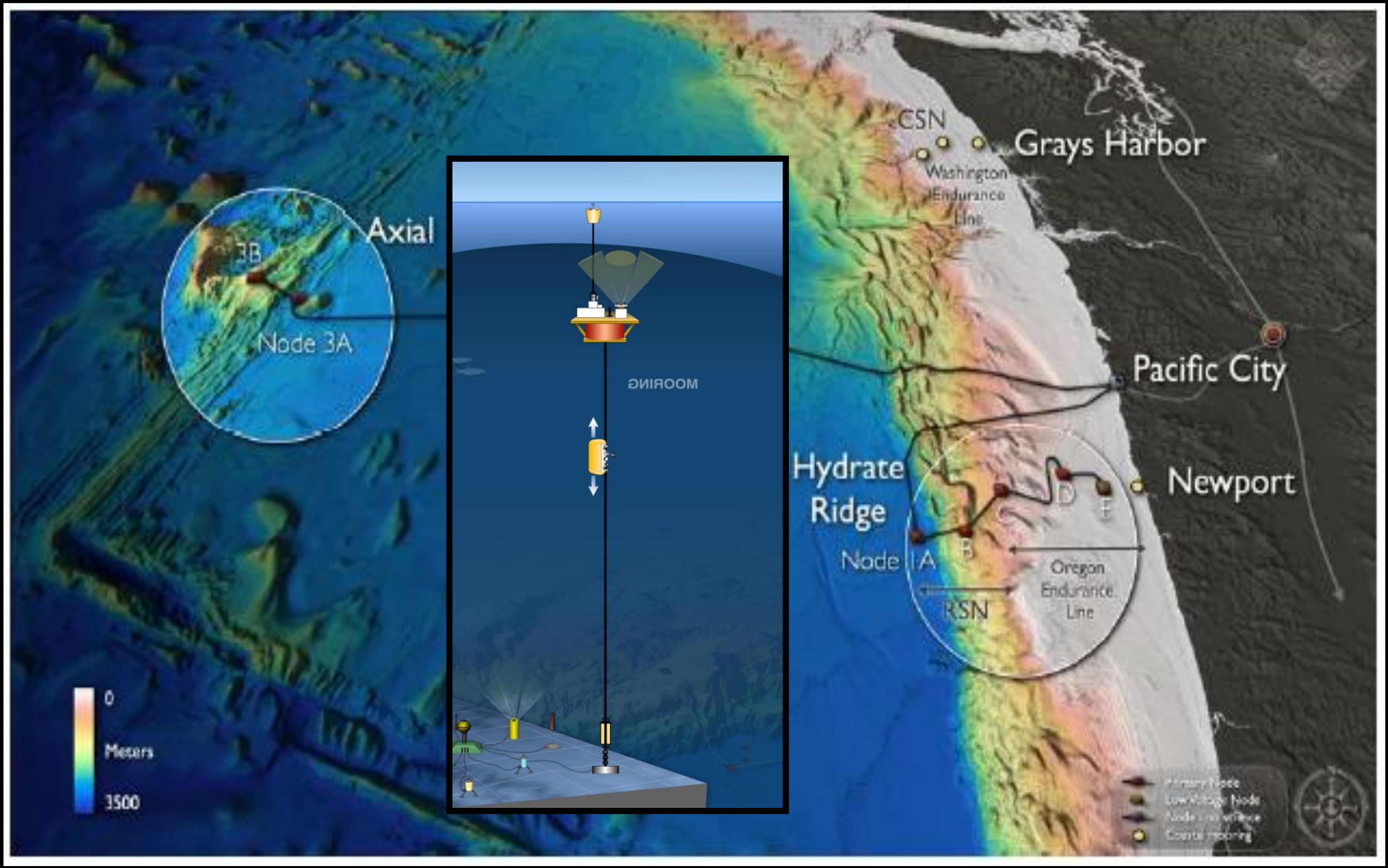
OOI Endurance Array





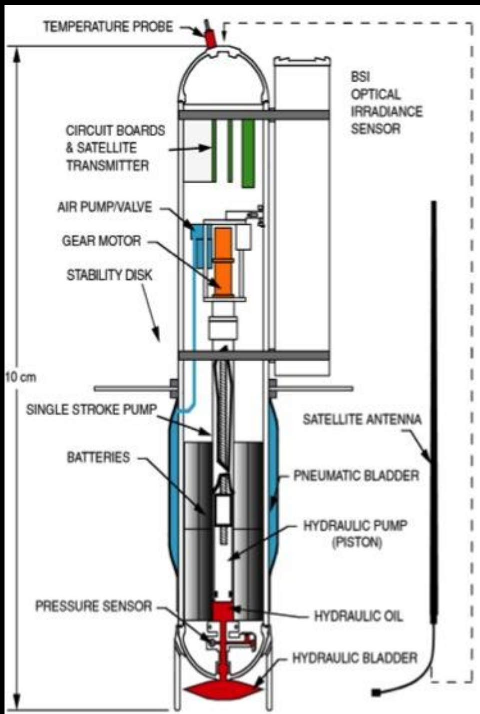
	Fixed Moorings	Moored Profilers	AUVs
PAR			5
$E_s(\lambda)$	3		
$E_d(\lambda)$		6	
$a(\lambda)$	1	6	
$c(\lambda)$	1	6	
$b_b(\lambda)$	1	6	5
Chl. Fluor.	1	6	5

OOI Deep Ocean Profiler
(Axial Seamount)

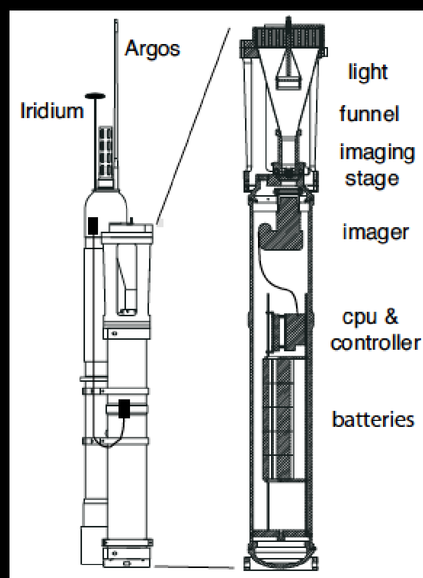


Biogeochemical Profiling Drifters

Bio-Optical/Biogeochemical Profiling Floats

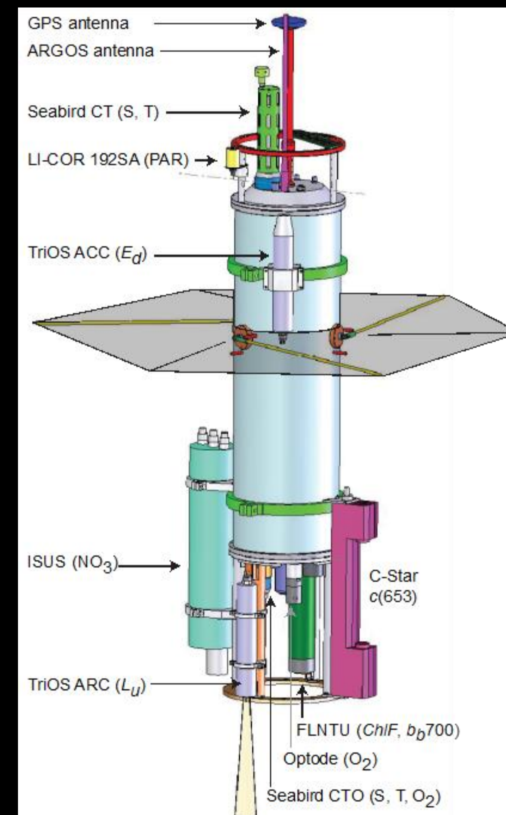


K-SOLO float
(Mitchell et al., 2000)



SOLO PIC float
(J. Bishop, 2009)

Boss et al., 2010
NOPP Project

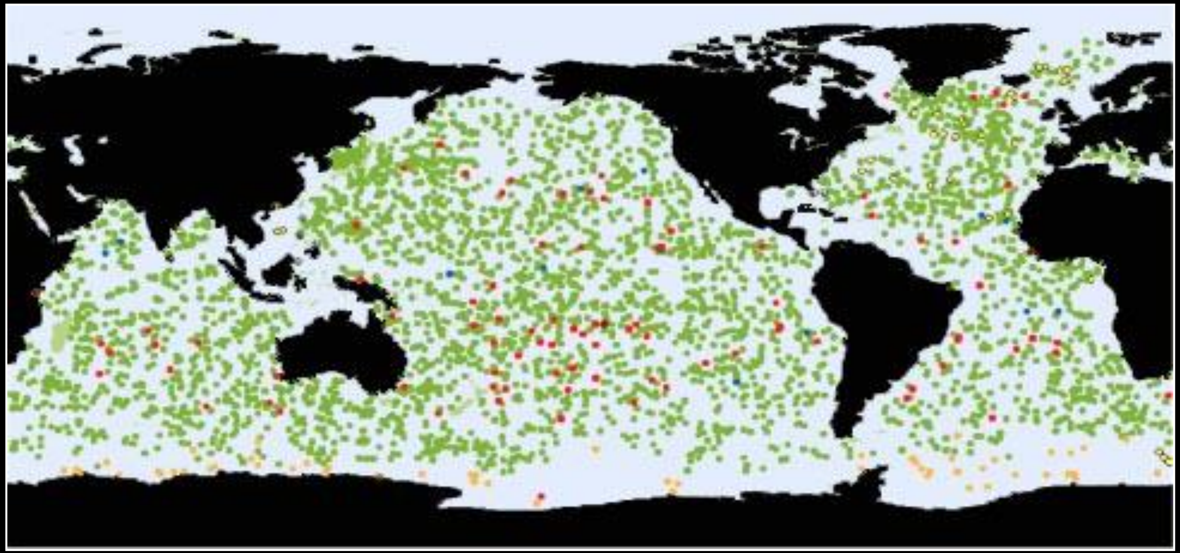


D'Asaro et al.,
2012 ASLO

Argo Profiling Floats Reporting July, 2012
(www.nodc.noaa.gov)

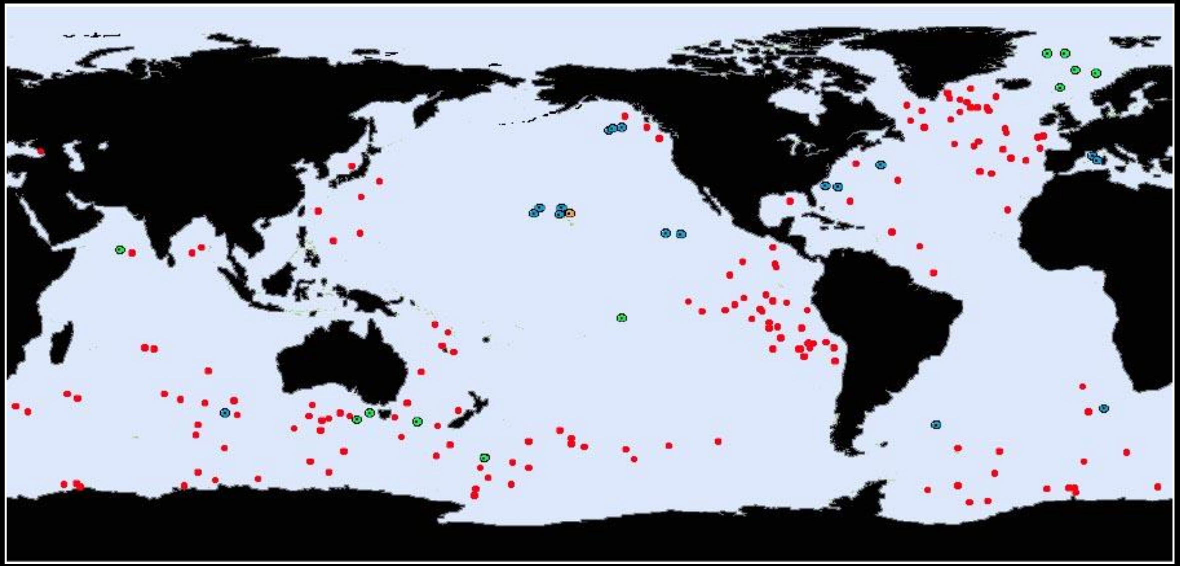
CTD:

- Operational
- Beached
- No Data
- Flaged - Altimetry
- Grey List
- Iced Over



Biogeochemistry:

- Dissolved Oxygen
- Nitrate
- Bio-Optics
- pH (coming soon)



BIO-OPTICAL SENSORS ON ARGO FLOATS

Hervé Claustre, Stewart Bernard, Jean-François Berthon, Jim Bishop, Emmanuel Boss,,
Christine Coatanoan, Fabrizio D'Ortenz, Ken Johnson, Aneesh Lotiker, Osvaldo Ulloa

Bio-Argo (600):

Chlorophyll Concentration (Fluorescence)
bb (proxy for POC)
O_2

Carbon Float (20-40):

POC
PIC
Chlorophyll Concentration

Val-Float (20-40):

$E_d(\lambda)$
$L_u(\lambda)$
$b_b(\lambda)$
Chlorophyll Concentration

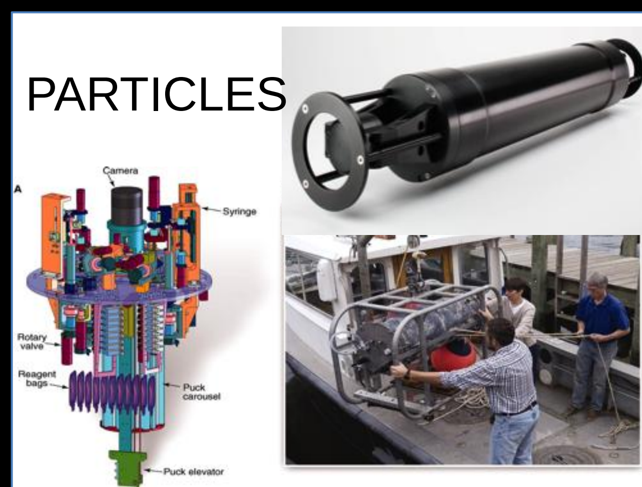
IOCCG Committee: Bio-Optical Sensors on Argo Floats; http://www.ioccg.org/reports/IOCCG_Report11.pdf
Argo Global Array of Profiling Drifters; http://www.argo.ucsd.edu/BGC1report.pdf

Sensors

Optical & Biogeochemical Sensors

pH

pCO_2



DISSOLVED OXYGEN

NUTRIENTS

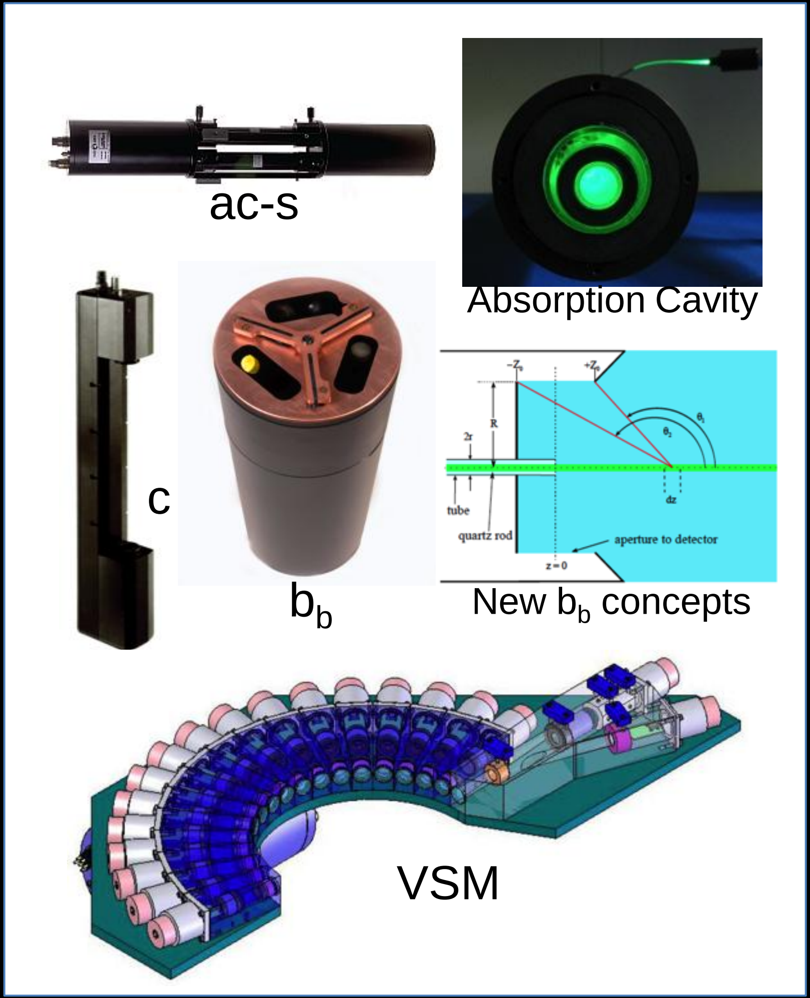
Water-Leaving Radiance/Reflectance from IOPs

$$[L_w]_n, [\rho_w]_n = f\,[a(z), b(z), \beta(z)]$$

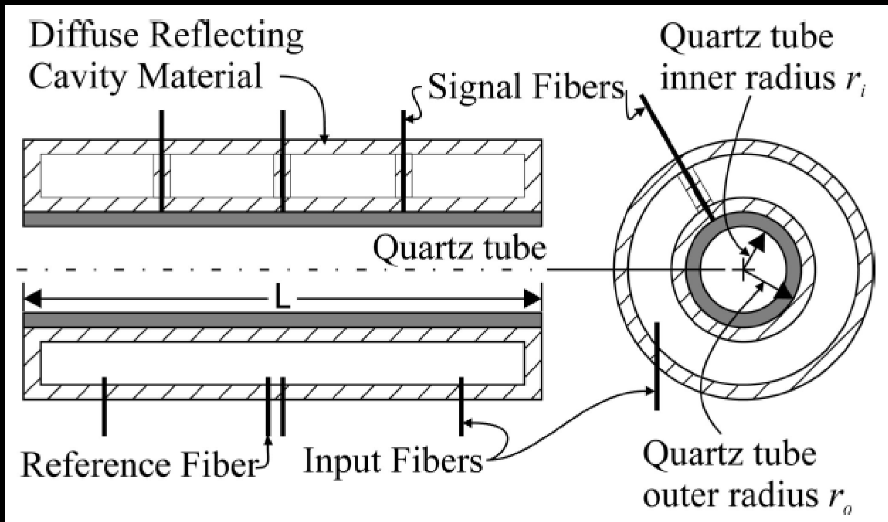
Absorption (a, a_{ph}, a_{CDOM})

Light Scatter (b, b_b)

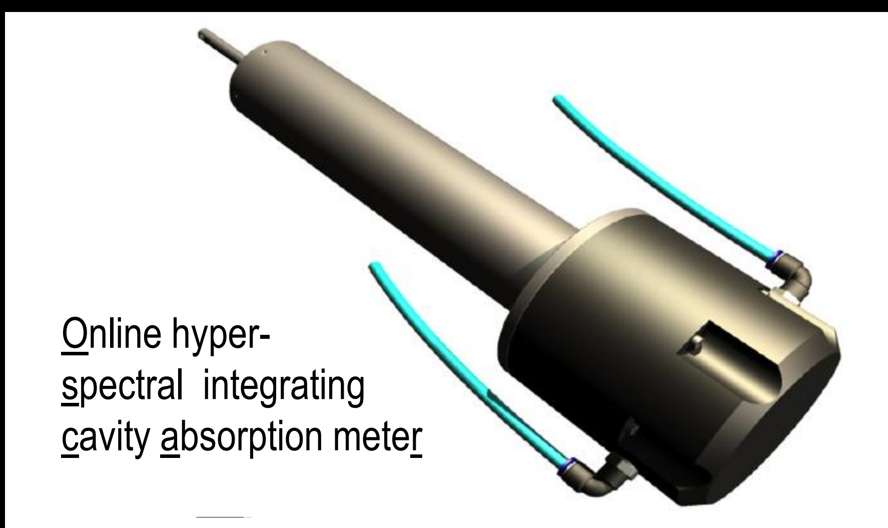
Volume Scattering Function (β)



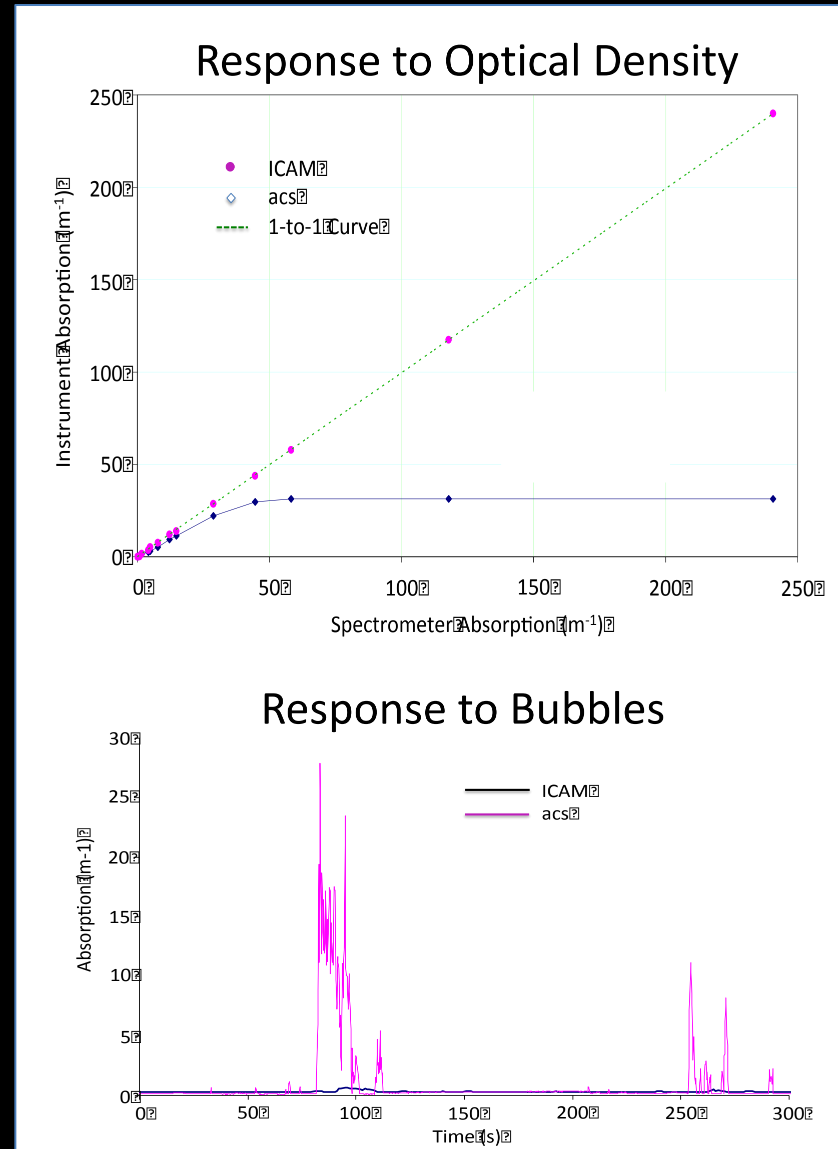
Integrating Cavity Absorption Mater



Gray, Kattaware, and Fry, 2006



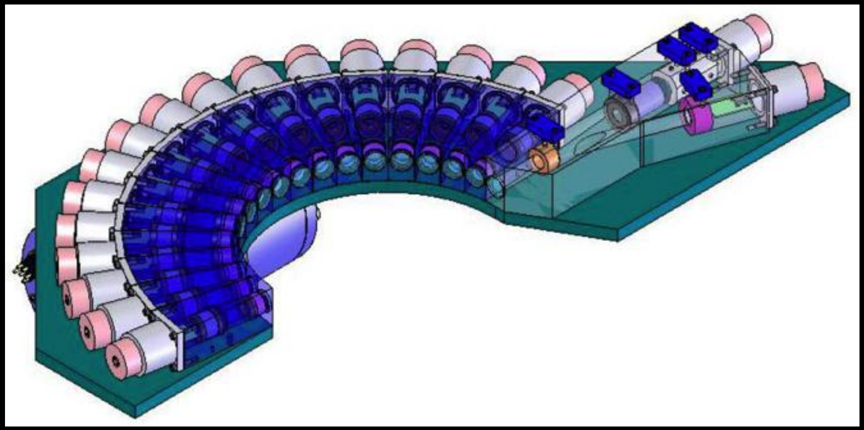
TriOS OSCAR



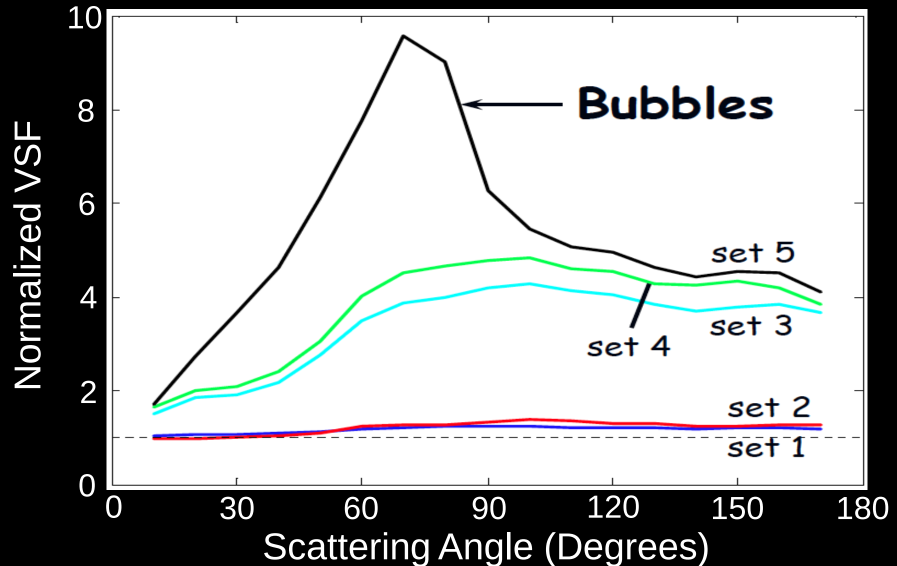
Craford, Turner Designs ICAM, 2012

MASCOT VSF Meter

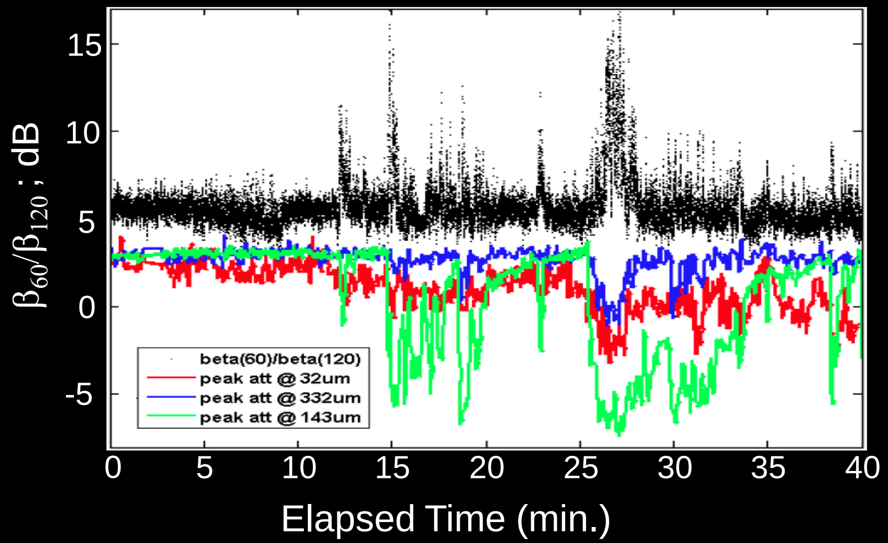
(Twardowski, 2008 Scripps Pier Data)



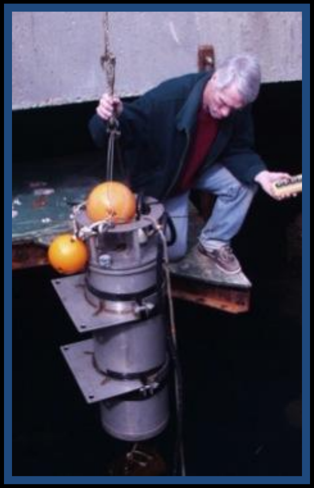
MASCOT (Multi-Angle SCattering Optical Tool)



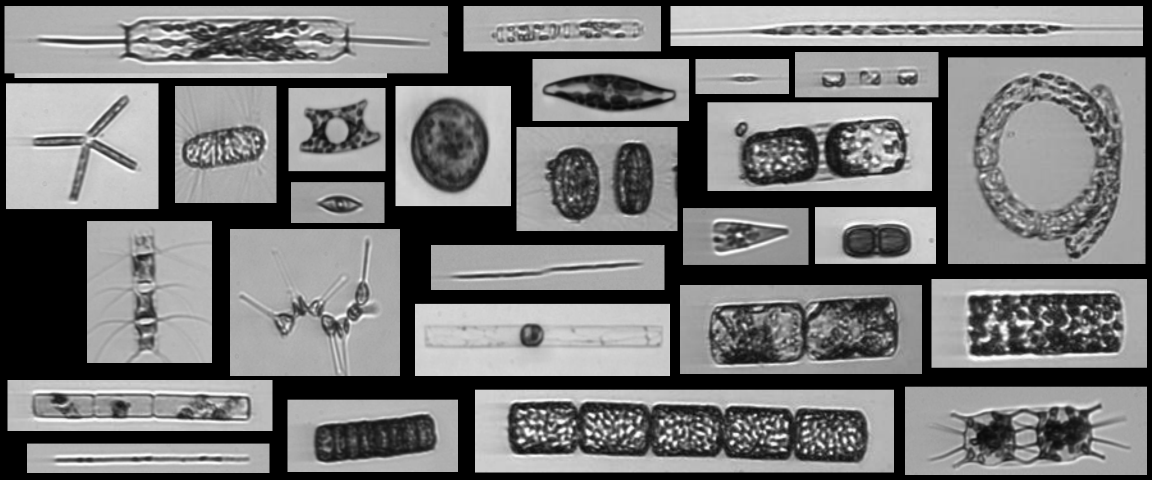
MASCOT deployment off SIO pier

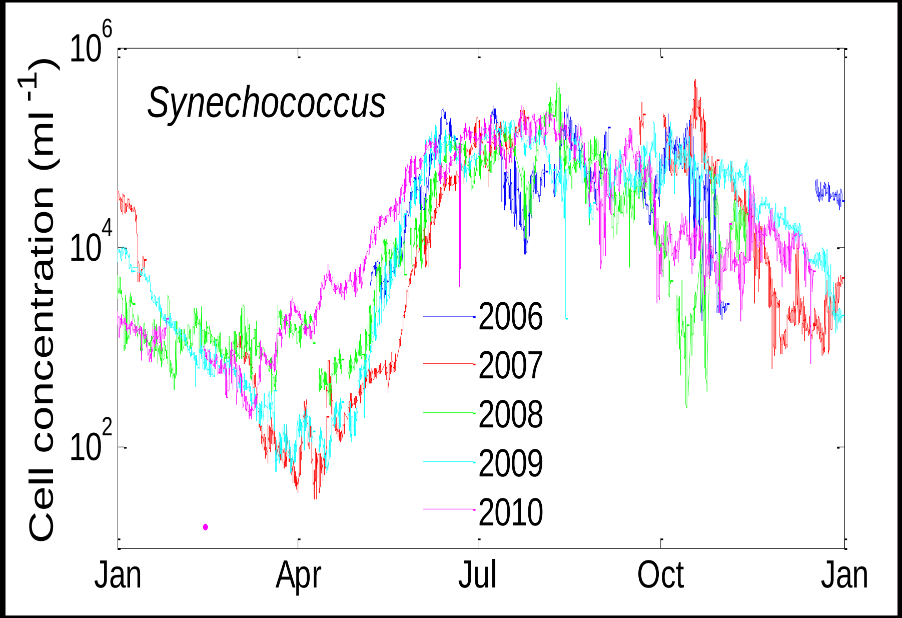


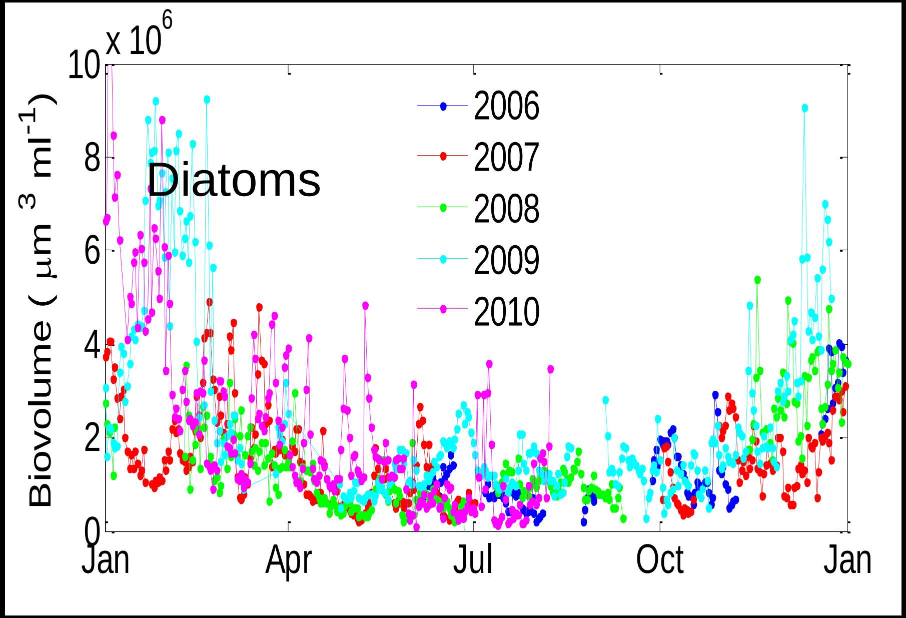
In Situ Imaging FlowCytobot



Single-Cell Cluorescence and Light Scatter
+
Automated Image Interpretation







Olsen & Sosik, 2007; Sosik et al. 2007

Data QA/QC

Data QA/QC Coordination Activities

QARTOD (Quality Assurance for Real-Time Oceanographic Data)

- Interagency effort supporting U.S. IOOS (started in 2003)
- Funded by NOAA/NDBC
- Five workshops convened between 2003 and 2009
- http://nautilus.baruch.sc.edu/twiki/bin/view/Main/WebHome

IMOS National Working Group on Bio-Optical Instrumentation

- Quality Control Workshop Proceedings: http://imos.org.au/qc.html

Bio-Argo profiling float coordination

- http://www.coriolis.eu.org

Ocean Biogeochemical Sensor QA/QC Workshops

- International participation
- 2 workshops convened in 2012, third planned for 2014
- Funded by NASA and MASTS
- Website: http://misclab.umeoce.maine.edu/research/research25.php

CHALLENGES & SUGGESTED ACTIONS

Define all OCS essential variables, required accuracies, and deployment protocols.

Consider co-locating MOBY with Ocean Station Aloha.

Develop plans for populating AERONET-OC sites with biogeochemical sensors and enhancing the radiometry with hyperspectral capability.

Work with ocean observatories to optimize operations for ocean color science.

Define the trade space for profiling float technology between cost, complexity, and science.

Formalize protocols for QA/QC procedures applied to in situ optical and and biogeochemical data.

Then ...

Today ...

Ecosystem
Based
Management