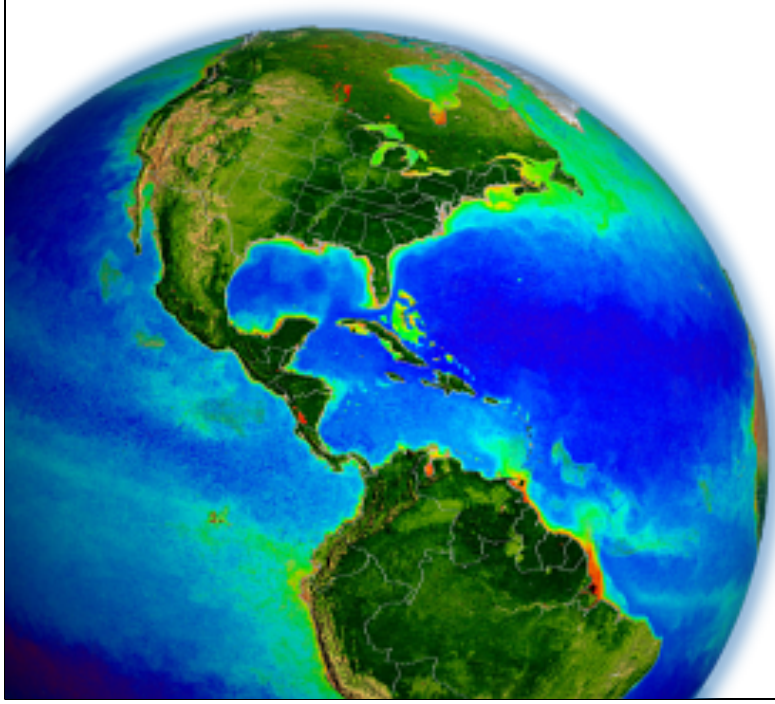
In situ data support for ocean color satellite calibration & validation



Jeremy Werdell

NASA Goddard Space Flight Center

UMaine Ocean Optics Summer Course
July 10 – Aug 4 2017

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“cal/val”

cal/val = **cal**ibration & **val**idation

cal/val has become the catch-all phrase in our community for all activities related to the:

- on-orbit calibration of a satellite instrument
- execution of field programs
- validation of biogeophysical satellite data records
- development of related atmospheric & bio-optical algorithms

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outline

the purpose of this presentation is to:

- provide an overview of how *in situ* data are used in an operational cal/val environment
- describe some of the issues we wrestle with within this environment

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outline

great field data enable great satellite data products

an abundance of field data is hard to come by

emerging technologies can provide rich data streams

QA/QC metrics are essential (or this all falls apart)
= quality assurance & quality control

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NASA Ocean Biology & Biogeochemistry Program

field work funded by OBB Program

QA/QC

by data contributor

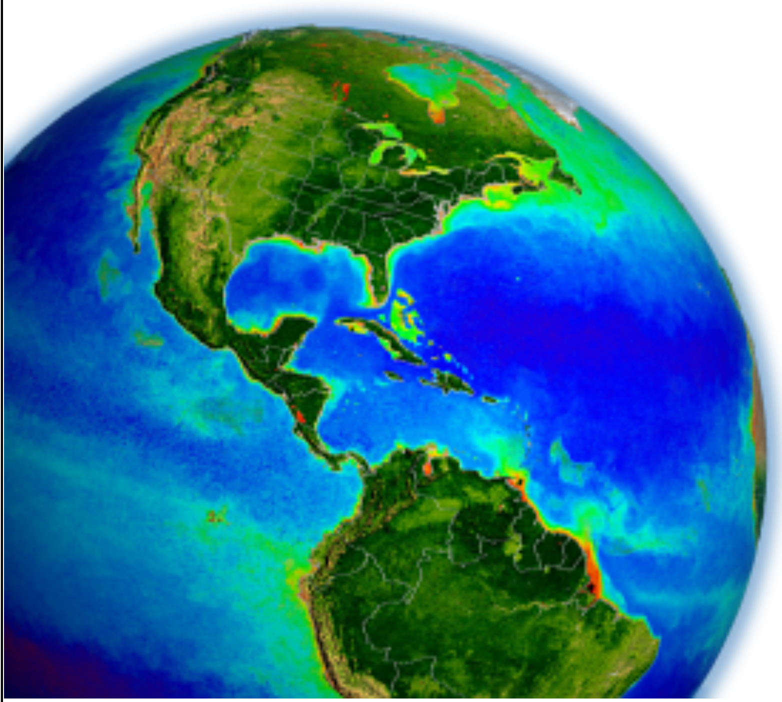
in situ data submitted to NASA SeaBASS (GSFC) within 1-year

by NASA

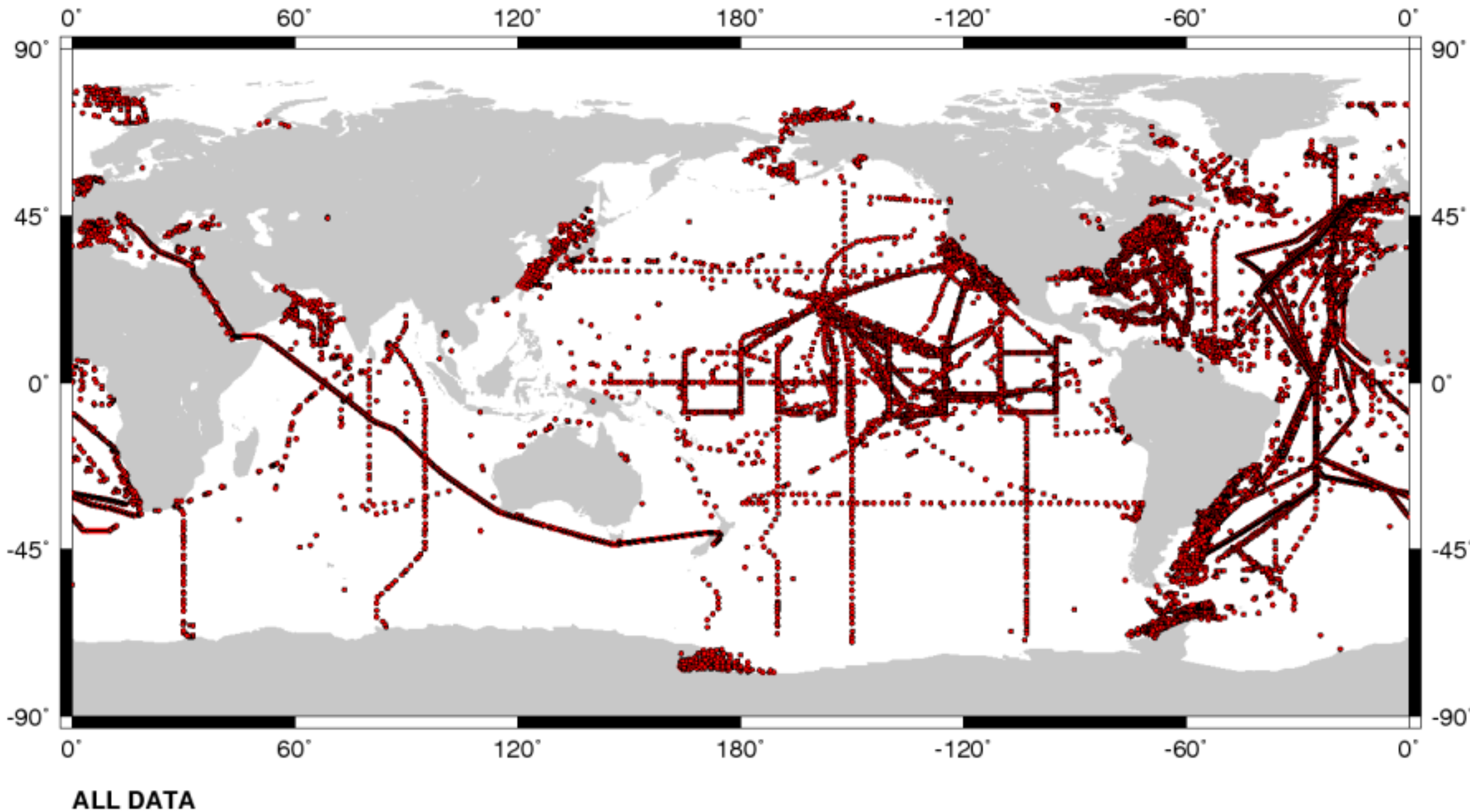
in situ data publicly released

in situ data used to validate satellite data products & to develop / evaluate algorithms

in situ used to calibrate satellite



SeaBASS @ seabass.gsfc.nasa.gov



AOPs, IOPs, carbon stocks, CTD, pigments, aerosols, etc.

continuous & discrete profiles; some fixed observing or along-track

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satellite vicarious calibration (instrument + algorithm adjustment)

satellite data product validation

bio-optical algorithm development, tuning, & evaluation

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vicarious calibration

what is vicarious calibration?

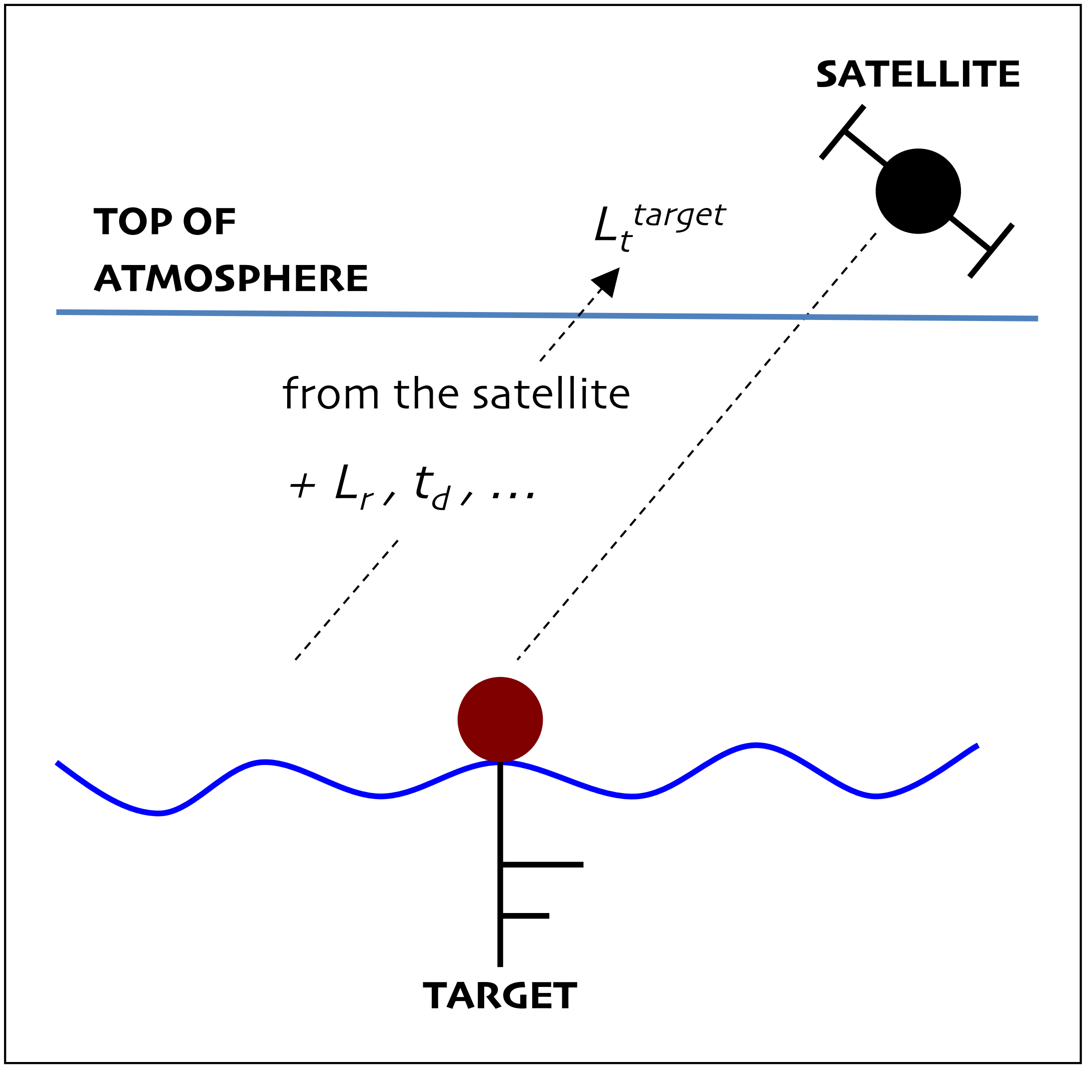
<u>spectral on-orbit calibrations</u>

1. pre-launch instrument calibration
   - e.g., focal plane temperature

2. temporal calibration
   - reference Sun or Moon

3. absolute (vicarious) calibration
   - reference Earth surface
   - final, single gain adjustment
   - calibration of the combined instrument + algorithm system

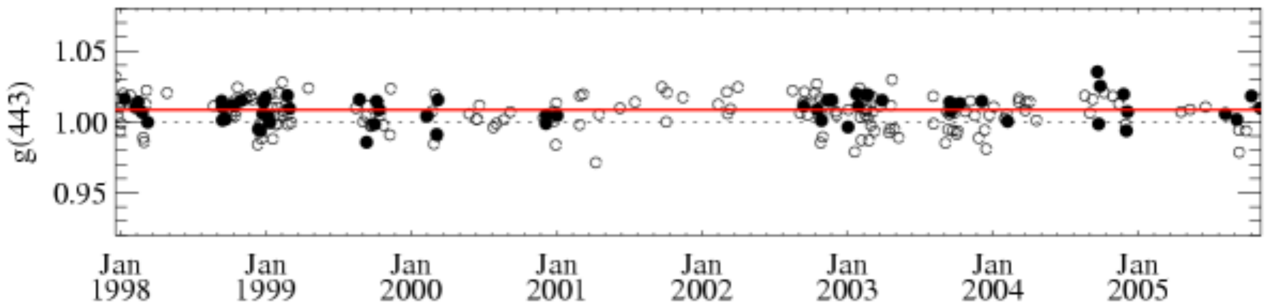
$g = L_t^{target} / L_t^{satellite}$



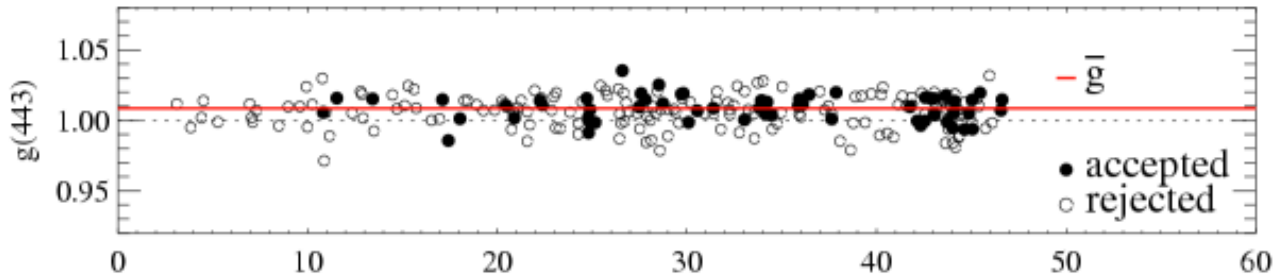
vicarious calibration

a single, spectral radiometric adjustment

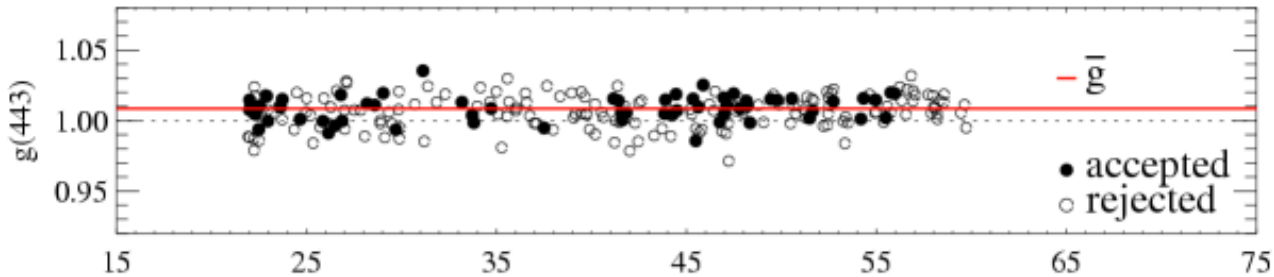
gain vs. time



gain vs. solar zenith angle



gain vs. satellite zenith angle



Franz et al. 2007

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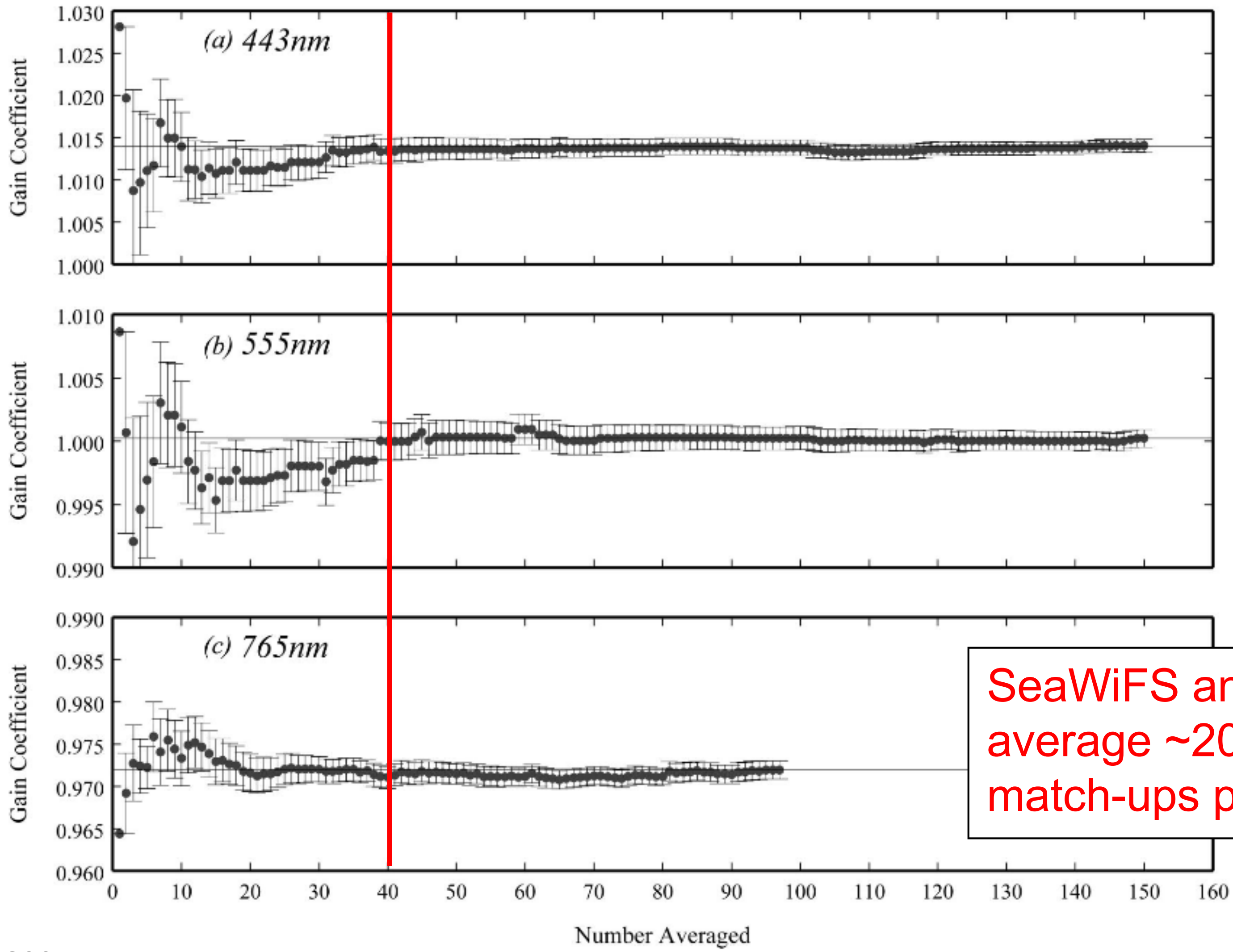
vicarious calibration

~40 match-ups required to achieve "stable" vicarious gain



SeaWiFS and Aqua average ~20 MOBY match-ups per year

Franz et al. 2007

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operational vicarious calibration

MOBY - the Marine Optical BuoY

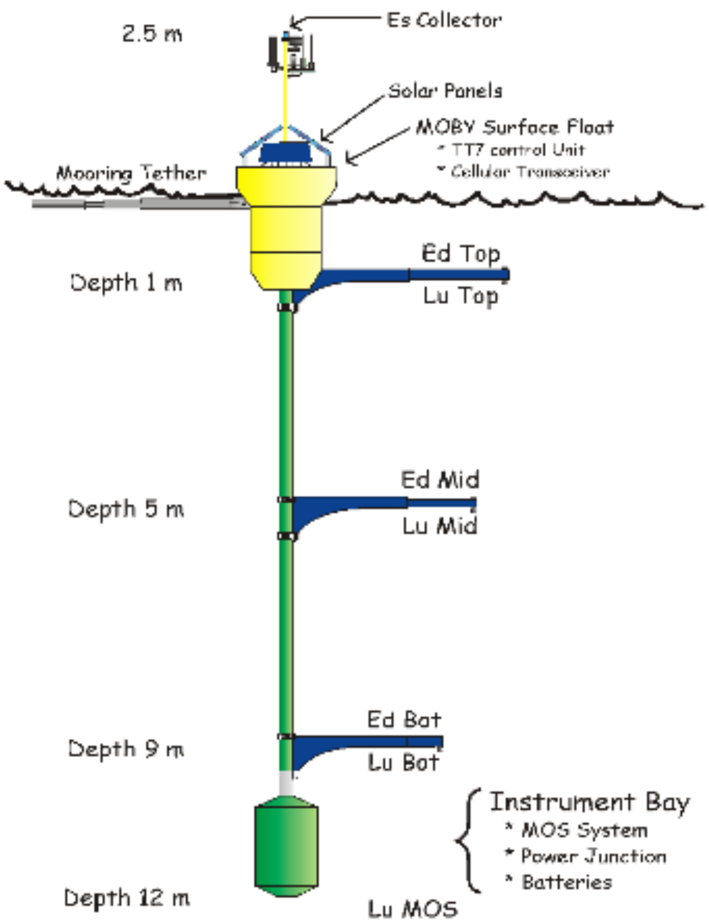

Fig. 1. Schematic diagram of MOBY.

maintained by UMiami, NOAA, NIST, & Moss Landing Marine Laboratory

20 miles west of Lanai, Hawaii

$L_u(\lambda)$ and $E_d(\lambda)$ at nominal depths of 1, 5, and 9 meters, plus $E_s(\lambda)$

spectral range is 340-955 nm & spectral resolution is 0.6 nm

hyperspectral data convolved to specific bandpasses of each satellite

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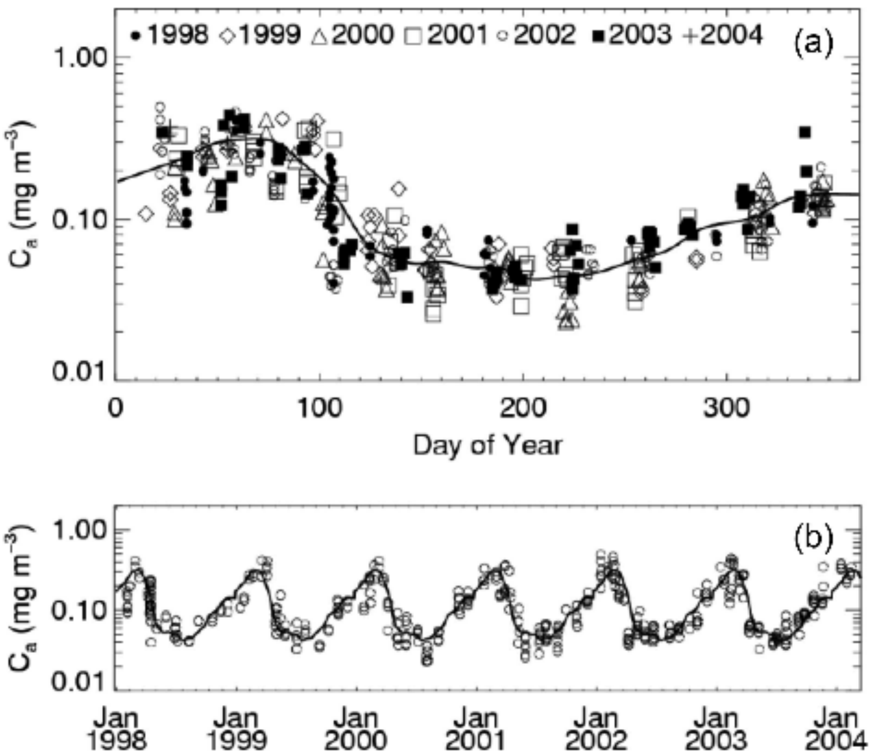
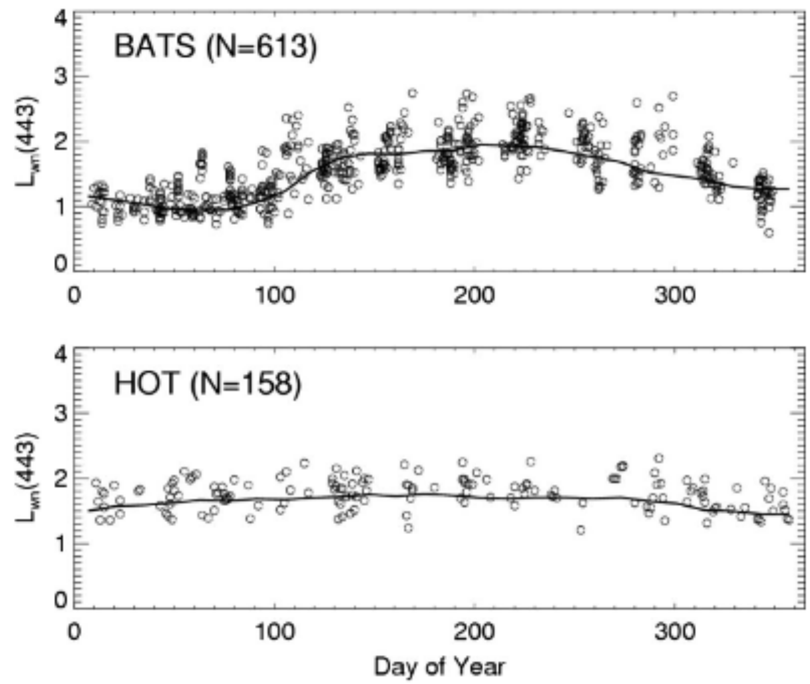
model-based vicarious calibration

build a climatology using a long-term Chl record (this is for BATS, near Bermuda) …





$$L_{wn}(\lambda) = F(\mathrm{Chl})$$

… then, develop a $L_{wn}(\lambda)$ or $R_{rs}(\lambda)$ climatology using an ocean reflectance model (e.g., Morel & Maritorena 2001)

Werdell et al. 2007

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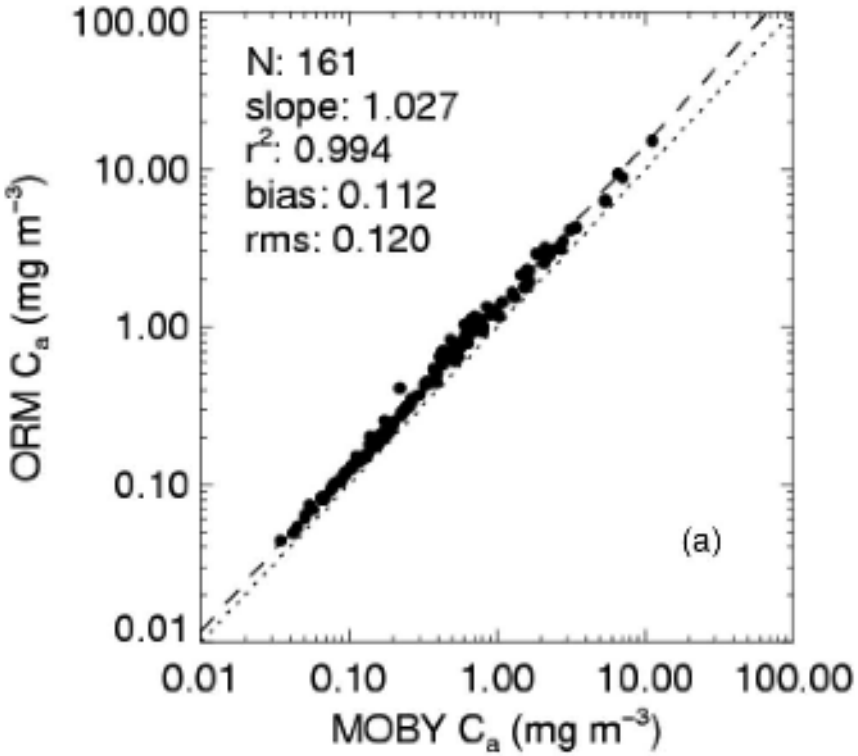
model-based vicarious calibration

Table 3. Percent Differences[a] Between the MOBY and ORM $\bar{g}$

	412	443	490	510	555	670
BATS	−0.31	−1.18	−1.14	−0.52	0.14	−0.07
HOTS	−0.74	−0.53	−0.48	−0.14	0.44	−0.21
BATS + HOTS	−0.52	−0.86	−0.81	−0.33	0.29	−0.13

[a]Calculated using $(\bar{g}_{ORM} - \bar{g}_{MOBY}) \times 100\%/\bar{g}_{MOBY}$.

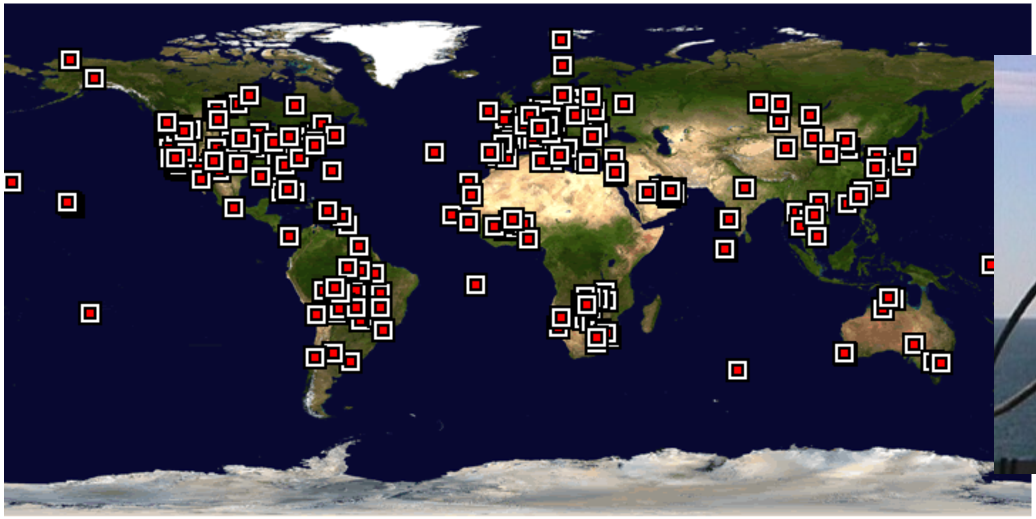


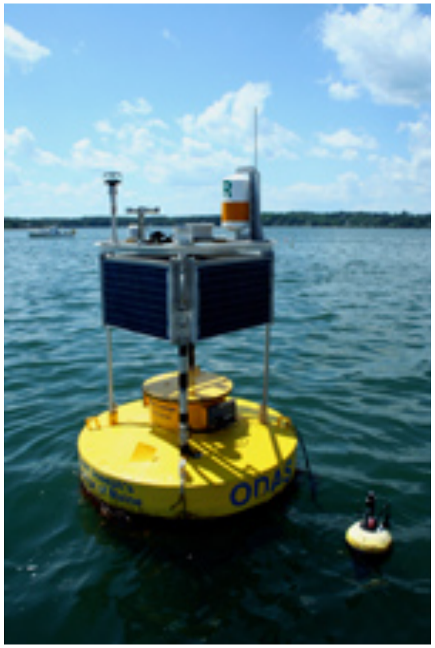
model-based gains typically differ from MOBY gains by < 1%

Werdell et al. 2007

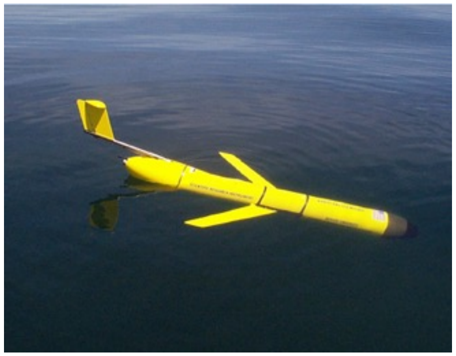
alternative data for vicarious calibration

AERONET (fixed-above water platforms)



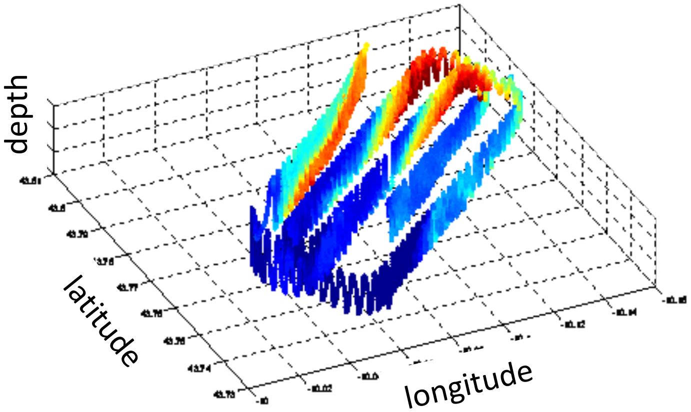


buoy networks



gliders, drifters, & other autonomous platforms

towed & underway sampling



alternative data for vicarious calibration

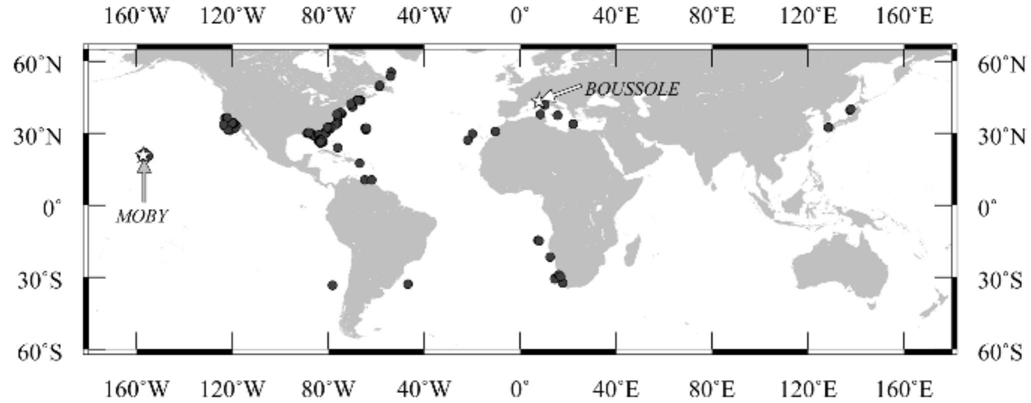


Fig. 1. Map showing the locations for the *in situ* data used in this study.

gains calculated using alternative *in situ* data typically differ from MOBY by < 0.3%

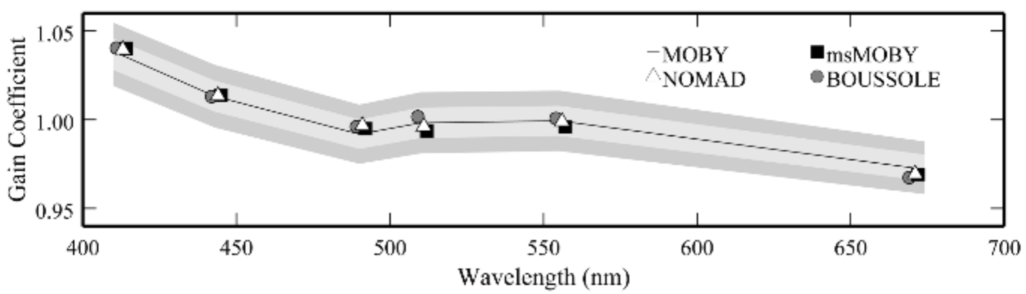


Fig. 3. Vicarious calibration coefficients as a function of wavelength. The standard MOBY-derived $\bar{g}_\lambda'$ (solid curve) are overplotted by the msMOBY-, NOMAD-, and BOUSSOLE-derived $\bar{g}_\lambda'$. The shaded regions indicate the ranges for the first (light-gray) and second (dark-gray) standard deviations of the mean for $\bar{g}_\lambda'$.

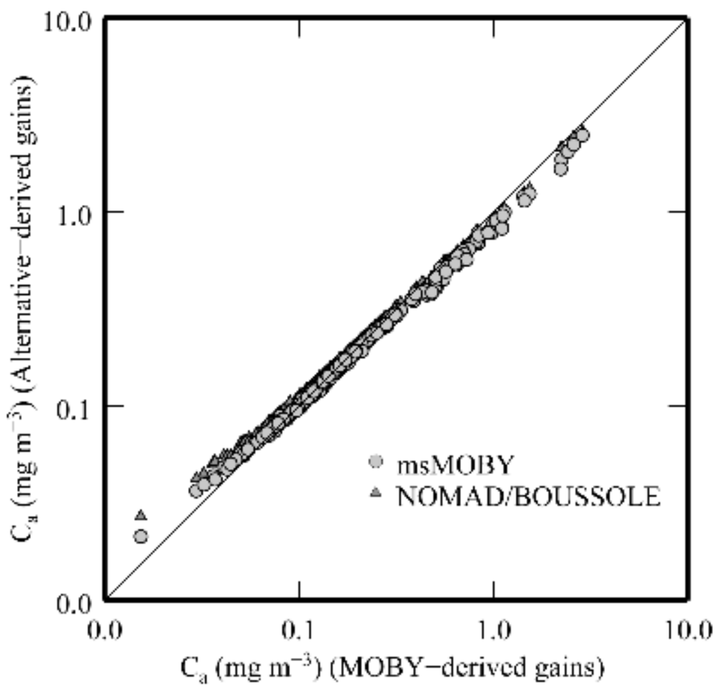


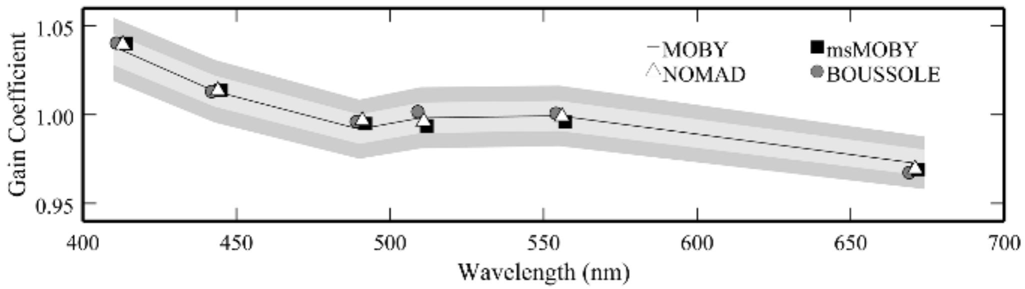
Fig. 7. Satellite-derived chlorophyll estimated from the two alternative $\bar{g}'$ gain sets (msMOBY and NOMAD/BOUSSOLE) plotted versus the corresponding chlorophyll estimated from the standard MOBY $\bar{g}$.

Bailey et al. 2008

selecting vicarious calibration sources

the gains shown previously for the multiple "ground-truth" targets differ only from 0.3 to 1%, but there are spectral dependencies in their differences …

spectral differences impart **changes** in derived products



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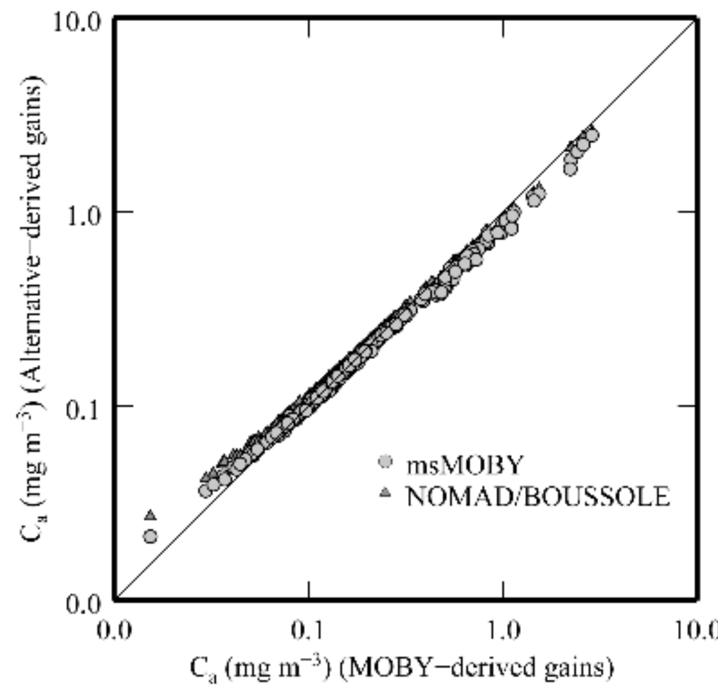

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great field data enable great satellite data products

satellite vicarious calibration (instrument + algorithm adjustment)

satellite data product validation

bio-optical algorithm development, tuning, & evaluation

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Level-2 match-ups

general flow of match-up process, with exclusion criteria

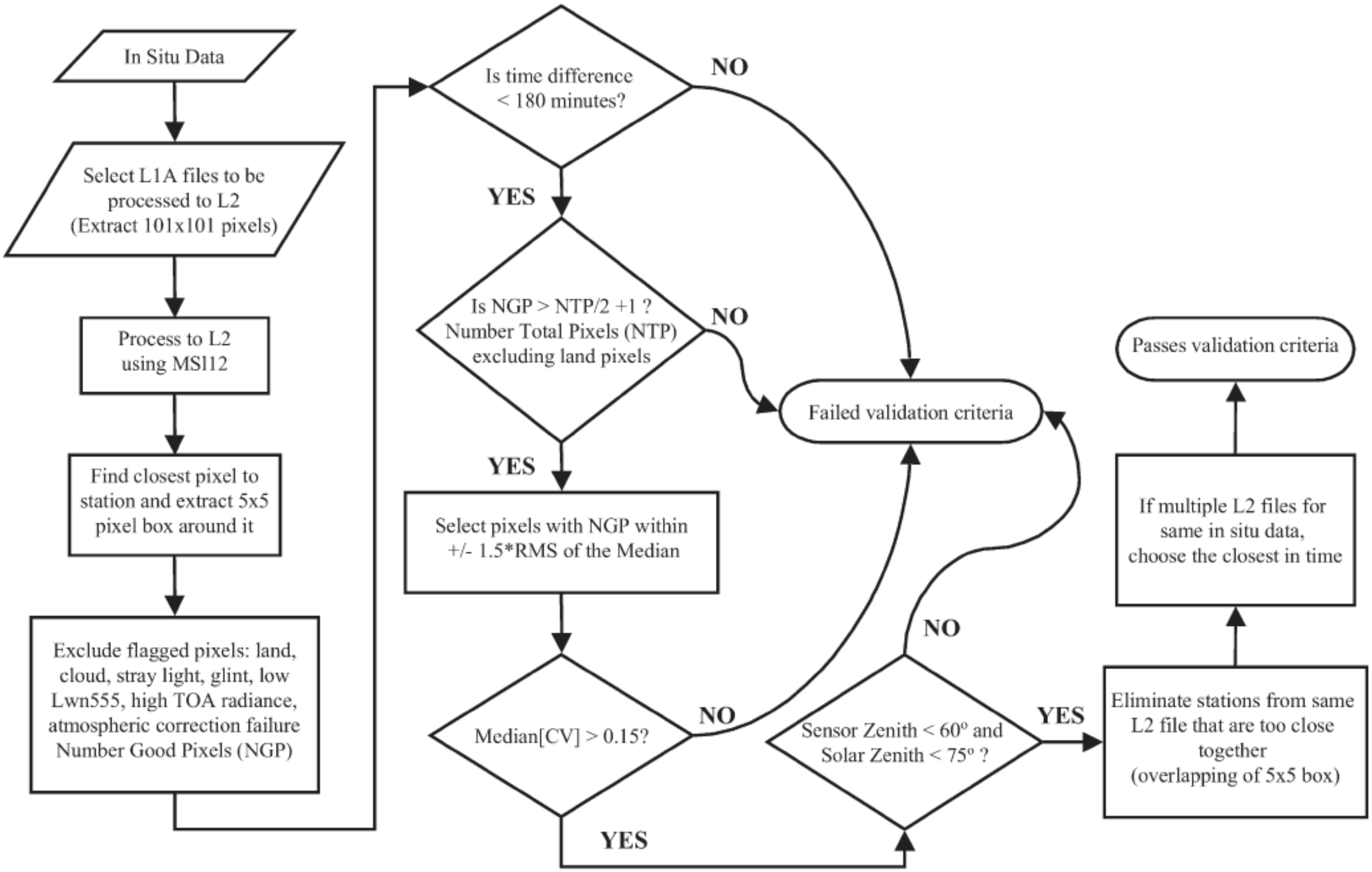

Fig. 1. Flowchart of the validation process highlighting the applied exclusion criteria.

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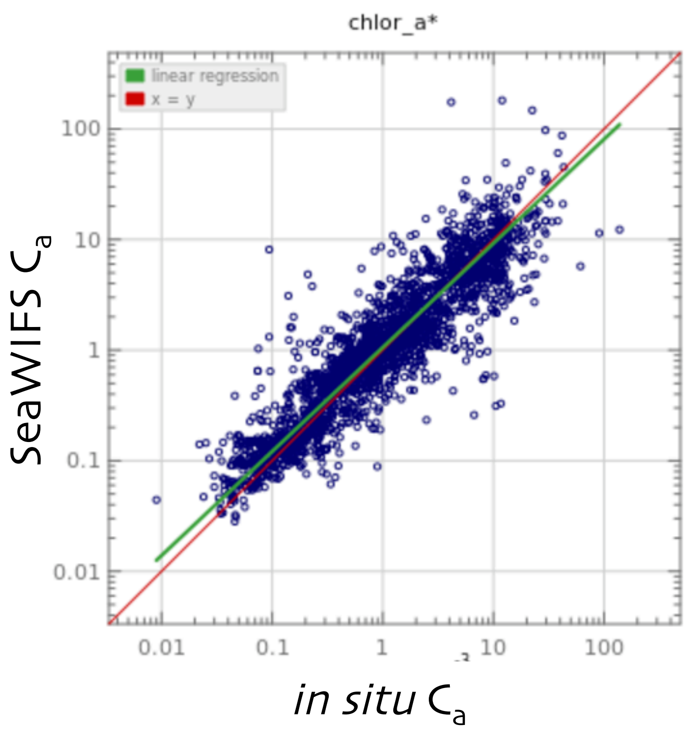
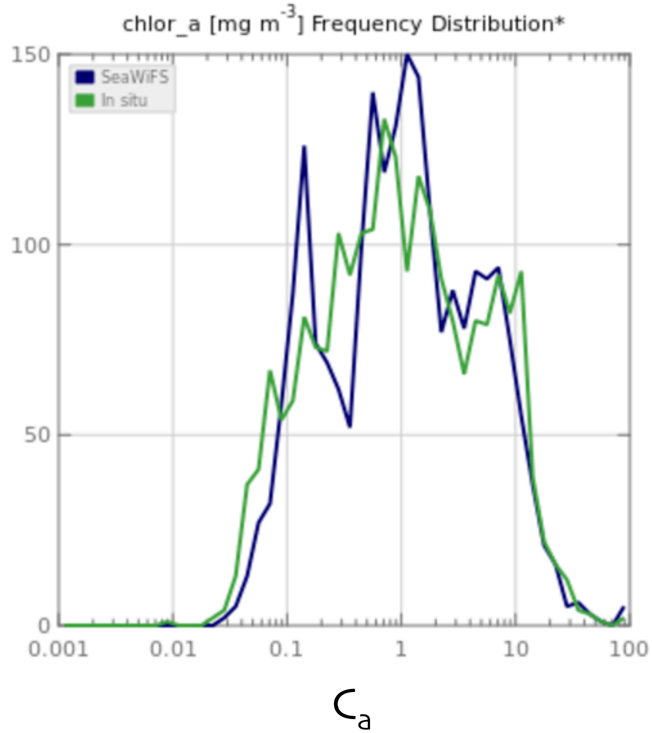
Level-2 match-ups

comparison of “coincident” *in situ* & satellite measurements

Product Name	SeaWiFS Range	In situ Range	#	Best Fit Slope*	Best Fit Intercept*	R^2*	Median Ratio	Median % Difference	RMSE*
chlor_a	0.02818 - 181.40287	0.00900 - 138.04700	2244	0.94136	0.02518	0.82849	1.07149	36.78435	0.29550

* statistical calculations based on log10 (implies ignoring values of zero)





Bailey & Werdell 2006

https://seabass.gsfc.nasa.gov/search

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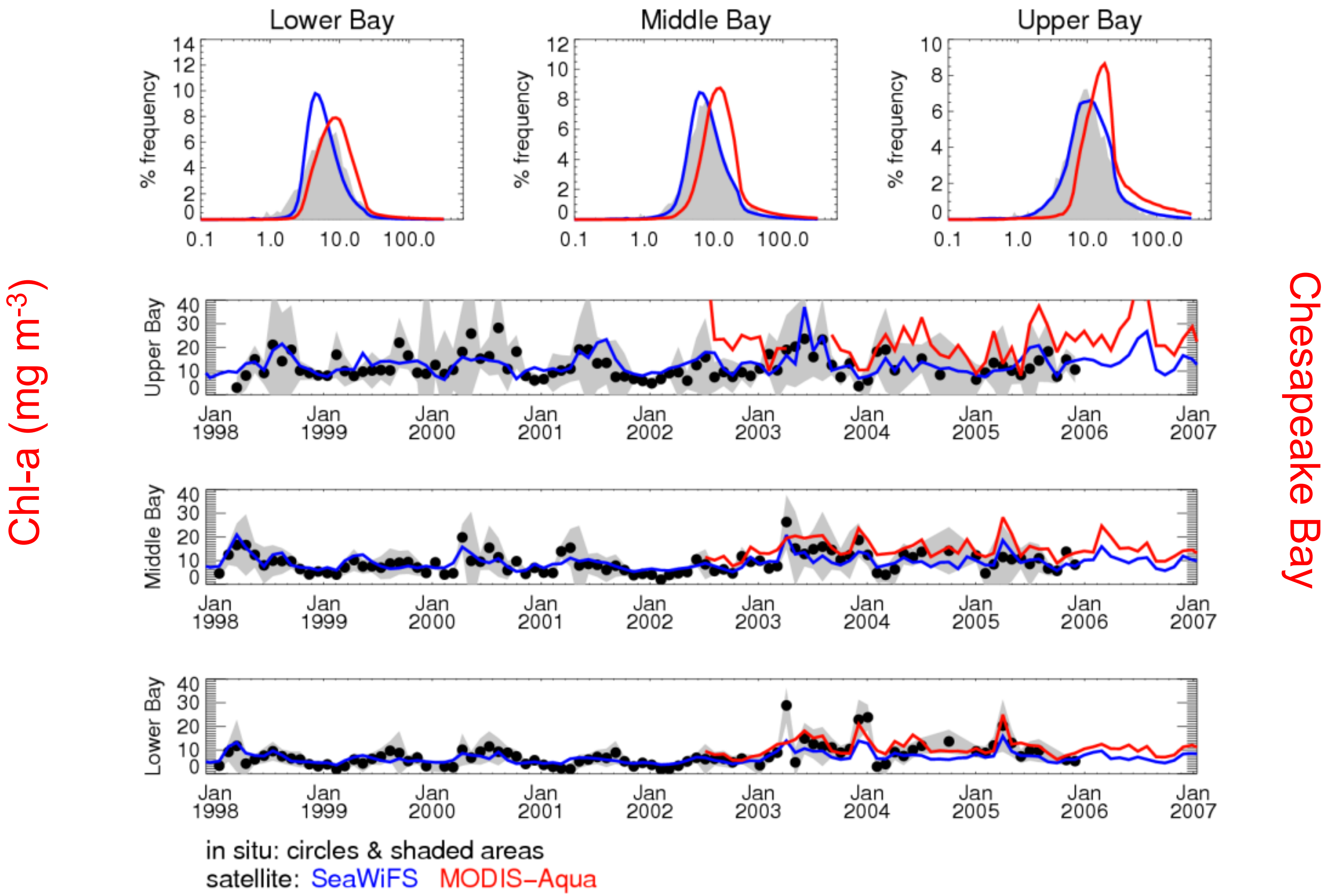
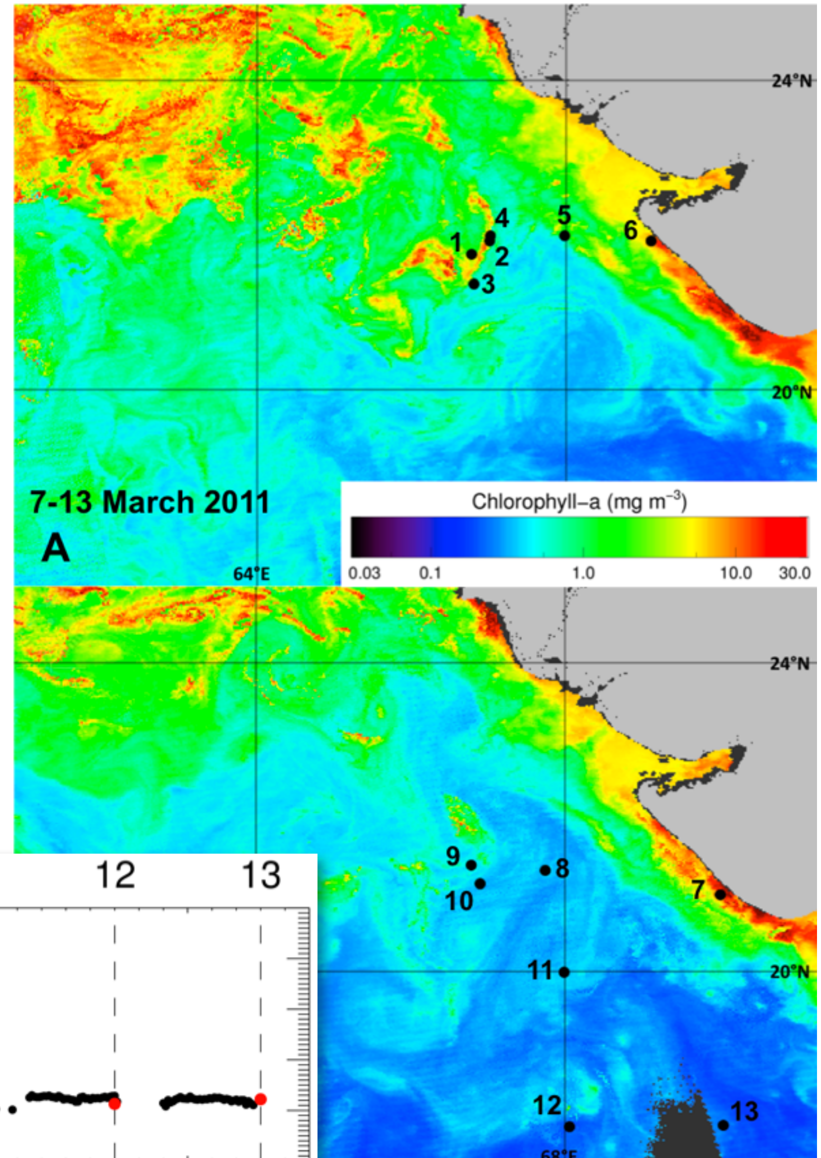
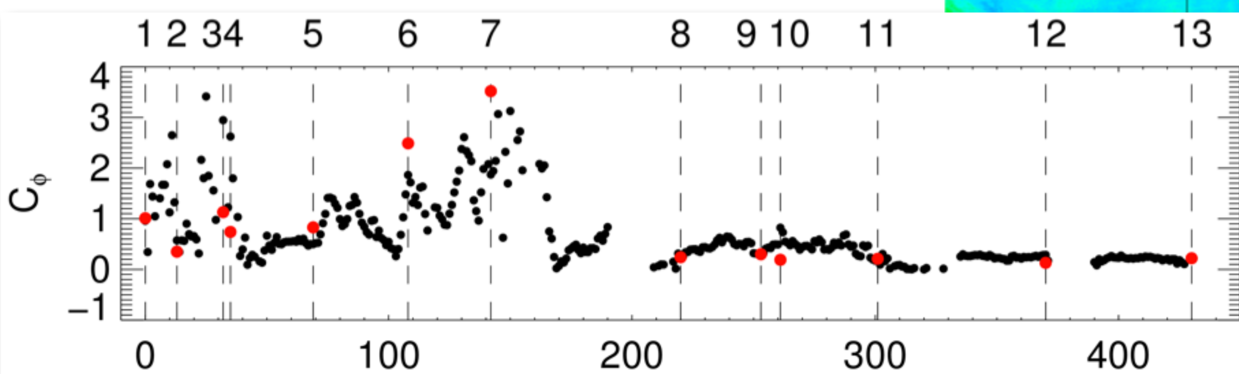
Level-2 time-series



Werdell et al. 2009

along-track comparisons





along track satellite pixel (in situ, Aqua)

common limitations

quality of *in situ* data is highly variable & difficult to assess

in situ data coverage is limited, both geographically & temporally

availability of *in situ* data in future is unknown

highly localized (~meters) measurements represent pixel (>km) area

satellite-to-*in situ* comparisons require expertise to prepare & evaluate

generally useful only for assessing static biases in final products

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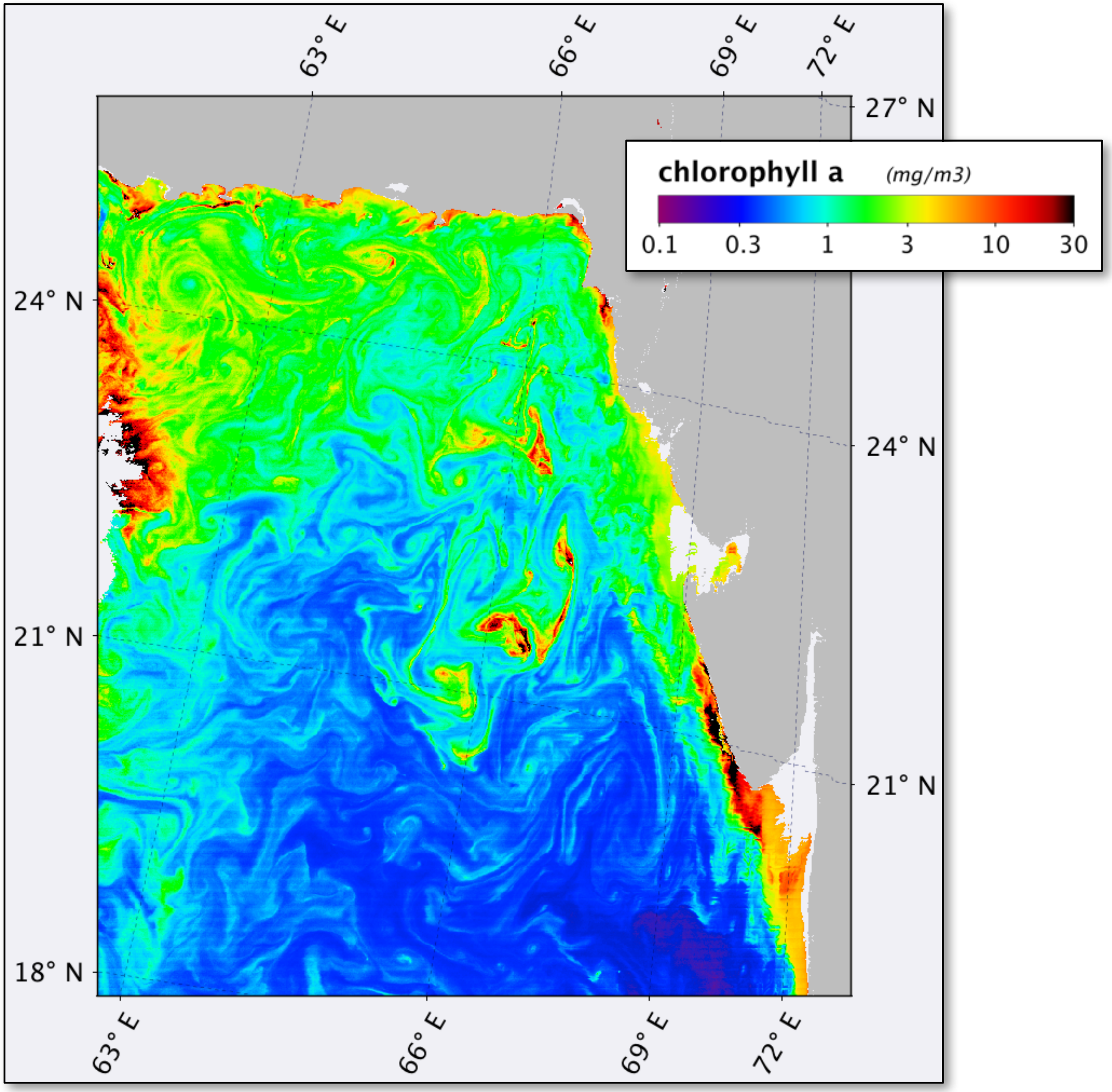
lessons learned & anticipated challenges

data collection

- horizontal resolution
- temporal resolution
- vertical resolution



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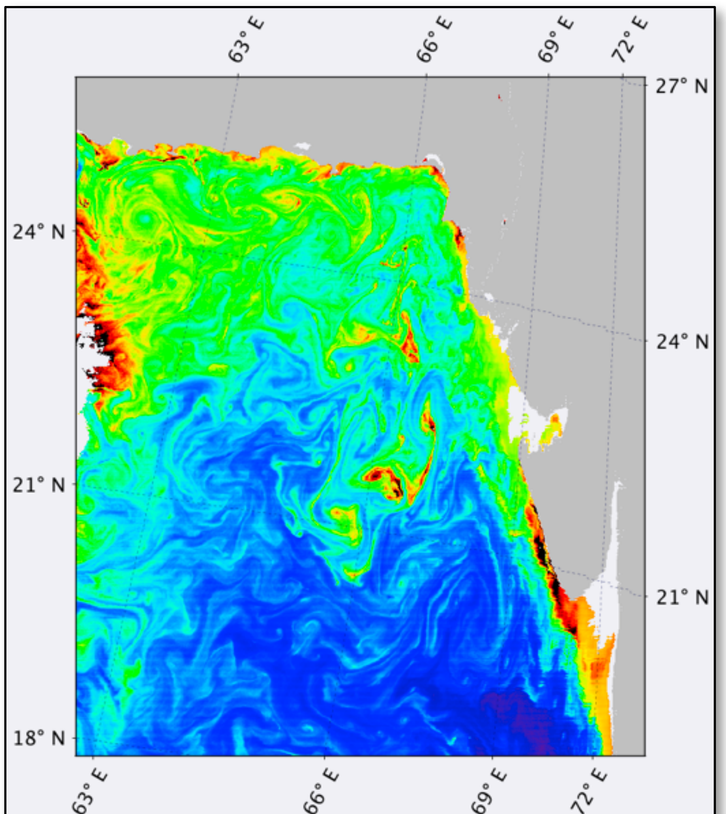

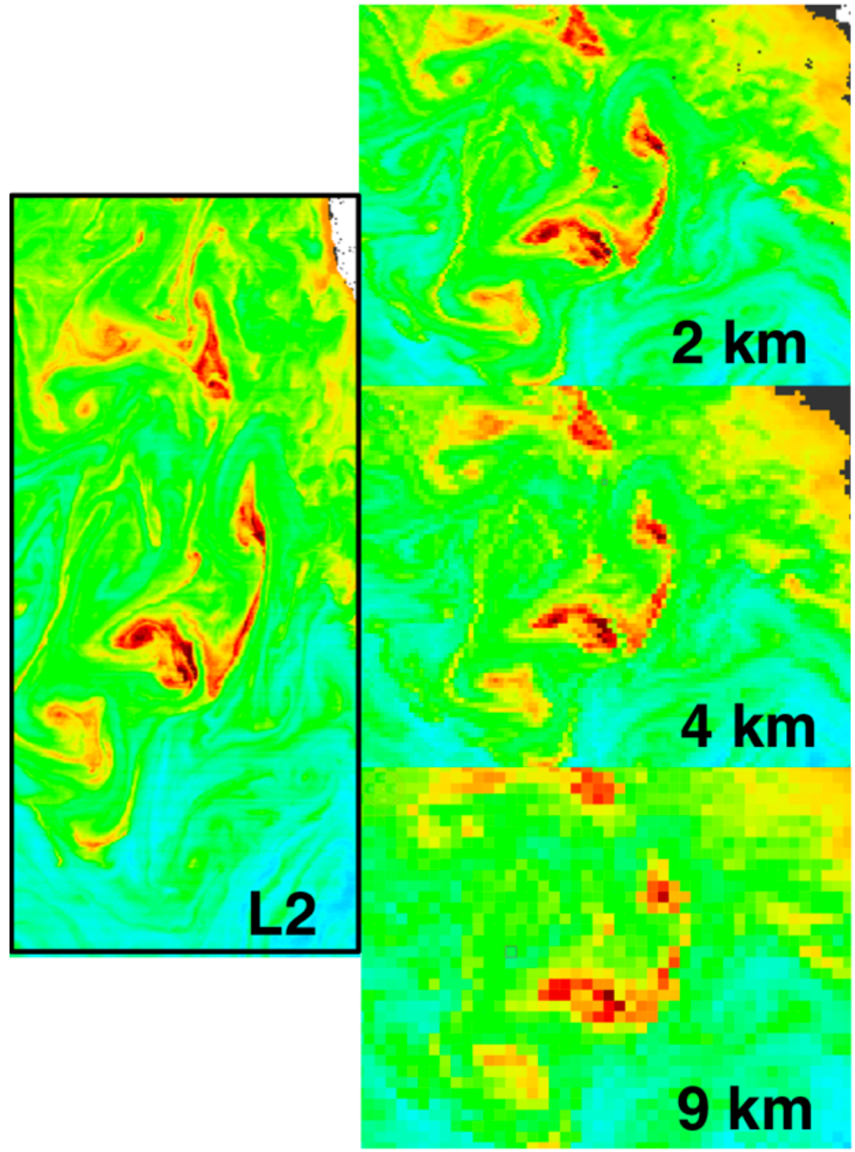

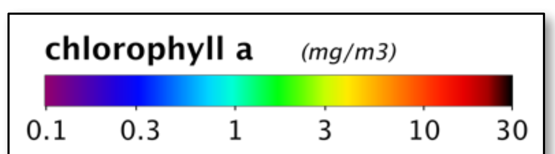

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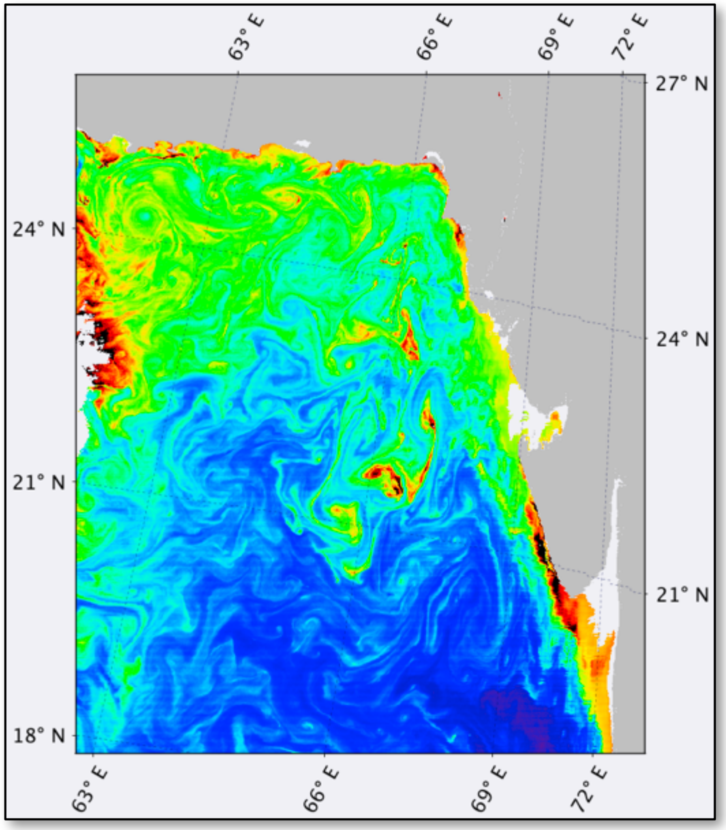

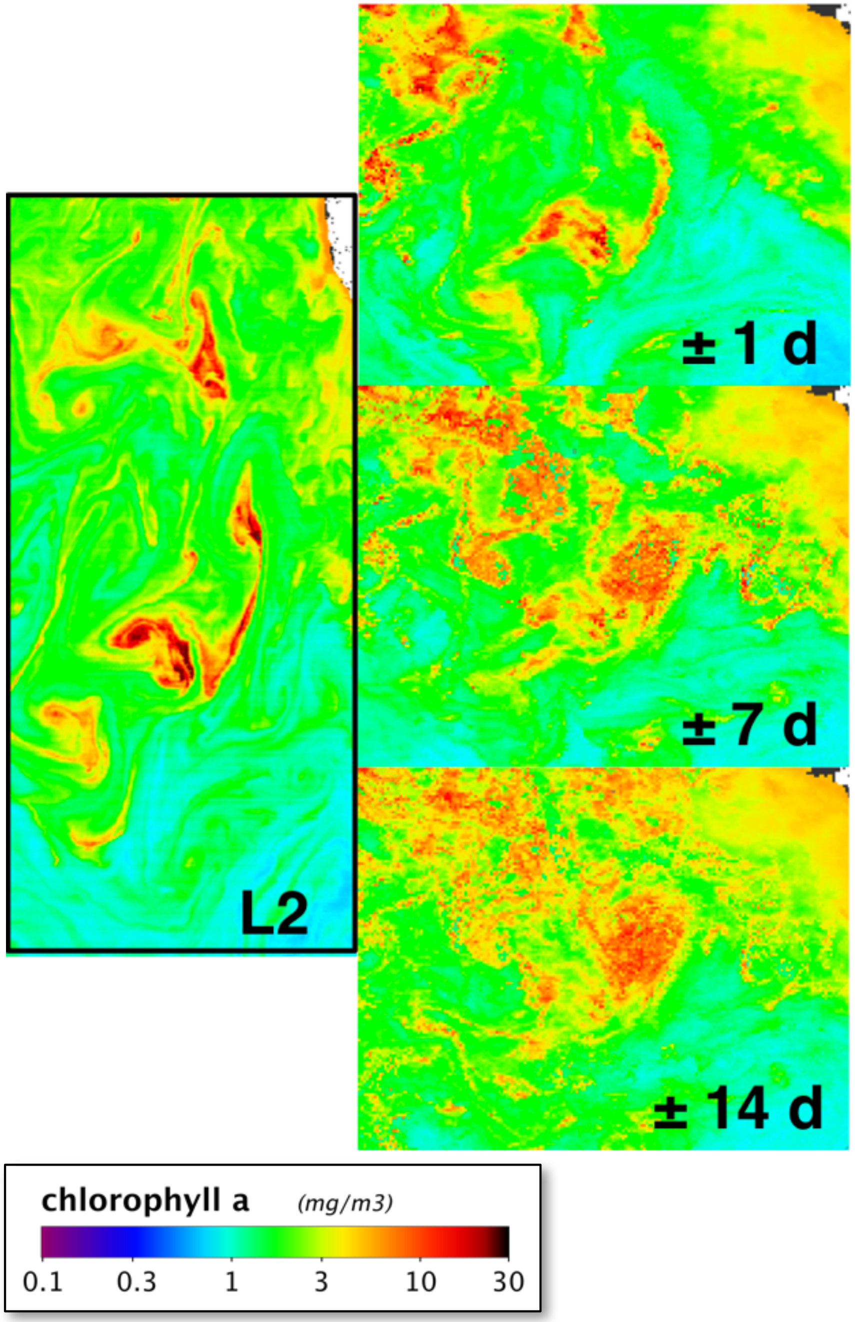

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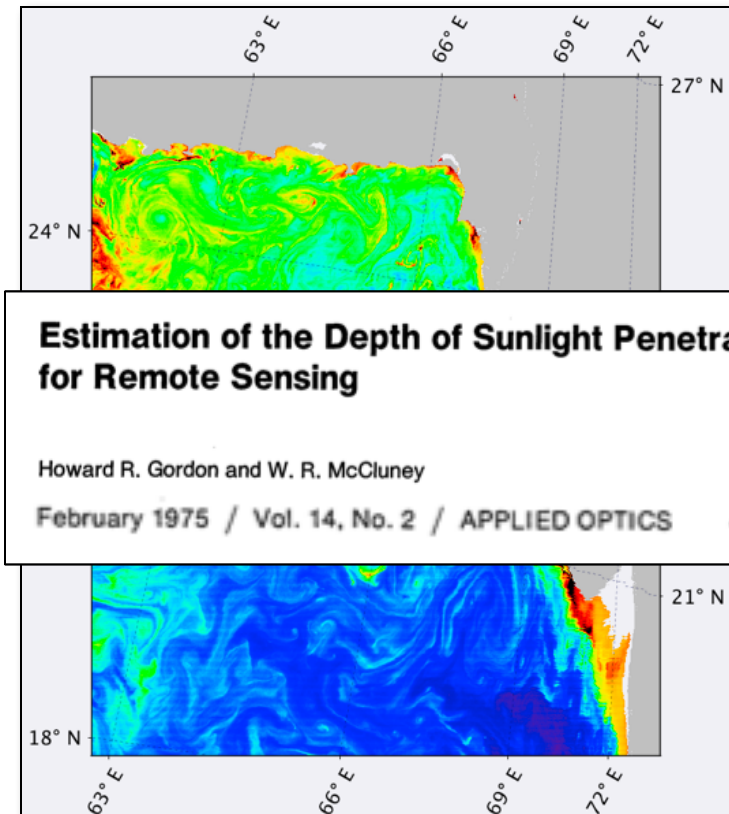
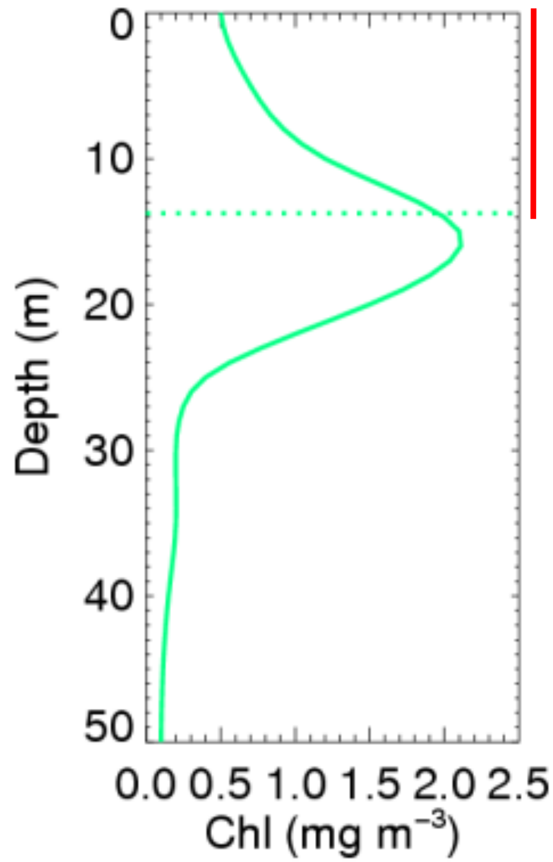


Estimation of the Depth of Sunlight Penetration in the Sea for Remote Sensing

Howard R. Gordon and W. R. McCluney

February 1975 / Vol. 14, No. 2 / APPLIED OPTICS 413



first optical depth

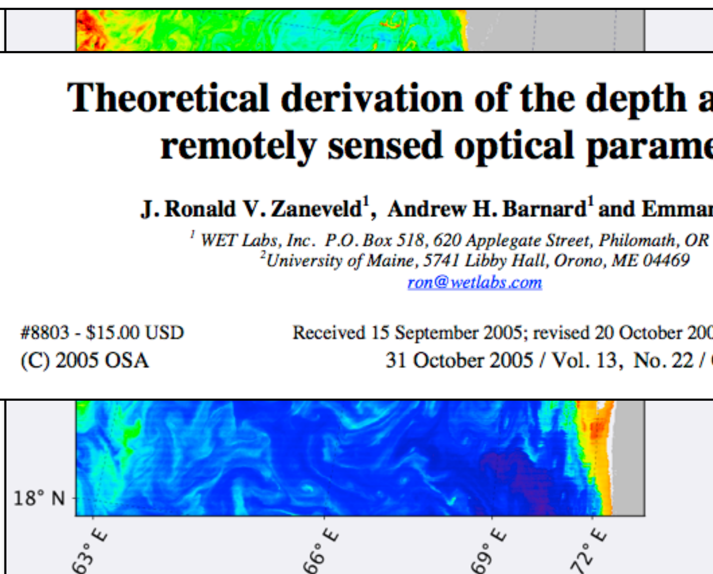
$0.37 = \exp(-K_d\, z)$

$-1 = -K_d\, z$

lessons learned & anticipated challenges

data collection
- horizontal resolution
- temporal resolution
- vertical resolution

not only is the resolution of vertical sampling important, but we must also understand (accept & ultimately consider) what the satellite sees & does not see



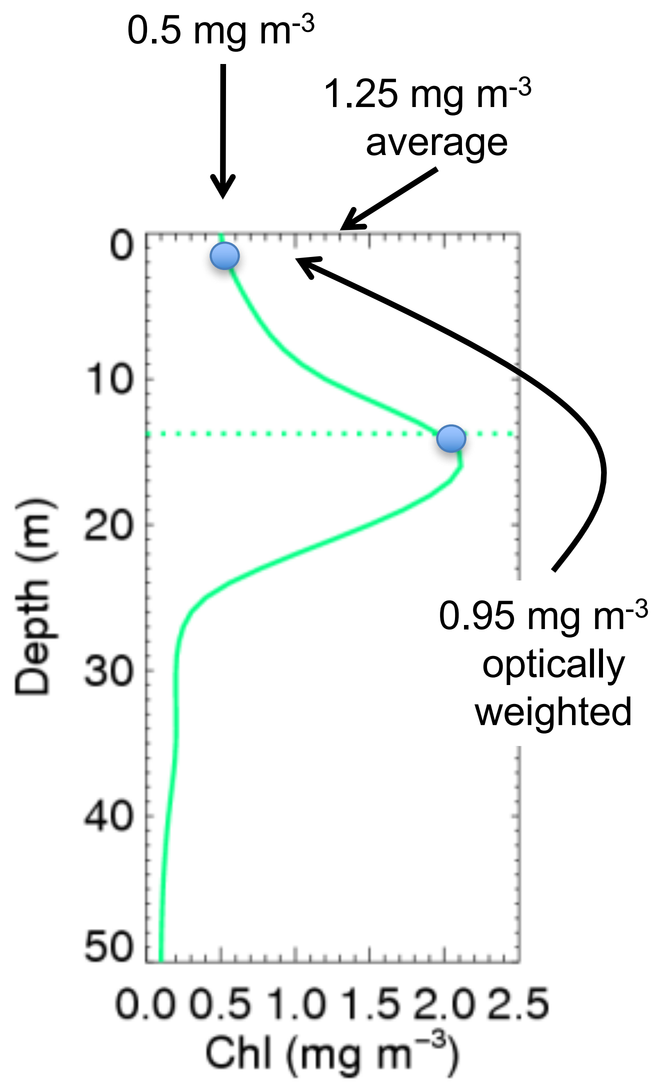
Theoretical derivation of the depth average of remotely sensed optical parameters

J. Ronald V. Zaneveld[1], Andrew H. Barnard[1] and Emmanuel Boss[2]

[1] WET Labs, Inc. P.O. Box 518, 620 Applegate Street, Philomath, OR 97370
[2] University of Maine, 5741 Libby Hall, Orono, ME 04469
ron@wetlabs.com

#8803 - $15.00 USD Received 15 September 2005; revised 20 October 2005; accepted 24 October 2005

31 October 2005 / Vol. 13, No. 22 / OPTICS EXPRESS 9052



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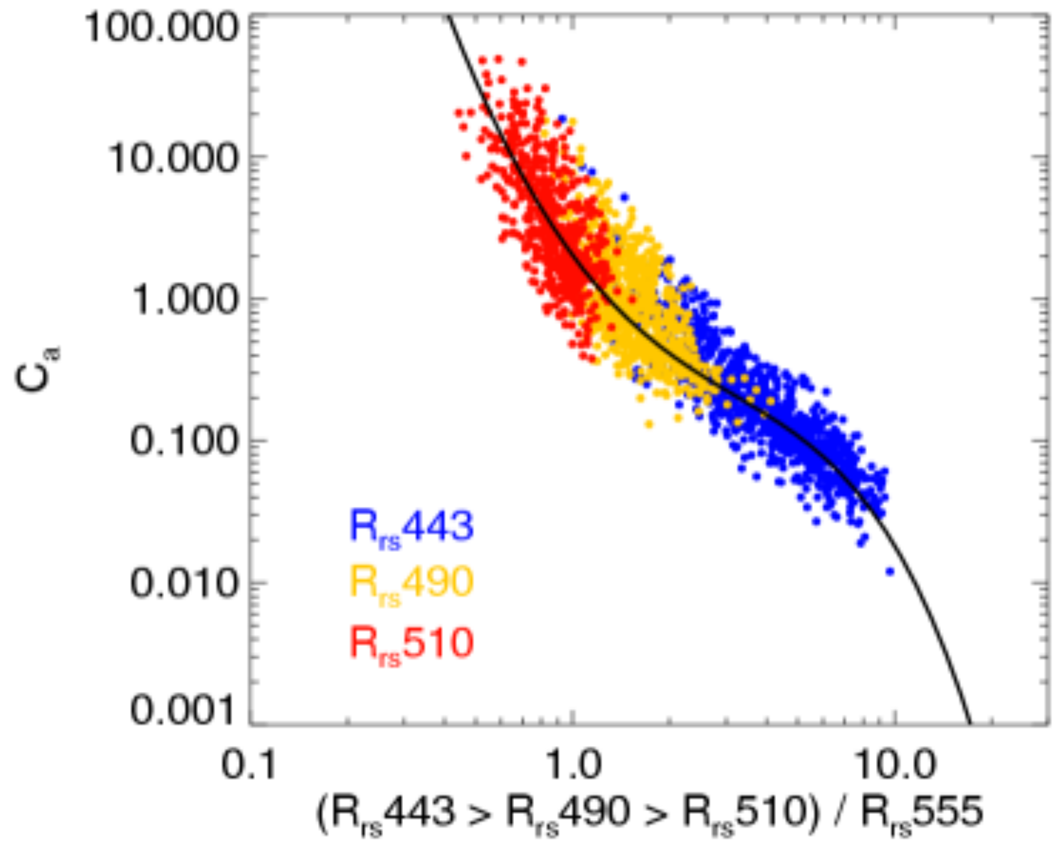
in-water algorithms



R_{rs} related to pigments, IOPs, carbon stocks, etc.

what satellite sees | what you might want to study

atmospheric correction

in situ data are used in the development of:

aerosol tables (via AERONET)

the correction for non-zero R_{rs}(NIR)

the correction for bidirectional effects (f/Q)

the correction for spectral bandpass effects

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an abundance of field data is hard to come by

spatial & temporal distributions

“complete” suites of measurements (R_{rs}, IOPs, biogeochemistry)

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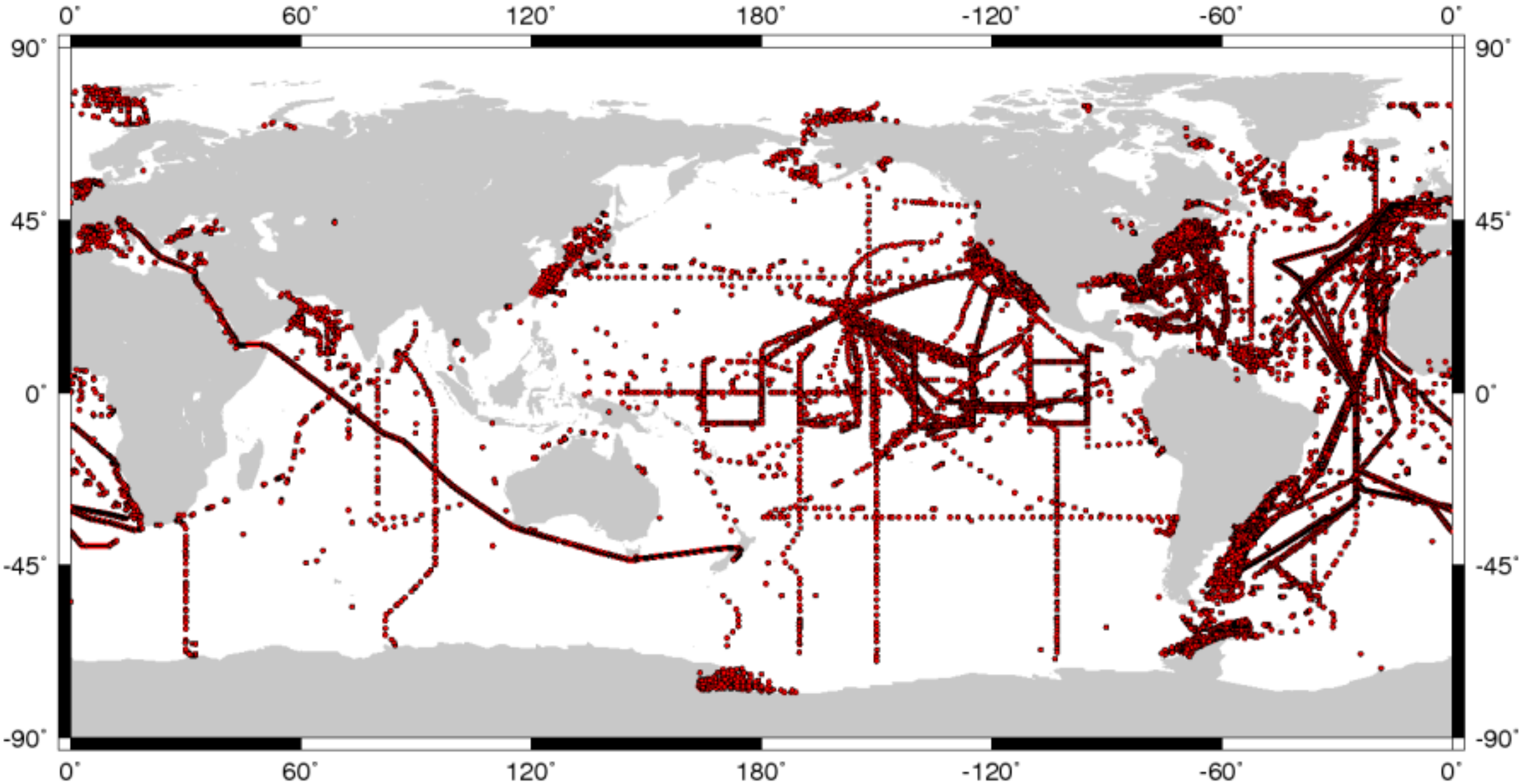
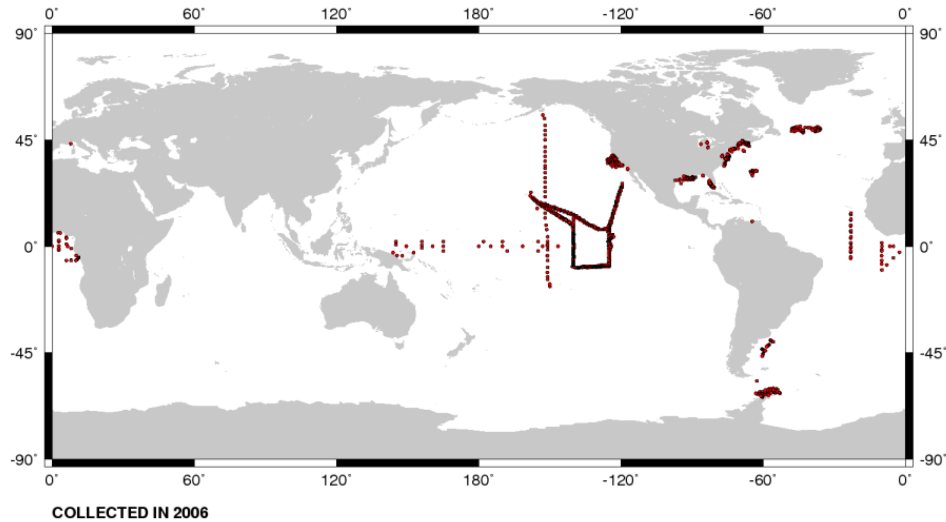
SeaBASS @ seabass.gsfc.nasa.gov



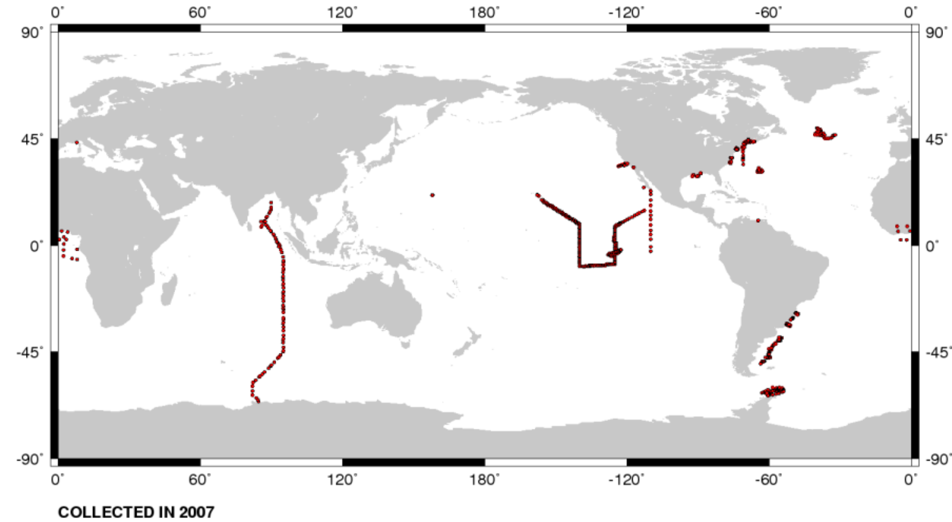
ALL DATA

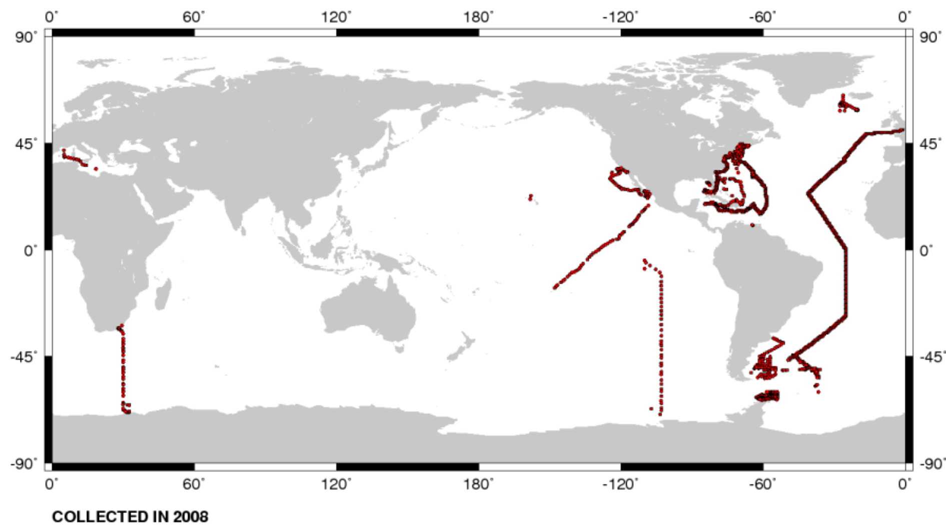
SeaBASS holdings by year: 2006-2009

2006

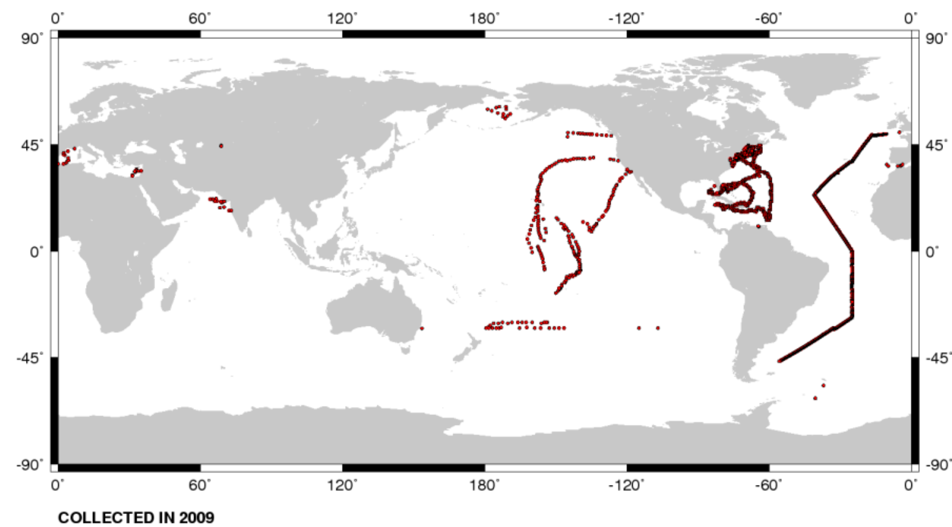


2007





2008



2009

Level-2 match-ups

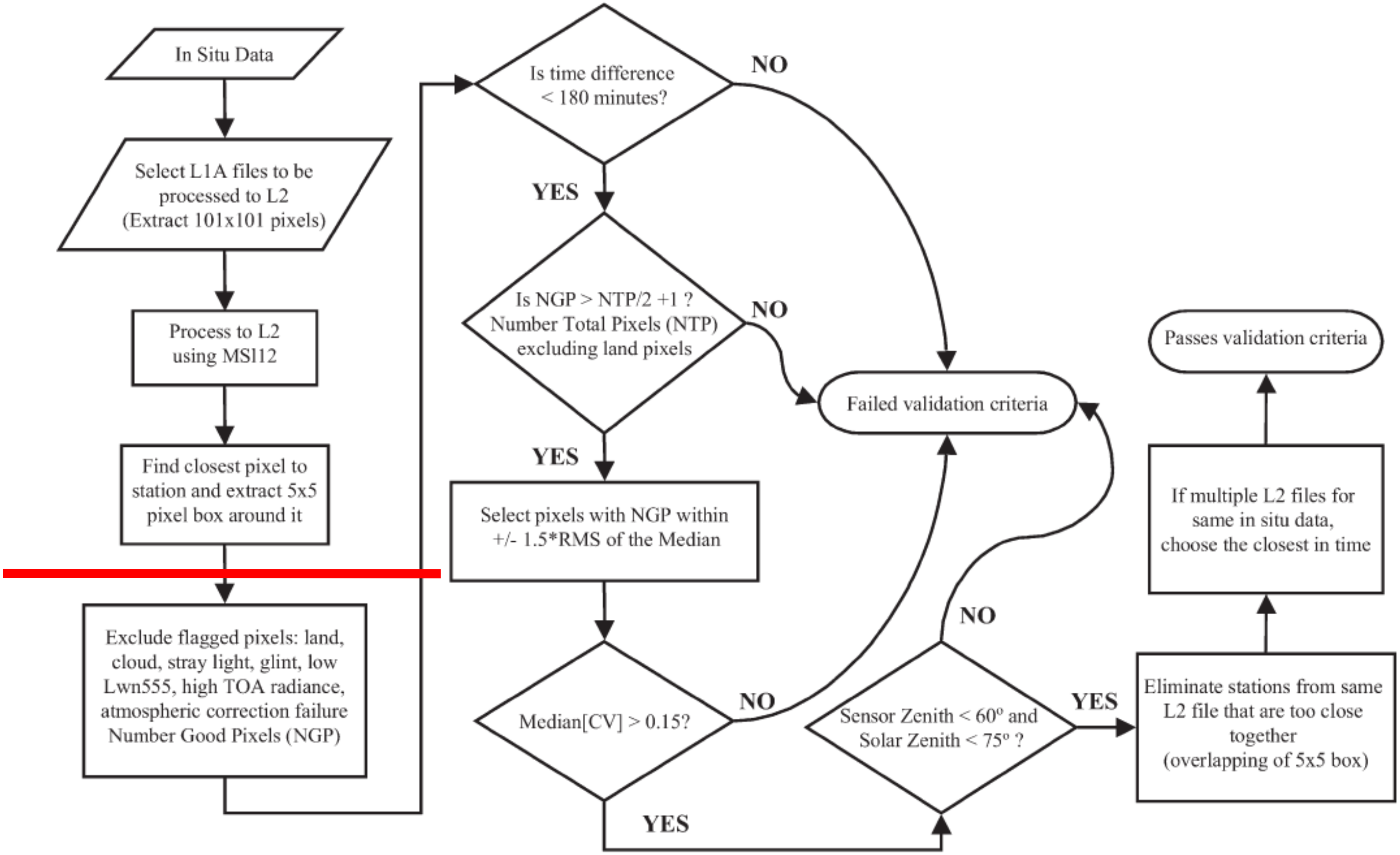
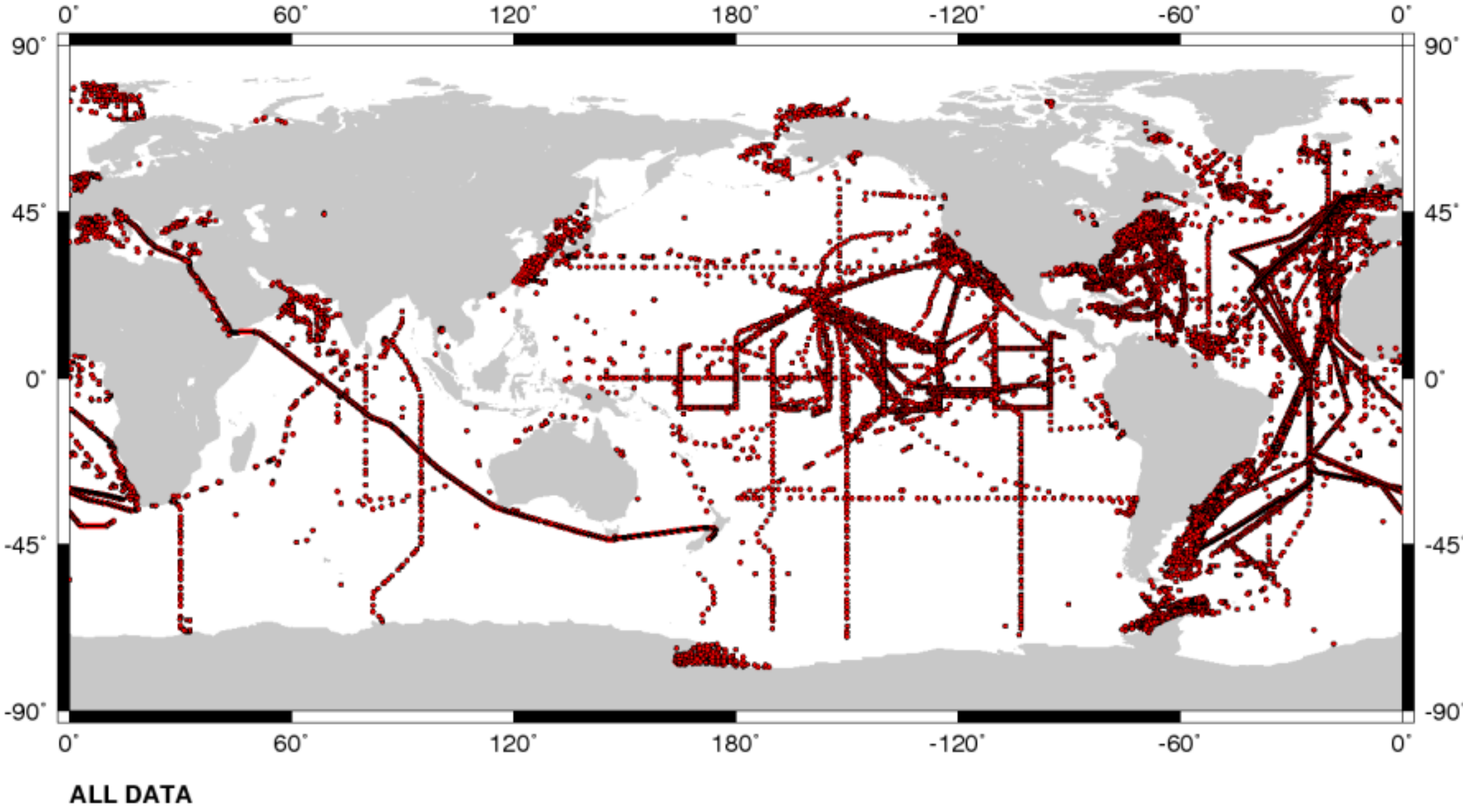


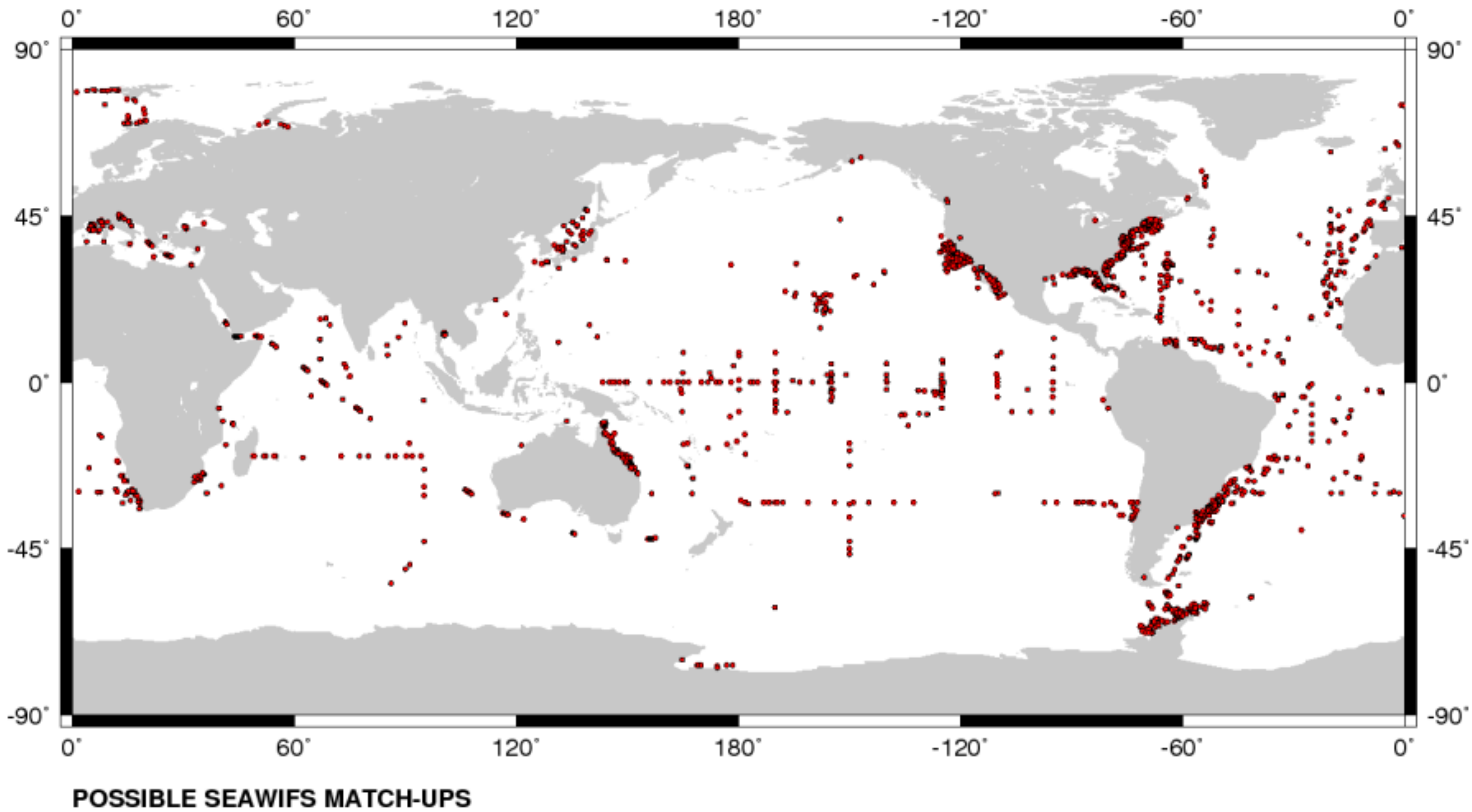
Fig. 1. Flowchart of the validation process highlighting the applied exclusion criteria.

S.W. Bailey and P.J. Werdell, "A multi-sensor approach for the on-orbit validation of ocean color satellite data products," Rem. Sens. Environ. 102, 12-23 (2006).

all available SeaBASS data



coincident SeaWiFS & in situ data



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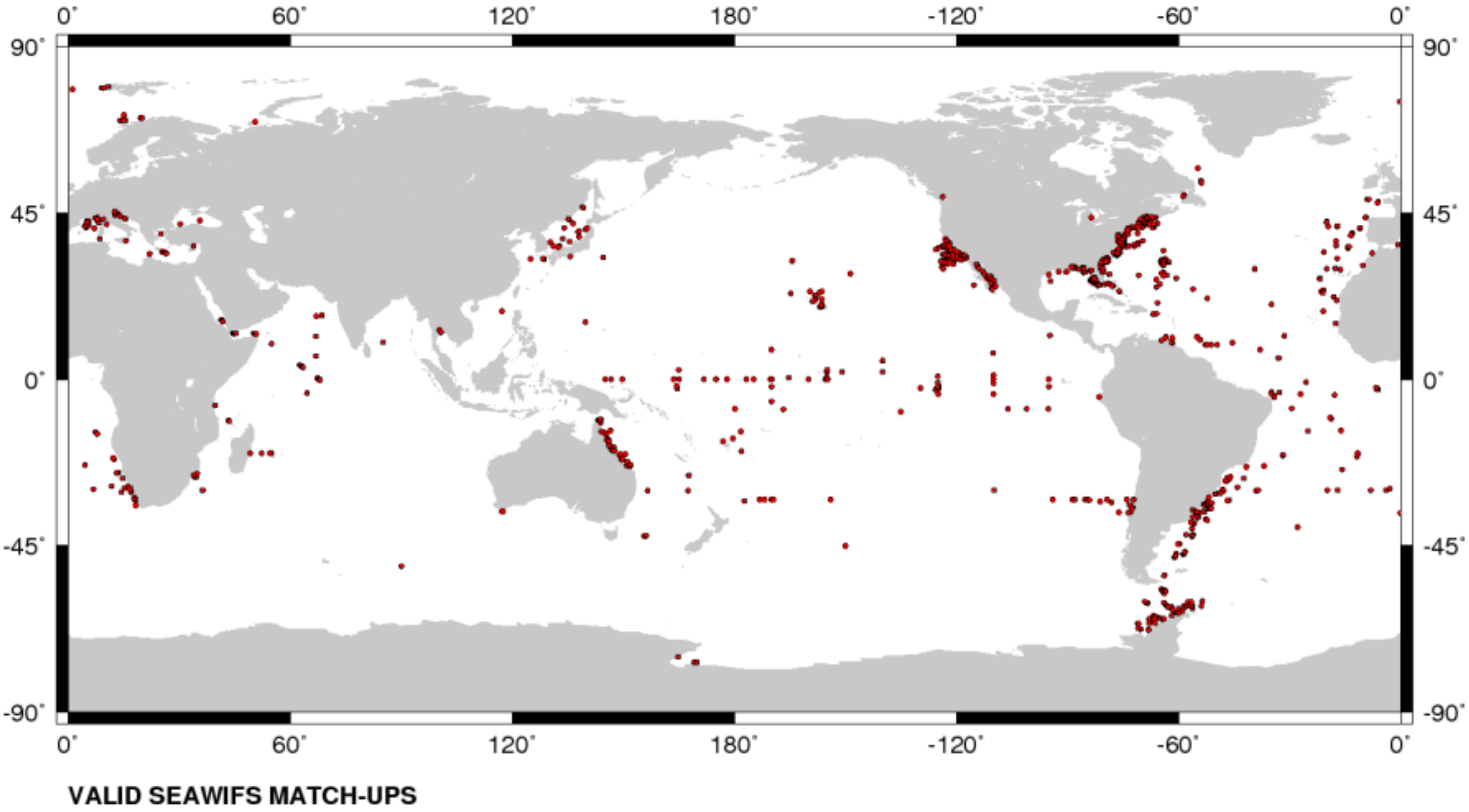
valid SeaWiFS match-ups



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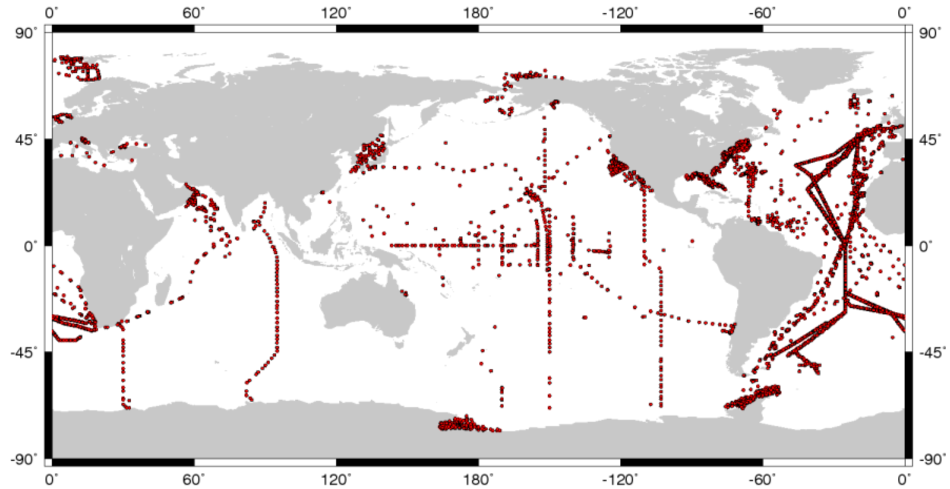
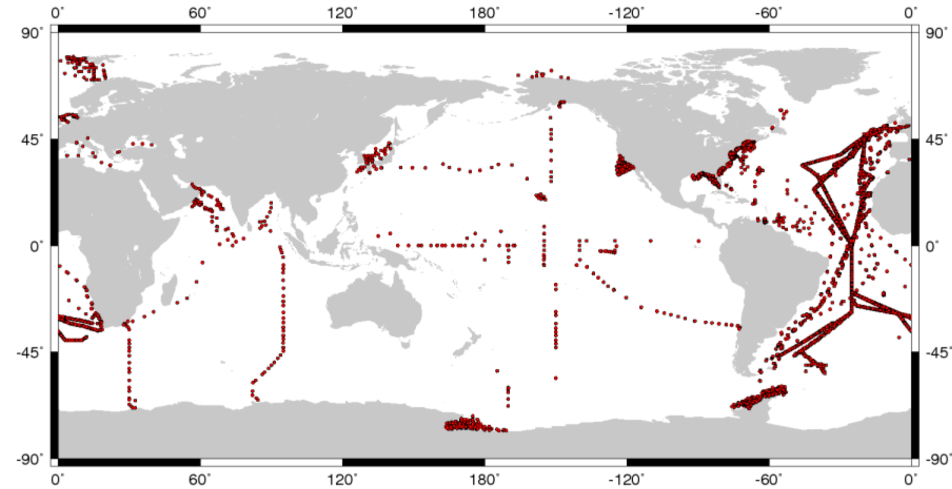
bio-optical algorithm development data sets

R_{rs}

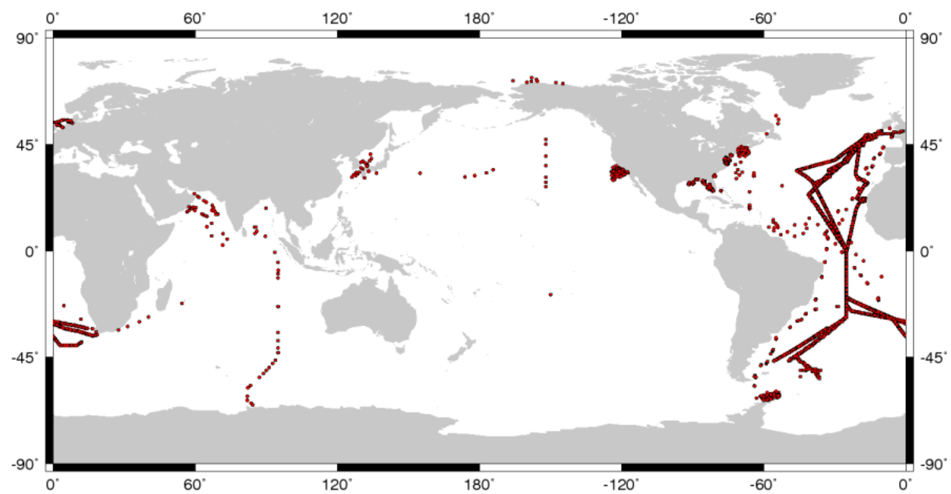


AOP

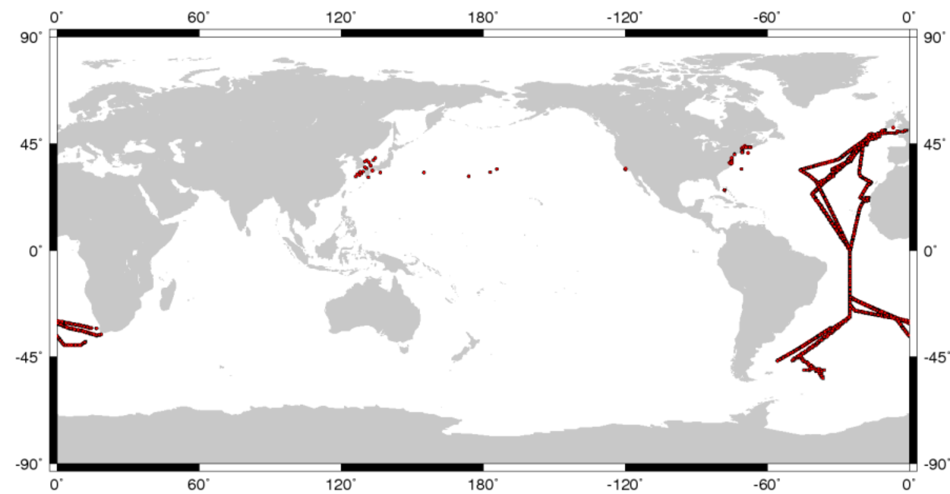
R_{rs} & Chl



AOP + CHL



AOP + CHL + ABSORPTION



AOP + CHL + ABSORPTION + BACKSCATTERING

R_{rs} & Chl & absorption

Rrs & Chl & absorption & backscattering

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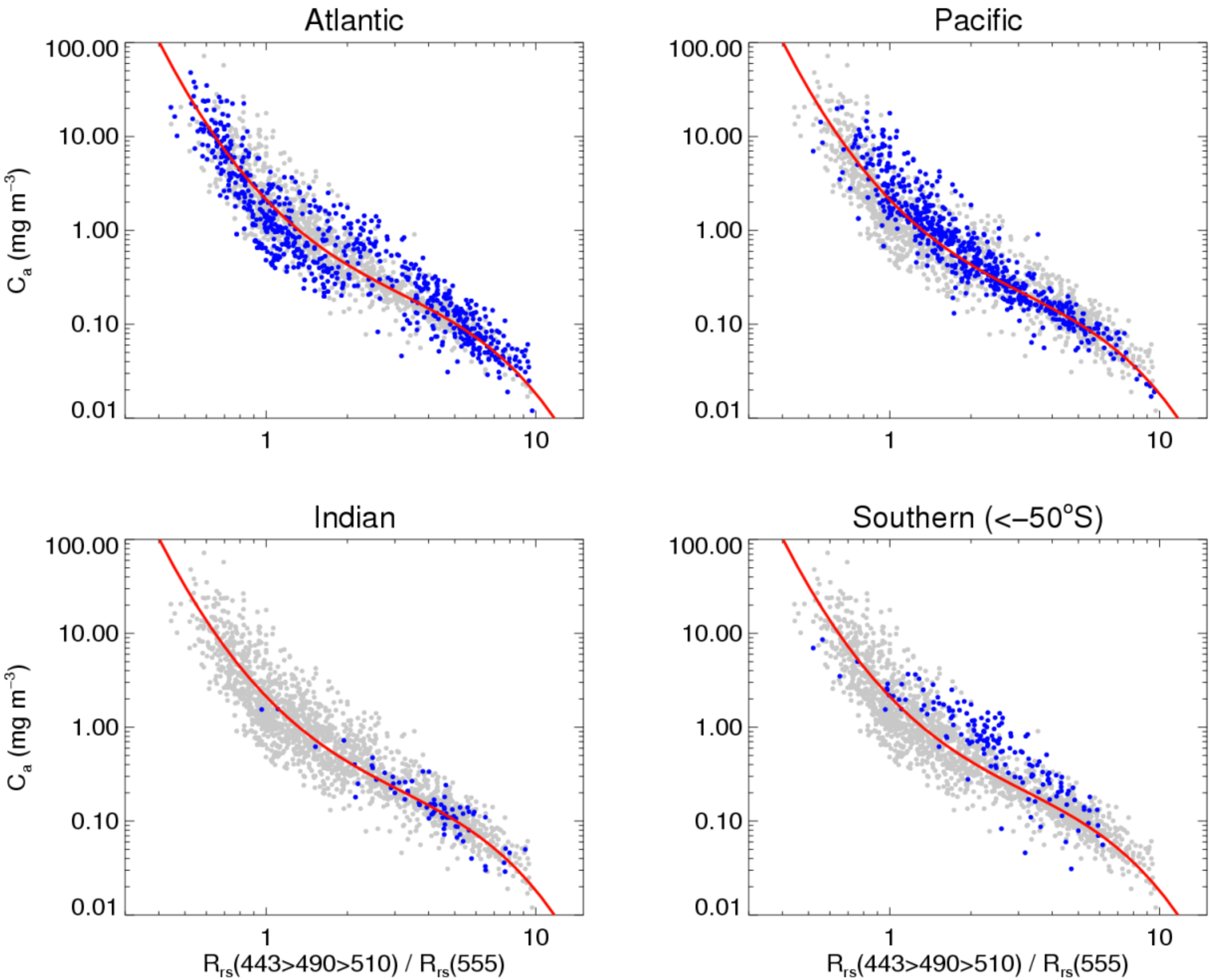
bio-optical algorithm development data sets



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outline

great field data enable great satellite data products

an abundance of field data is hard to come by

emerging technologies can provide rich data streams

QA/QC metrics are essential (or this all falls apart)

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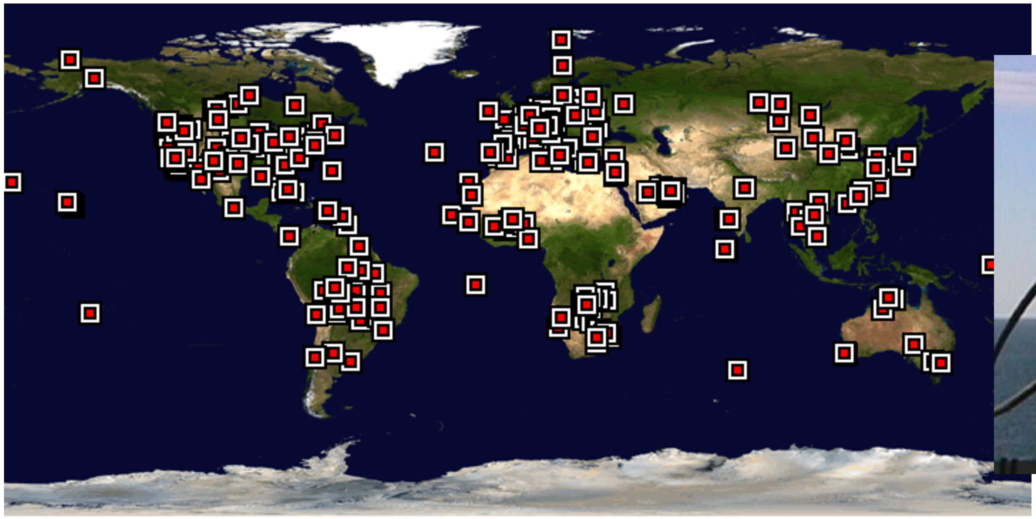
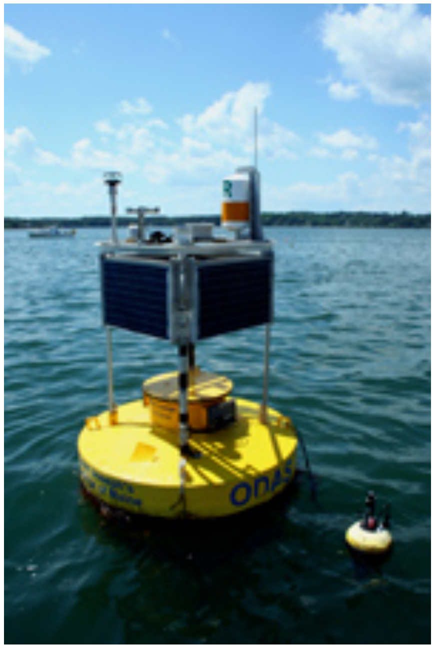
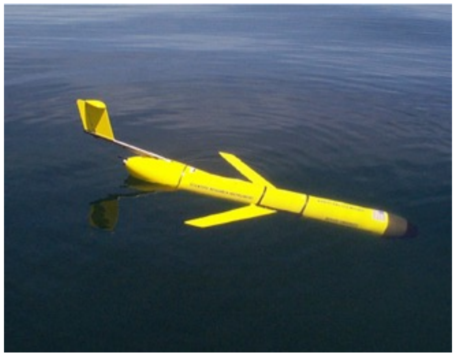
moving forward – community innovations

AERONET (fixed-above water platforms)



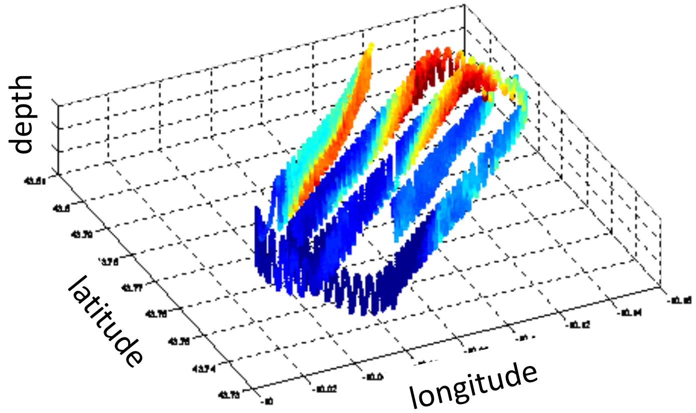


buoy networks



gliders, drifters, & other autonomous platforms

towed & underway sampling



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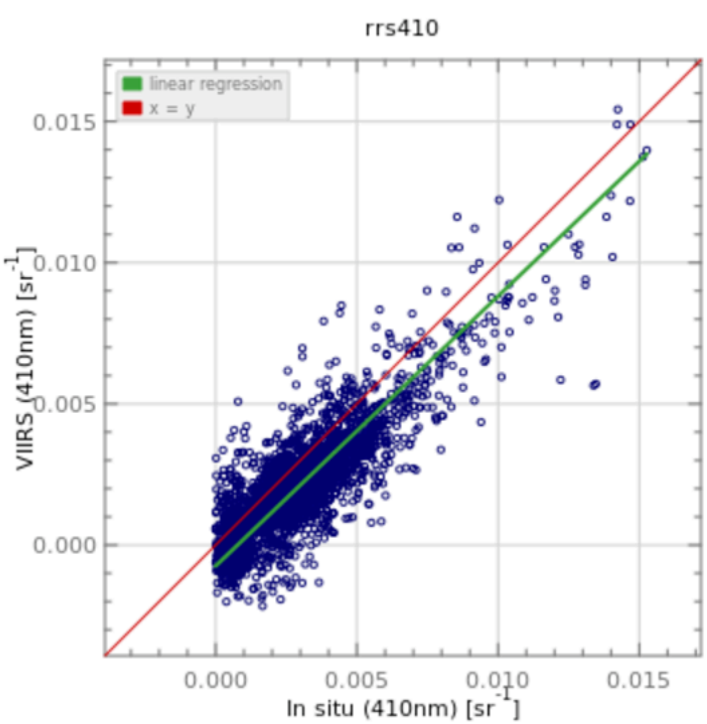
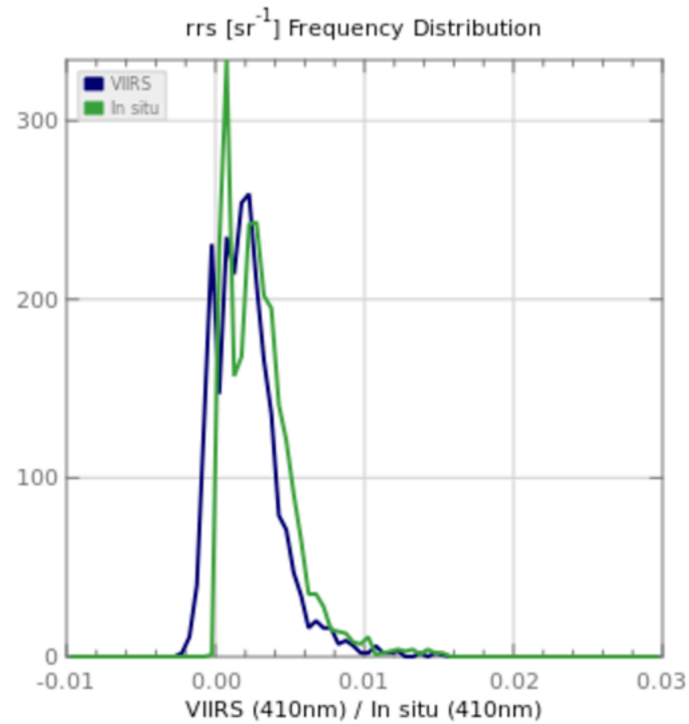
validation exercises using autonomous data

AERONET-OC match-ups with VIIRS (satellite data since Feb 2012)

Product Name	VIIRS Range	In situ Range	#	Best Fit Slope	Best Fit Intercept	R^2	Median Ratio	Median % Difference	RMSE
rrs410	-0.00216 - 0.01543	-0.00000 - 0.01527	2381	0.95545	-0.00074	0.73282	0.66572	47.77592	0.00148
rrs443	-0.00075 - 0.02072	0.00017 - 0.01871	2385	1.01295	-0.00055	0.85972	0.81181	28.55564	0.00110
rrs486	0.00045 - 0.02578	0.00058 - 0.02530	2387	0.90566	-0.00030	0.91740	0.81652	21.65905	0.00127
rrs551	0.00087 - 0.02462	0.00128 - 0.02633	2385	0.91013	-0.00023	0.93221	0.84637	17.41917	0.00121
rrs671	-0.00024 - 0.00985	-0.00000 - 0.01048	2384	0.96901	-0.00014	0.86795	0.82075	24.85650	0.00043





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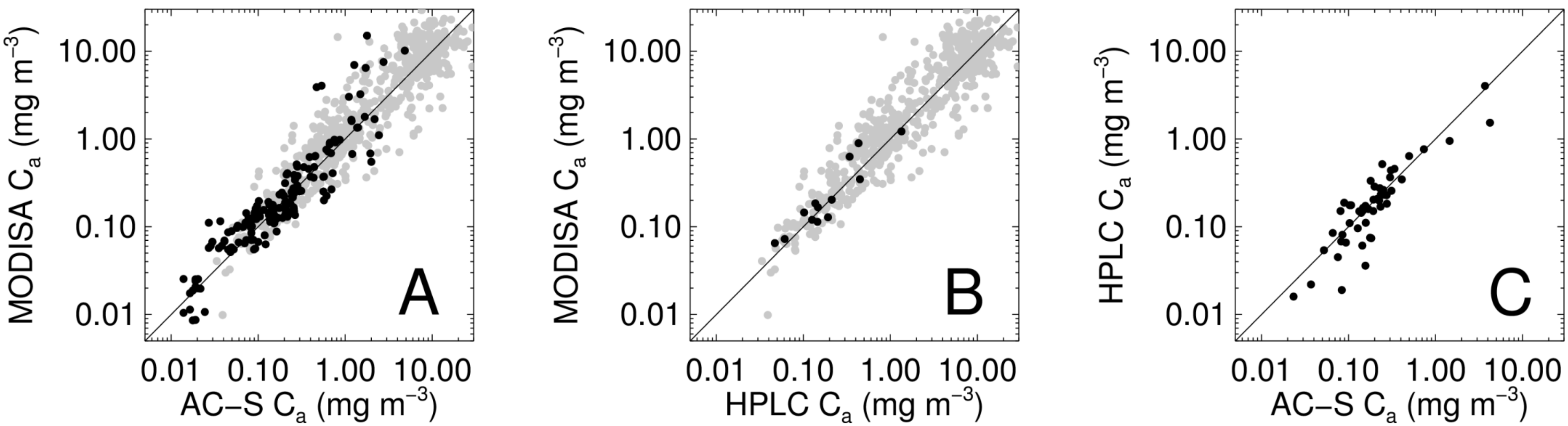
validation exercises using autonomous data

Tara Oceans expedition (2009-2012) AC-S products vs. MODISA



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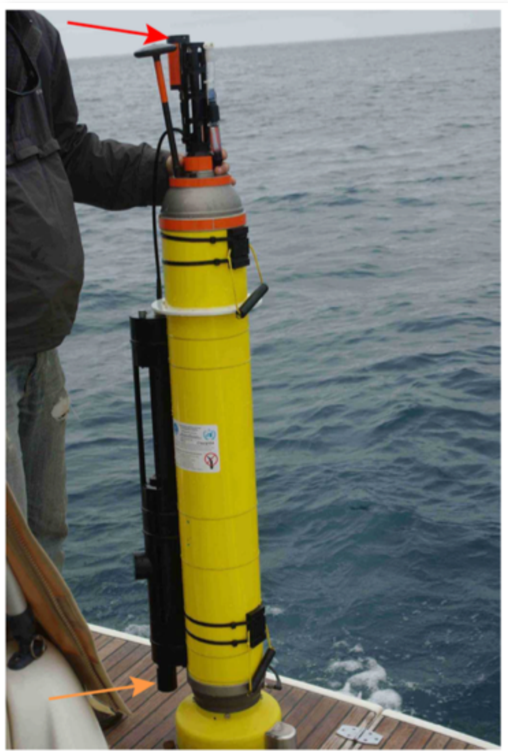
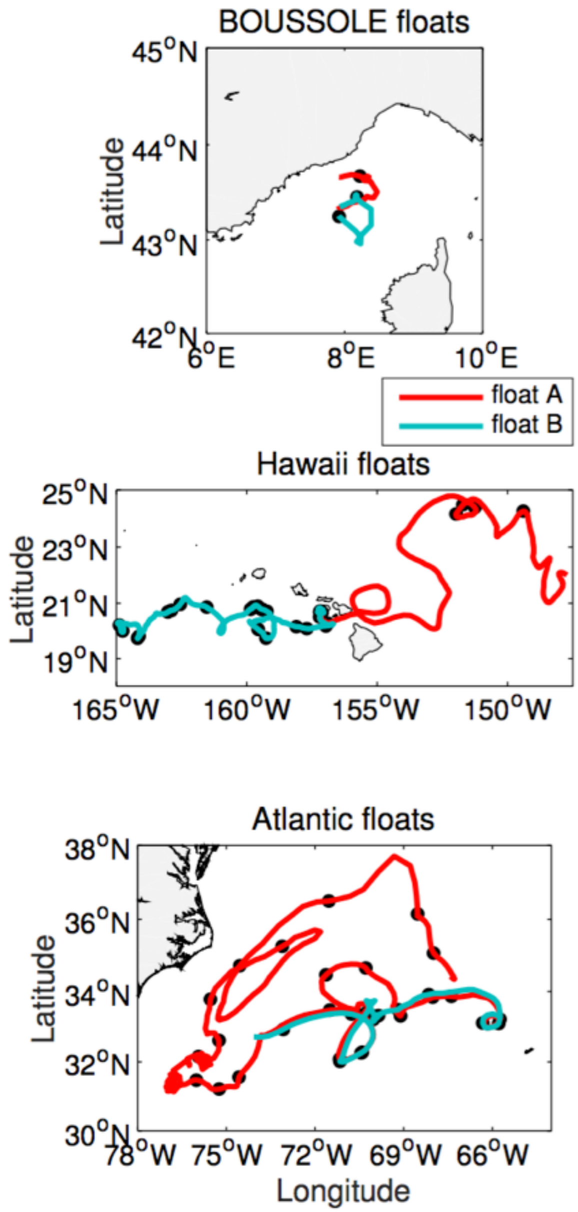
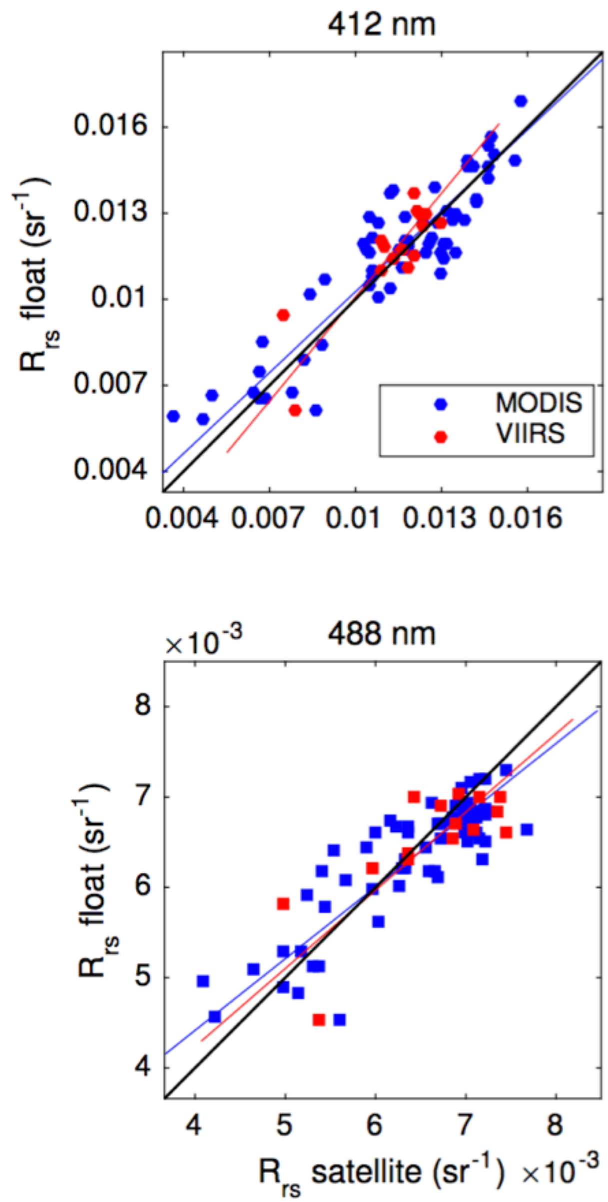
validation exercises using autonomous data

Autonomous profiling float radiometry vs. MODISA & VIIRS







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outline

great field data enable great satellite data products

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emerging technologies can provide rich data streams

QA/QC metrics are essential (or this all falls apart)

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QA/QC metrics are essential

a single entity (e.g., NASA or equivalent) cannot collect sufficient volumes of *in situ* data to satisfy its operational calibration & validation needs

following, flight projects rely on multiple entities to collect *in situ* data

protocols for data collection & QA/QC ensures measurements are of the highest possible quality – well calibrated & understood, properly & consistently acquired, within anticipated ranges

robust QA/QC provides confidence in utility & quality of data

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QA/QC metrics are essential

QA/QC methods vary in maturity – exist for many established instruments & platforms, but not always for newer or autonomous systems

QA/QC methods are **ideal** when:

they accommodate routine time-series reprocessing
they are well documented
they consistently maintain consensus from vendor ➔ institution ➔ end user
revisited by subject matter experts routinely

recommend invested agencies/institutions facilitate routine activities (workshops, round robins, inter-comparisons) to revisit QA/QC protocols

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consider, e.g., variance in AOP data sets

AOP instrumentation in SeaBASS or available commercially:

- many companies & instruments
  Biospherical, Satlantic, HOBI, Trios/Ramses, DALEC, SIMBAD-A, ASD, Spectron, custom
- many platforms & deployment strategies
  profilers, buoys, above-water (ship, permanent, hand-held), gliders, AUVs

dynamic range of problem set is growing:

- new missions emphasize research in shallow, optically complex water
- spectral domain stretching to UV and SWIR
- new missions have immediate, operational requirements

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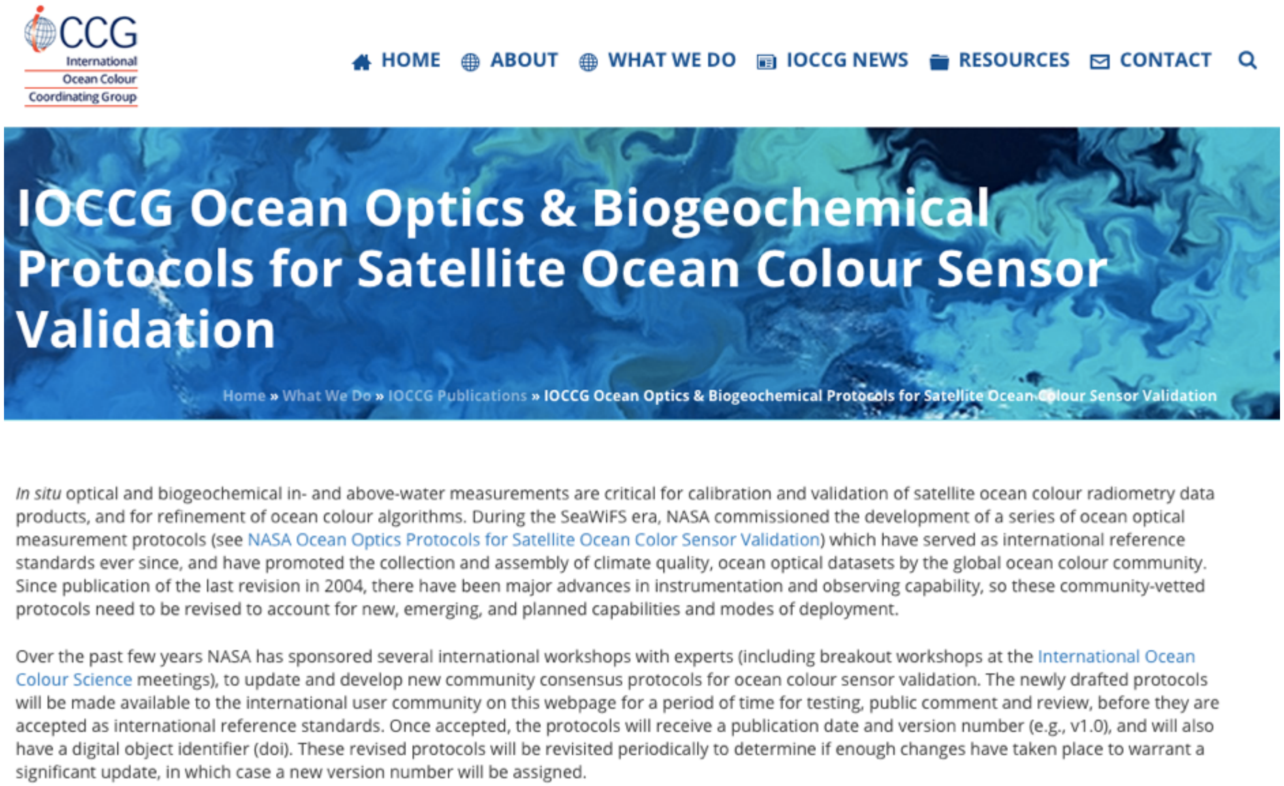
the future of ocean color protocols


IOCCG International Ocean Colour Coordinating Group

HOME ABOUT WHAT WE DO IOCCG NEWS RESOURCES CONTACT

IOCCG Ocean Optics & Biogeochemical Protocols for Satellite Ocean Colour Sensor Validation

Home » What We Do » IOCCG Publications » IOCCG Ocean Optics & Biogeochemical Protocols for Satellite Ocean Colour Sensor Validation

In situ optical and biogeochemical in- and above-water measurements are critical for calibration and validation of satellite ocean colour radiometry data products, and for refinement of ocean colour algorithms. During the SeaWiFS era, NASA commissioned the development of a series of ocean optical measurement protocols (see NASA Ocean Optics Protocols for Satellite Ocean Color Sensor Validation) which have served as international reference standards ever since, and have promoted the collection and assembly of climate quality, ocean optical datasets by the global ocean colour community. Since publication of the last revision in 2004, there have been major advances in instrumentation and observing capability, so these community-vetted protocols need to be revised to account for new, emerging, and planned capabilities and modes of deployment.

Over the past few years NASA has sponsored several international workshops with experts (including breakout workshops at the International Ocean Colour Science meetings), to update and develop new community consensus protocols for ocean colour sensor validation. The newly drafted protocols will be made available to the international user community on this webpage for a period of time for testing, public comment and review, before they are accepted as international reference standards. Once accepted, the protocols will receive a publication date and version number (e.g., v1.0), and will also have a digital object identifier (doi). These revised protocols will be revisited periodically to determine if enough changes have taken place to warrant a significant update, in which case a new version number will be assigned.

http://ioccg.org/what-we-do/ioccg-publications/ocean-optics-protocols-satellite-ocean-colour-sensor-validation/

- NASA resumed efforts in 2013 (last effort 2003)
- IOCCG joined as a collaborator
- NASA T/M style
- 30-60 days for public comment
- digital updates ~1-3 years as appropriate
- reprinting ~10-15 years with accumulated or major updates

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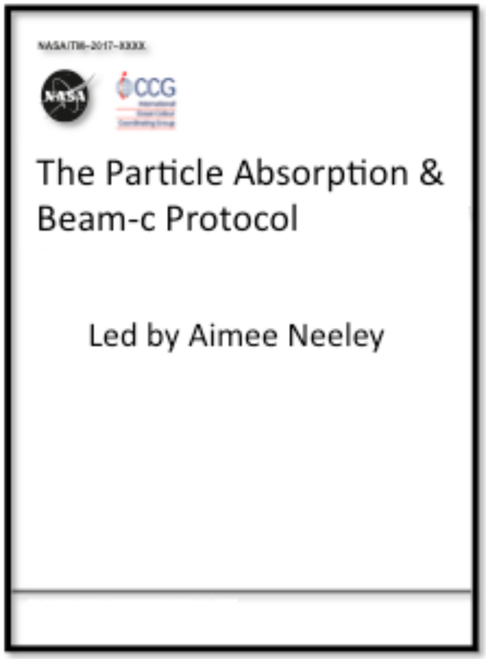
the future of ocean color protocols

online for public comment (end of June 2017)

online for public comment (Fall 2017)


NASA/TM–2017–XXXX

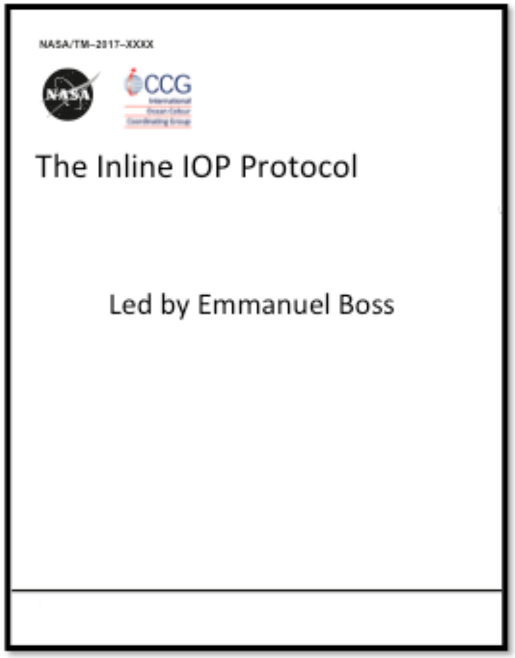
The Particle Absorption & Beam-c Protocol

Led by Aimee Neeley


NASA/TM–2017–XXXX

The CDOM Protocol

Led by Mike Novak and Antonio Mannino


NASA/TM–2017–XXXX

The Inline IOP Protocol

Led by Emmanuel Boss

the future of ocean color protocols

ongoing and in development

NASA/TM-2017-XXXX

The Particulate Organic Carbon Protocol

Led by Joaquin Chaves and Mike Novak

NASA/TM-2017-XXXX

Ongoing Activity: AOP Protocol Updates

Leads Ken Voss and Giuseppe Zibordi

NASA/TM-2017-XXXX

The Particle Backscatter and VSF Protocol

Led by Jim Sullivan and Wayne Slade

the future of ocean color protocols


Ocean Carbon & Biogeochemistry

Studying marine ecosystems and biogeochemical cycles in the face of environmental change

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Phytoplankton Taxonomy Working Group

Working group to establish data standards and practices for taxon-resolved phytoplankton observations - PIs: Heidi Sosik (WHOI), Christopher Proctor (NASA GSFC/SSAI), Aimee Neeley (NASA GSFC/SSAI), Ivona Cetinić (NASA GSFC/USRA)

Objective: In an effort to facilitate community-wide access to phytoplankton data products that support critical satellite algorithm development and validation, this working group will convene relevant expertise (e.g., phytoplankton ecology and taxonomy, data systems, informatics, etc.) to develop a set of standards and best practices for phytoplankton taxonomy data.

For the future:

Particle sizes

Productivity

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questions?
comments?
concerns?

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backup slides

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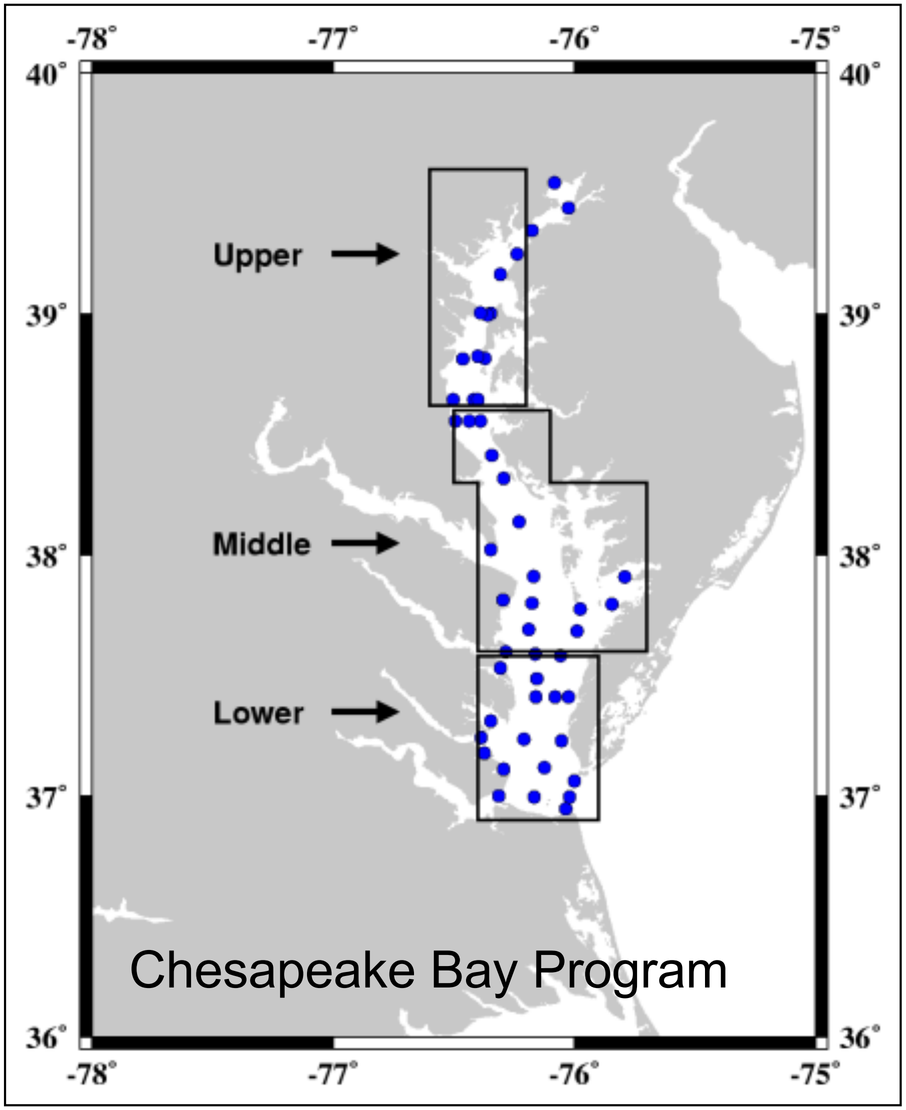
Level-2 time-series



Chesapeake Bay Program
A Watershed Partnership

http://www.chesapeakebay.net

routine data collection since 1984
12-16 cruises / year

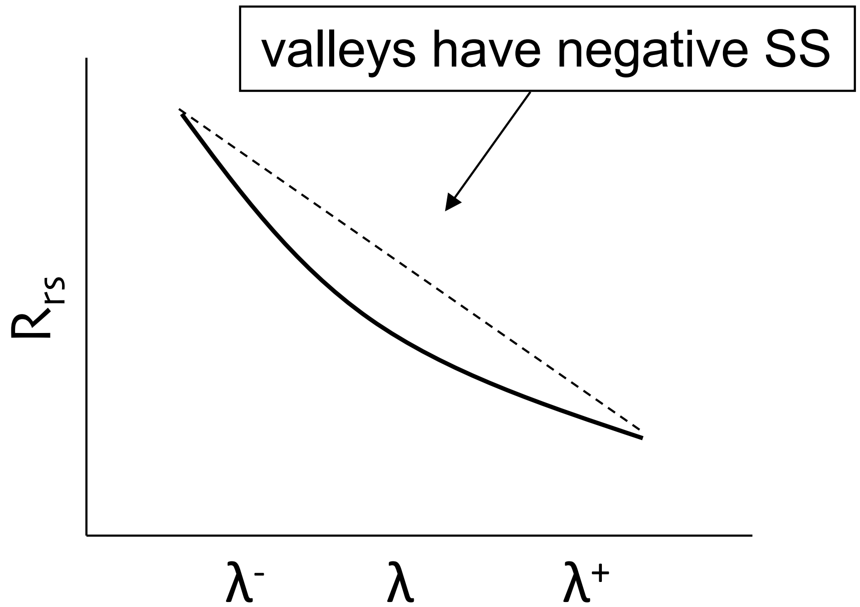
49 stations
19 hydrographic measurements

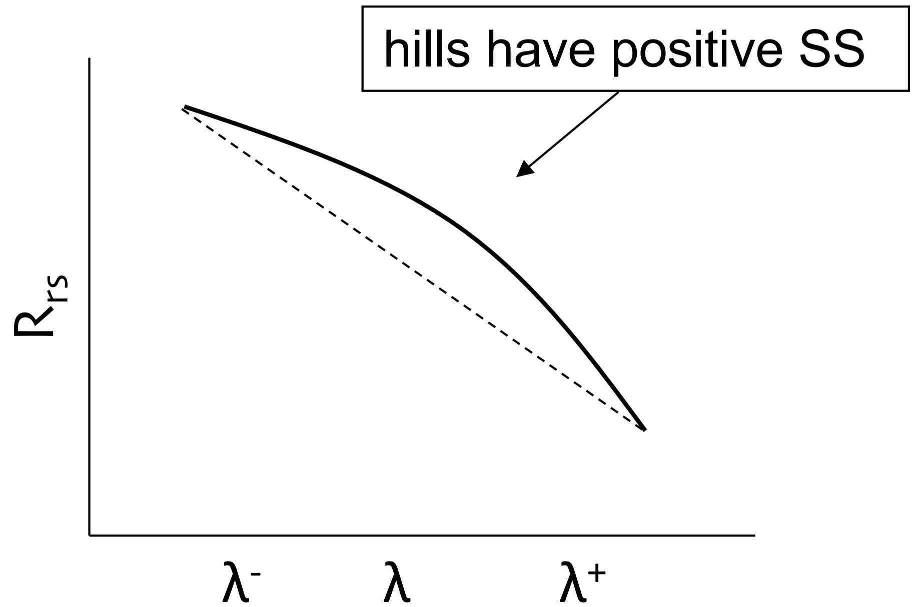
algal biomass
water clarity
dissolved oxygen
others

population statistics for vicarious calibration

compare spectral shapes of *in situ* & satellite populations

$$SS(\lambda) = R_{rs}(\lambda) - R_{rs}(\lambda^-) - \left[R_{rs}(\lambda^+) - R_{rs}(\lambda^-)\right]\left(\frac{\lambda - \lambda^-}{\lambda^+ - \lambda^-}\right)$$





spectral shape @ 443 nm, SS(443), uses $R_{rs}(412)$, $R_{rs}(443)$, & $R_{rs}(490)$

Stumpf & Werdell 2010

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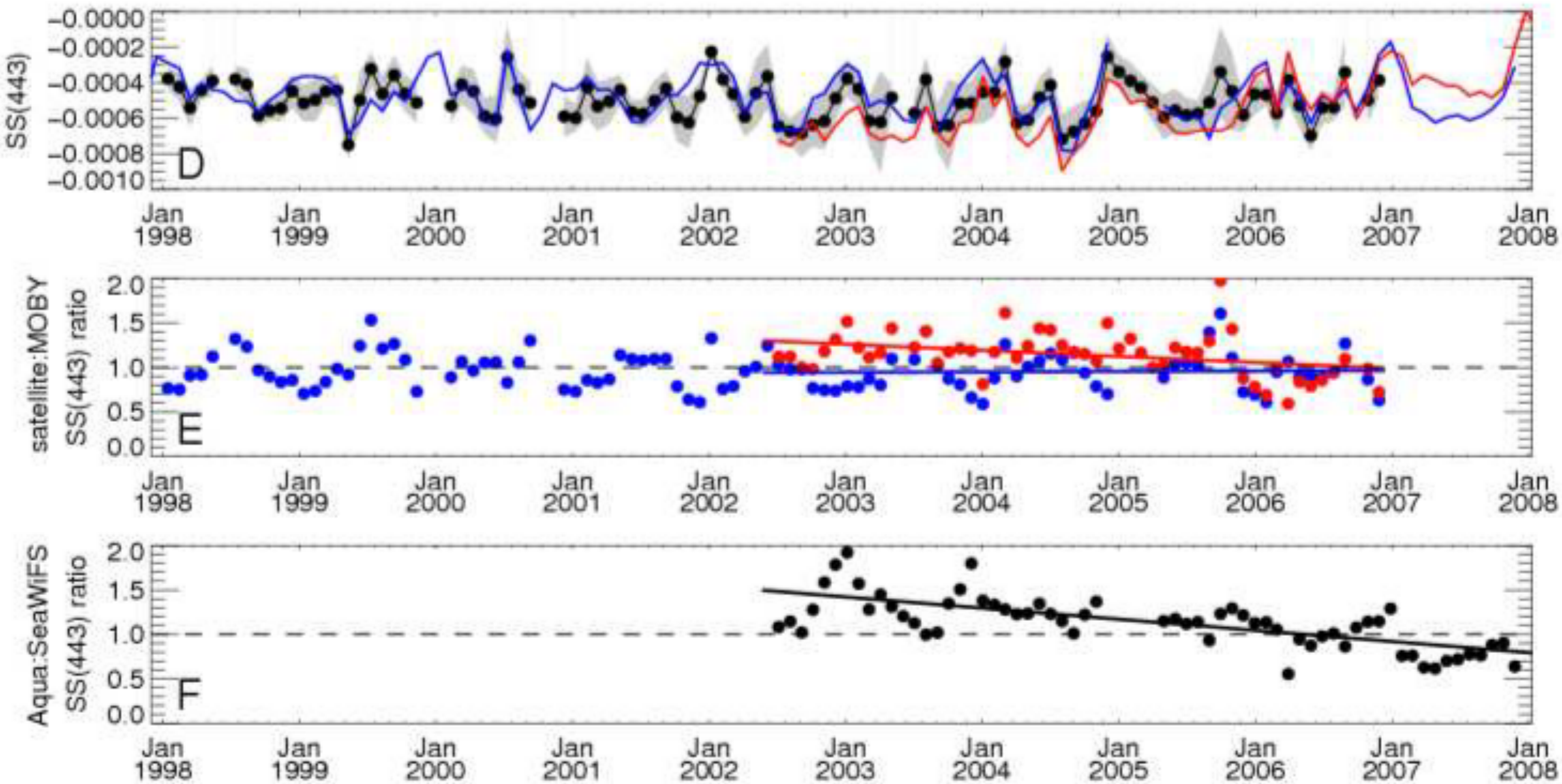
population statistics for vicarious calibration

in situ, SeaWiFS, & MODIS-Aqua spectral shapes compared at MOBY site



Stumpf & Werdell 2010

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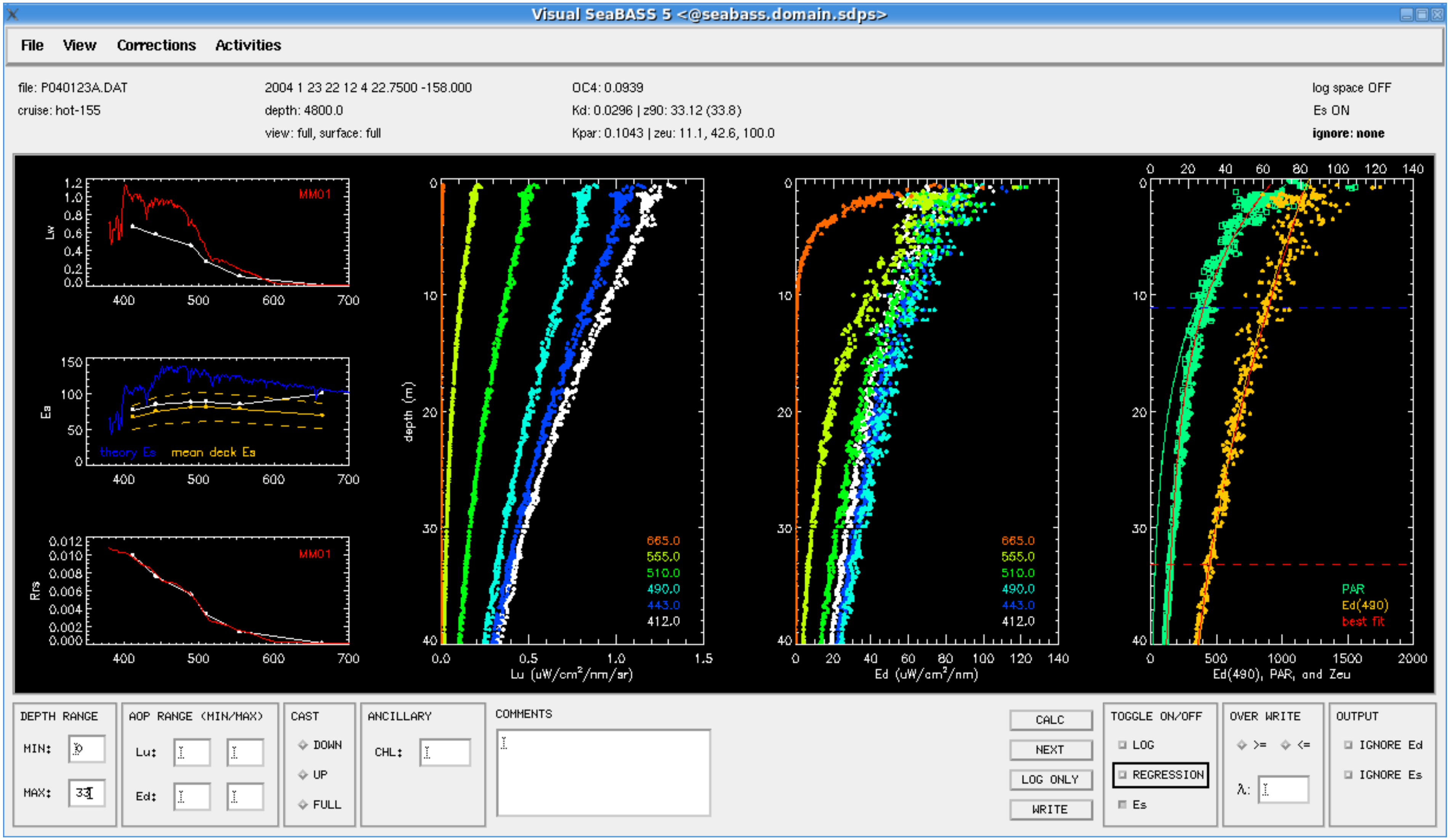
AOP data analysis

$L_u(z), E_d(z) \rightarrow L_w, E_s$



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inversion models

several flavors of a "semi-analytical" inversion algorithm …

$$R_{rs} \approx func\left(\frac{b_b}{a+b_b}\right)$$

satellite provides $R_{rs}(\lambda)$

$a(\lambda)$ and $b_b(\lambda)$ are desired products

1

Spectral Optimization:

- define shape functions for (e.g.) $b_{bp}(\lambda)$, $a_{dg}(\lambda)$, $a_{ph}(\lambda)$
- solution via L-M, matrix inversion, etc.
- ex: RP95, HL96, GSM

2

Spectral Deconvolution:

- partially define shape functions for $b_{bp}(\lambda)$, $a_{dg}(\lambda)$
- piece-wise solution: $b_{bp}(\lambda)$, then $a(\lambda)$, then $a_{dg}(\lambda) + a_{ph}(\lambda)$
- ex: QAA, PML, NIWA

3

Bulk Inversion:

- no predefined shapes
- piece-wise solution: $b_{bp}(\lambda)$, then $a(\lambda)$, via empirical $K_d(\lambda)$ via RTE
- ex: LS00

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