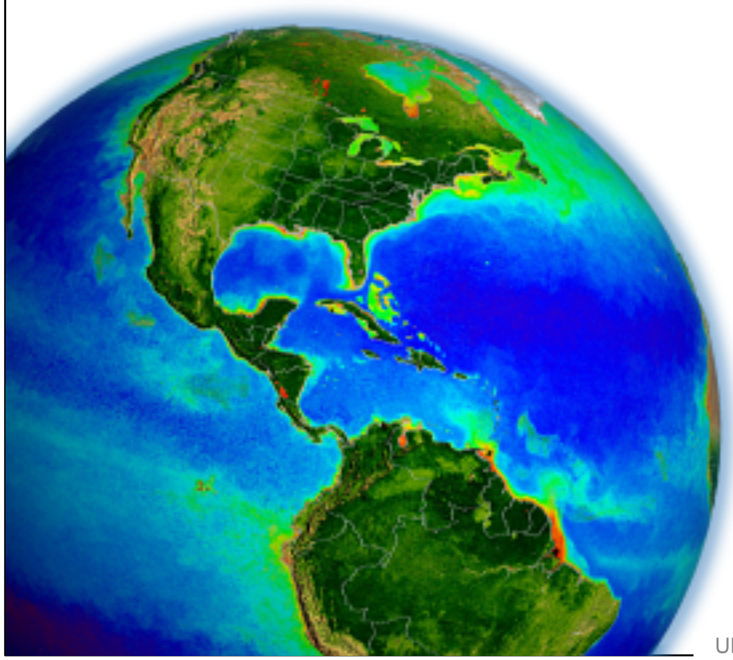
In situ data support for ocean color satellite calibration & validation



Jeremy Werdell
NASA Goddard Space Flight Center

UMaine Ocean Optics Summer Course
Jul 7 – Aug 3, 2013

“cal/val”

“cal/val” has become the catch-all phrase in our community for all activities related to the on-orbit calibration of a satellite instrument, the execution of field programs, the validation of biogeophysical satellite data records, & the development of related atmospheric & bio-optical algorithms

outline

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

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)

NASA Ocean Biology & Biogeochemistry Program

field work funded by OBB Program

QA/QC

by data contributor

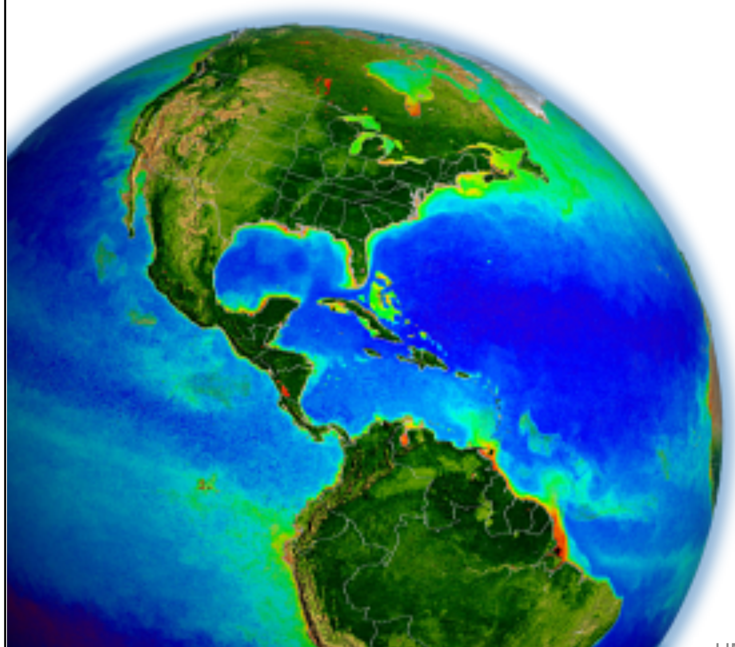
in situ data submitted to NASA SeaBASS (GSFC) within 1-year

by NASA

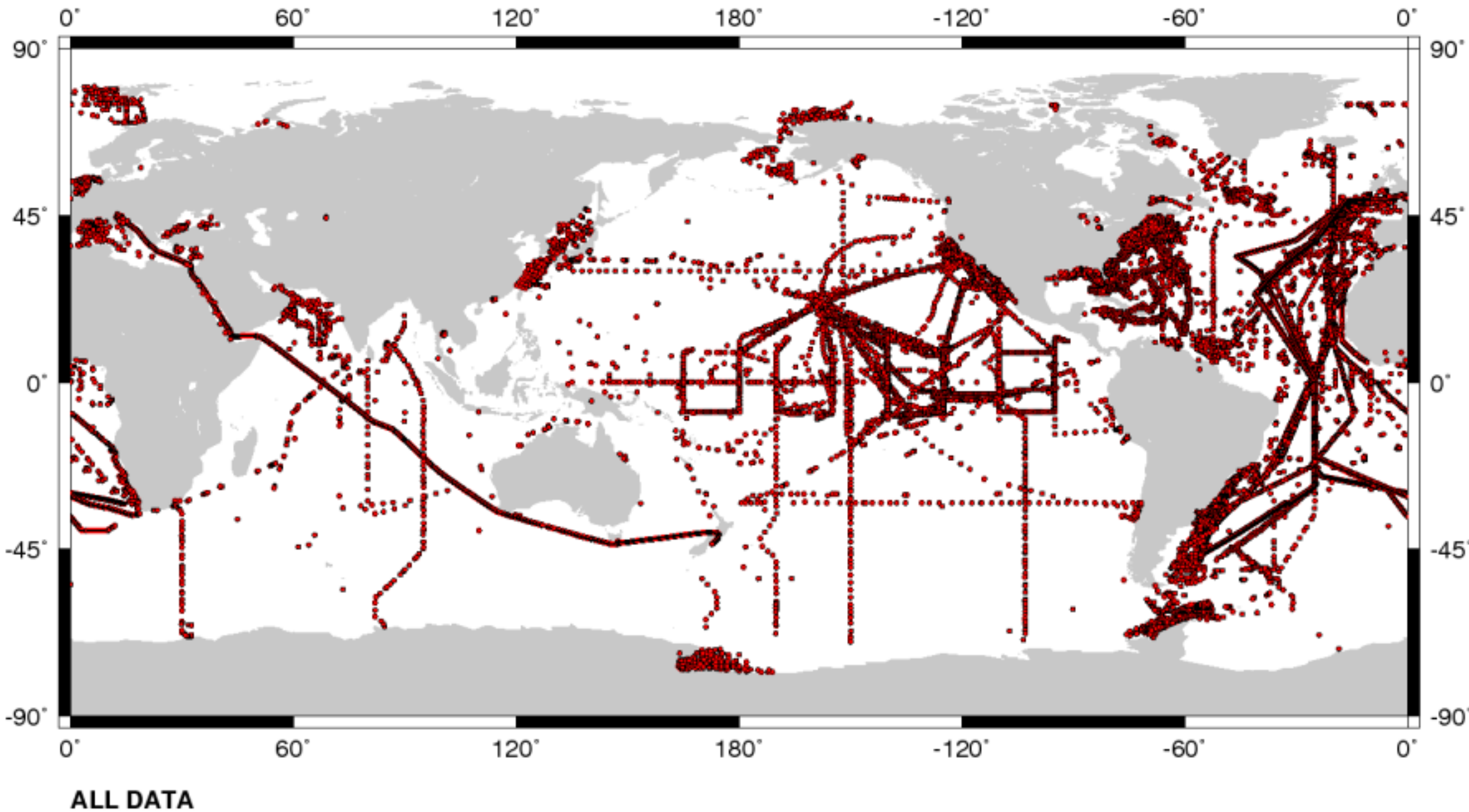
in situ data publicly released

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

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)

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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vicarious calibration

what is vicarious calibration?

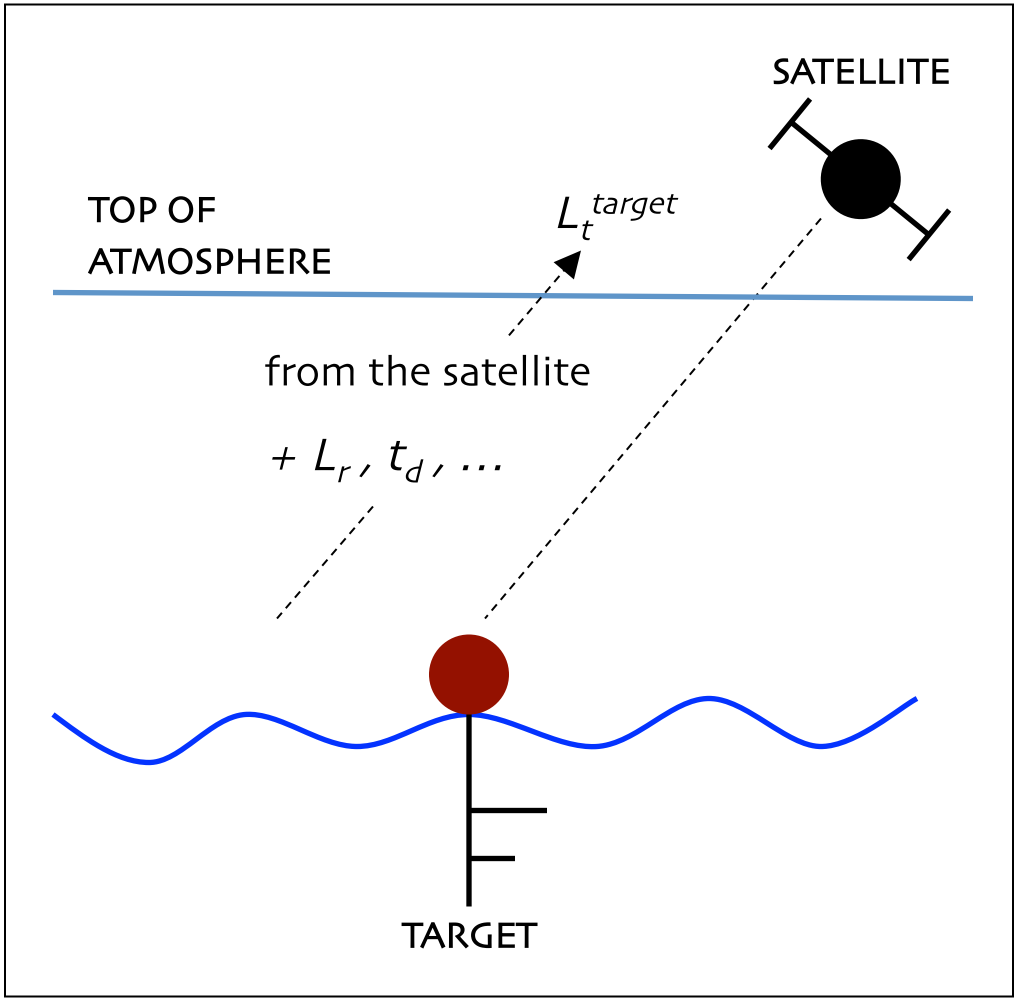
<u>spectral on-orbit calibrations</u>

1. 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

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



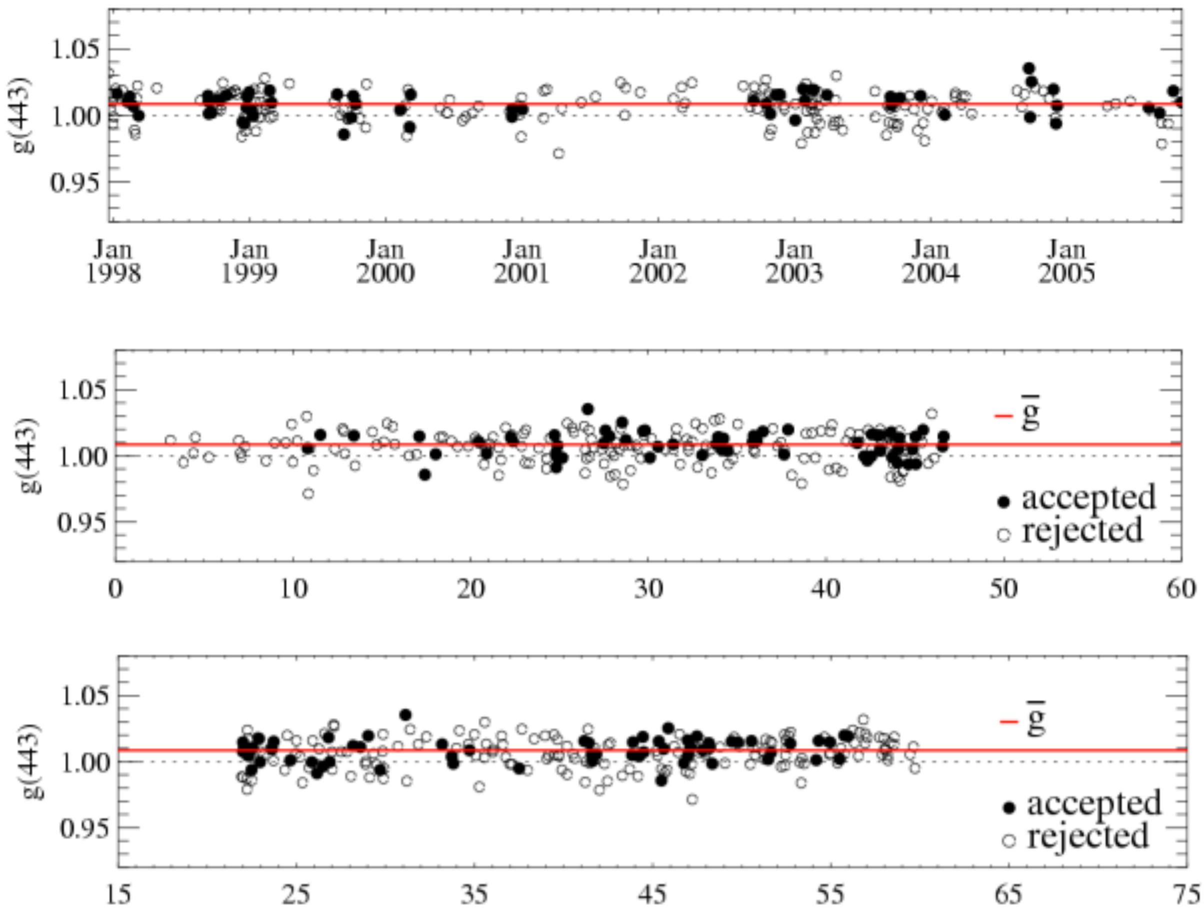
vicarious calibration

a single, spectral radiometric adjustment

gain vs. time

gain vs. solar zenith angle

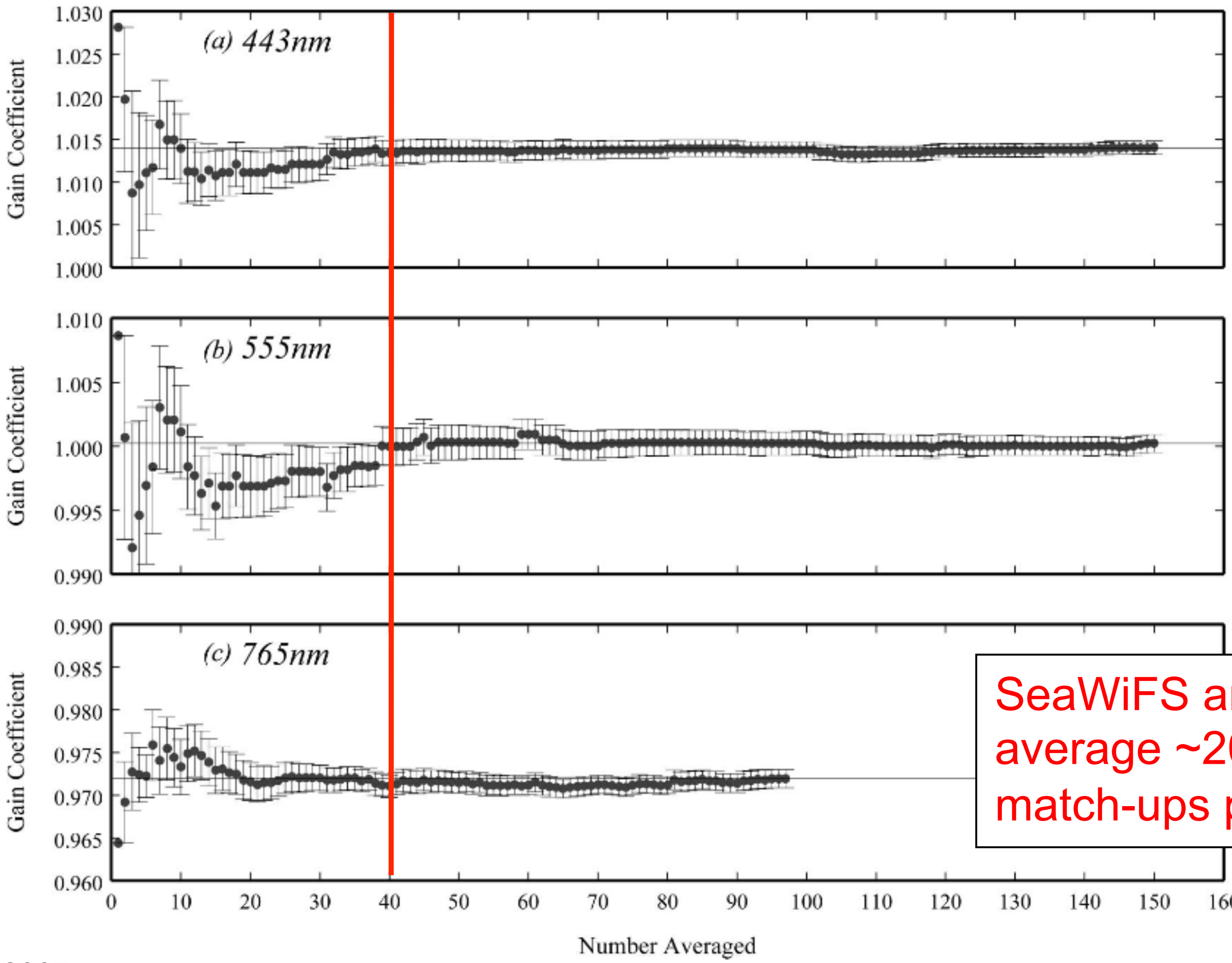
gain vs. satellite zenith angle



Franz et al. 2007

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

operational vicarious calibration

MOBY - the Marine Optical BuoY

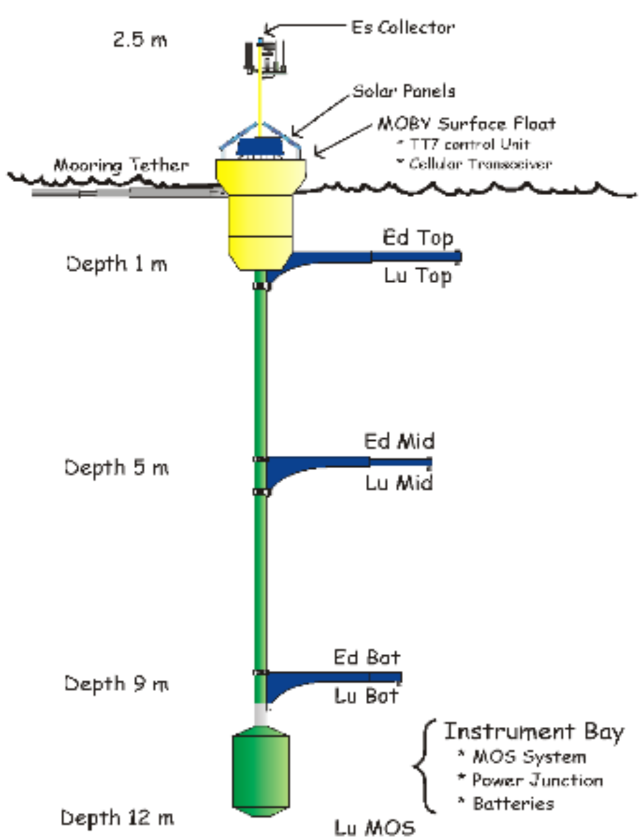


Fig. 1. Schematic diagram of MOBY.

maintained by NOAA & 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 $E_s(\lambda)$

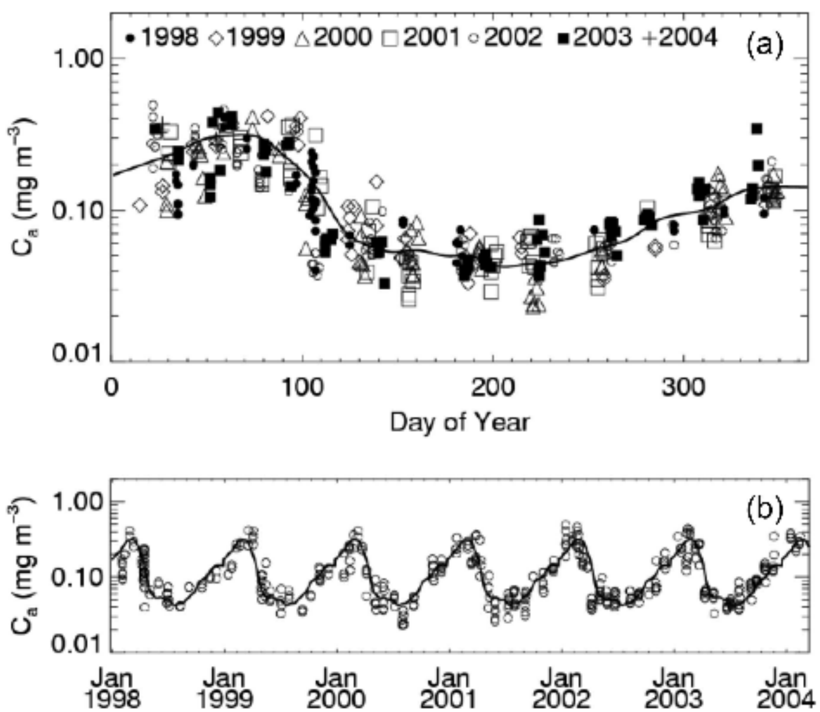
spectral range is 340-955 nm & spectral resolution is 0.6 nm

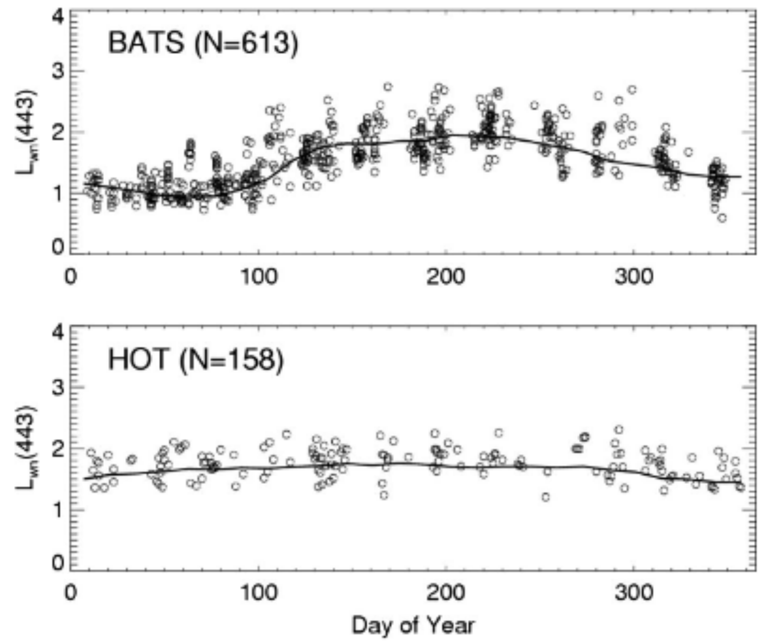
hyperspectral data convolved to specific bandpasses of each satellite

approximately 450-700 samples per year for MODIS-Aqua

model-based vicarious calibration

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





$$L_{wn}(\lambda) = fcn(\text{Chl-a})$$

… then, develop a radiometric climatology using an ocean reflectance model (e.g., Morel and Maritorena 2001)

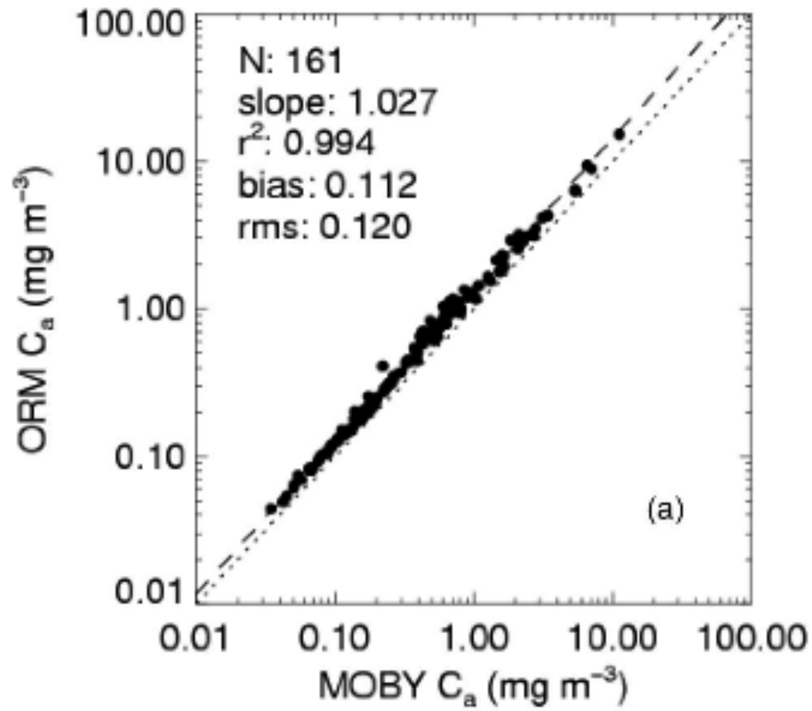
Werdell et al. 2007

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 $(\bar{g}_{\mathrm{ORM}} - \bar{g}_{\mathrm{MOBY}}) \times 100\%/\bar{g}_{\mathrm{MOBY}}$.

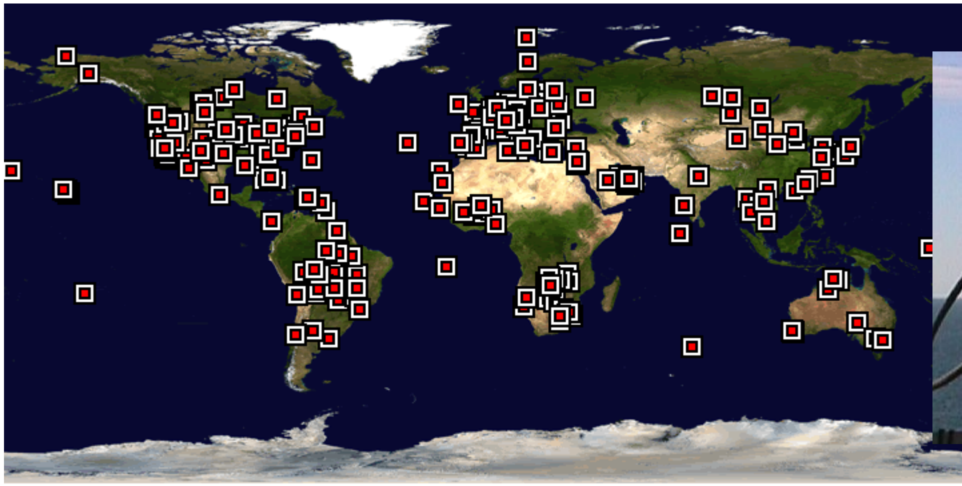


model-based gains typically differ from MOBY gains by < 1%

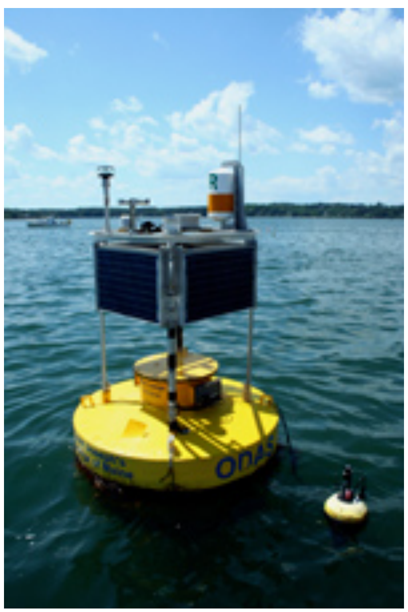
Werdell et al. 2007

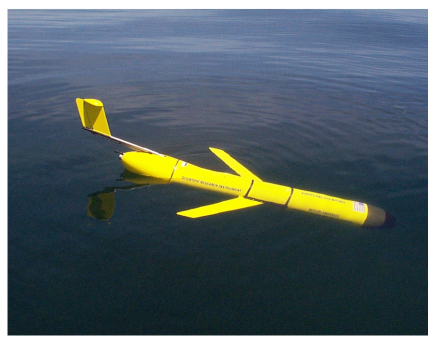
alternative data for vicarious calibration

AERONET (fixed-above water platforms)



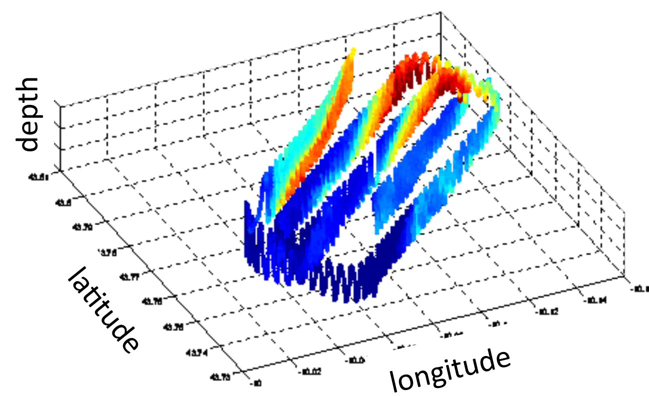
buoy networks





gliders, drifters, & other autonomous platforms

towed & underway sampling



alternative for vicarious calibration

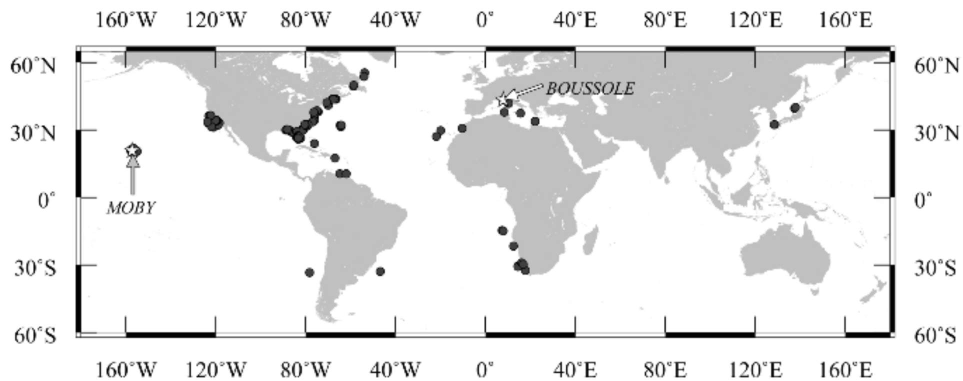


Fig. 1. Map showing the locations for the *in situ* data used in this study.

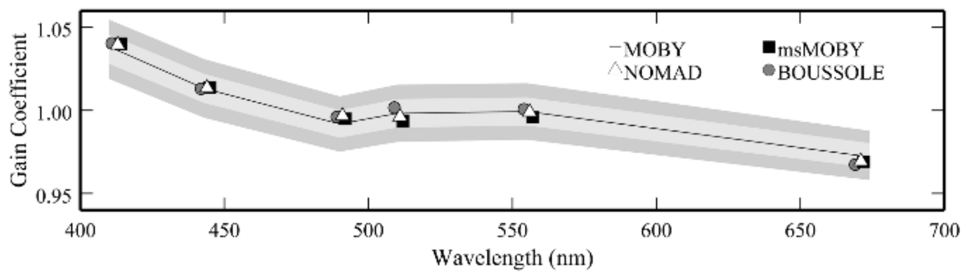


Fig. 3. Vicarious calibration coefficients as a function of wavelength. The standard MOBY-derived $\bar{g}_{\lambda}'$ (solid curve) are overplotted by the msMOBY-, NOMAD-, and BOUSSOLE-derived $\bar{g}_{\lambda}'$. The shaded regions indicate the ranges for the first (light-gray) and second (dark-gray)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

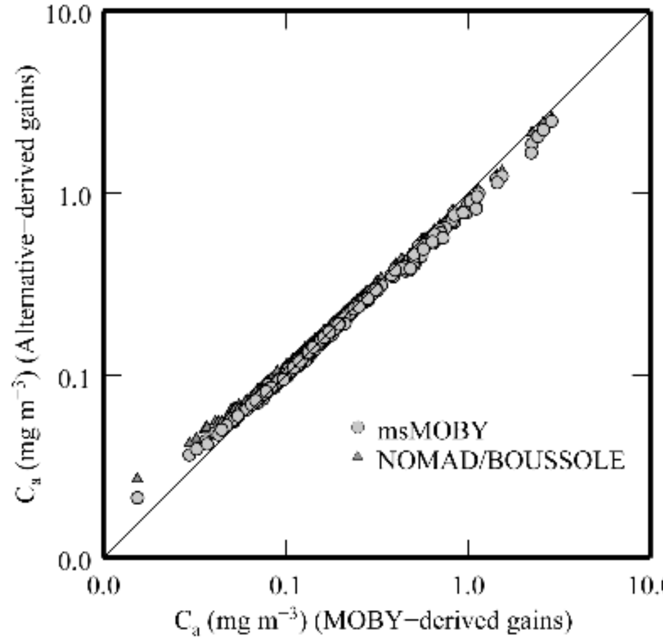


Fig. 7. Satellite-derived chlorophyll estimated from the two alternative $\bar{g}'$ gain sets (msMOBY and NOMAD/BOUSSOLE) plotted versus the corresponding chlorophyll estimated from the standard MOBY $\bar{g}$.

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

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

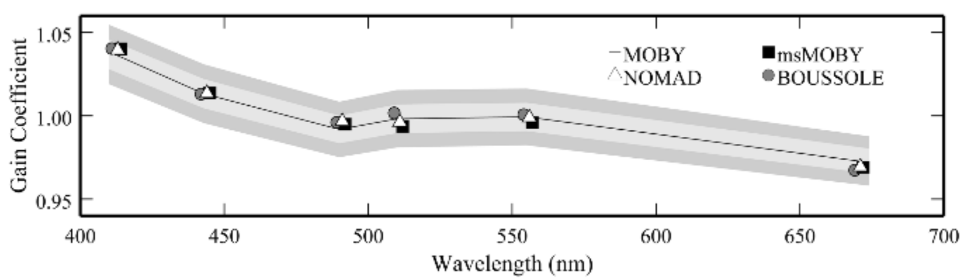


Fig. 3. Vicarious calibration coefficients as a function of wavelength. The standard MOBY-derived $\bar{g}_\lambda'$ (solid curve) are overplotted by the msMOBY-, NOMAD-, and BOUSSOLE-derived $\bar{g}_\lambda'$. The shaded regions indicate the ranges for the first (light-gray) and second (dark-gray)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

great field data enable great satellite data products

satellite vicarious calibration (instrument + algorithm adjustment)

satellite data product validation

bio-optical algorithm development, tuning, & evaluation

Level-2 match-ups

general flow of match-up process, with exclusion criteria

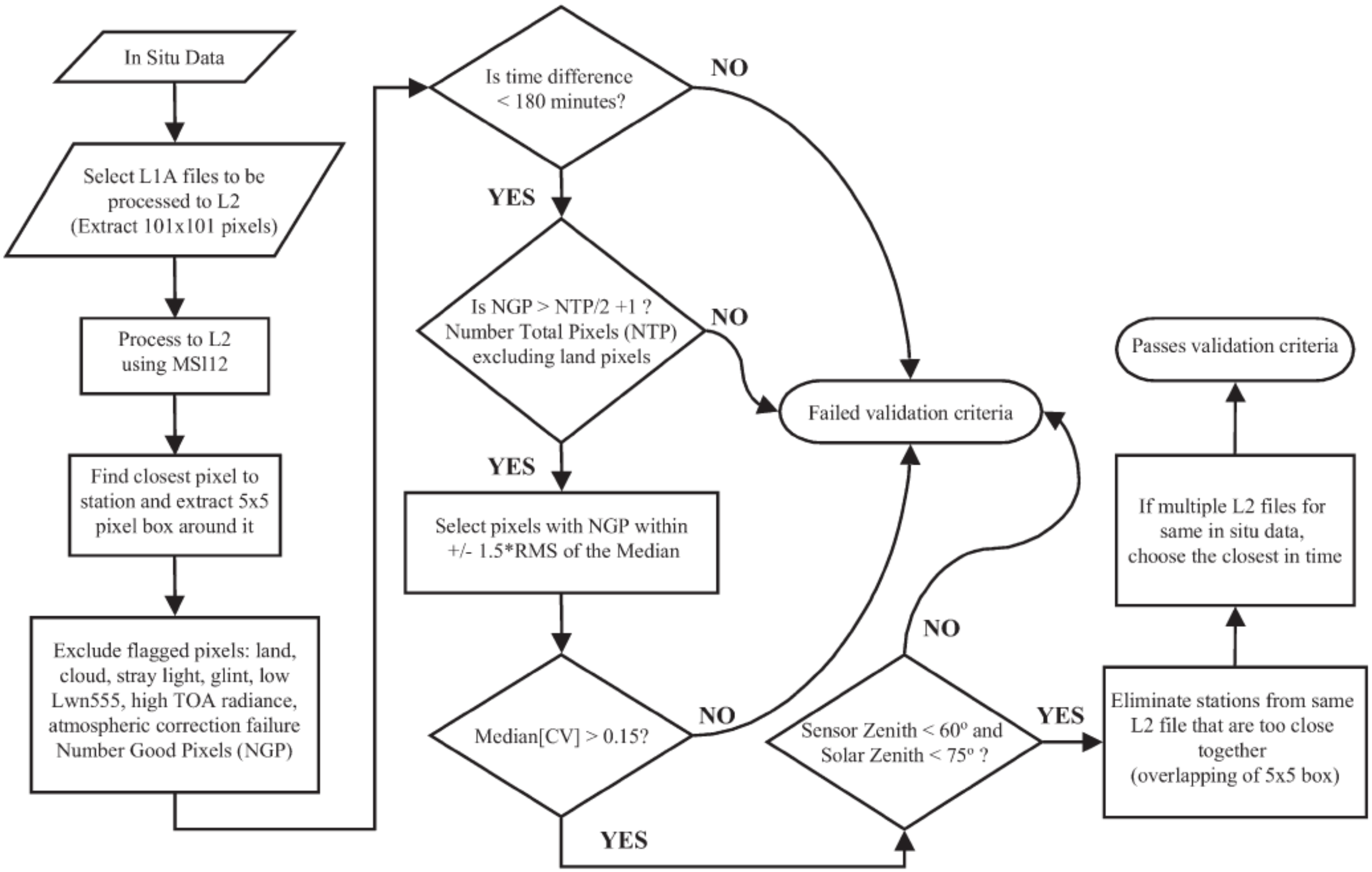


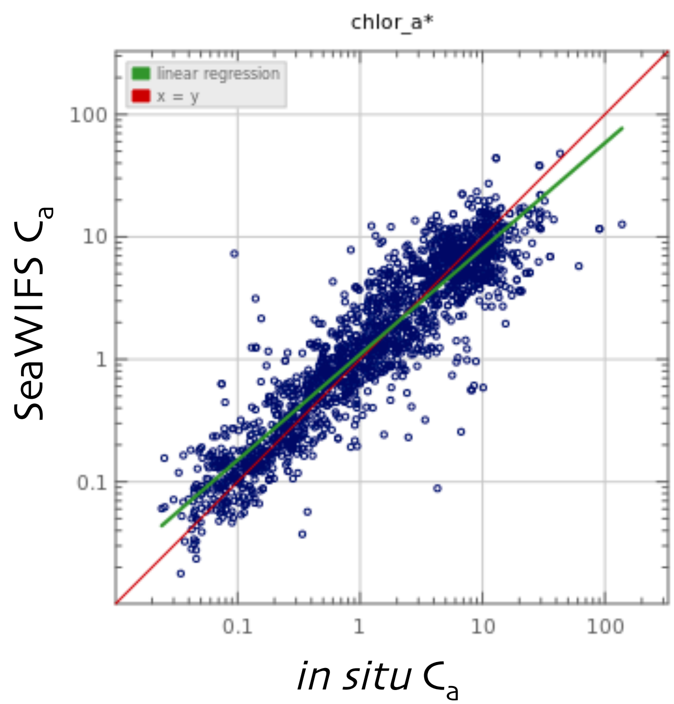
Fig. 1. Flowchart of the validation process highlighting the applied exclusion criteria.

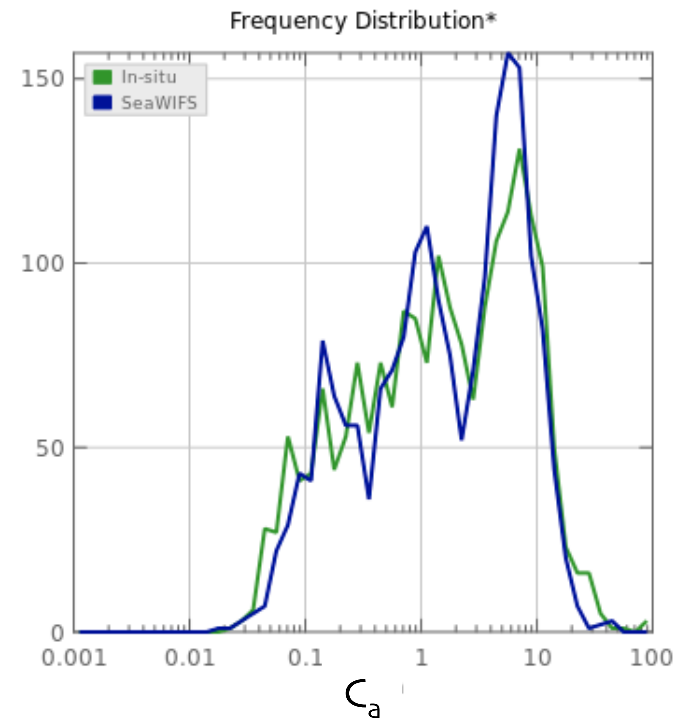
Level-2 match-ups

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

Product Name	SeaWIFS Range	In-situ Range	#	Best Fit Slope*	Best Fit Intercept*	R^2*	Median Ratio	Abs % Difference	RMSE*
chlor_a	0.01782, 48.08236	0.02400, 138.04700	1968	0.86322	0.03969	0.84667	1.05656	36.22945	0.28465

* statistical calculations based on log10





Bailey & Werdell 2006

seabass.gsfc.nasa.gov/seabasscgi/search.cgi

Level-2 match-ups

Level-2 satellite-to-*in situ* "match-ups"

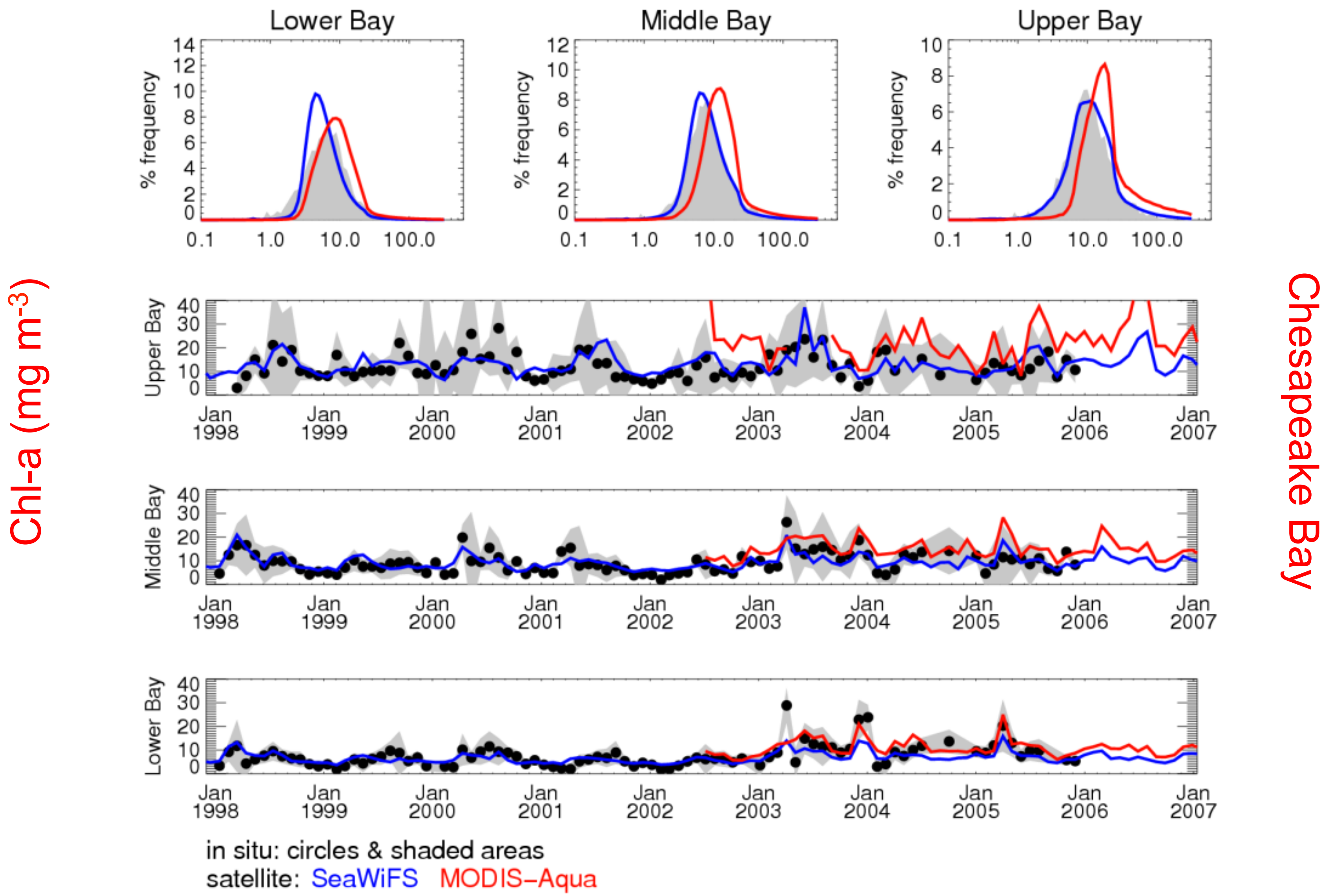
strengths:

- the only truly independent validation of the science data products using ground truth measurements.

limitations:

- quality of *in situ* data is highly variable and difficult to assess
- coverage for OC *in situ* data is limited, both geographically & temporally
- assumes that highly localized (~meters) measurements are representative of pixel (km) area
- *in situ* measurements require discipline expertise to analyze & compare with satellite values
- generally useful only for assessing static biases in final products
- availability of *in situ* data in future (e.g., VIIRS) is unknown

Level-2 time-series



Werdell et al. 2009

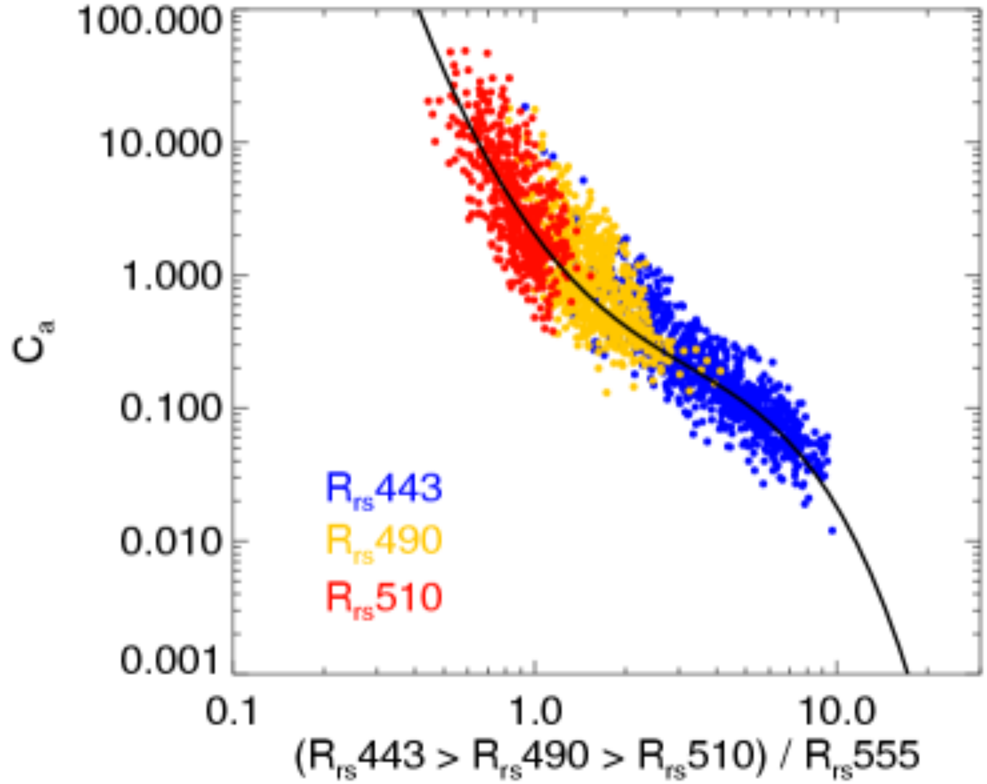
great field data enable great satellite data products

satellite vicarious calibration (instrument + algorithm adjustment)

satellite data product validation

bio-optical algorithm development, tuning, & evaluation

empirical algorithms



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

what satellite sees — what you might want to study

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

atmospheric correction

development of new aerosol tables (via AERONET)

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

refinement of the correction bidirectional effects (f/Q)

evaluation of the correction for spectral bandpass effects

outline

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an abundance of field data is hard to come by

emerging technologies can provide rich data streams

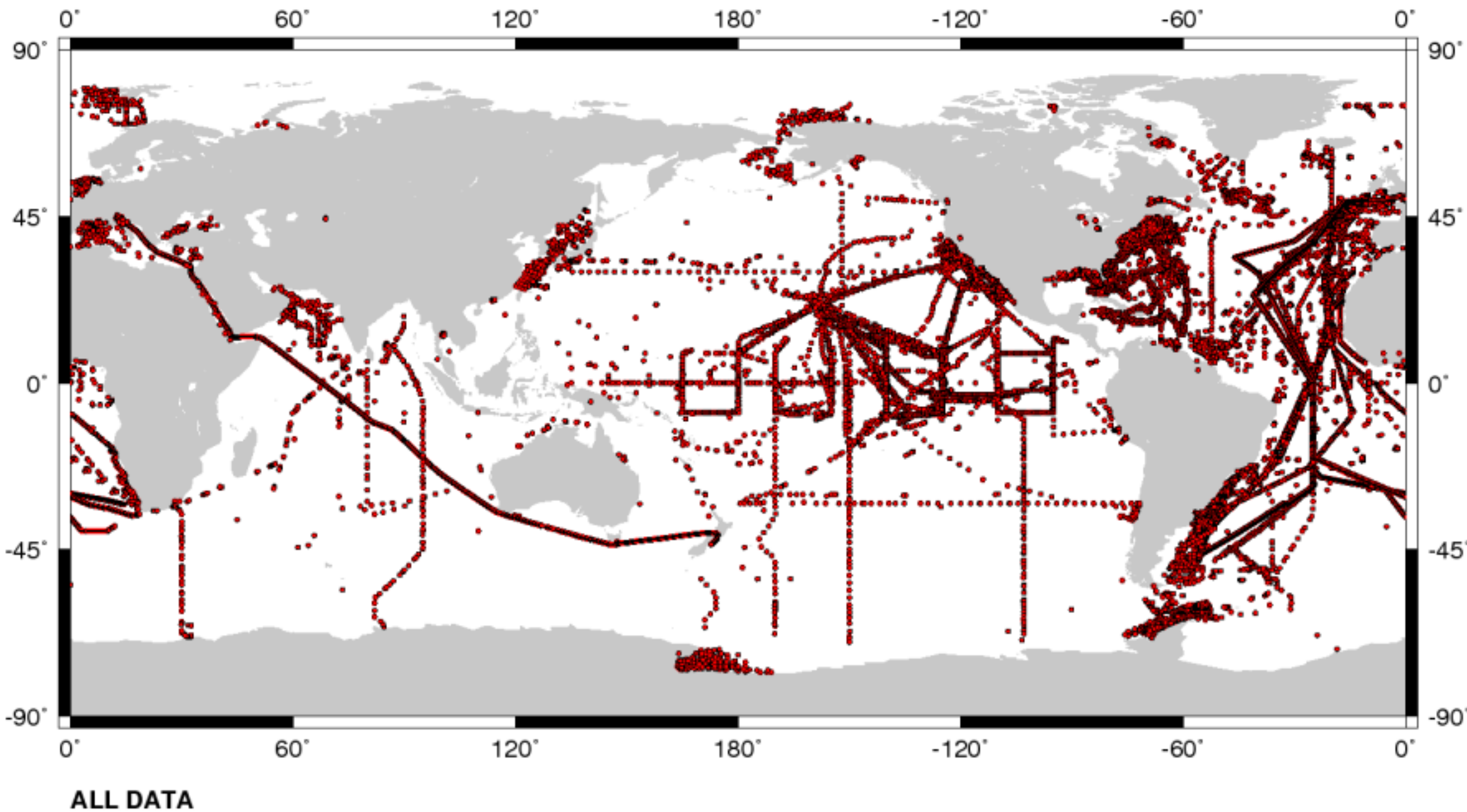
QA/QC metrics are essential (or this all falls apart)

an abundance of field data is hard to come by

spatial & temporal distributions

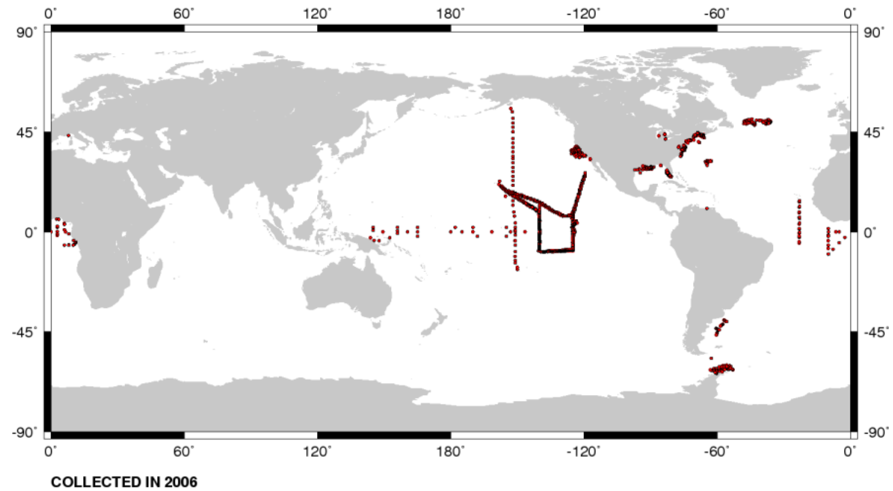
“complete” suites of measurements (R_{rs}, IOPs, biogeochemistry)

SeaBASS @ seabass.gsfc.nasa.gov

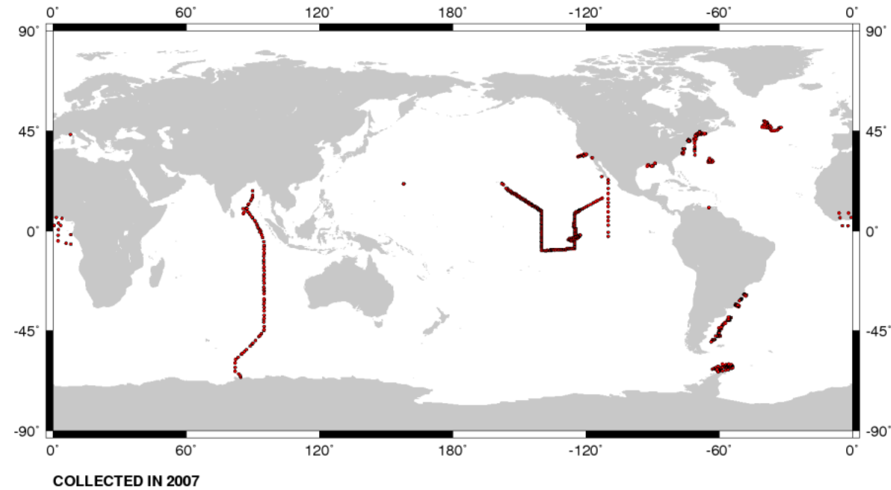


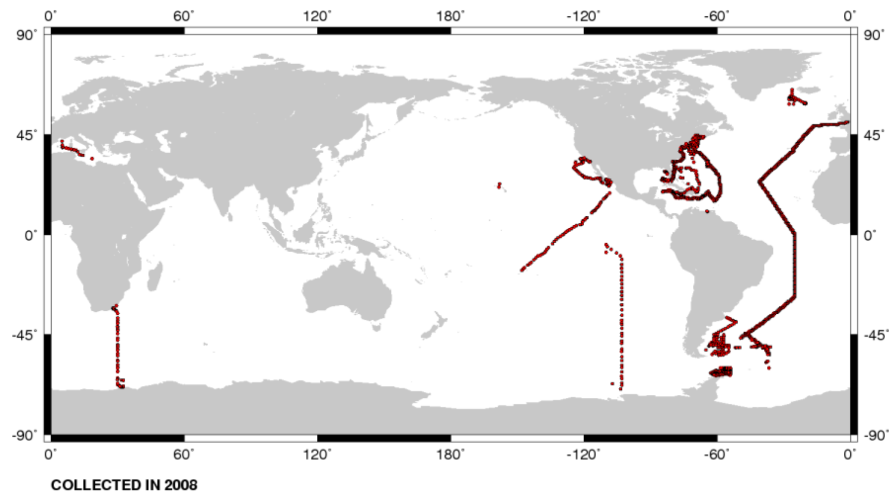
SeaBASS holdings by year: 2006-2009

2006

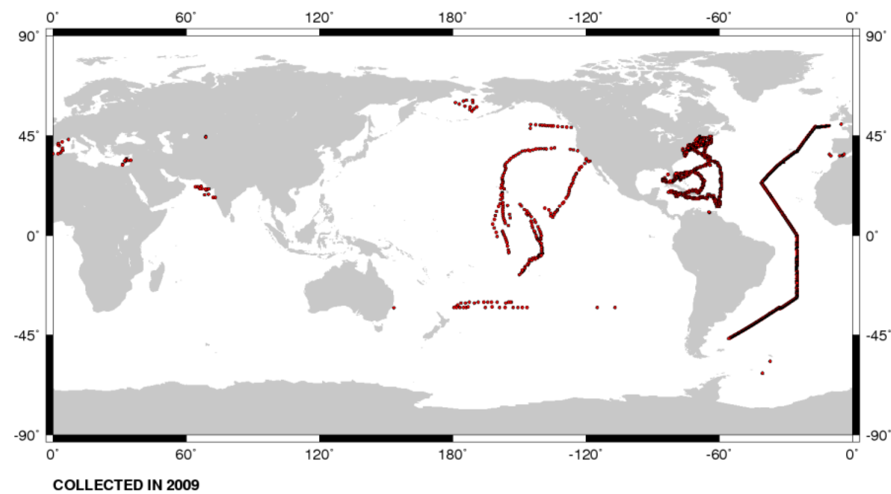


2007





2008



2009

Level-2 match-ups

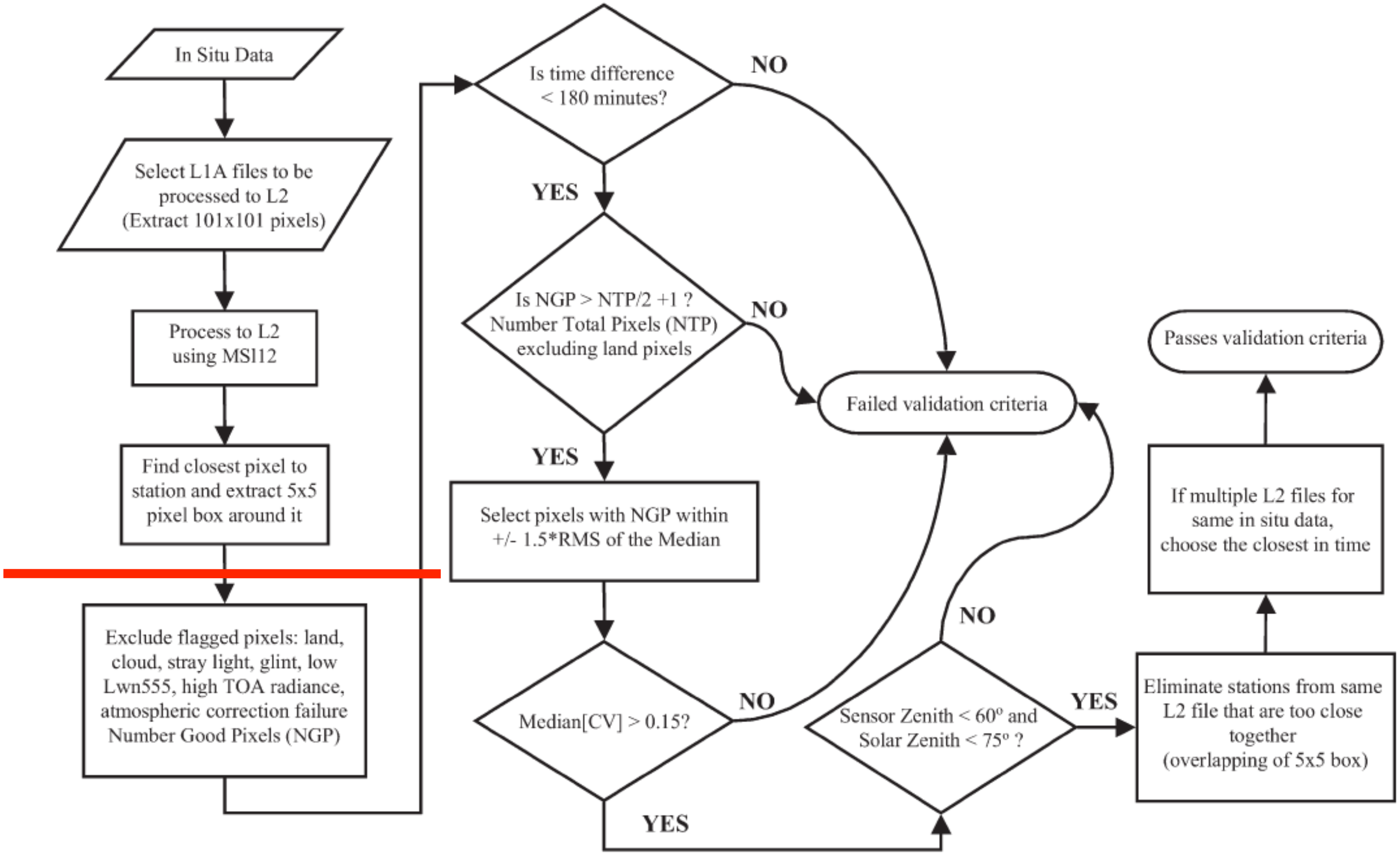
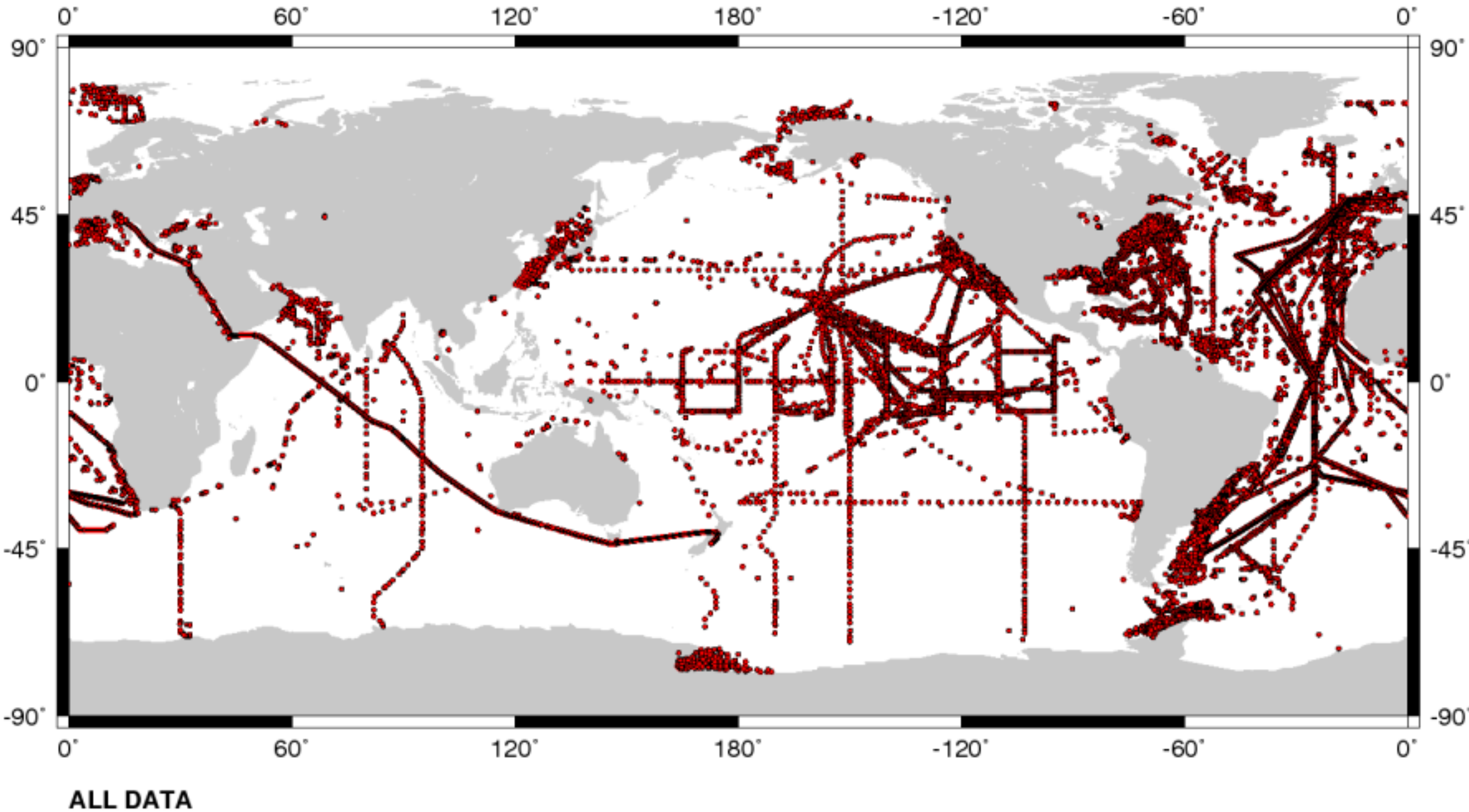


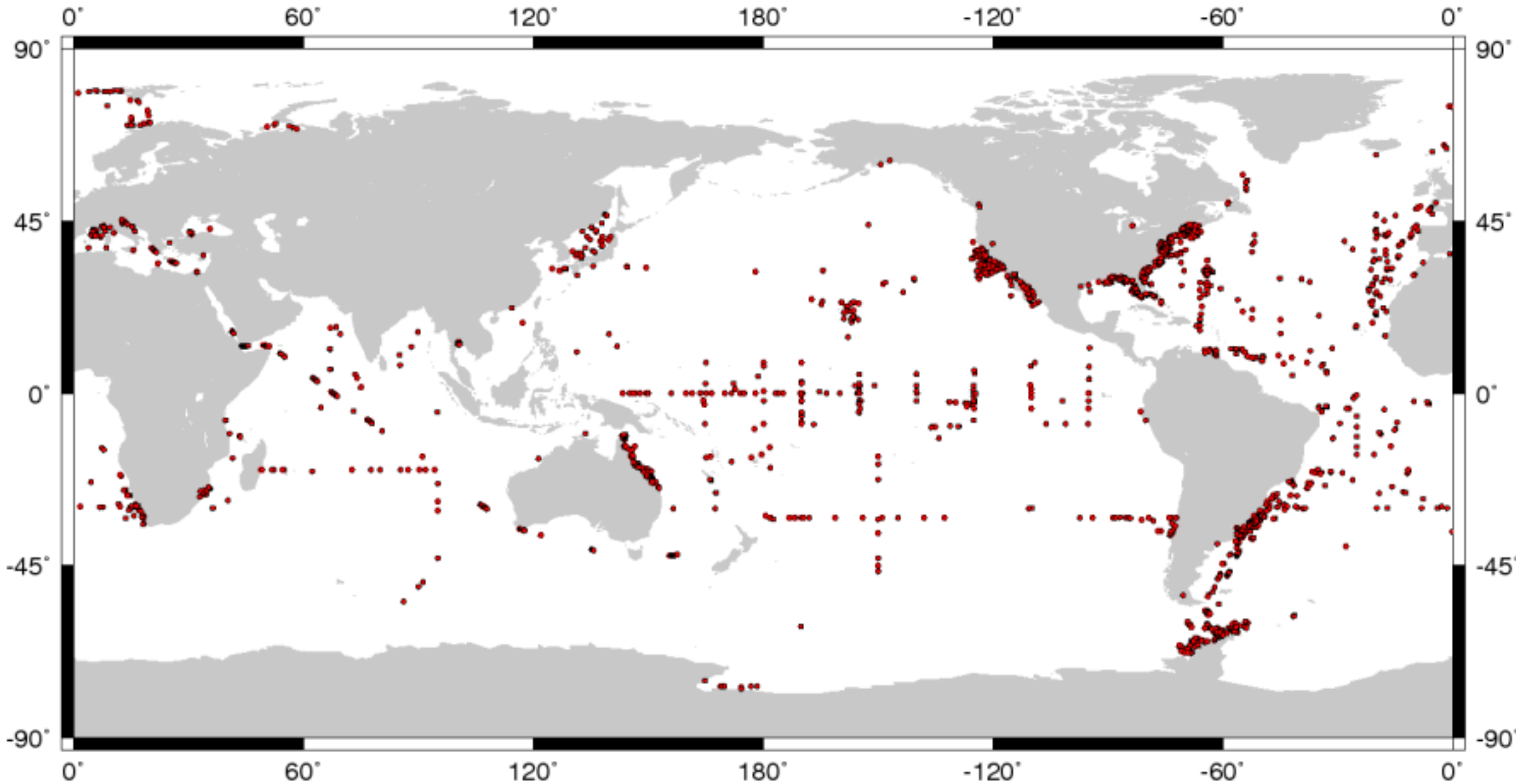
Fig. 1. Flowchart of the validation process highlighting the applied exclusion criteria.

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

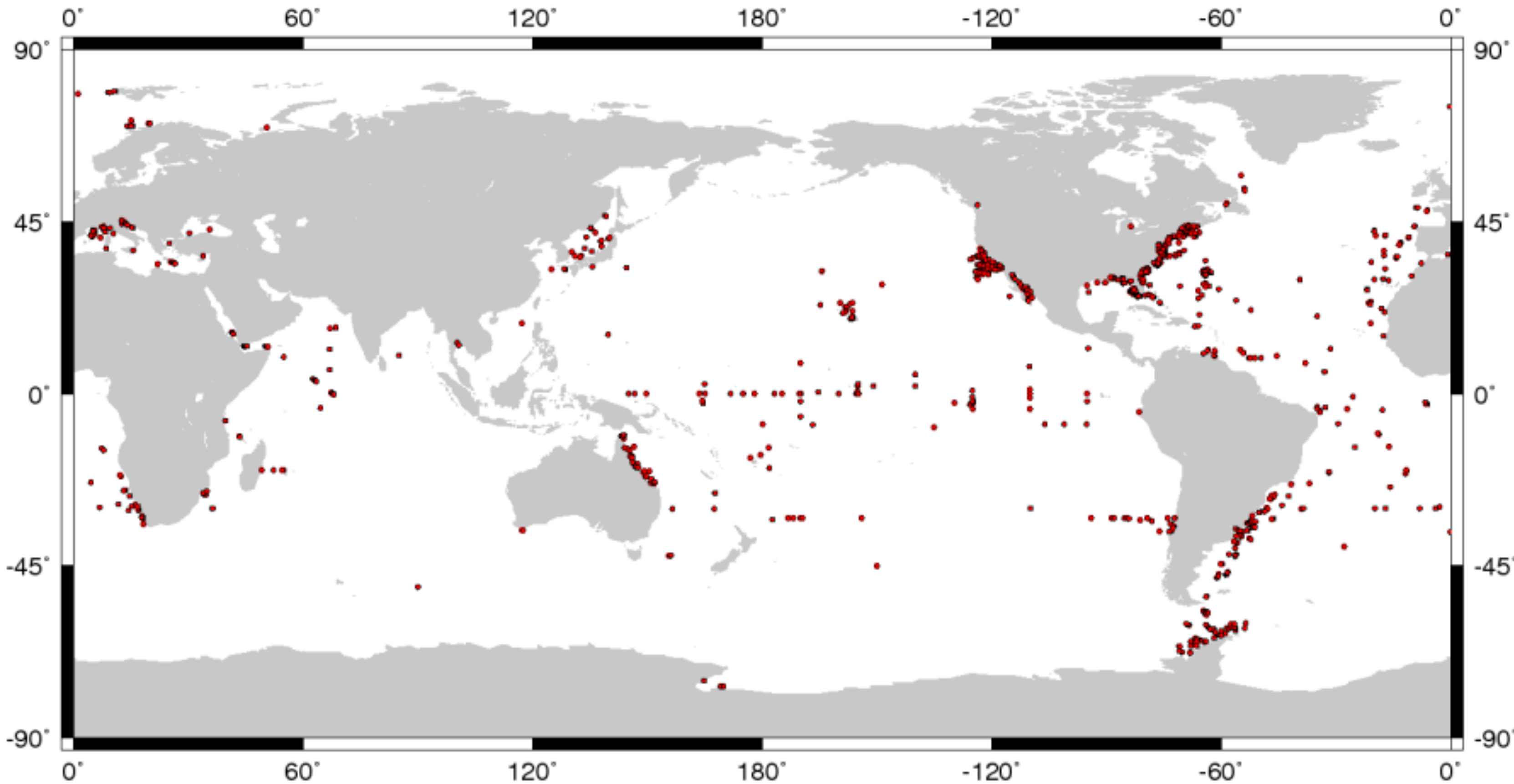


coincident SeaWiFS & in situ data



POSSIBLE SEAWIFS MATCH-UPS

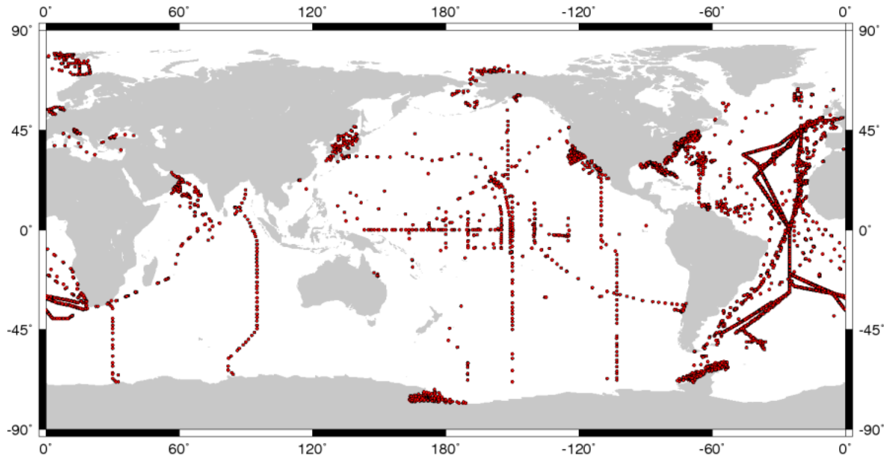
valid SeaWiFS match-ups



VALID SEAWIFS MATCH-UPS

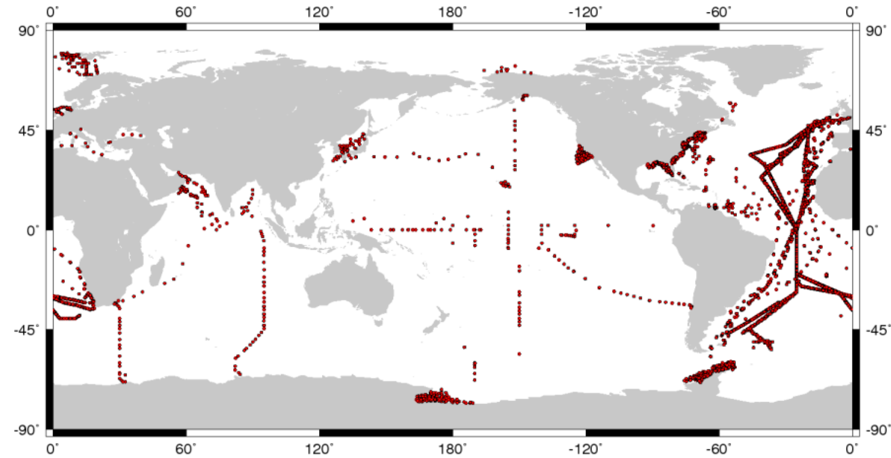
bio-optical algorithm development data sets

R_{rs}

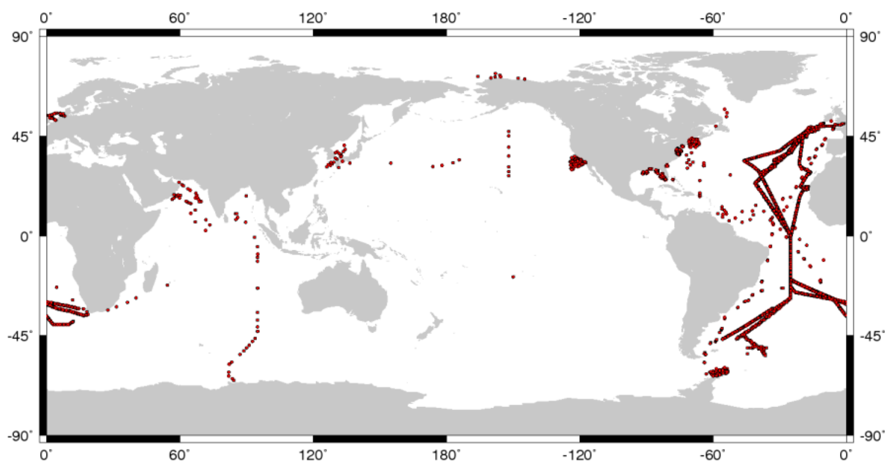


AOP

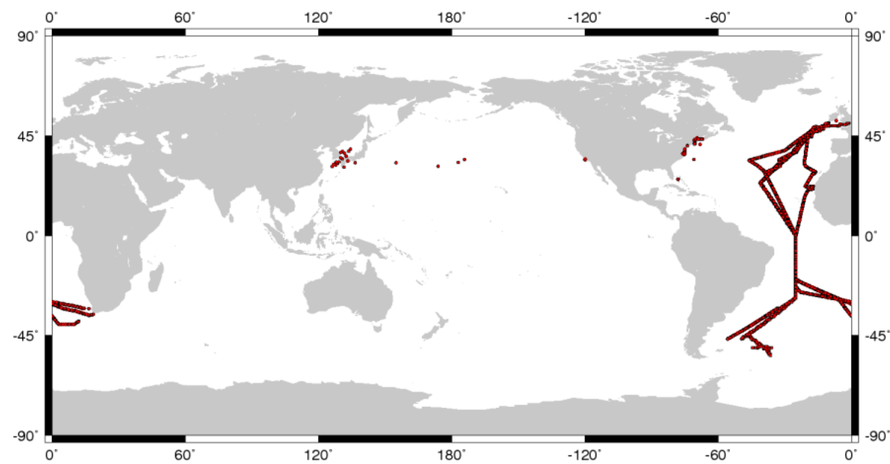
R_{rs} & Chl



AOP + CHL



AOP + CHL + ABSORPTION

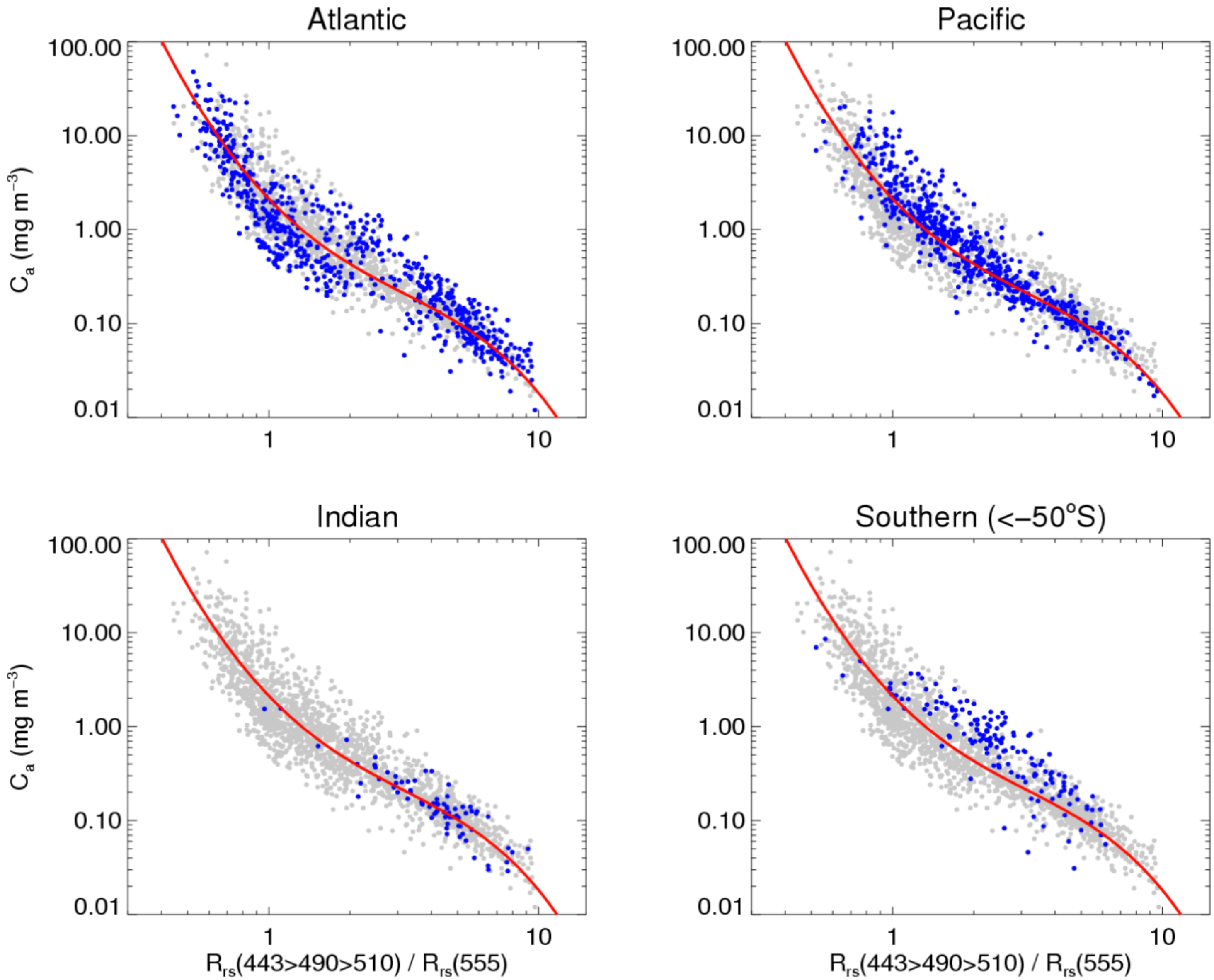


AOP + CHL + ABSORPTION + BACKSCATTERING

R_{rs} & Chl & absorption

Rrs & Chl & absorption & backscattering

bio-optical algorithm development data sets



new missions, new requirements

new missions

VIIRS: launched Oct 2011, viable data Feb 2012

OLCI (Europe), SGLI (Japan): scheduled for CY13, CY15

PACE: scheduled for CY20

ACE, GEO-Cape: scheduled for ~CY23

dynamic range of problem set is growing

emphasis on research in shallow, optically complex water

emphasis on “new” products (carbon, rates, etc.)

spectral domain stretching to UV and SWIR

immediate, operational requirements

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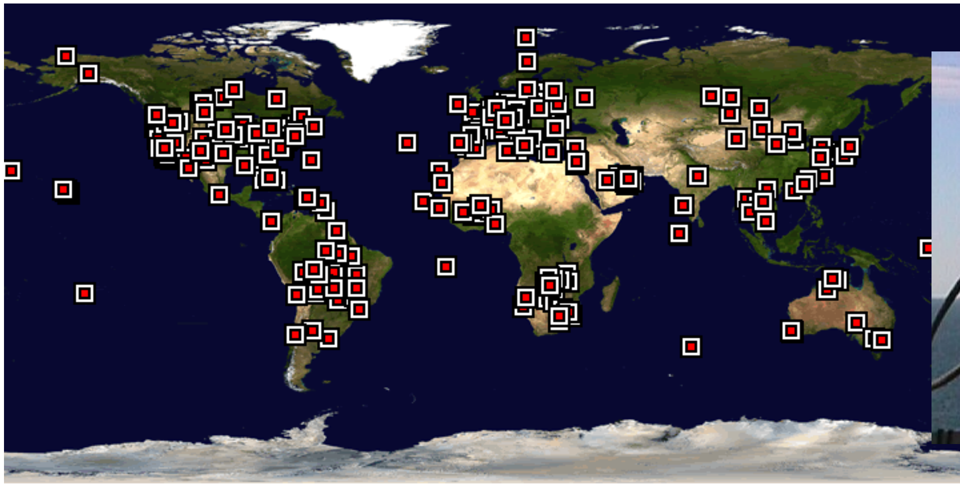
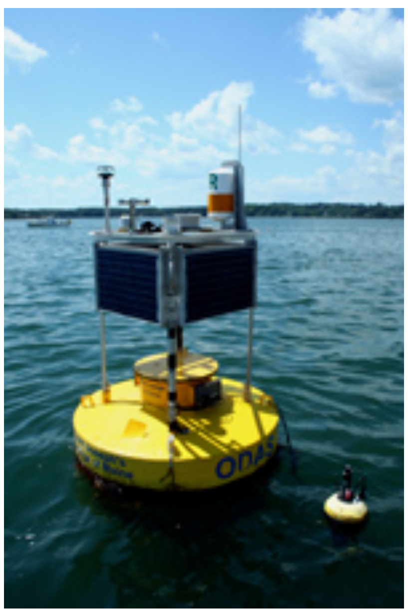
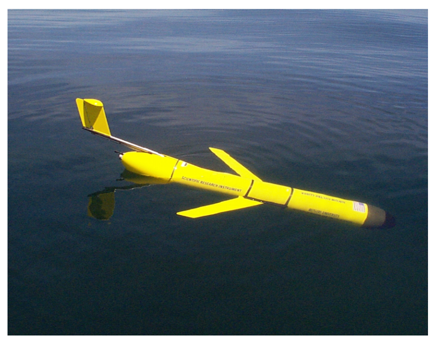
moving forward – community innovations

AERONET (fixed-above water platforms)



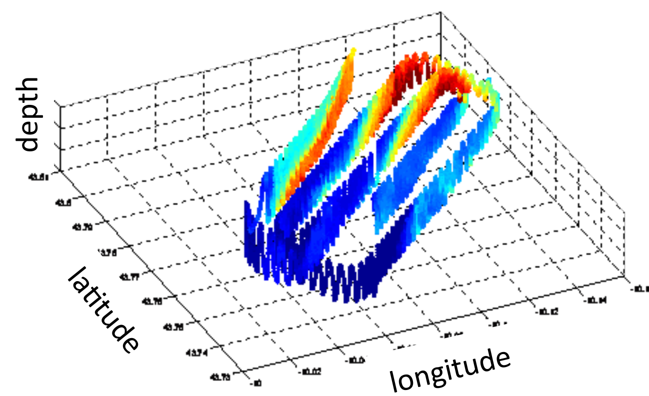


buoy networks



gliders, drifters, & other autonomous platforms

towed & underway sampling

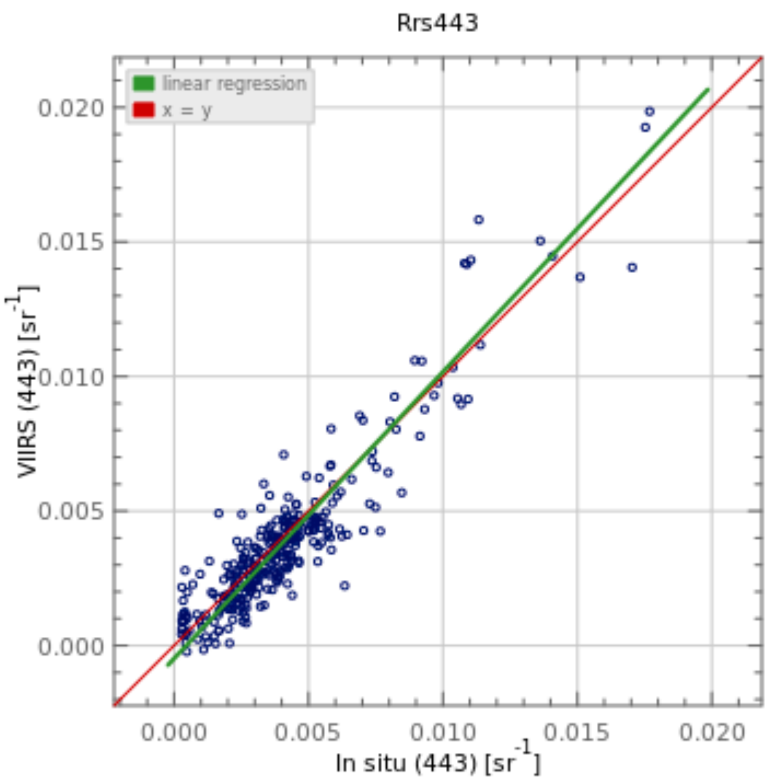


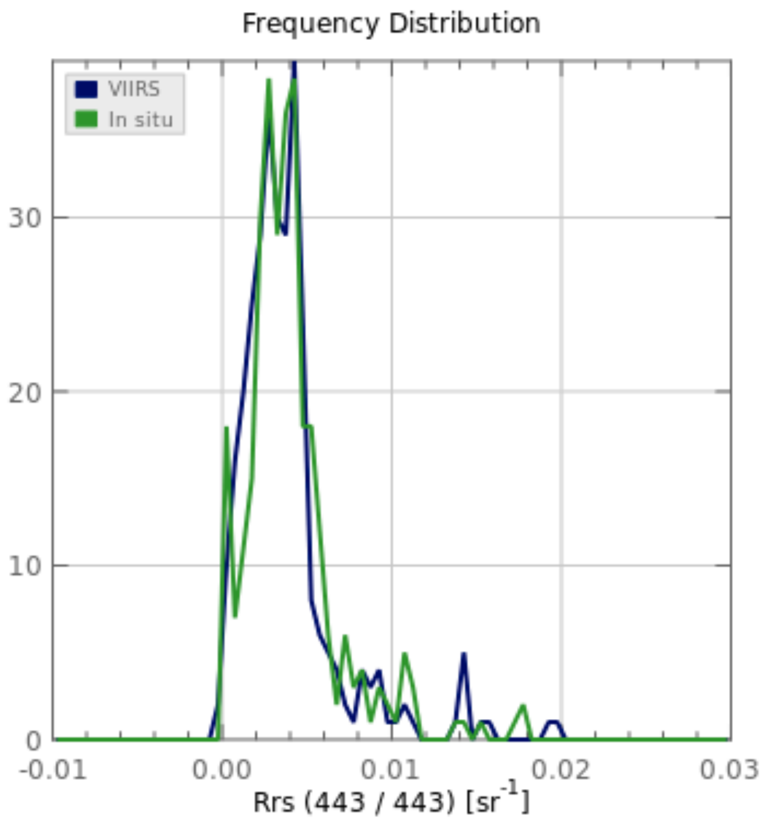
validation exercises using autonomous data

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	Abs % Difference	RMSE
Rrs410	-0.00188, 0.01572	0.00006, 0.01480	370	1.15891	-0.00075	0.72848	0.91371	30.62030	0.00151
Rrs443	-0.00022, 0.01985	0.00028, 0.01769	312	1.06528	-0.00048	0.86995	0.92035	18.64367	0.00114
Rrs486	0.00066, 0.02486	0.00101, 0.02520	370	0.95921	-0.00056	0.92048	0.83444	18.33002	0.00130
Rrs551	0.00097, 0.02519	0.00008, 0.02453	370	0.93824	-0.00055	0.94017	0.81644	18.58145	0.00131
Rrs671	-0.00007, 0.00920	0.00007, 0.00864	296	1.05955	-0.00043	0.86652	0.57489	45.94727	0.00057

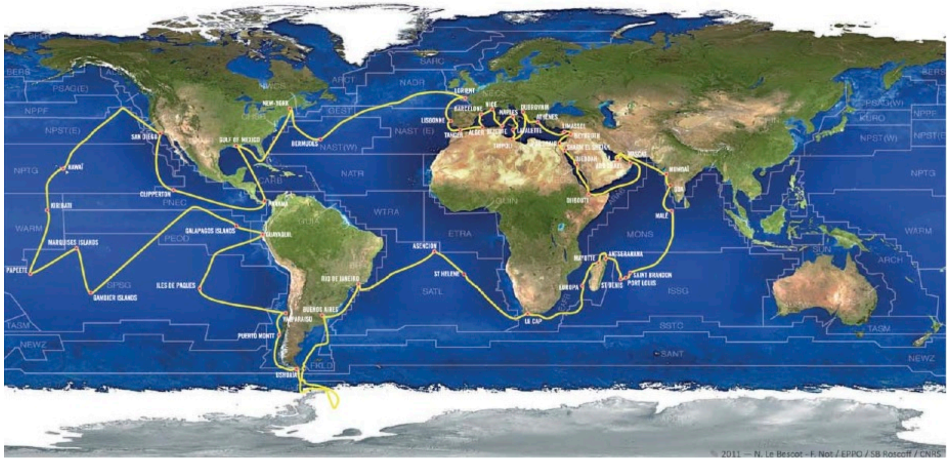
The linear regression algorithm has been changed to reduced major axis.

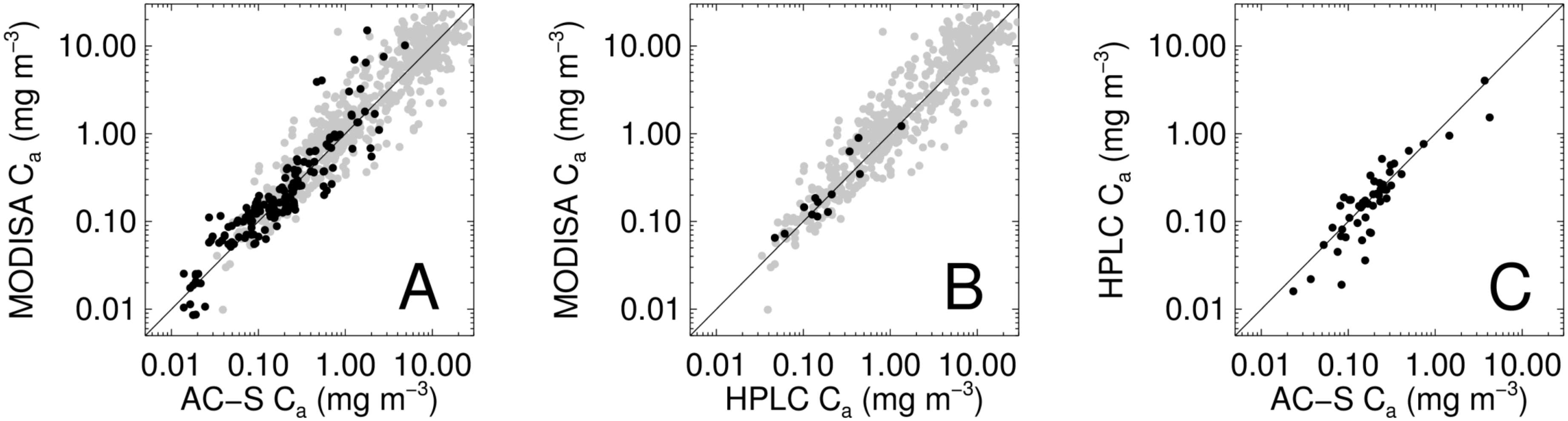




validation exercises using autonomous data

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





outline

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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)

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

robust 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

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

where do we want to be in 10 years?

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

for example, 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

a word on data collection & processing for cal/val

<u>Measurement in field</u>

AOP(λ,z), IOP(λ,z), & C_a/CTD/bottle(z)

format provided by PI

minimal exclusion

$L_U(\lambda,z) \rightarrow L_W(\lambda)$

<u>Remote-sensing relevant values</u>

AOP(λ,0$^+$), IOP(λ, 0$^+$), & C_a/CTD/bottle(0$^+$)

no restrictions on coincidence

exclusion criteria applied (×2) / data reduction

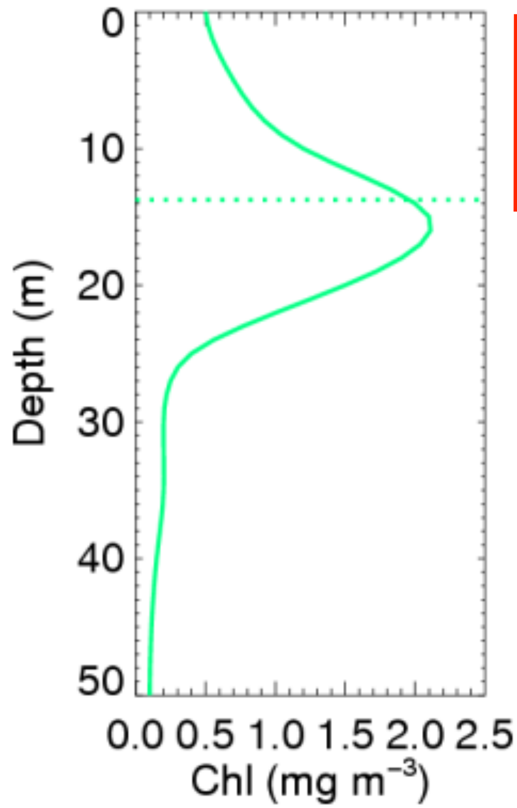
calibration quality with protocol adherence

<u>Algorithm Development</u>

AOP(λ,0$^+$) + IOP(λ, 0$^+$) + C_a/CTD/bottle(0$^+$)

coincidence requirement

a word on data collection & processing for cal/val



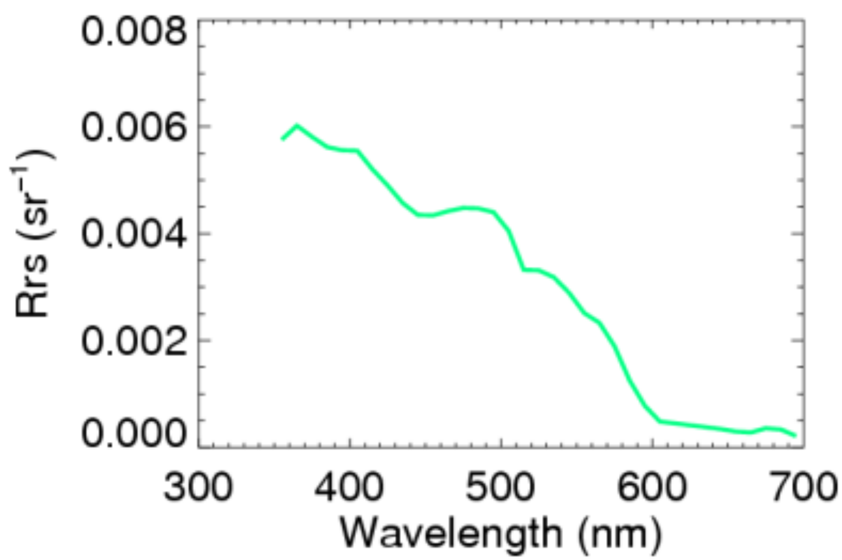
first optical depth
$0.37 = \exp(-K_d z)$
$-1 = -K_d z$

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

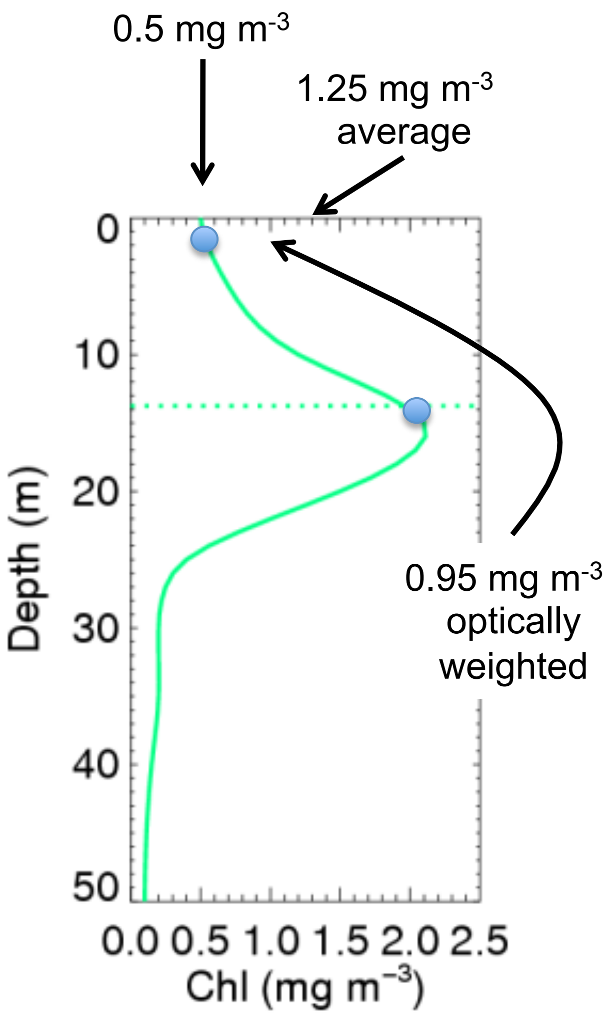
Howard R. Gordon and W. R. McCluney

The penetration depth of light in the sea is defined for remote sensing purposes as the depth above which 90% of the diffusely reflected irradiance (excluding specular reflectance) originates. It is demonstrated that for a homogeneous ocean, this is the depth at which the downwelling in-water irradiance falls to 1/e of its value at the surface. Penetration depths as a function of wavelength are presented for a variety of water types, and a mean penetration depth z_{90} for a broadband sensor is defined and applied to the MSS on ERTS-1. The maximum z_{90} expected for ERTS-1 is found to be somewhat less than 20 m.

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



a word on data collection & processing for cal/val



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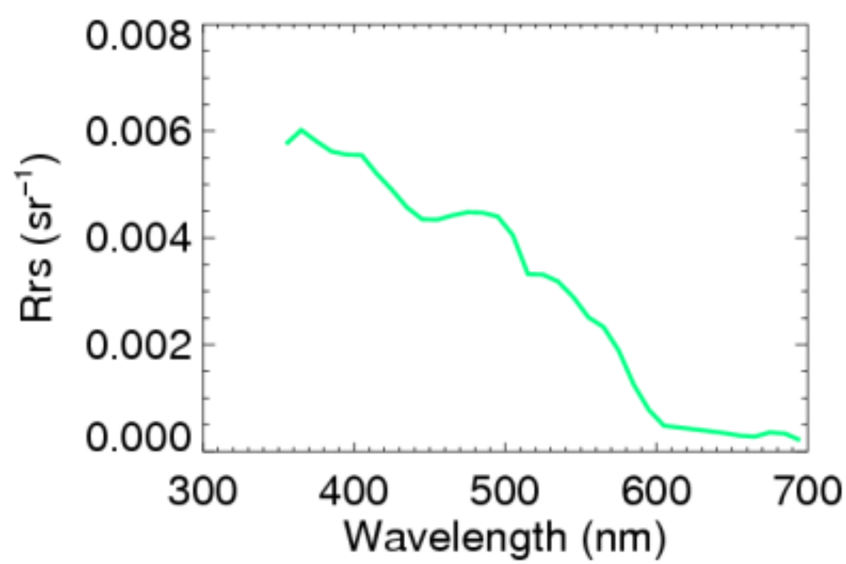
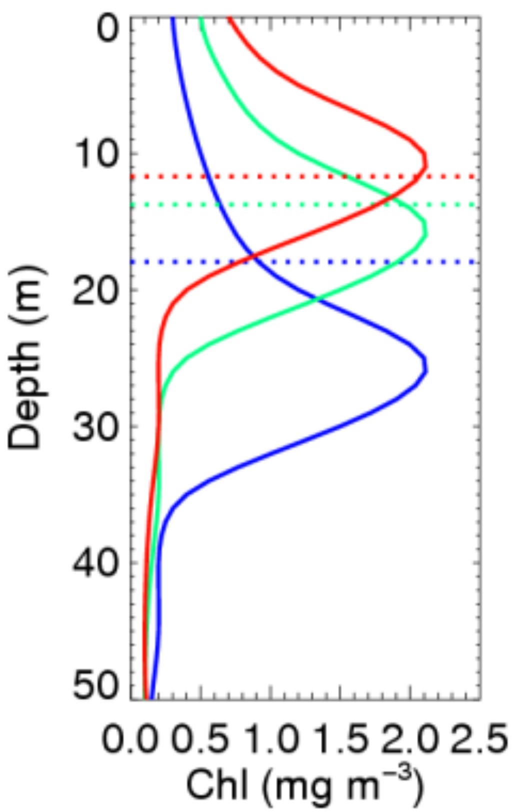


a word on data collection & processing for cal/val



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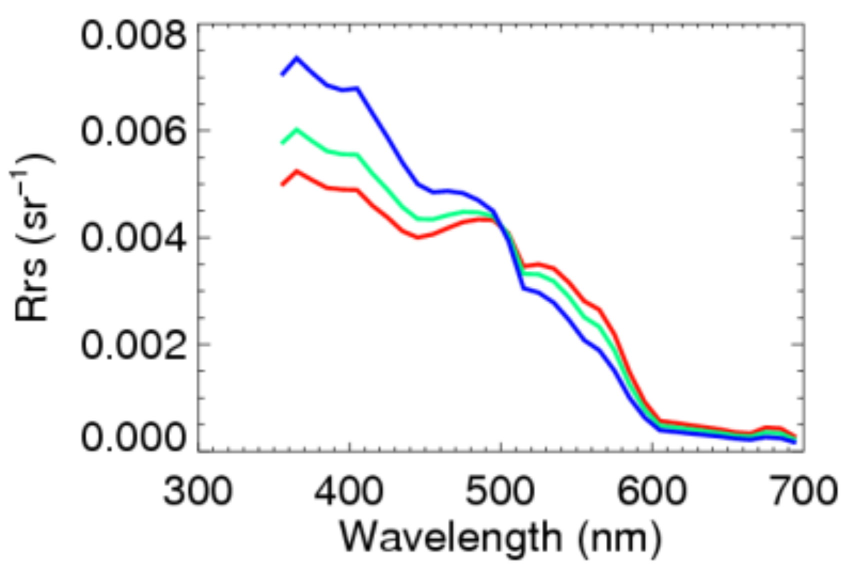
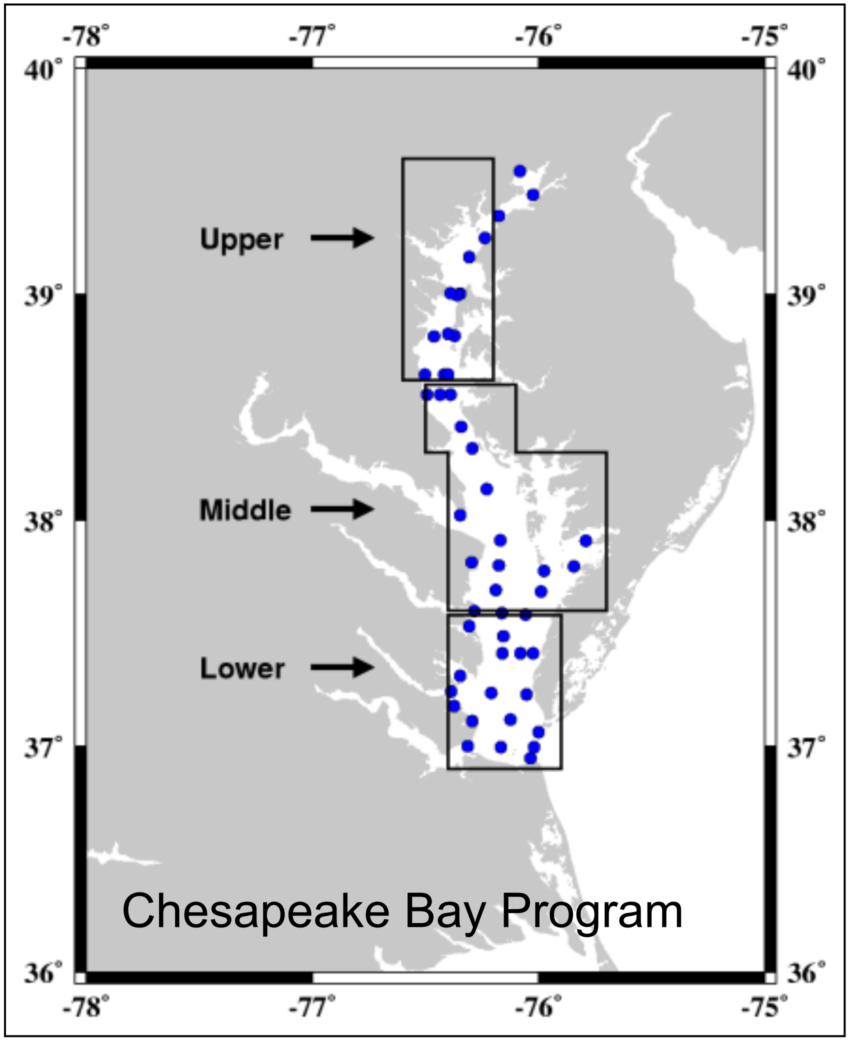


questions?
comments?
concerns?

backup slides

Level-2 time-series



Chesapeake Bay Program
A Watershed Partnership

http://www.chesapeakebay.net

routine data collection since 1984
12-16 cruises / year

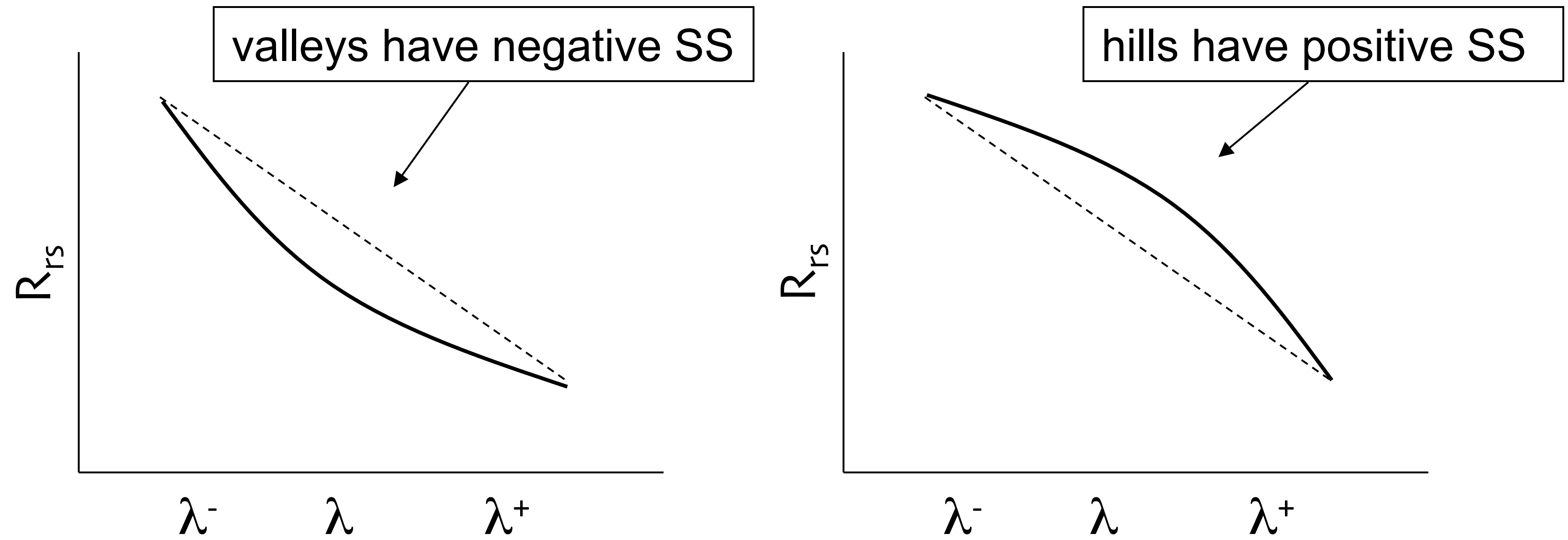
49 stations
19 hydrographic measurements

algal biomass
water clarity
dissolved oxygen
others

population statistics for vicarious calibration

compare spectral shapes of *in situ* & satellite populations

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

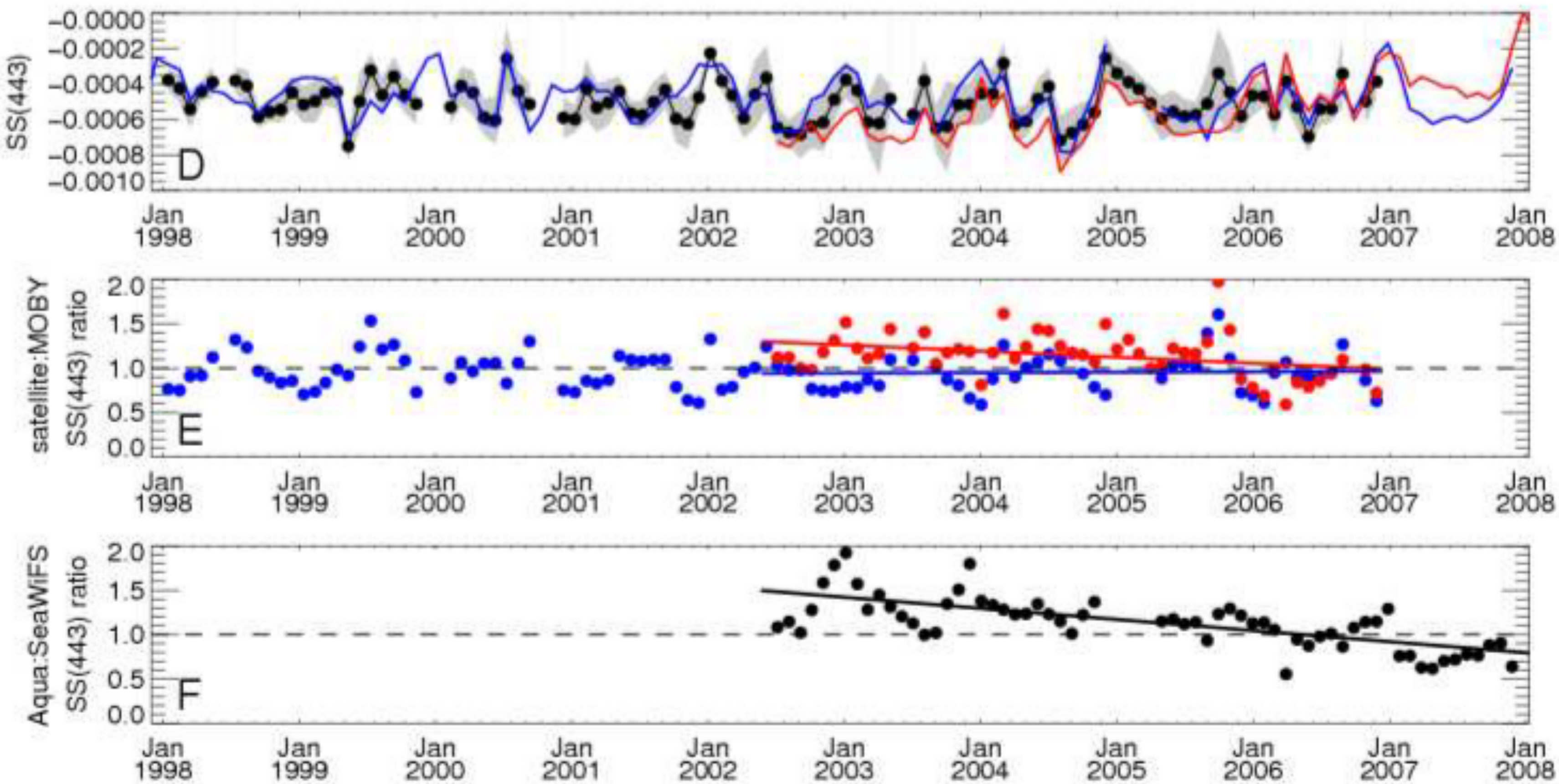


spectral shape @ 443 nm, SS(443), uses $R_{rs}(412)$, $R_{rs}(443)$, & $R_{rs}(490)$

Stumpf & Werdell 2010

population statistics for vicarious calibration

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



Stumpf & Werdell 2010

AOP data analysis

$L_u(z)$, $E_d(z)$ -> L_w, E_s