Marine inherent optical properties (IOPs) from MODIS & VIIRS with Extension to Optically Shallow Waters

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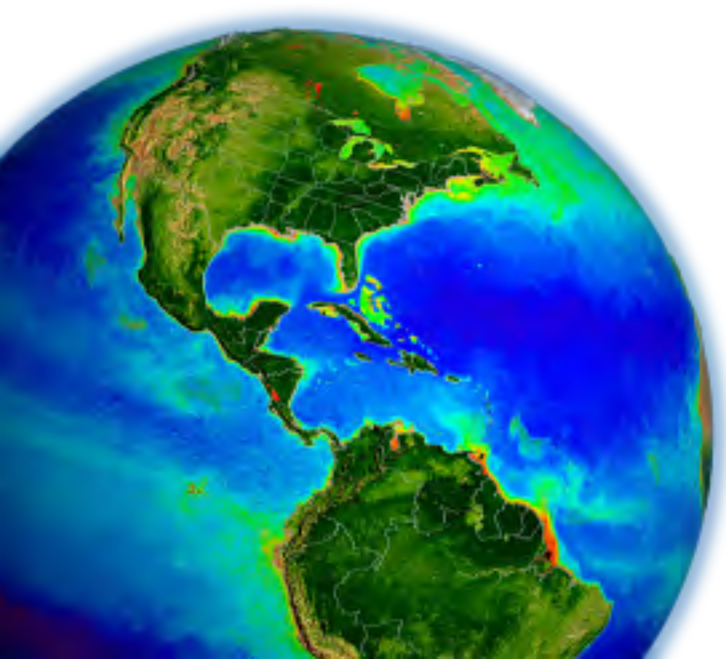


MODIS Science Team Meeting
Silver Spring, Maryland
21 May 2015

what are marine inherent optical properties (IOPs)?
spectral absorption & scattering coefficients

what can marine IOPs tell me?
they describe the contents of the upper ocean

- phytoplankton abundance & community structure
- non-algal suspended particles
- particulate & dissolved carbon
- diffuse attenuation / water clarity

why study marine IOPs from space?
satellite time-series provide “big picture” views to better understand responses to climate change & for inclusion in bio-hydrographic models

presentation outline

Part 1: implementation review

Part 2: validation matchup

Part 3: algorithm updates

Part 4: status overview

relating ocean color & in-water optical properties

$$R_{rs} = G\left(\frac{b_{bw} + M_{bp} b_{bp}^{*}}{a_w + M_{dg} a_{dg}^{*} + M_{\varphi} a_{\varphi}^{*}}\right)$$

Optically-active constituents

- *w* = water
- *dg* = colored dissolved and detrital matter
- φ = phytoplankton
- *p* = particles

relating ocean color & in-water optical properties

$$R_{rs} = G\left(\frac{b_{bw} + M_{bp} b_{bp}^{*}}{a_w + M_{dg} a_{dg}^{*} + M_{\varphi} a_{\varphi}^{*}}\right)$$

Constants*

Spectral shapes

<u>Magnitudes</u>

- 3 unknowns: M_{dg}, M_{ϕ}, M_{bp}
- *6* knowns (the 6 visible MODISA R_{rs}), or, 5 for VIIRS
- solve for unknown M coefficients → non-linear least squares

relating ocean color & in-water optical properties

SAAs developed routinely over 30 yrs
many successfully retrieve **three** components
many overlapping approaches exist

power-law, η:
Fixed; Lee et al. (2002)
Ciotti et al. (1999);
Hoge & Lyon (1996);
Loisel & Stramski (2001);
Morel (2001)

$$R_{rs} = G\left(\frac{b_{bw} + M_{bp} b^{*}_{bp}}{a_w + M_{dg} a^{*}_{dg} + M_{\phi} a^{*}_{\phi}}\right)$$

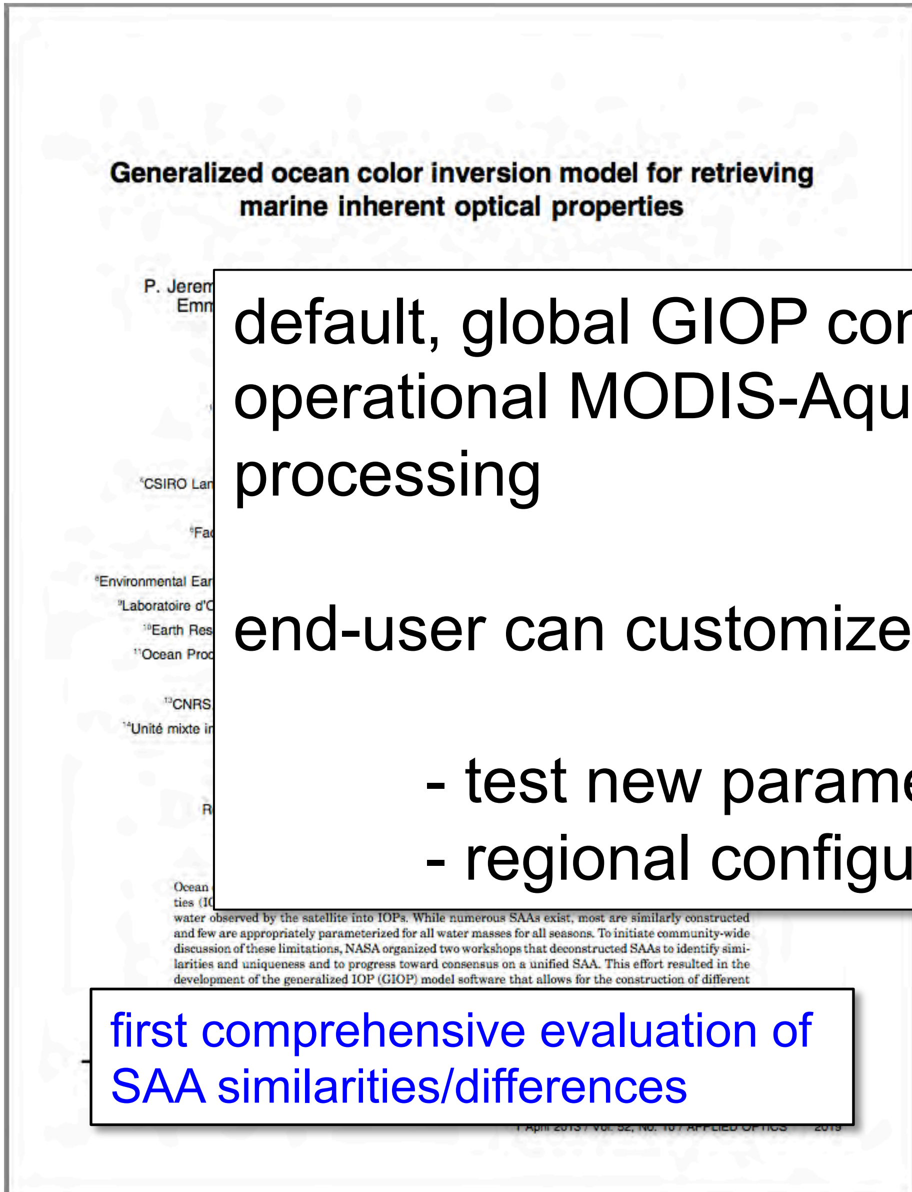
Inverse method:
Levenberg-Marquardt
SVD matrix inversion

Morel f/Q
Gordon quadratic

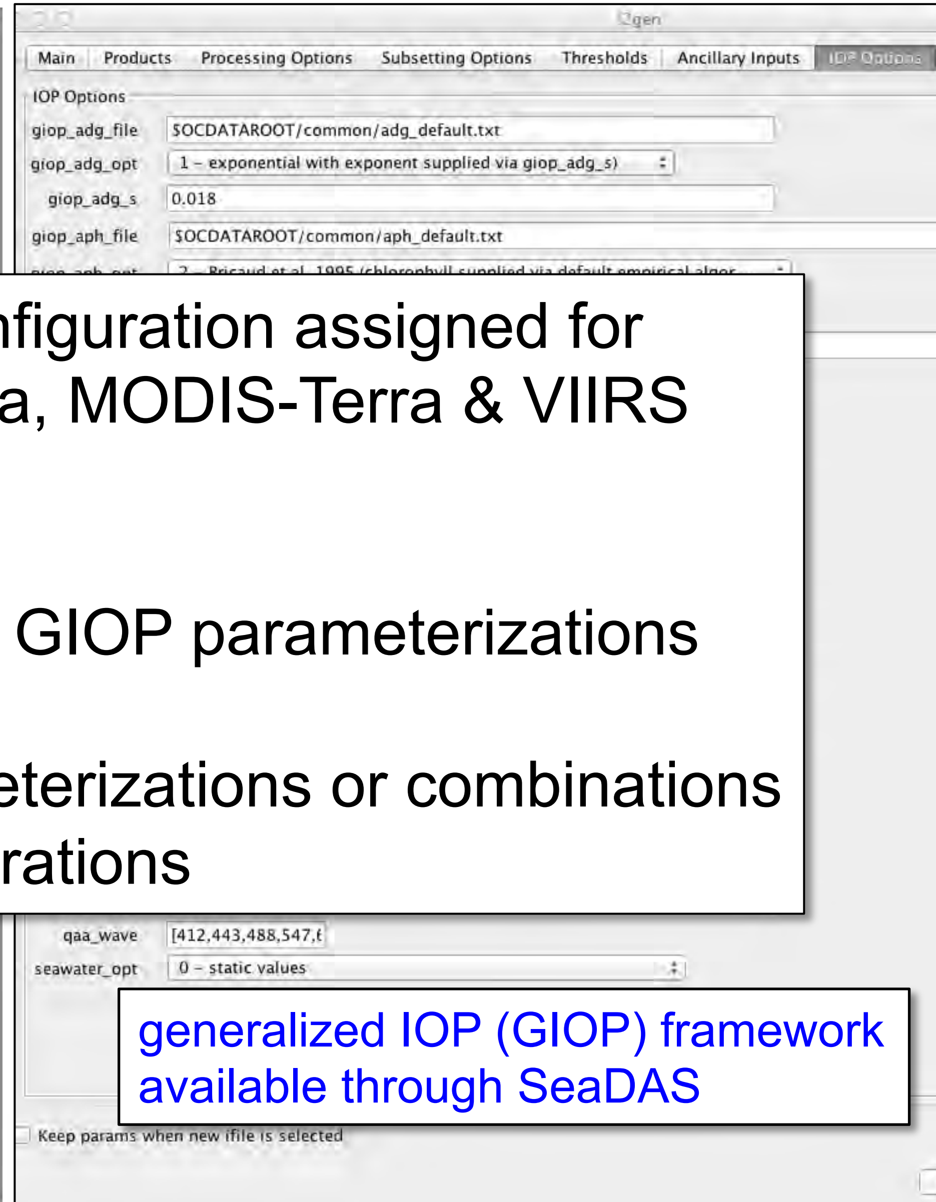
exponential, S_{dg}:
fixed (= 0.018)
Lee et al. (2002)
Werdell (2010)
tabulated $a^{*}_{dg}(\lambda)$

tabulated $a^{*}_{\phi}(\lambda)$
Bricaud et al. (1998)
Ciotti & Bricaud (2006)

Implementation


Generalized ocean color inversion model for retrieving marine inherent optical properties

water observed by the satellite into IOPs. While numerous SAAs exist, most are similarly constructed and few are appropriately parameterized for all water masses for all seasons. To initiate community-wide discussion of these limitations, NASA organized two workshops that deconstructed SAAs to identify similarities and uniqueness and to progress toward consensus on a unified SAA. This effort resulted in the development of the generalized IOP (GIOP) model software that allows for the construction of different



default, global GIOP configuration assigned for operational MODIS-Aqua, MODIS-Terra & VIIRS processing

end-user can customize GIOP parameterizations

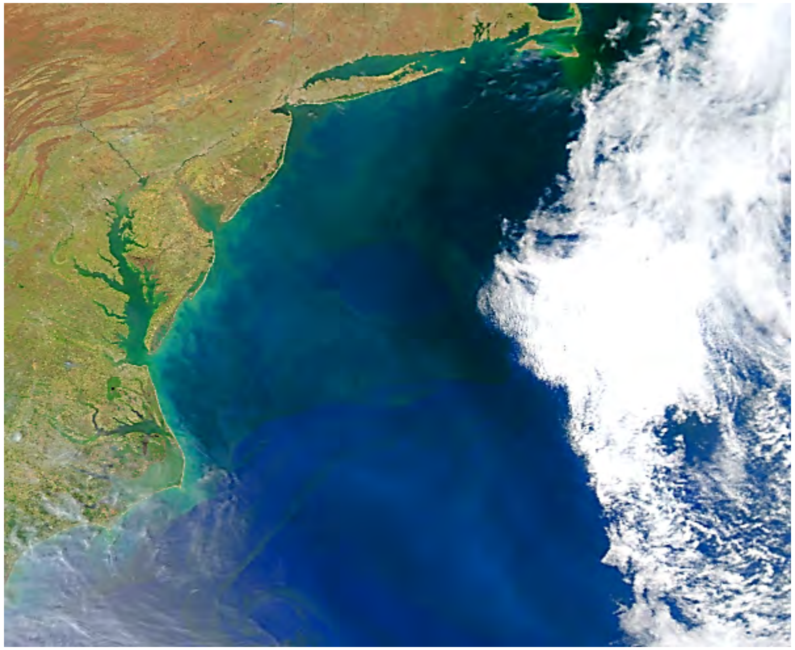
- test new parameterizations or combinations
- regional configurations

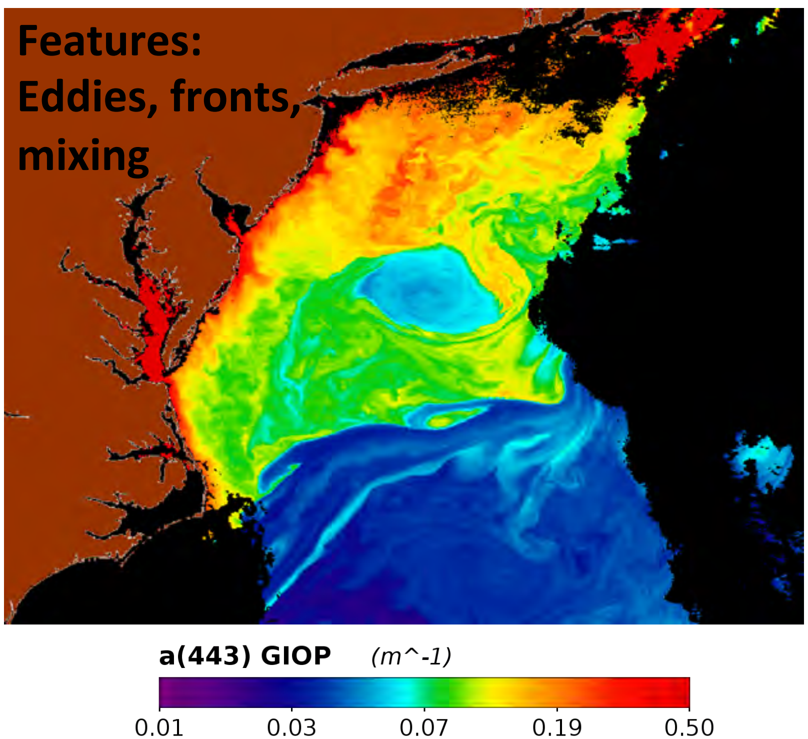
first comprehensive evaluation of SAA similarities/differences

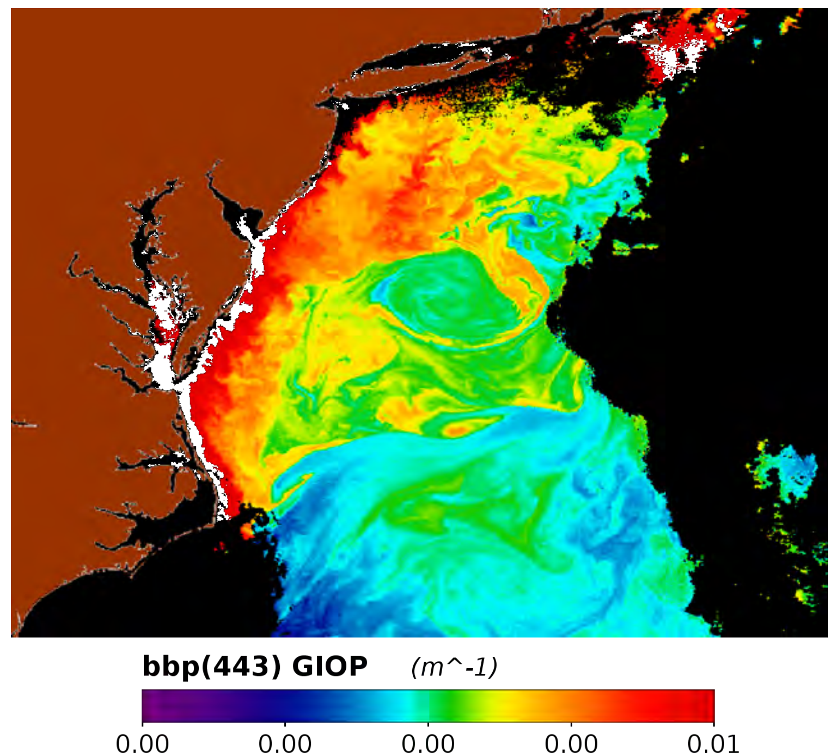
generalized IOP (GIOP) framework available through SeaDAS

MODIS Aqua 18 April 2008

Data: NASA OBPG
Processing: SeaDAS, GIOP Algorithm with default options







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SeaBASS

SeaWiFS Bio-optical Archive and Storage System

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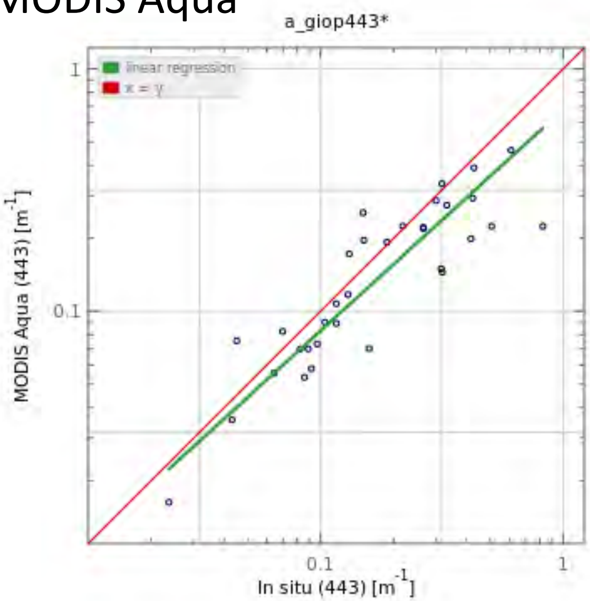
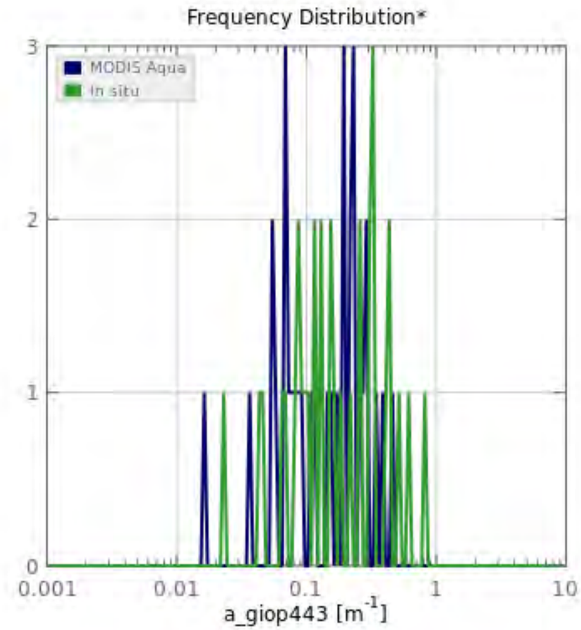
a(443) MODIS Aqua





R^2=0.81

Slope=0.91

Intercept =-0.17

Ratio = 0.83

Product Name	MODIS Aqua Range	In situ Range	#	Best Fit Slope*	Best Fit Intercept*	R^2*	Median Ratio	Abs % Difference	RMSE*
a_giop412	0.01899, 0.59110	0.03112, 1.11607	33	0.94109	-0.11355	0.67249	0.86065	26.77913	0.26994
a_giop443	0.01629, 0.46147	0.02368, 0.82533	33	0.91213	-0.16850	0.80958	0.82752	23.32340	0.19566
a_giop488	0.01912, 0.30815	0.02306, 0.51810	33	0.86918	-0.24917	0.87421	0.80311	22.52950	0.16997
a_giop531	0.04570, 0.21564	0.04743, 0.34321	33	0.77114	-0.32126	0.81197	0.83466	16.53372	0.13213
a_giop547	0.05470, 0.19041	0.05926, 0.27440	33	0.79497	-0.28821	0.79859	0.84145	15.85549	0.11162
a_giop667	0.36955, 0.57674	0.43053, 0.54554	33	1.63666	0.21462	0.58994	1.00351	2.30077	0.02902

* statistical calculations based on log10

seabass.gsfc.nasa.gov

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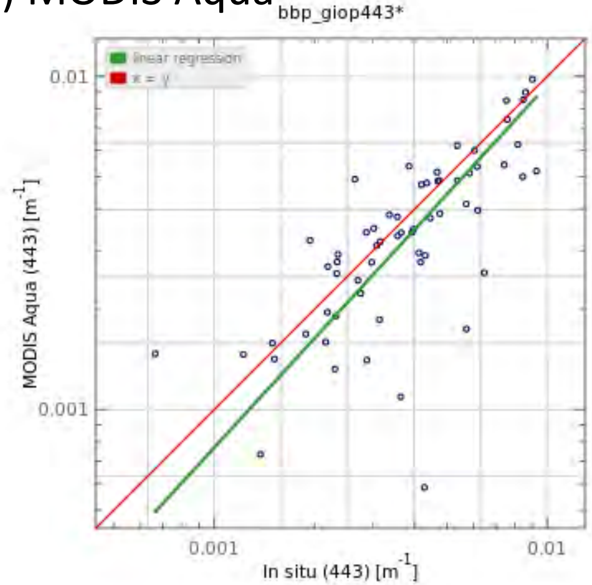
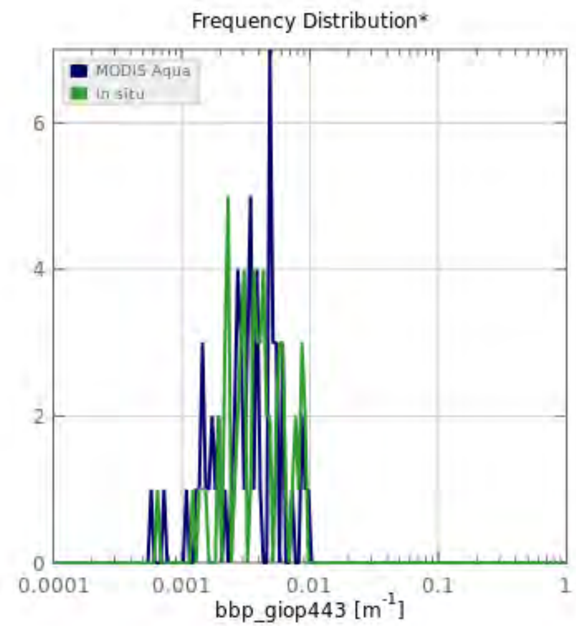
b_{bp}(443) MODIS Aqua



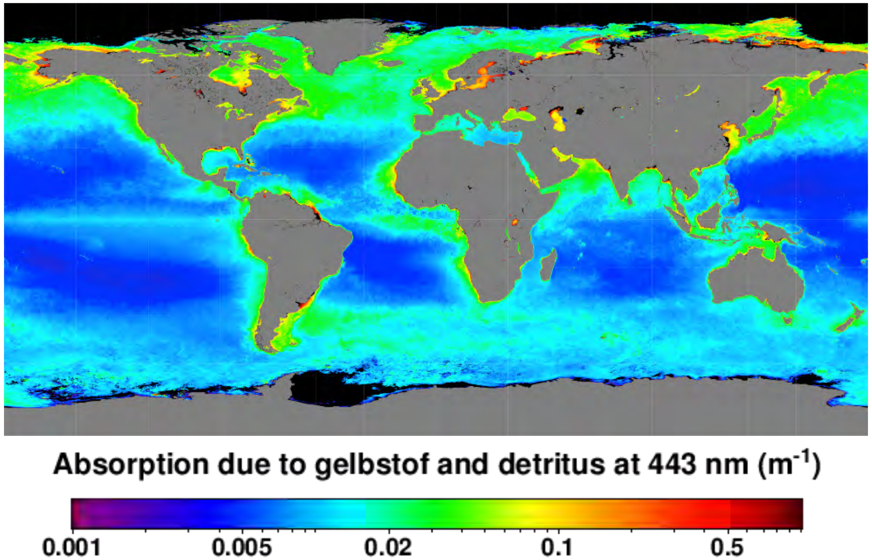


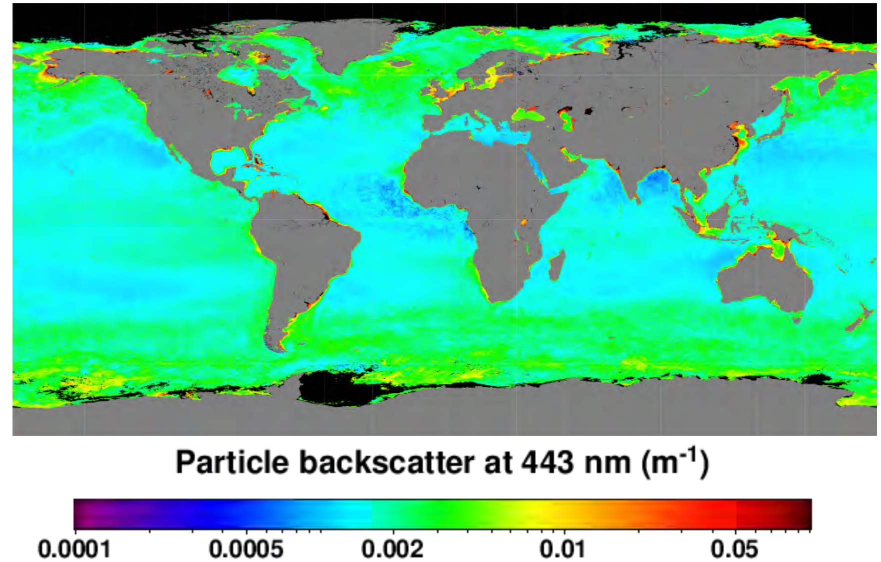
R^2=0.64
Slope=1.09
Intercept =0.15
Ratio = 0.93

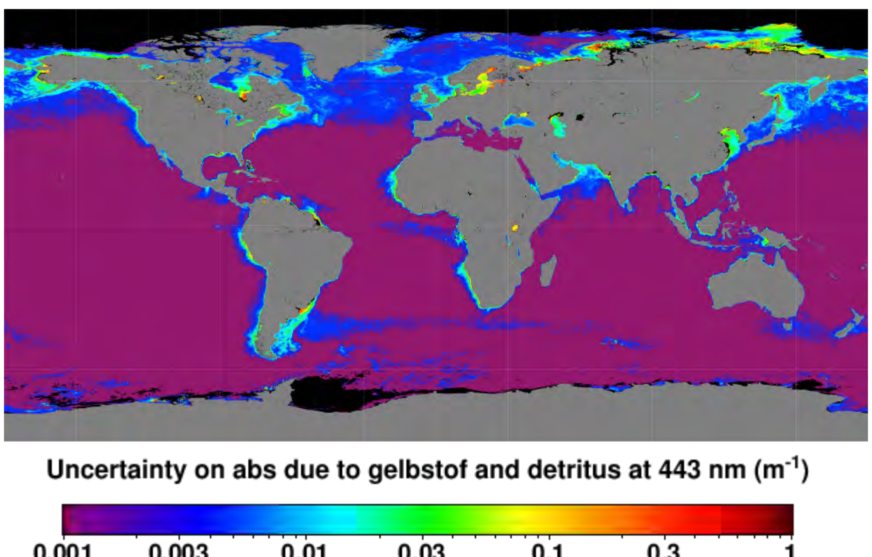
Product Name	MODIS Aqua Range	In situ Range	#	Best Fit Slope*	Best Fit Intercept*	R^2*	Median Ratio	Abs % Difference	RMSE*
bbp_giop412	0.00060, 0.01068	0.00077, 0.00985	62	1.07118	0.10505	0.63020	0.93040	15.08312	0.20073
bbp_giop443	0.00058, 0.00980	0.00066, 0.00928	62	1.08746	0.14842	0.63965	0.93172	15.91361	0.19685
bbp_giop488	0.00057, 0.00874	0.00055, 0.00876	62	1.10368	0.19250	0.64923	0.93105	15.03007	0.19389
bbp_giop531	0.00055, 0.00802	0.00046, 0.00836	63	1.10532	0.20120	0.65546	0.93266	14.13480	0.19226
bbp_giop547	0.00054, 0.00788	0.00043, 0.00818	62	1.11514	0.22898	0.65346	0.94149	15.73514	0.19367
bbp_giop667	0.00039, 0.00699	0.00030, 0.00732	62	1.12178	0.25239	0.64448	0.95457	18.34813	0.20438

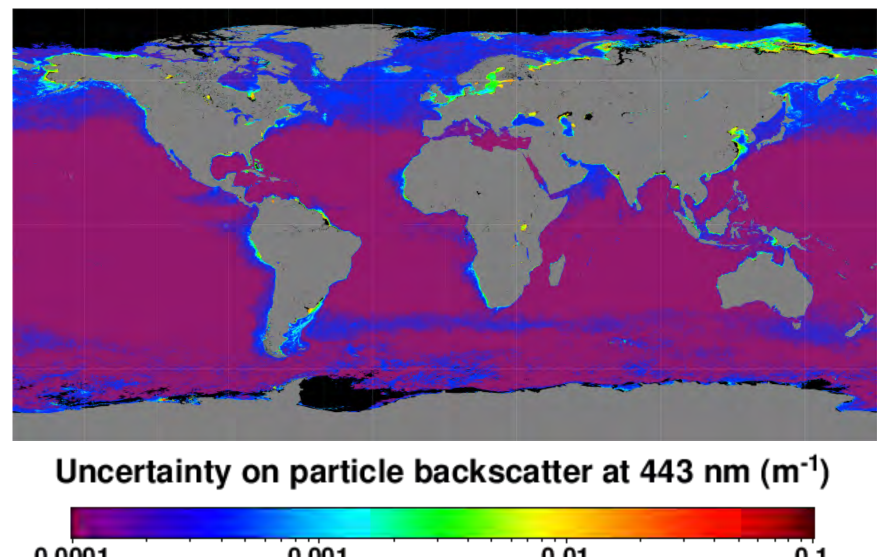
* statistical calculations based on log10

MODIS Aqua IOP Products & Uncertainties









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Part 1: implementation review

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Algorithm updates

Retrieving marine inherent optical properties from satellites using temperature and salinity-dependent backscattering by seawater

P. Jeremy Werdell,[1,2,*] Bryan A. Franz,[1] Jason T. Lefler,[1,3] Wayne D. Robinson,[1,4] and Emmanuel Boss[2]

[1]NASA Goddard Space Flight Center, Code 616, Greenbelt, Maryland 20771, USA
[2]School of Marine Sciences, 458 Aubert Hall, University of Maine, Orono, Maine 04401, USA
[3]JHT Incorporated, 2710 Discovery Drive, Suite 100, Orlando, Florida 32826, USA
[4]Science Applications International Corporation, 1710 SAIC Drive, McLean, Virginia 22102, USA
[*]jeremy.werdell@nasa.gov

Temperature-salinity dependence of b_{bw}

AGU PUBLICATIONS

JGR

Journal of Geophysical Research: Oceans

RESEARCH ARTICLE

10.1002/2014JC010224

A semianalytical ocean color inversion algorithm with explicit water column depth and substrate reflectance parameterization

Lachlan I. W. McKinna[1,2], Peter R. C. Fearns[2], Scarla J. Weeks[3], P. Jeremy Werdell[4], Martina Reichstetter[3], Bryan A. Franz[4], Donald M. Shea[4,5], and Gene C. Feldman[4]

[1]NASA Postdoctoral Program Fellow, Ocean Ecology Laboratory, NASA Goddard Space Flight Center, Greenbelt, Maryland, USA, [2]Remote Sensing and Satellite Research Group, Department of Imaging and Applied Physics, Curtin University, Perth, Western Australia, Australia, [3]Biophysical Oceanography Group, School of Geography, Planning and Environmental Management, University of Queensland, Queensland, Brisbane, Australia, [4]Ocean Ecology Laboratory, NASA Goddard Space Flight Center, Greenbelt, Maryland, USA, [5]Science Applications International Corporation, Greenbelt, Maryland, USA

Key Points:

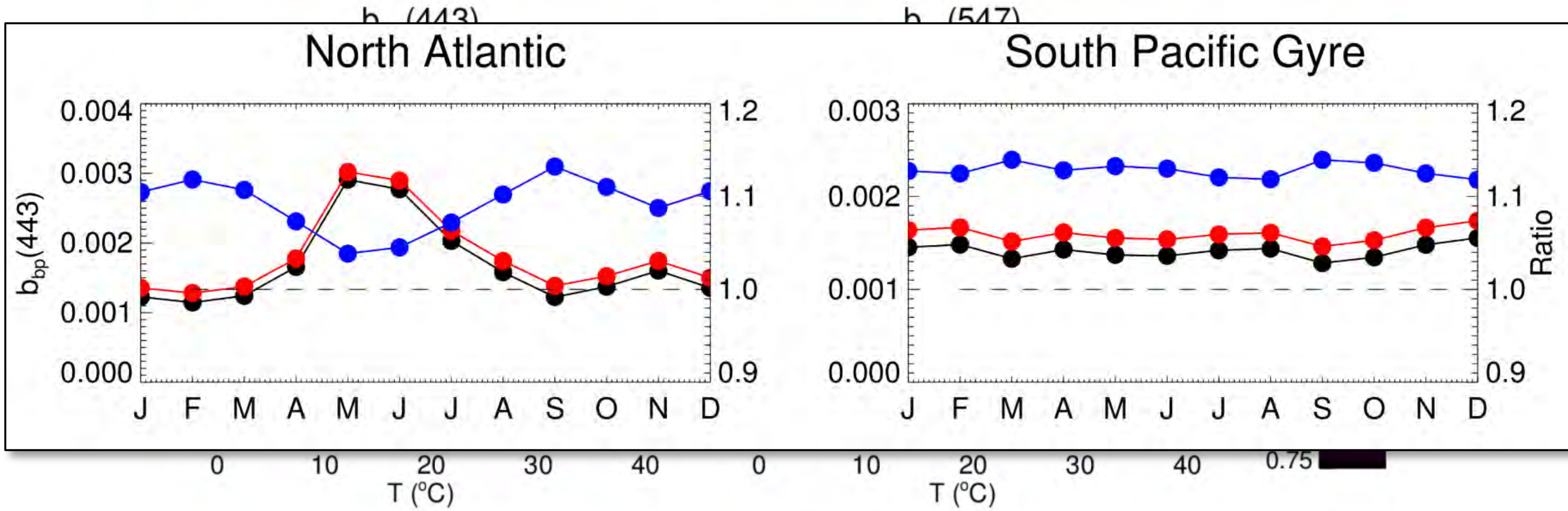
- A new ocean color algorithm for optically shallow waters is described
- The algorithm was tested in waters of the Great Barrier Reef, Australia
- Shallow water effects are corrected using bathymetry and benthic albedo maps

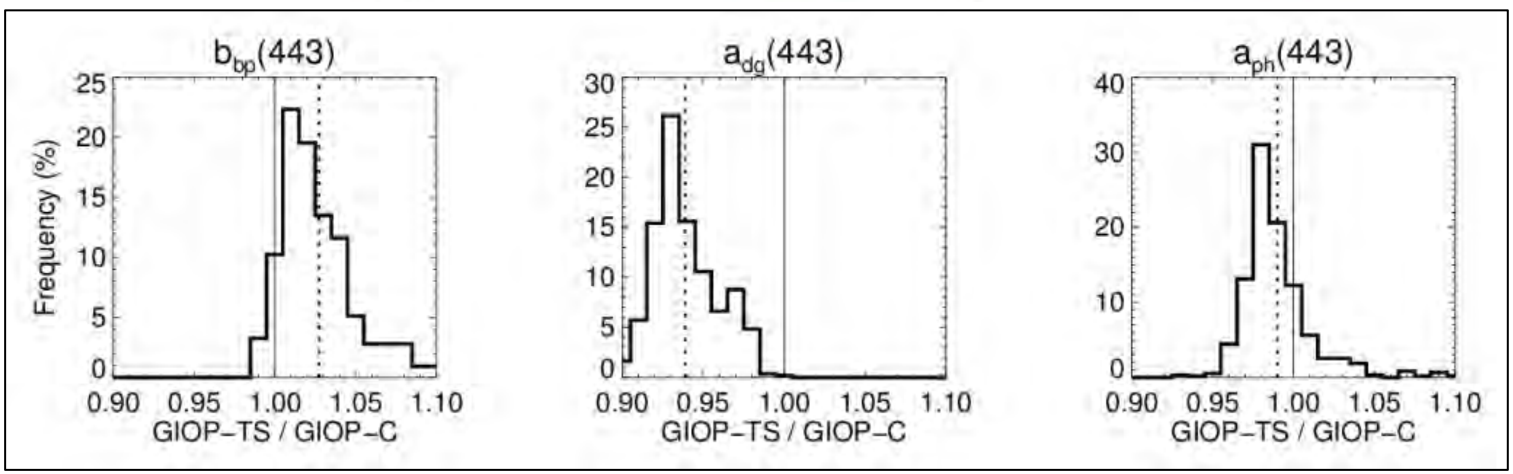
Supporting Information:

- Readme
- Table S1

Optically shallow waters

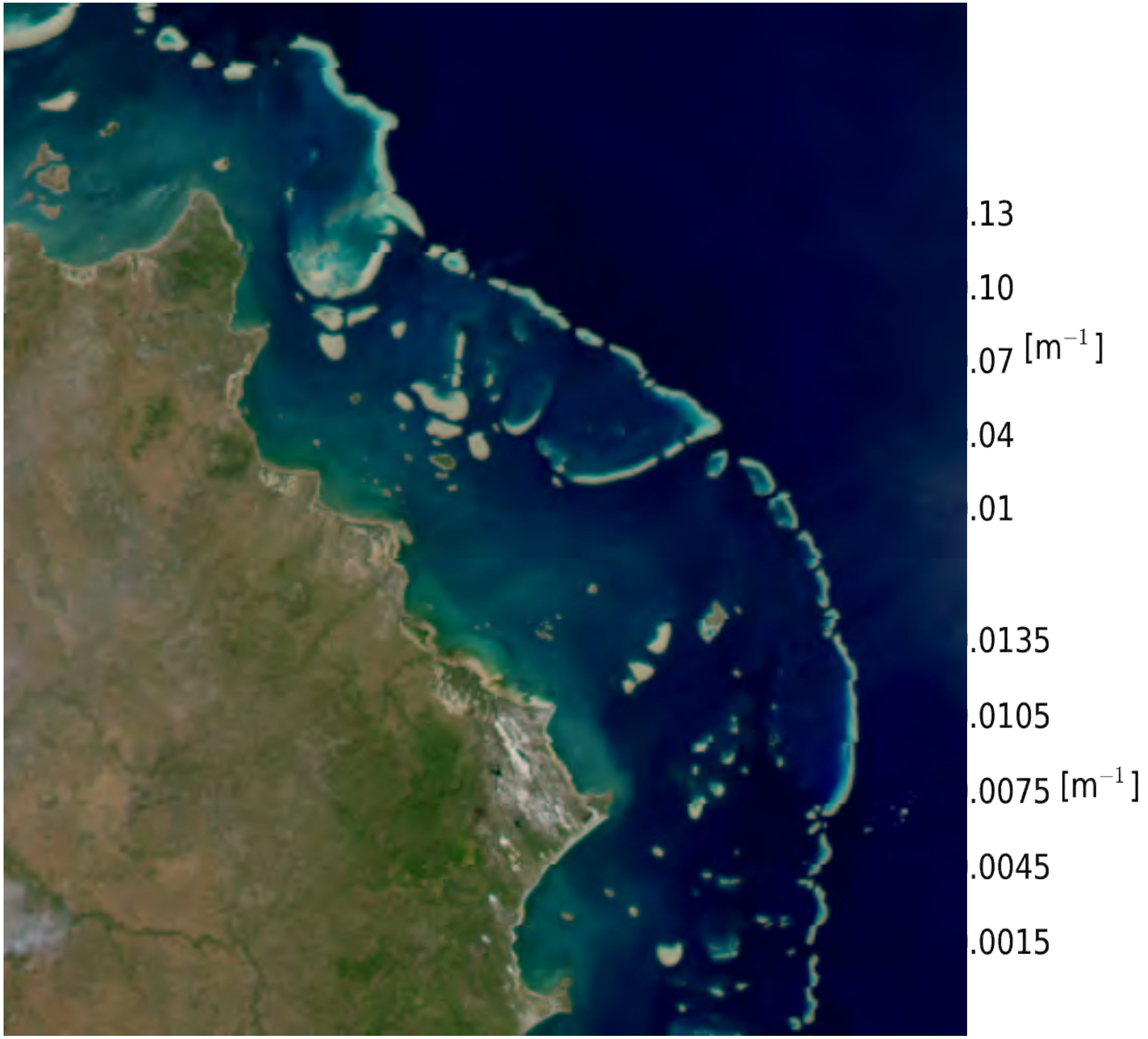
Algorithm updates:
temperature & salinity dependence of b_{bw}





Algorithm updates:
Shallow Water Inversion Model (SWIM):

- Clear, shallow water
- Light reflected off seafloor contaminates R_{rs}
- Solution: use Ancillary data inputs (depth and seafloor albedo).

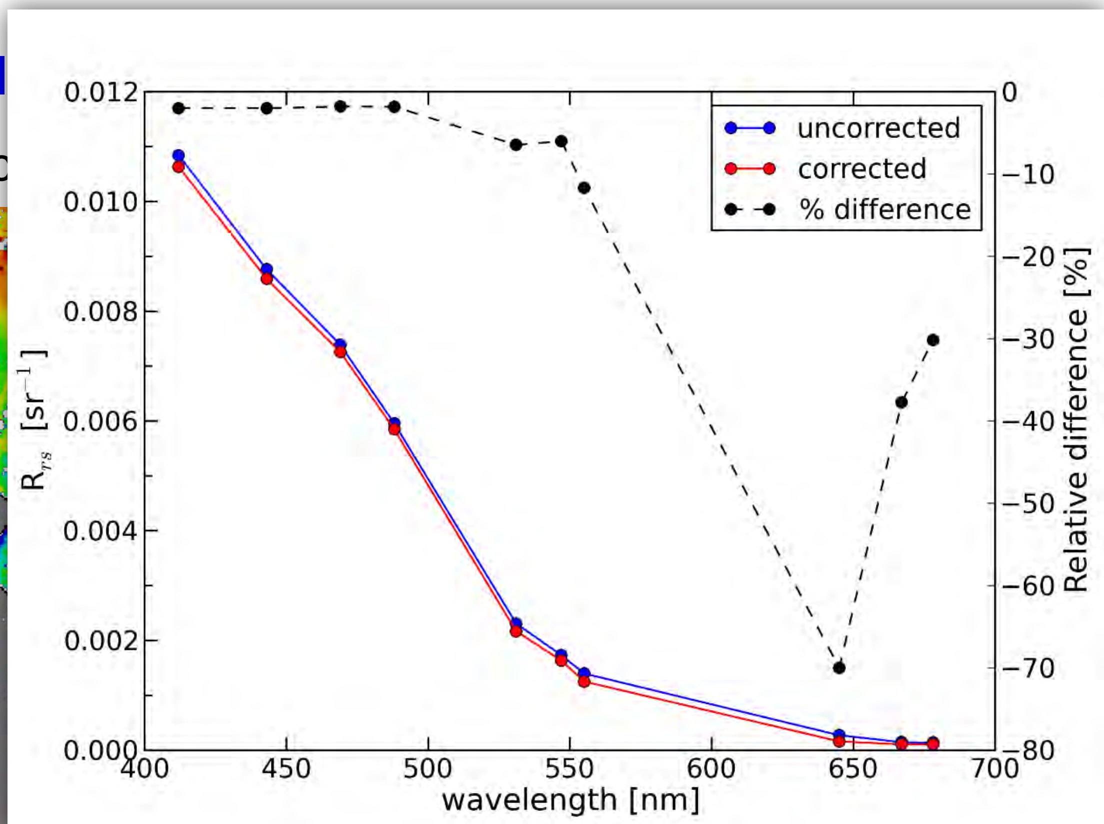


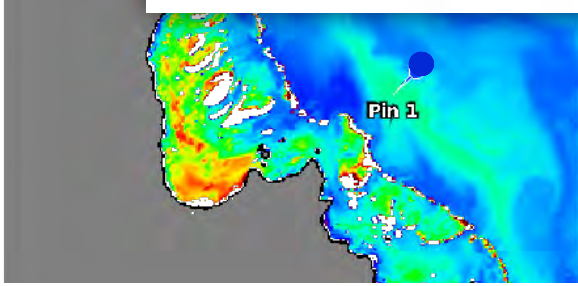
Sample scene: MODIS Aqua 22 May 2009

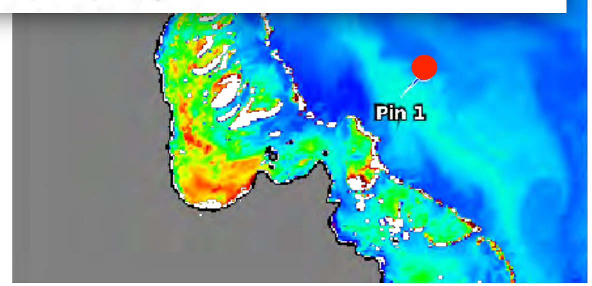
Algorithm updates:
Raman scattering correction for Rrs

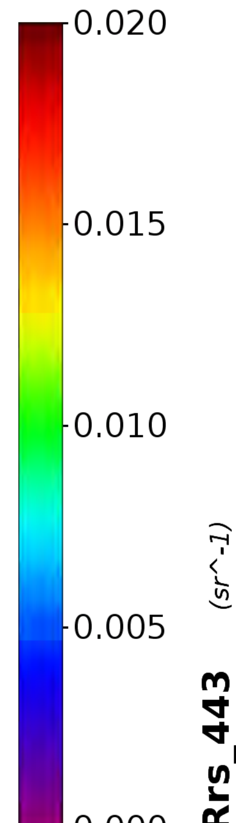
Exampl

Unc







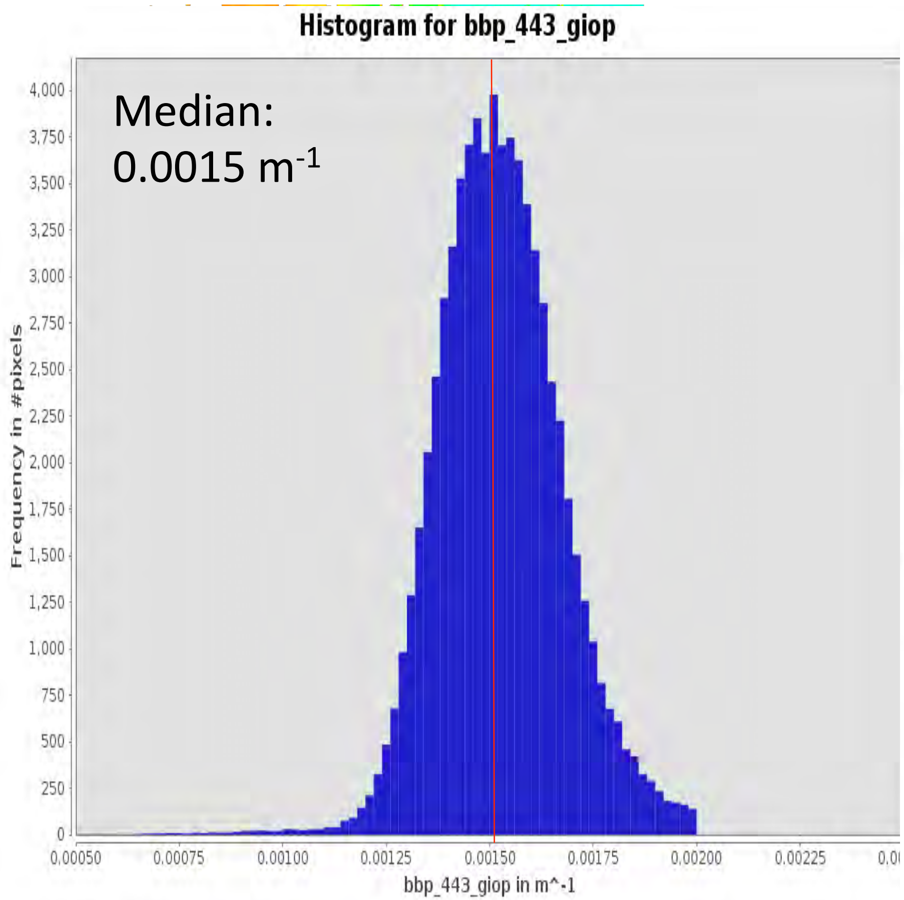


Sample scene: MODIS Aqua 22 May 2009

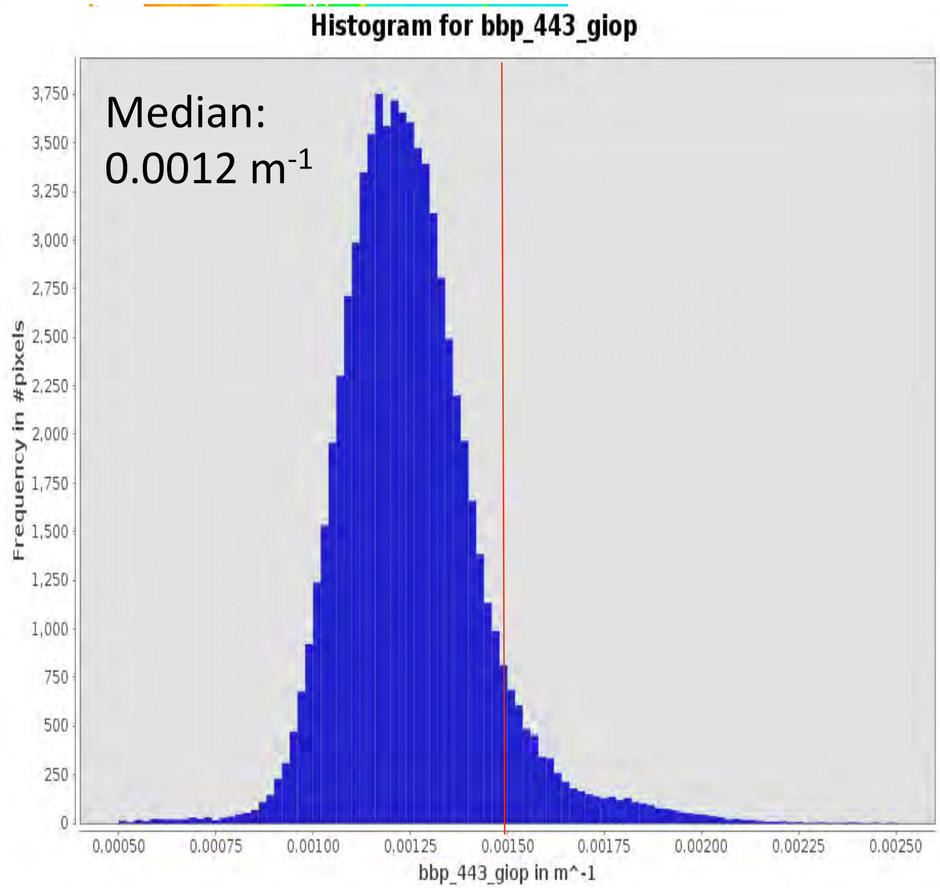
Algorithm updates:
Raman scattering correction for Rrs

Example outputs: GIOP-derived $\mathbf{b_{bp}(443)}$

Uncorrected $b_{bp}(443)$



Corrected $b_{bp}(443)$



Sample scene: MODIS Aqua 22 May 2009

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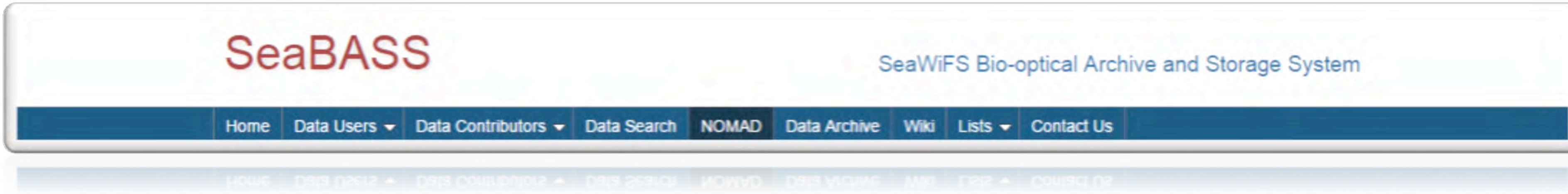
Status overview

- ✓ Temperature-salinity correction
- ✓ Shallow water inversion module
- ✓ Raman scattering correction

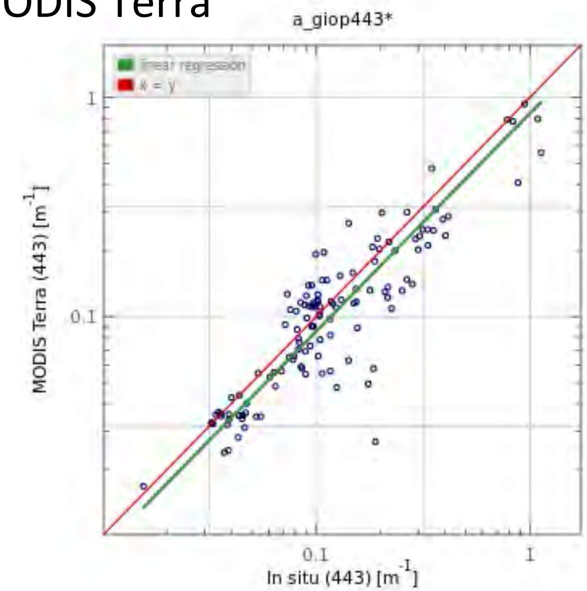
- Ensemble methods – aLMI
- Spectral decomposition a total absorption – e.g. Zheng et al. (2015)
- Bayesian optimization – uncertainties
- Multi-mission algorithm compatibility
- Hyperspectral extension – PACE mission

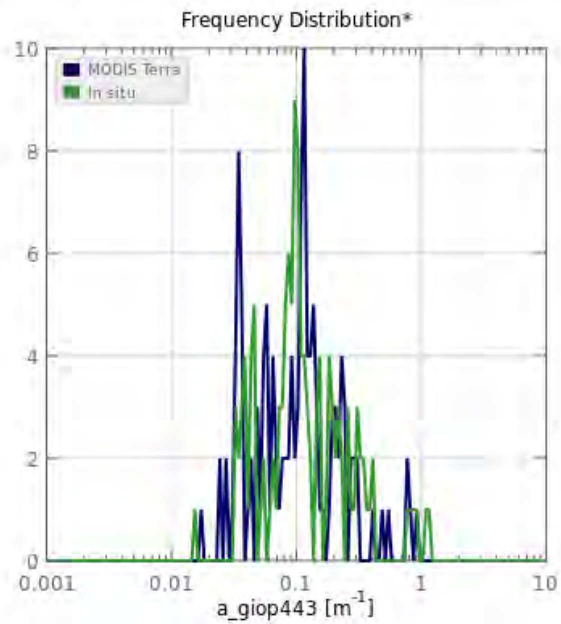
thanks

Extras…



a(443) MODIS Terra





R^2=0.82
Slope=0.99
Intercept -0.07
Ratio = 0.87

Product Name	MODIS Terra Range	In situ Range	#	Best Fit Slope*	Best Fit Intercept*	R^2*	Median Ratio	Abs % Difference	RMSE*
a_giop412	0.01739, 1.70778	0.01492, 1.48437	126	1.05205	0.03830	0.73412	0.97825	26.40903	0.23664
a_giop443	0.01679, 0.93324	0.01553, 1.12670	126	0.99449	-0.07251	0.82424	0.87428	21.94047	0.17698
a_giop488	0.01998, 0.51737	0.01956, 0.60427	126	0.91819	-0.19864	0.83927	0.81589	19.22044	0.16998
a_giop531	0.04560, 0.36592	0.04553, 0.37732	126	0.81243	-0.27393	0.80899	0.91143	11.25729	0.11525
a_giop547	0.05460, 0.32344	0.05789, 0.29862	126	0.84761	-0.23014	0.78559	0.90259	11.18629	0.10076
a_giop667	0.35244, 0.85431	0.43105, 0.79128	126	1.24002	0.07474	0.43052	0.99936	1.58109	0.04516

* statistical calculations based on log10

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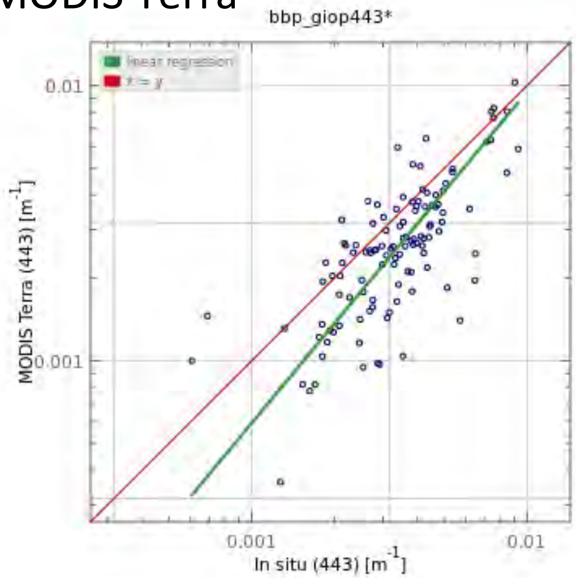
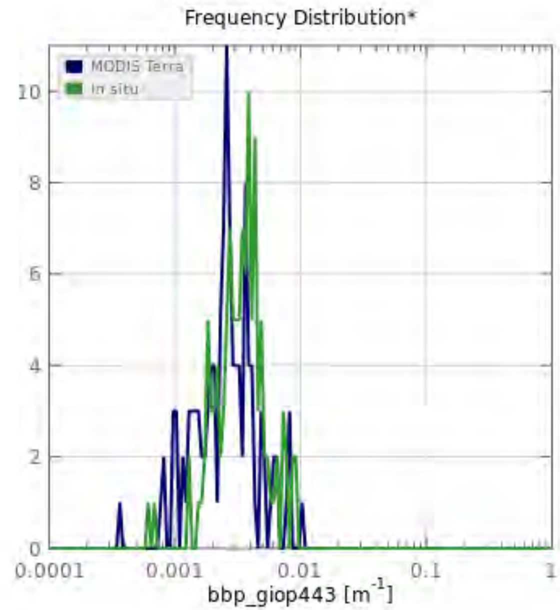
$b_{bp}(443)$ MODIS Terra





R^2=0.65
Slope=1.2
Intercept =0.38
Ratio = 0.77

Product Name	MODIS Terra Range	In situ Range	#	Best Fit Slope*	Best Fit Intercept*	R2*	Median Ratio	Abs % Difference	RMSE*
bbp_giop412	-0.00021, 0.01120	0.00073, 0.00985	117	1.21255	0.39953	0.64137	0.78727	29.69195	0.20910
bbp_giop443	-0.00021, 0.01027	0.00061, 0.00928	117	1.20387	0.38492	0.65140	0.77731	28.82437	0.20814
bbp_giop488	-0.00021, 0.00915	0.00048, 0.00876	117	1.18332	0.33986	0.66091	0.76668	26.92732	0.20915
bbp_giop531	-0.00021, 0.00827	0.00039, 0.00836	117	1.16406	0.29400	0.66399	0.76288	25.69888	0.21285
bbp_giop547	-0.00021, 0.00798	0.00035, 0.00818	117	1.15178	0.26799	0.66364	0.77430	25.25570	0.21240
bbp_giop667	-0.00018, 0.00638	0.00022, 0.00732	117	1.09712	0.12958	0.65585	0.74758	27.85617	0.22721

* statistical calculations based on log10

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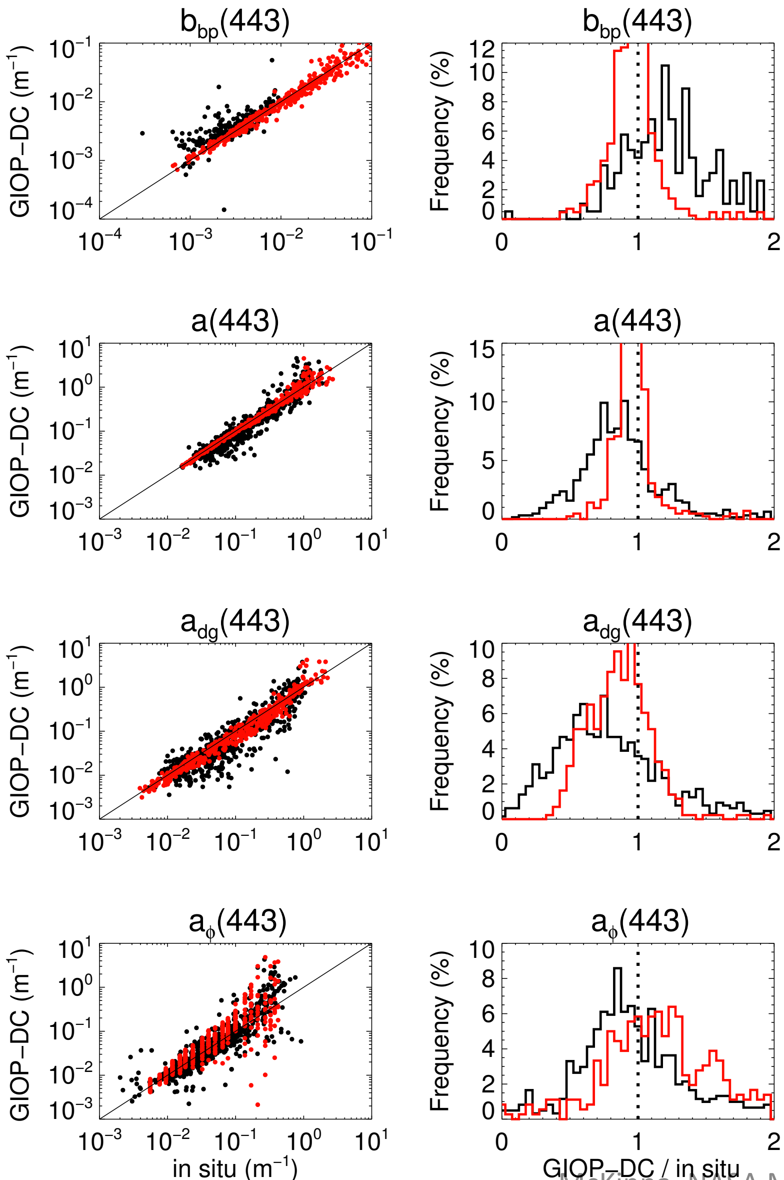
a generalized IOP (GIOP) inversion model

in situ (NOMAD) & synthesized (IOCCG) data



SeaWiFS & MODISA data

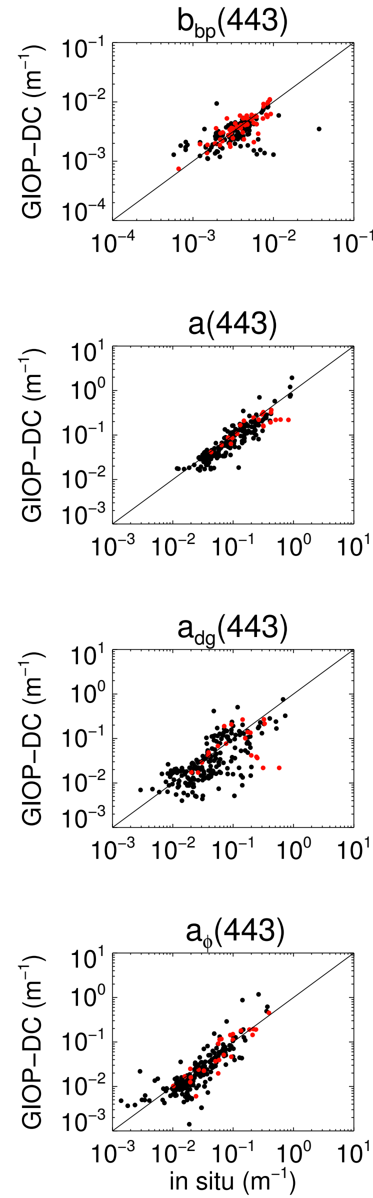


Table 3. Regression Statistics for GIOP-DC Using the SeaWiFS and MODISA Match-Up Data Sets

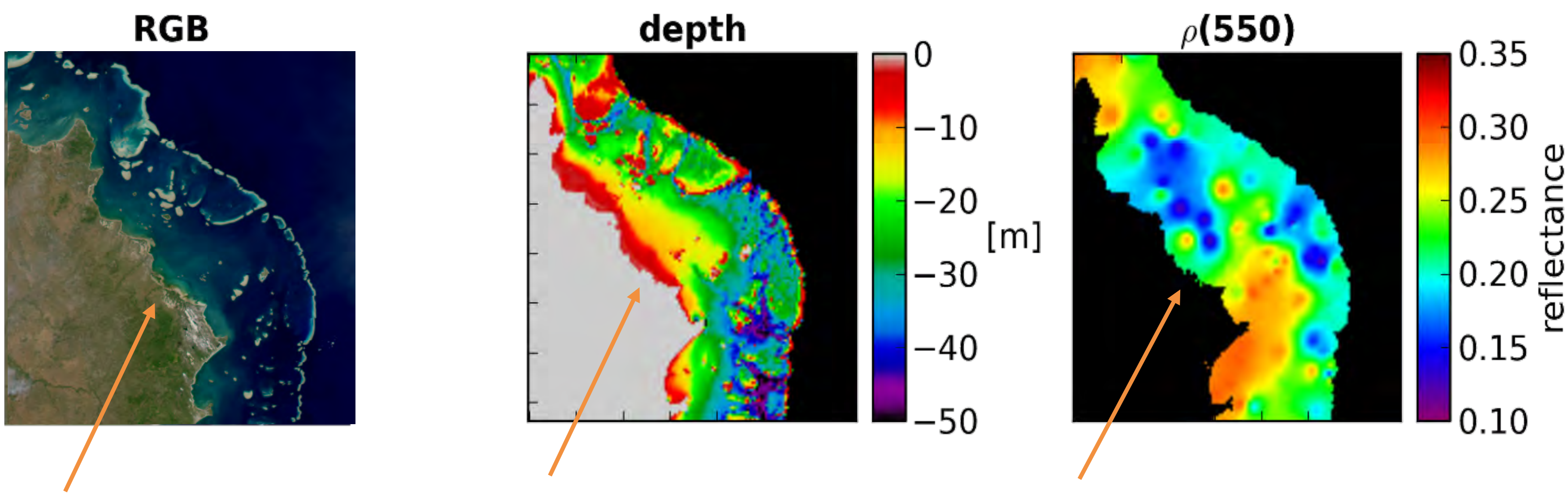
		SeaWiFS					MODISA				
		N	r^2	Slope (SE)	Ratio	MPD	N	r^2	Slope (SE)	Ratio	MPD
b_{bp}	412	123	0.30	0.77 (0.07)	0.93	25.2	56	0.69	0.92 (0.07)	1.00	13.2
	443	123	0.31	0.79 (0.07)	0.92	25.0	56	0.69	0.95 (0.08)	1.02	17.2
	490	123	0.32	0.82 (0.07)	0.90	24.2	56	0.69	1.00 (0.08)	0.99	18.2
	555[a]	123	0.32	0.84 (0.07)	0.87	25.2	56	0.68	1.05 (0.09)	0.99	18.8
	670[b]	123	0.31	0.87 (0.07)	0.83	28.5	56	0.63	1.06 (0.09)	1.04	23.0
a	412	192	0.74	1.12 (0.04)	0.87	30.9	21	0.45	0.76 (0.14)	0.89	36.9
	443	192	0.81	1.07 (0.03)	0.81	25.5	21	0.73	0.77 (0.10)	0.88	16.9
	490	192	0.80	1.01 (0.03)	0.76	29.3	21	0.84	0.79 (0.07)	0.79	21.1
	555[a]	192	0.67	1.03 (0.05)	0.68	42.3	21	0.86	0.74 (0.07)	0.75	28.9
	670[b]	180	0.69	1.19 (0.05)	0.87	45.0	17	0.47	0.91 (0.19)	1.88	87.8
a_{dg}	412	192	0.51	1.12 (0.06)	0.86	45.7	20	0.07	0.96 (0.27)	0.88	40.2
	443	192	0.51	1.08 (0.06)	0.78	49.8	20	0.09	0.96 (0.27)	0.81	34.8
	490	192	0.48	1.01 (0.06)	0.64	54.2	20	0.11	0.96 (0.26)	0.68	41.8
	555[a]	191	0.42	0.93 (0.06)	0.50	62.5	20	0.12	0.96 (0.26)	0.46	55.3
	670[b]	183	0.44	0.82 (0.05)	0.34	72.0	20	0.13	0.98 (0.26)	0.32	67.7
a_{ϕ}	412	195	0.72	1.17 (0.05)	0.73	35.5	25	0.85	1.14 (0.09)	0.91	22.5
	443	197	0.68	1.14 (0.05)	0.80	31.5	25	0.82	1.20 (0.11)	0.90	31.0
	490	197	0.68	1.12 (0.05)	0.86	30.1	25	0.81	1.13 (0.11)	0.93	33.2
	555[a]	186	0.71	1.17 (0.05)	0.95	44.8	25	0.82	1.14 (0.10)	0.97	36.6
	670[b]	195	0.73	1.05 (0.04)	1.11	48.6	24	0.81	1.24 (0.12)	1.35	49.3

[a]indicates that the wavelength is 547 nm for MODISA.
[b]indicates that the wavelength is 667 nm for MODISA.

Werdell et al. (2013)

Algorithm updates:
Optically shallow waters:

- Semi-analytical algorithm following Lee et al. (1998, 1999)
- Spectral matching type algorithm (other approaches exist – e.g. Barnes et al. (2013))
- Water-column **depth** and **benthic albedo** maps used **as ancillary data inputs**



Clear waters of northern Great Barrier Reef, Australia

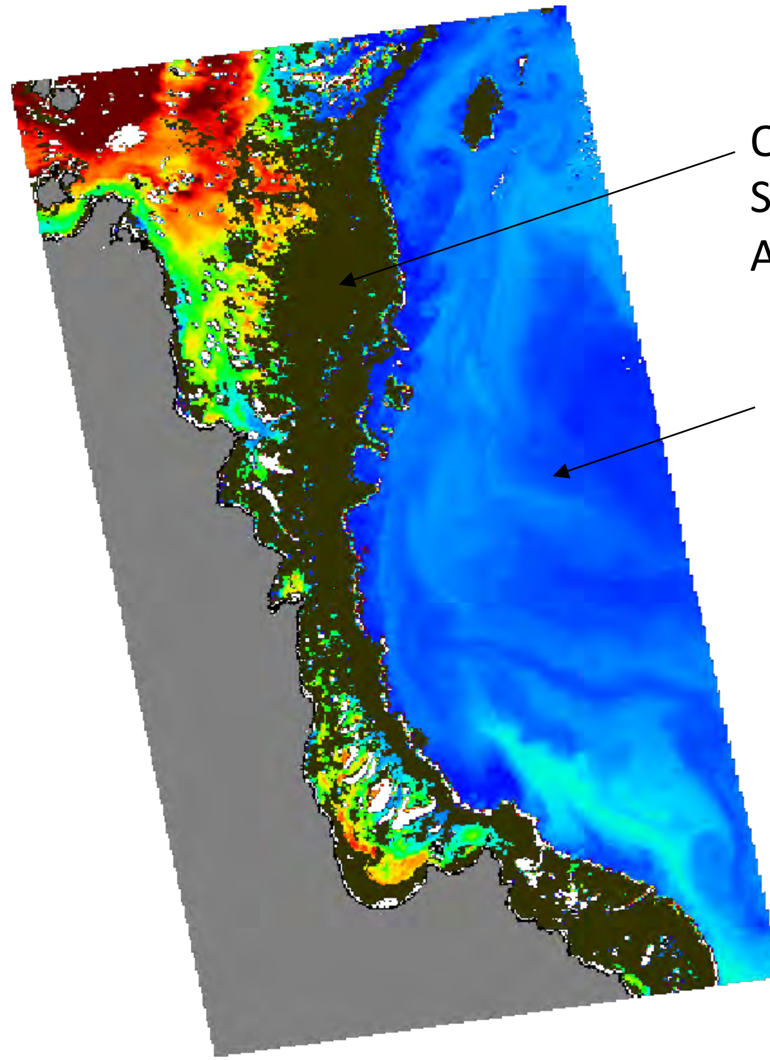
Geometrically shallow shelf waters

Bright silica sand near-shore

Sample scene: MODIS Aqua 22 May 2009

Algorithm updates:

Optically Shallow Flag – function of IOPs and geometric depth



Sample scene: MODIS Aqua 22 May 2009

Algorithm updates:
Raman scattering correction for Rrs

Model for the interpretation of hyperspectral remote-sensing reflectance

Zhongping Lee, Kendall L. Carder, Steve K. Hawes, Robert G. Steward, Thomas G. Peacock, and Curtiss O. Davis

1994

Semianalytical

$$R_{rs}^{R}(\lambda) \approx 0.072 \frac{b_R(\lambda_x)E_d(0^-, \lambda_x)}{[2a(\lambda) + a(\lambda_x)]E_d(0^-, \lambda)}. \quad \text{(B12)}$$

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Penetration of UV-visible solar radiation in the global oceans: Insights from ocean color remote sensing

Zhongping Lee,[1] Chuanmin Hu,[2] Shaoling Shang,[3] Keping Du,[4] Marlon Lewis,[5] Robert Arnone,[6] and Robert Brewin[7]

2013

Empirical

$$RF(\lambda) = \alpha(\lambda)\left(\frac{R_{rs}^{T}(440)}{R_{rs}^{T}(550)}\right) + \beta_1(\lambda)\left(R_{rs}^{T}(550)\right)^{\beta_2(\lambda)}. \quad (11)$$

$$R_{rs} = \frac{R_{rs}^{T}}{1 + RF}, \quad (13)$$

Influence of Raman scattering on ocean color inversion models

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2013

Semianalytical

$$R_{rs,\mathrm{Raman}}(0^+, \lambda_{em}) = \frac{t^2}{n^2}\frac{\tilde{\beta}^{r}(\theta_s \to \pi)b_r(\lambda_{em})E_d(0^+, \lambda_{ex})}{(K_d(\lambda_{ex}) + \kappa_L(\lambda_{em}))E_d(0^+, \lambda_{em})} \times \left[1 + \frac{b_b(\lambda_{ex})}{\mu_u(K_d(\lambda_{ex}) + \kappa(\lambda_{ex}))} + \frac{b_b(\lambda_{em})}{2\mu_u\kappa(\lambda_{em})}\right]. \quad (7)$$

Algorithm updates: Raman scattering correction for Rrs

Example implementations: GIOP-derived $\mathbf{b_{bp}(443)}$