

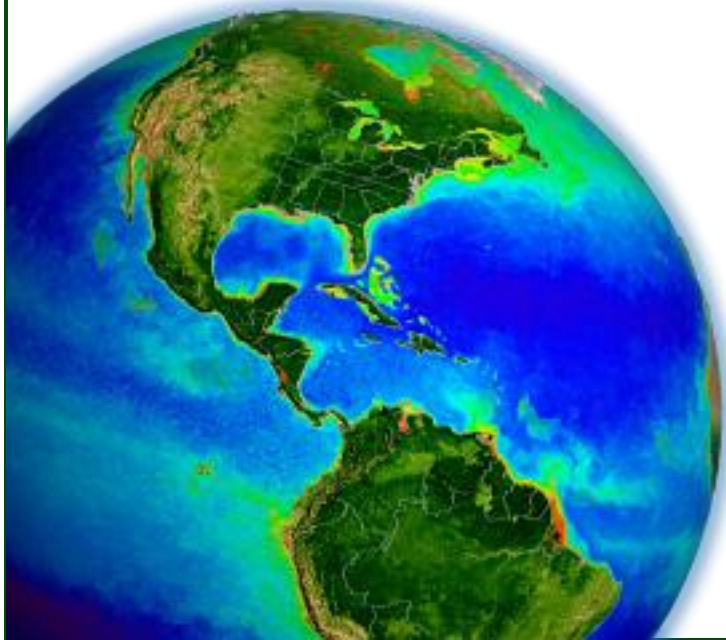
NASA Satellite Ocean Color Timeseries

Bryan Franz

and the
NASA Ocean Biology
Processing Group

International Ocean Color Science Meeting

6-8 May 2013



Ocean Biology Processing Group

Multi-mission Ocean Color

SST for MODIS, GHRSSST

Salinity and Ocean Winds from Aquarius

+ Mission Operations

Ocean Color End-to-End

Sensor calibration/characterization

Processing software & algorithms

Product validation (SeaBASS)

Algorithm development (NOMAD)

User processing and display (SeaDAS)

User support (Ocean Color Forum)

Ocean Data Processing System

automated data acquisition, distributed processing, data management

Data archive and distribution

~3 PB online storage (RAID)



oceancolor.gsfc.nasa.gov

Missions Supported

Aquarius/SAC-D : 2011-present

VIIRS/NPP: 2011-present

MODIS/Aqua: 2002-present

MODIS/Terra: 1999-present

SeaWiFS/Orbview-2: 1997-2010

CZCS/NIMBUS-7: 1978-1986

MERIS/Envisat: 2002-2012

OCM-2/Oceansat-2: 2009-present

MOS/IRS-P3: 1996-2004

OCTS/ADEOS: 1996-1997

OSMI/Kompsat: 1999-

SeaBASS In Situ Validation Tool

Support Services

SeaDAS

A comprehensive image analysis package for the processing, display, analysis, and quality control of ocean color data.

SeaBASS

An archive of *in situ* oceanographic and atmospheric data for use in algorithm development and satellite data product validation.

Registration for support services:

- Data access and Subscriptions
- Forgotten password
- Email change
- SeaWiFS Access Authorization

Near Real-Time (NRT) Services:

- NRT Data Subscriptions
Subscriptions allow users to specify regions for NRT data to be continually staged on our FTP server for download.

Information Services:

- Ocean Color Forum
- Ocean Color Mailing List
- Ocean Color Data Processing

Other Services:

- Satellite Overflight Predictions
- Data subscription status
- L1/L2 browser order status
- File Search Utility
Search for satellite and ancillary data archived by the ocean color data production system.

Search Type:

Bio-optical Pigment Validation

The validation search allows visitors to search for match-ups between water measurements and coincident satellite products. Water leaving values are calculated by SeaBASS staff using select data files that were submitted to SeaBASS. For more information on how match-ups were performed, refer to: S.W. Bailey and P.J. Werdell, "A multi-sensor approach for the on-orbit Rem. Sens. Environ. 102, 12-23 (2006).

Compare:

MODIS Aqua vs. In situ

MODIS Aqua vs. MODIS Terra

Water Depth:

Minimum: 0.0 Maximum: 10000

Exclusion Criteria:

- Minimum Valid satellite pixels (in %):
- Maximum Solar Zenith Angle:
- Maximum Satellite Zenith Angle:
- Maximum Time Difference between satellite and in situ (in hours):
- Maximum Coefficient of Variation of satellite pixels:
- Maximum difference between measured and modeled Irradiance (in %):
- Maximum Windspeed:

Satellite Version(s):

aqua: operational terra: operational

Products:

- a adg aot aph bbp chl a
- Kd par pic poc Rrs
- Zeu Zsd

Data Sources:

- SeaBASS Only All* AERONET-OC Only* MOBY Only*

*MOBY and AERONET results are preliminary. Data acquired from the Aerosol Robotic Network - Ocean Color (AERONET-OC) web site. details. Additional data usage policies apply.

Search

chlor_a [dropdown] Download Stats/Plots Generate CSV Download CSV

Statistics Data


Product Name	MODIS Aqua Range	In situ Range	#	Best Fit Slope*	Best Fit Intercept*	R ² *	Median Ratio	Abs % Difference	RMSE*
chlor_a	0.03340, 29.04500	0.00781, 55.23780	631	1.01529	0.06471	0.86487	0.86773	32.88839	0.27831

* statistical calculations based on log10
The linear regression algorithm has been changed to reduced major axis.

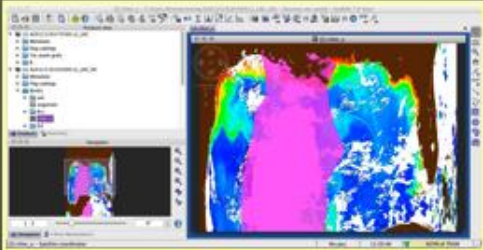
Enable clustering: Satellite [dropdown]

SeaDAS 7 Release

SeaDAS processing capabilities and BEAM Analysis and Display



General Description



The SeaWiFS Data Analysis System (SeaDAS) is a comprehensive image analysis package for the processing, display, analysis, and quality control of ocean color data. The latest version (SeaDAS 7) is the result of a collaboration with the developers of ESA's BEAM software package. The core visualization package for SeaDAS 7 is based on the BEAM framework, with extensions that provide the functionality provided by previous versions of SeaDAS..

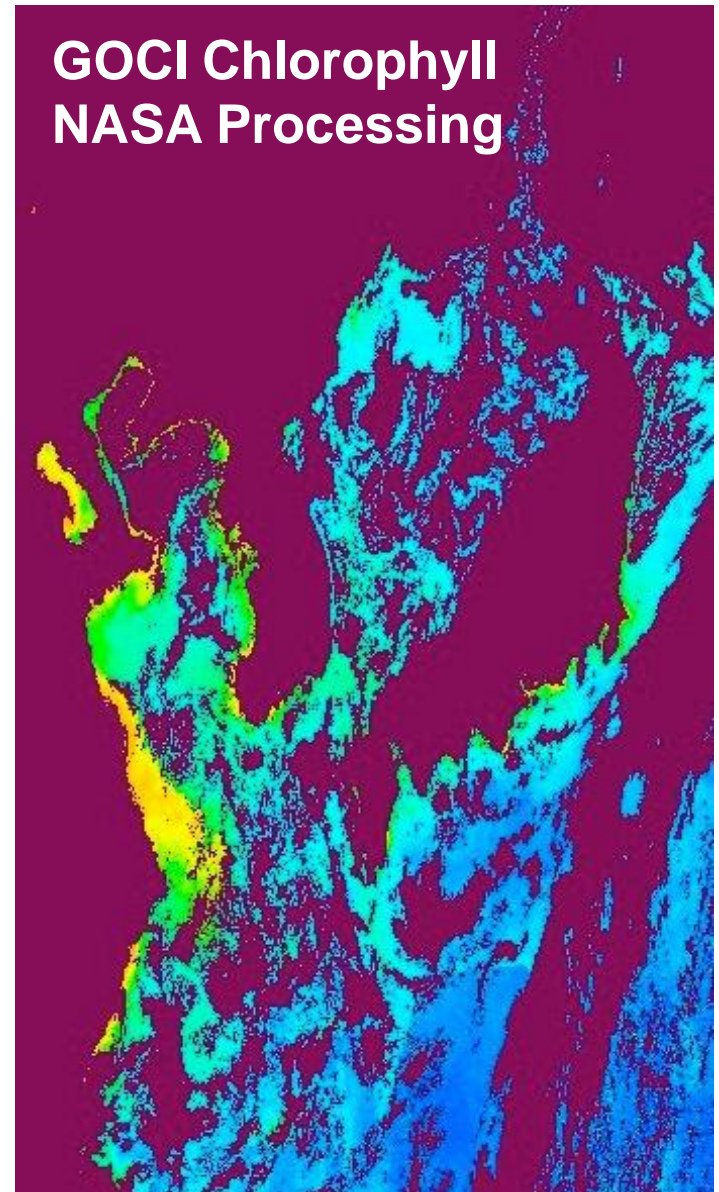
Features
Requirements
Download

Supported Missions	User Support	Other
<ul style="list-style-type: none"> o MODIS o SeaWiFS o CZCS o VIIRS o HICO o Aquarius 	<ul style="list-style-type: none"> o MERIS o OCTS o OCM o OCM-2 o OSMI o MOS 	<ul style="list-style-type: none"> o SeaDAS FAQ o Online Help o Ocean Color Web o Ocean Color Forum o Ocean Mailing Lists o SeaDAS Visualization Source Code o Processing Binaries and Source Code o SeaDAS version 6.4 o MODISL1DB 1.8

GOCI Collaboration with KIOST

distribution through ocean color web
SeaDAS analysis and display
NASA processing implementation
collaboration on calibration & algorithms

Coming
Soon!

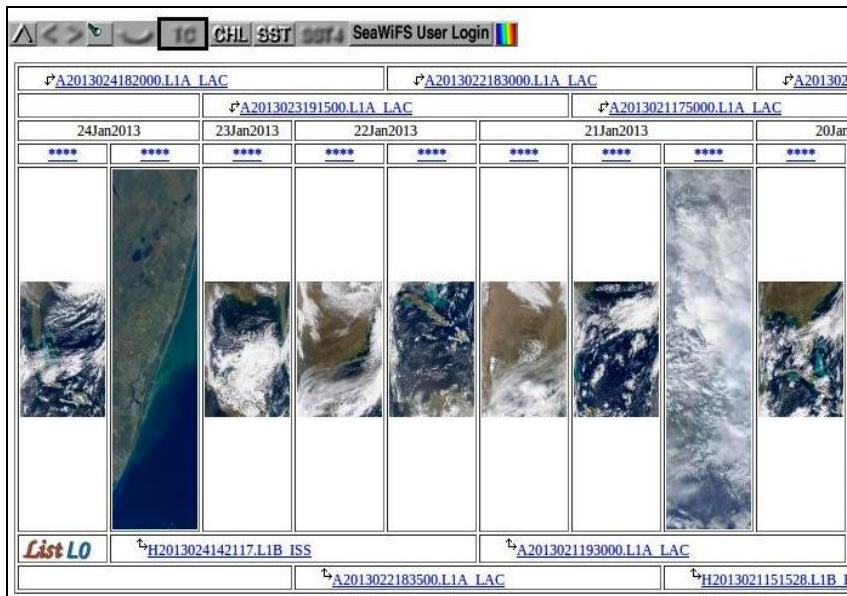


HICO

Hyperspectral Imager for Coastal Oceans

operating on ISS since 2009
128 spectral bands 350-1080nm
2000 scenes per year

coming very soon:
distribution through OCW
SeaDAS support



SeaWiFS User Login

CHL SST SST4

H2013024182000.L1A_LAC H2013022183000.L1A_LAC H2013024182000.L1A_LAC

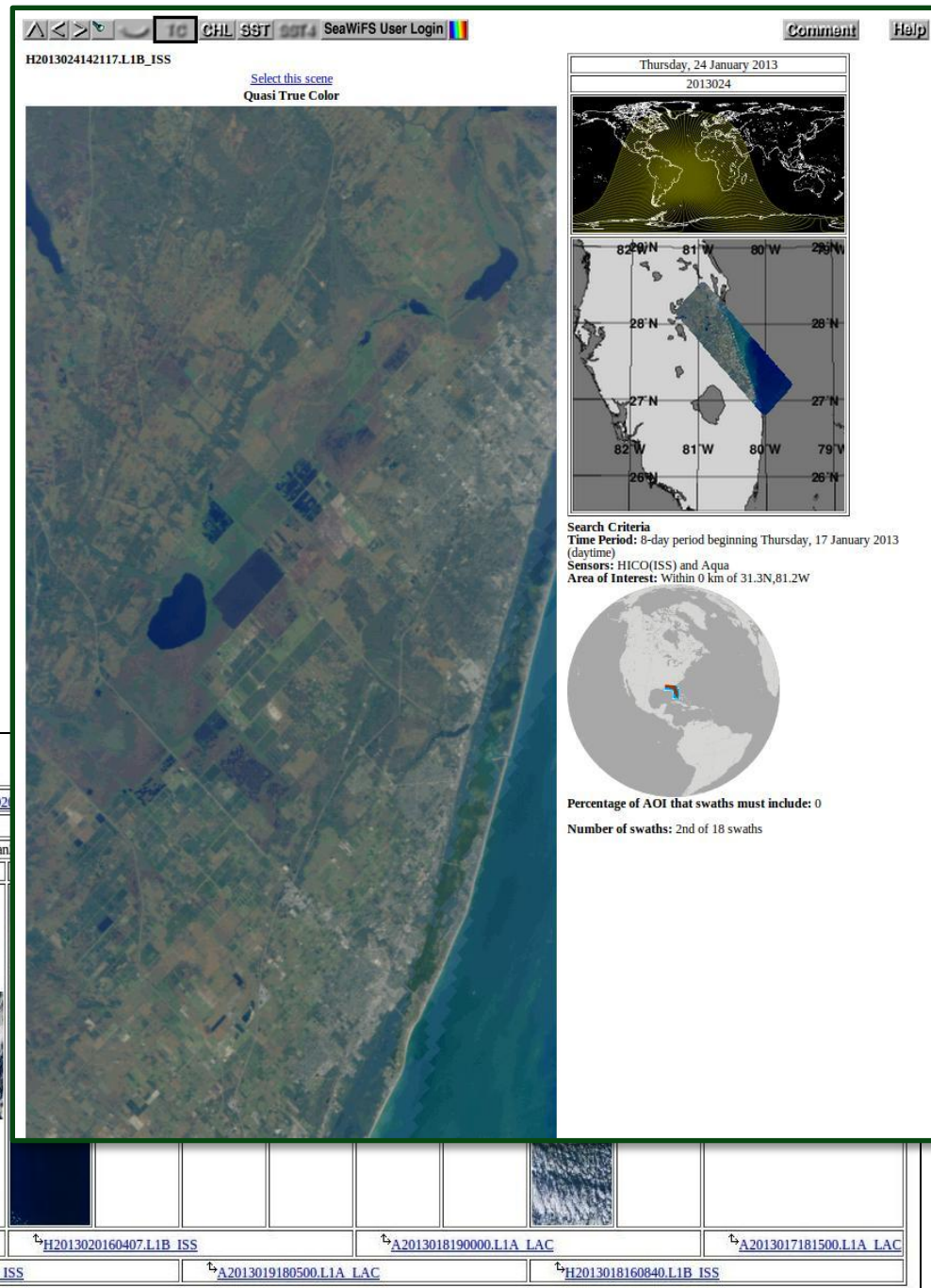
H2013023191500.L1A_LAC H2013021175000.L1A_LAC

24Jan2013 23Jan2013 22Jan2013 21Jan2013 20Jan

List LO

H2013024142117.L1B_ISS H2013021193000.L1A_LAC H2013020160407.L1B_ISS H2013018190000.L1A_LAC H2013017181500.L1A_LAC

H2013022183500.L1A_LAC H2013021151528.L1B_ISS H2013019180500.L1A_LAC H2013018160840.L1B_ISS



SeaWiFS User Login

CHL SST SST4

H2013024142117.L1B_ISS

Select this scene
Quasi True Color

Thursday, 24 January 2013
2013024

82°W 81°W 80°W 79°W
28°N 27°N 26°N

Search Criteria
Time Period: 8-day period beginning Thursday, 17 January 2013 (daytime)
Sensors: HICO (ISS) and Aqua
Area of Interest: Within 0 km of 31.3N, 81.2W

Percentage of AOI that swaths must include: 0
Number of swaths: 2nd of 18 swaths

List LO

H2013024142117.L1B_ISS H2013021193000.L1A_LAC H2013020160407.L1B_ISS H2013018190000.L1A_LAC H2013017181500.L1A_LAC

H2013022183500.L1A_LAC H2013021151528.L1B_ISS H2013019180500.L1A_LAC H2013018160840.L1B_ISS

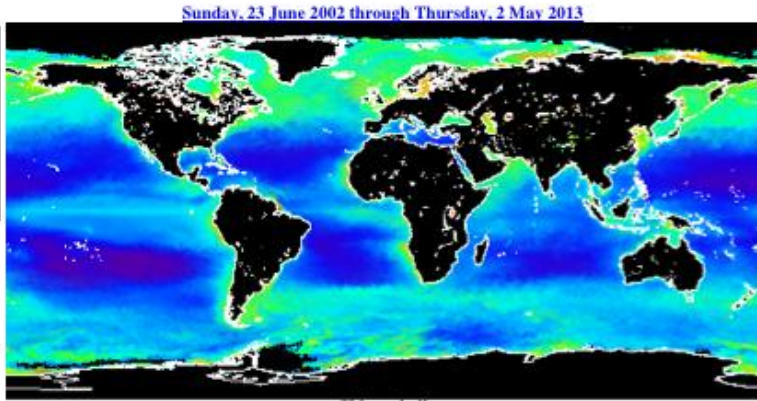
Multi-Mission Data Distribution

now serving MERIS and VIIRS

TC **OC2** SST SST4 SeaWiFS User Login

[Comment](#) [Help](#)

SeaWiFS	MODIS	MERIS	Select <input checked="" type="checkbox"/> Day <input type="checkbox"/> Night
<input type="checkbox"/> GAC	<input checked="" type="checkbox"/> Aqua	<input type="checkbox"/> RR	
<input type="checkbox"/> MLAC	<input type="checkbox"/> Terra	<input type="checkbox"/> FRS	
<input type="checkbox"/> VIIRS (NPP)	<input type="checkbox"/> OCTS (ADEOS)	<input type="checkbox"/> CZCS (Nimbus-7)	



Select one or more regions:

- AdriaticSea
- AegeanSea
- Antarctica
- ArabianSea
- AralSea
- Arctic
- Australia
- AustraliaCoast
- Azores
- Bahamas
- BalticSea

Radius (km) about map click or about typed-in location:

- 72
- 400
- 800
- 1200
- 1500

Select swaths containing (at least):

- any part
- 25 %
- 50 %
- 75 %
- all

Select only scenes having in situ matchups.

or specify boundary coordinates or a single location:

N:

W: E:

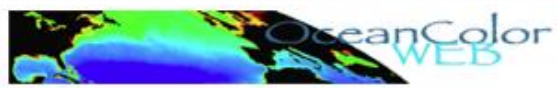
S:

[Find swaths](#)

Display results 10 at a time.

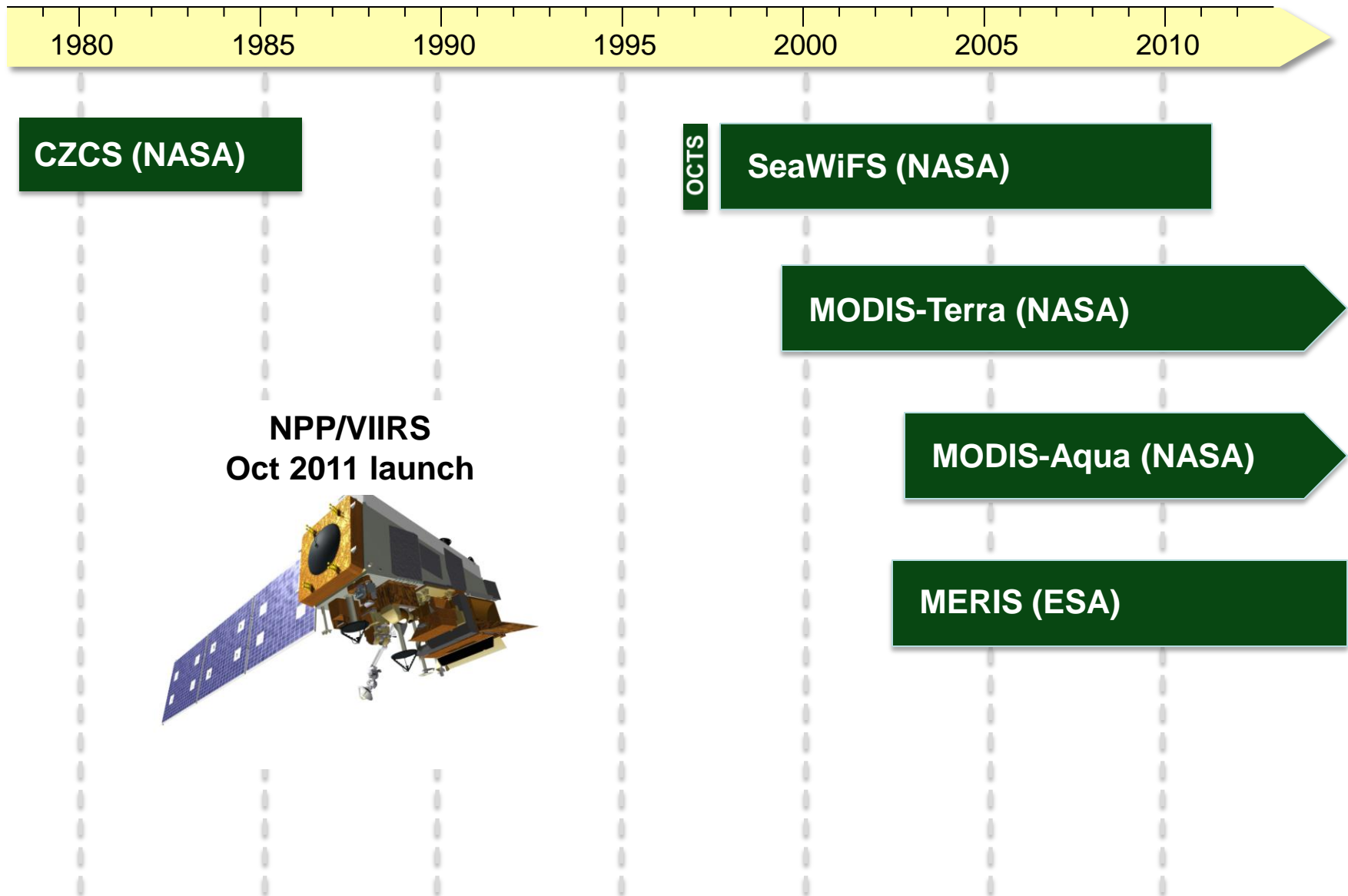
[Reconfigure page](#)

Mission	2002	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	March 2013					April 2013					May 2013																	
	2003	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	S	M	T	W	T	F	S	S	M	T	W	T	F	S	S	M	T	W	T	F	S							
	2004	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	3	4	5	6	7	8	9	1	2	3	4	5	6	1	2	3	4	1	2	3	4							
	2005	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	AAA	AAA	AAA	000	000	000	000	AAA	AAA	AAA	AAA	AAA	AAA	AAA	AAA	AAA	AAA	AAA	AAA	AAA	AAA							
	2006	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	10	11	12	13	14	15	16	7	8	9	10	11	12	13	5	6	7	8	9	10	11	12	13	14	15	16	17	18
	2007	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	000	000	000	000	***	***	***	14	15	16	17	18	19	20	19	20	21	22	23	24	25	19	20	21	22	23	24	25
	2008	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	17	18	19	20	21	22	23	000	***	***	***	***	***	***	21	22	23	24	25	26	27	000	000	000	000	000	***	***
	2009	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	24	25	26	27	28	29	30	***	***	***	***	***	***	***	28	29	30	19	20	21	22	23	24	25				
	2010	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	***	***	***	***	***	***	AAA	***	***	***	***	***	***	***	26	27	28	29	30	31	***	***	***	***	***	***	***	
	2011	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	31	***	***	***	***	***	***	26	27	28	29	30	31	***	***	***	***	***	***	***								
	2012	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***							
	2013	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***	***							



Global Multi-Mission Ocean Color Timeseries

the man with two watches doesn't know what time it is ...

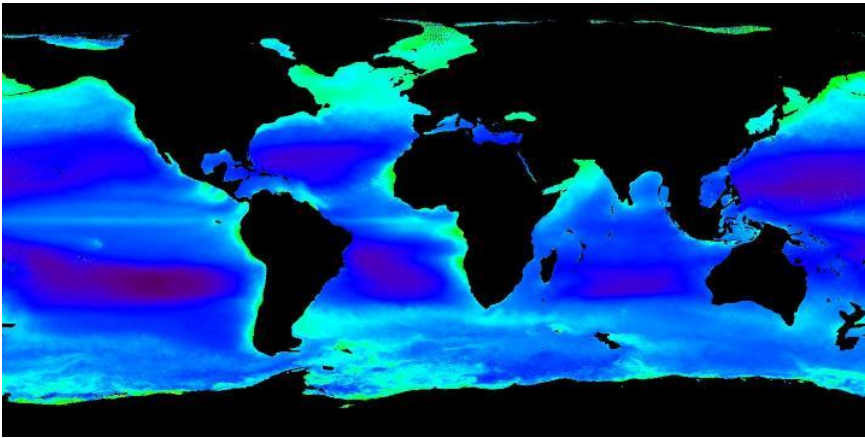


How do we achieve consistency?

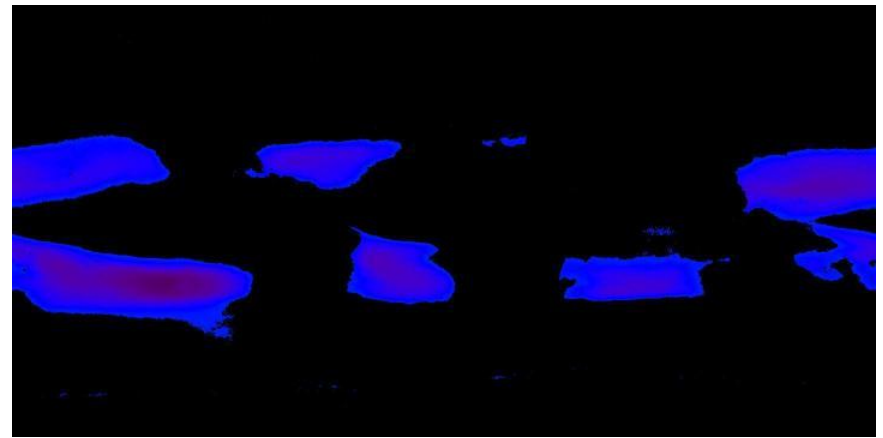
- Focus on instrument calibration
 - establishing temporal and spatial stability within each mission
- Apply common algorithms
 - ensuring consistency of processing across missions
- Apply common vicarious calibration approach
 - ensuring spectral and absolute consistency of water-leaving radiance retrievals under idealized conditions
- Reprocess multi-mission timeseries
 - incorporating new instrument knowledge and algorithm advancements
- Perform detailed trend analyses
 - assessing temporal stability & and mission-to-mission consistency

Global Trophic Subsets

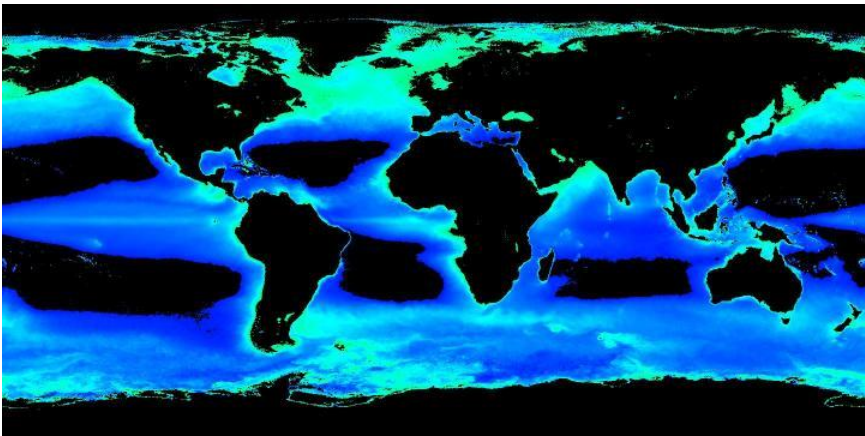
Deep-Water (Depth > 1000m)



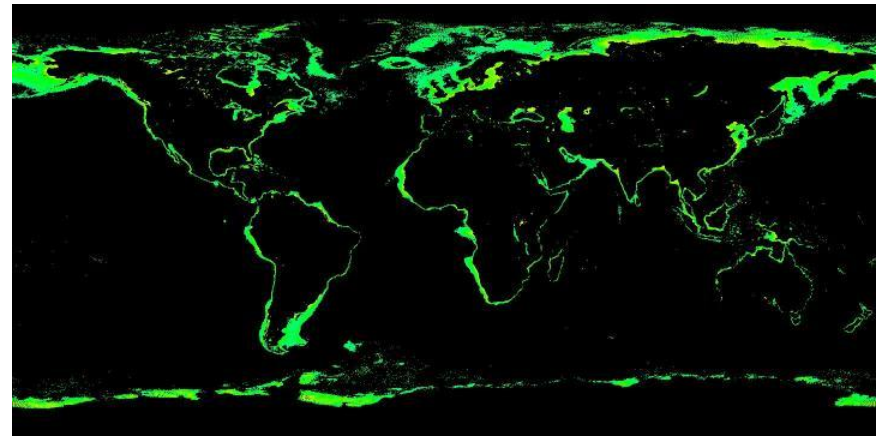
Oligotrophic (Chlorophyll < 0.1)



Mesotrophic (0.1 < Chlorophyll < 1)

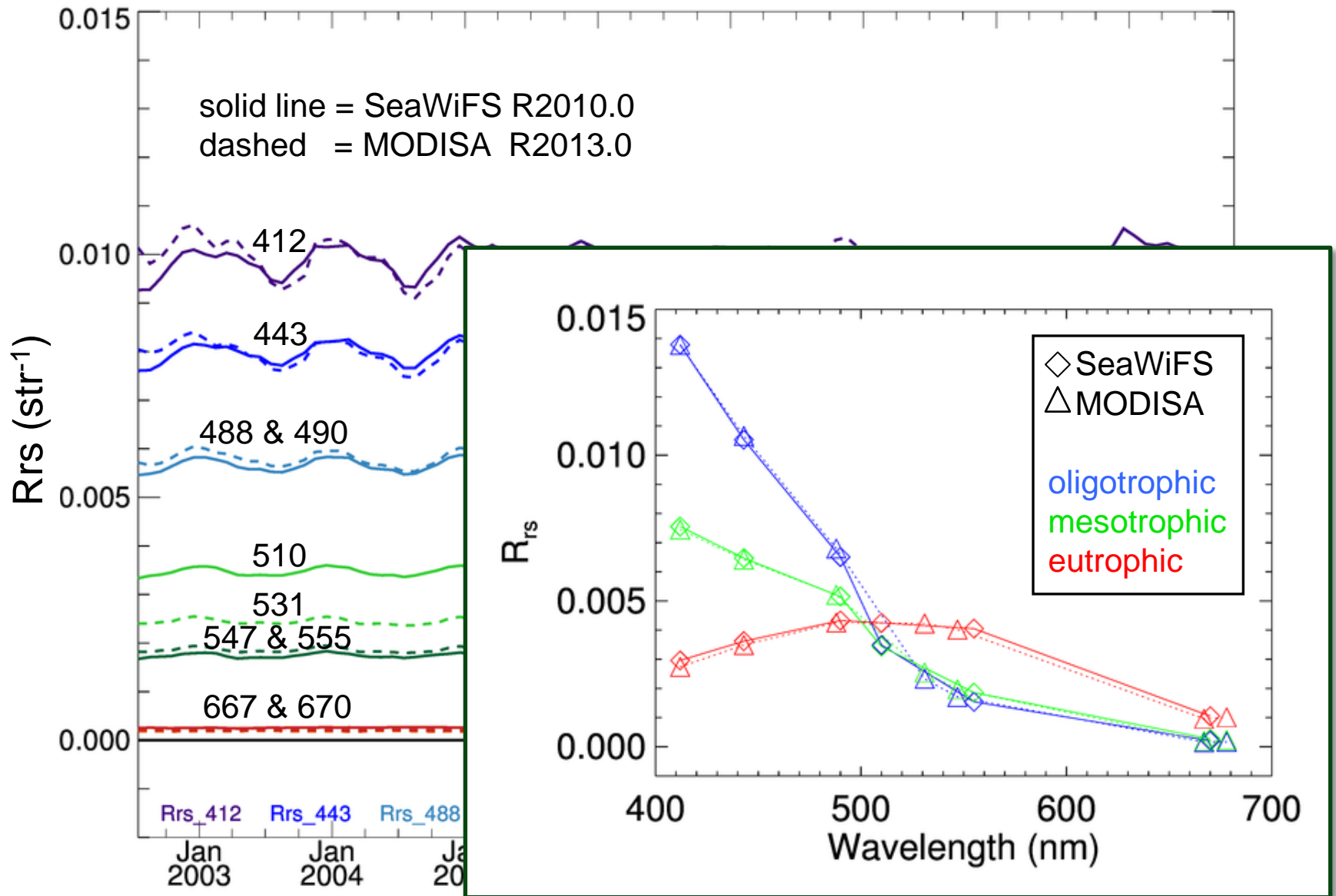


Eutrophic (1 < Chlorophyll < 10)



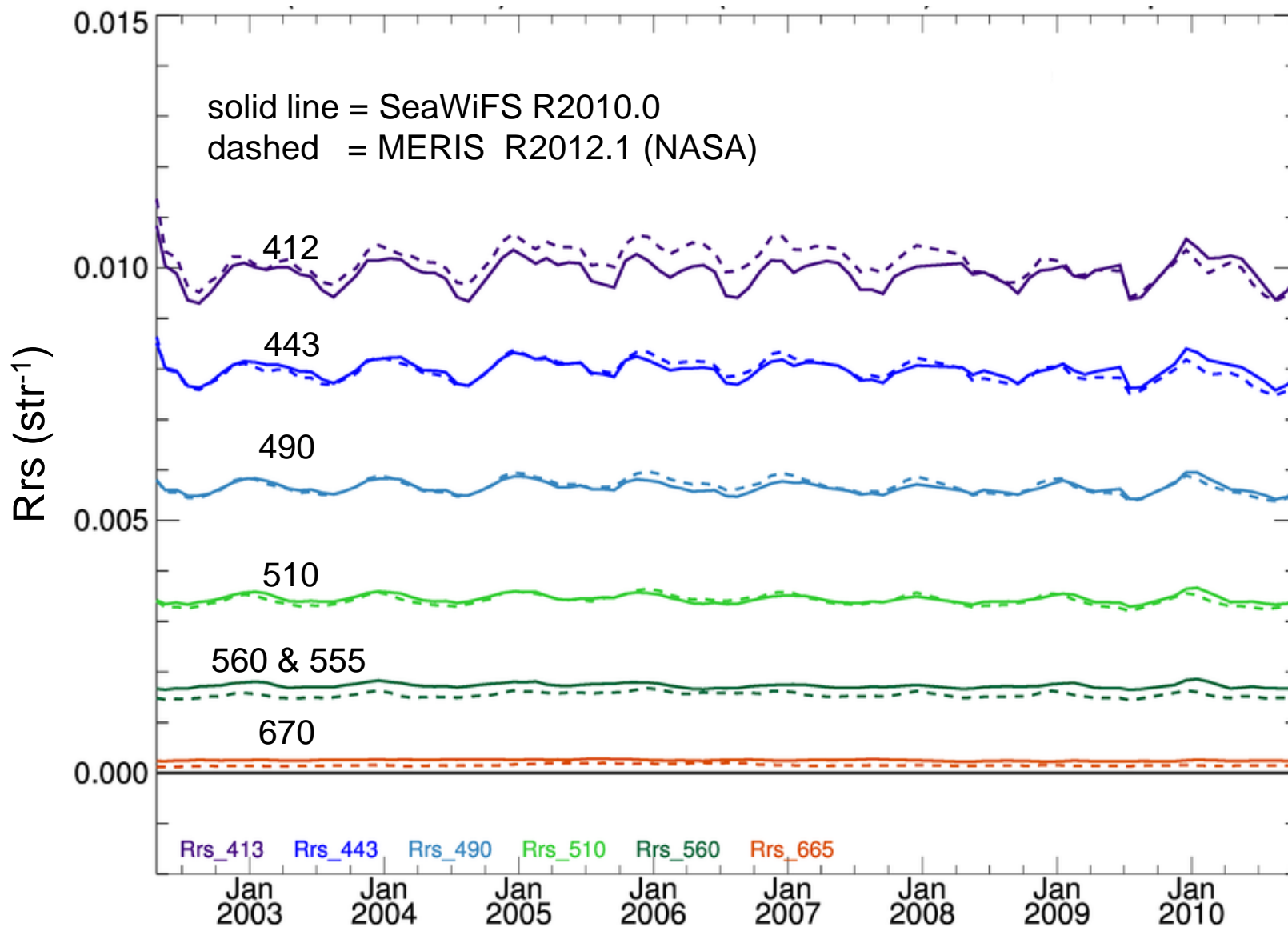
Radiometric Consistency of MODISA & SeaWiFS

Deep-Water



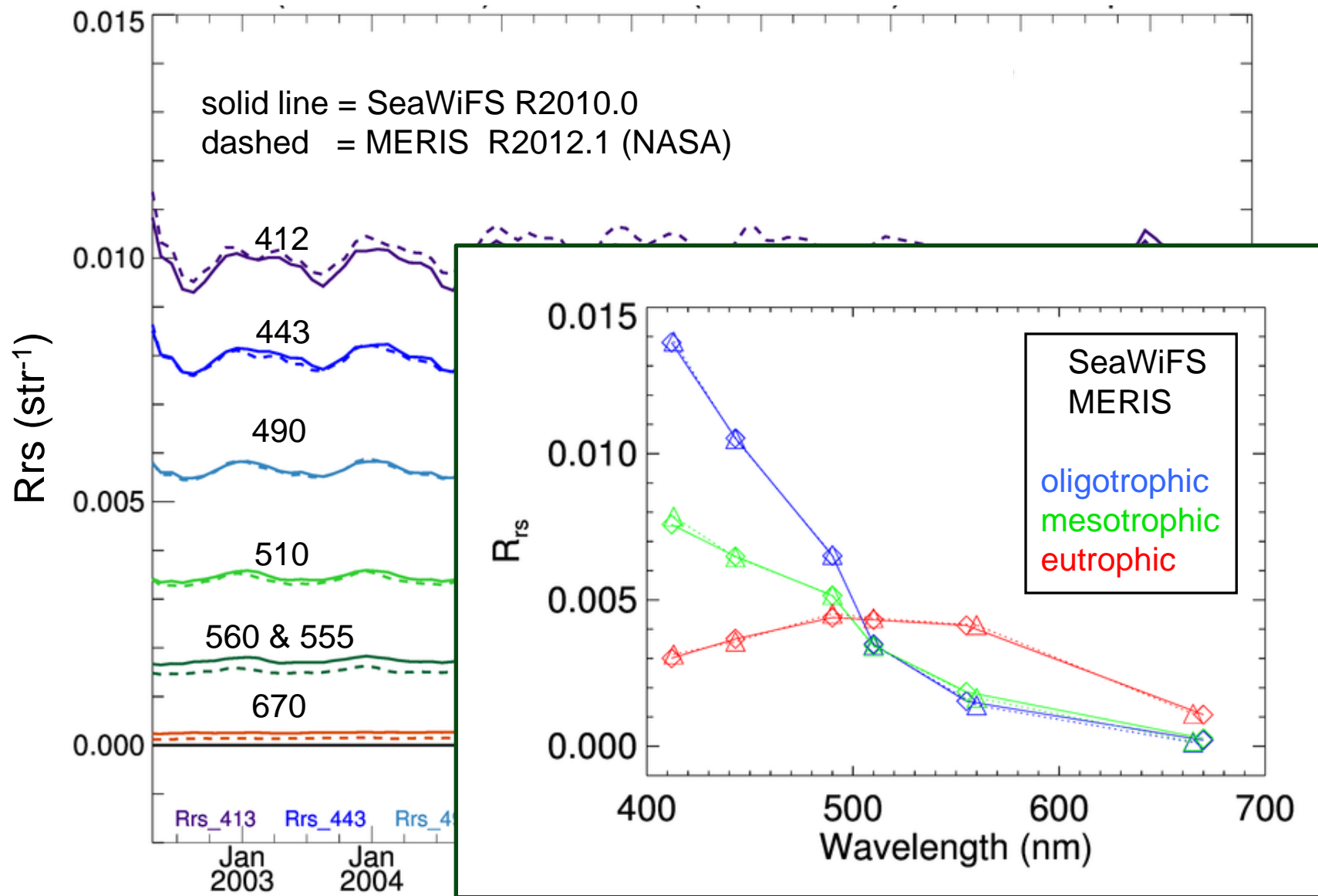
Radiometric Consistency of MERIS & SeaWiFS

Deep-Water

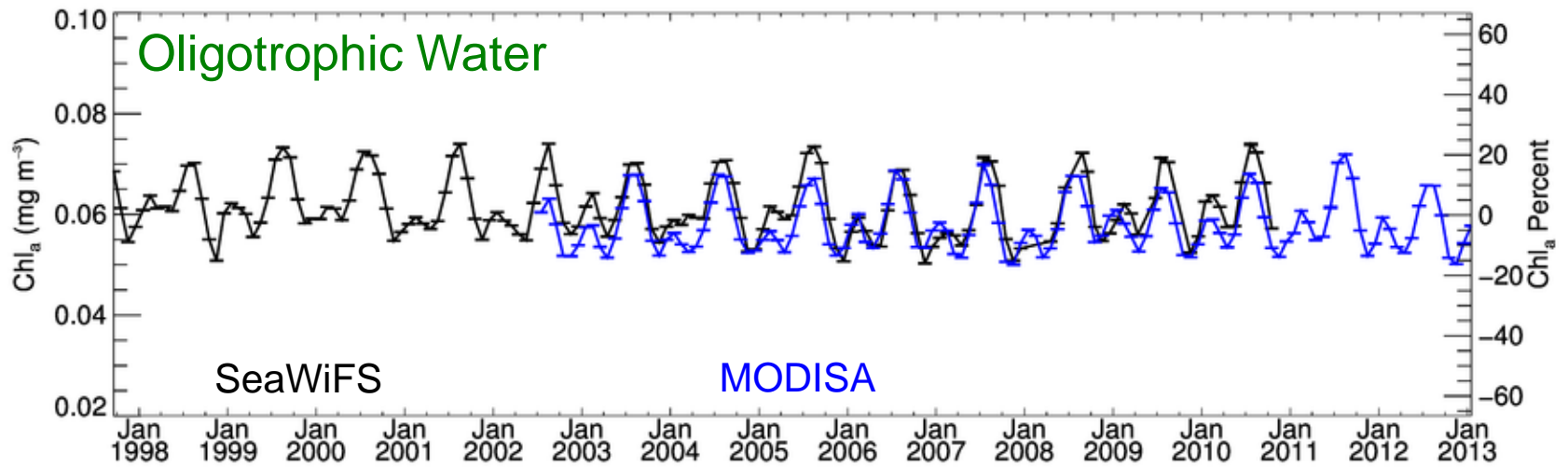


Radiometric Consistency of MERIS & SeaWiFS

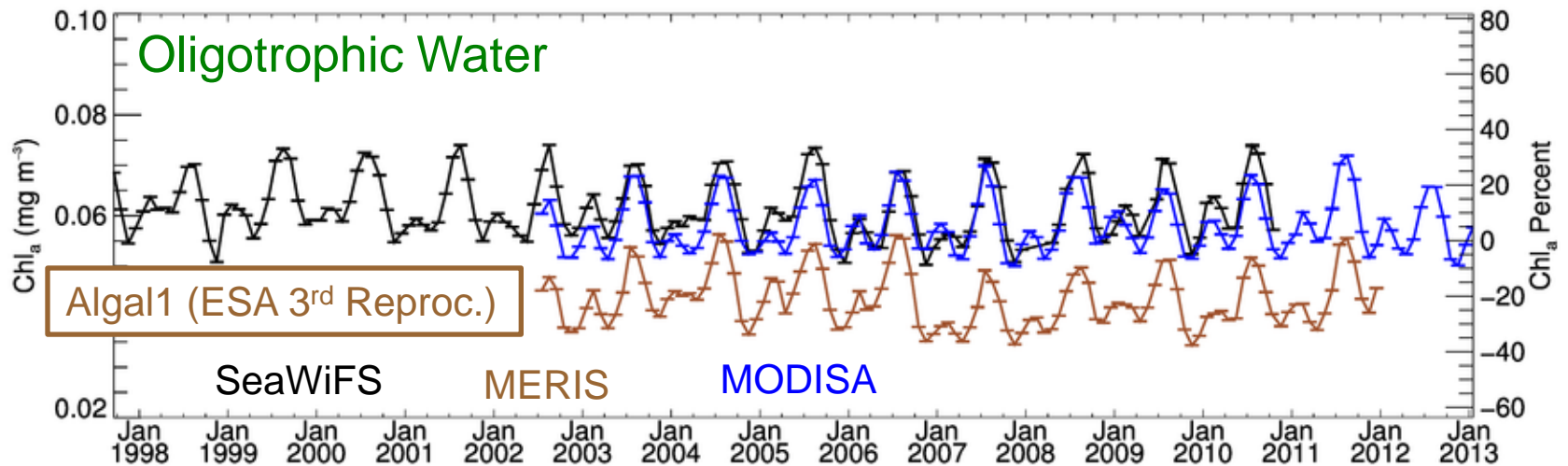
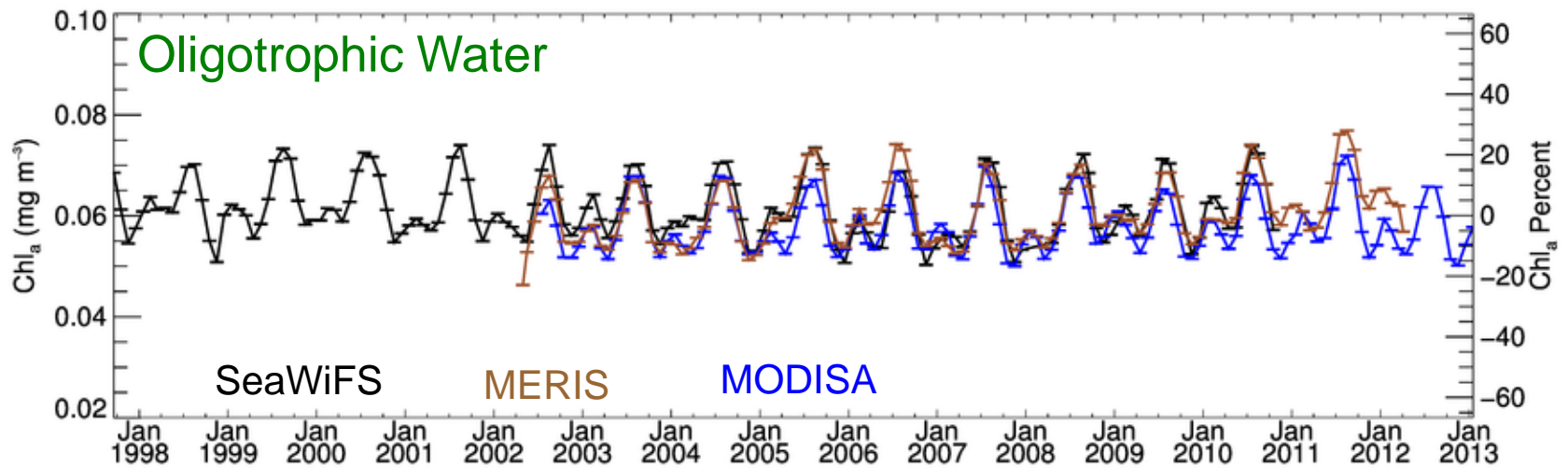
Deep-Water



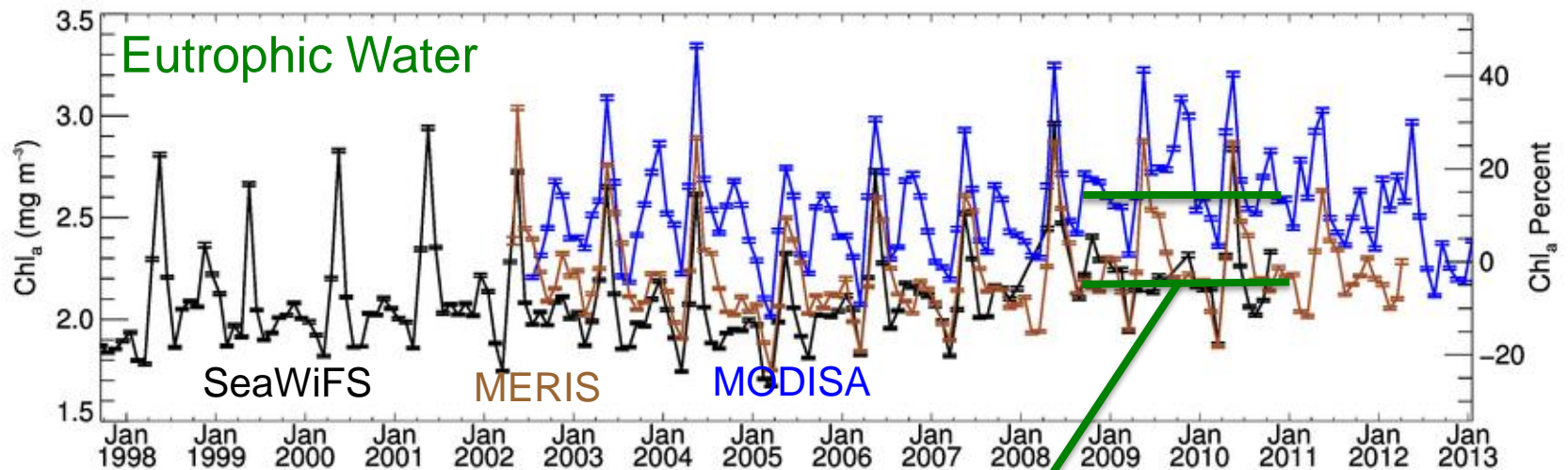
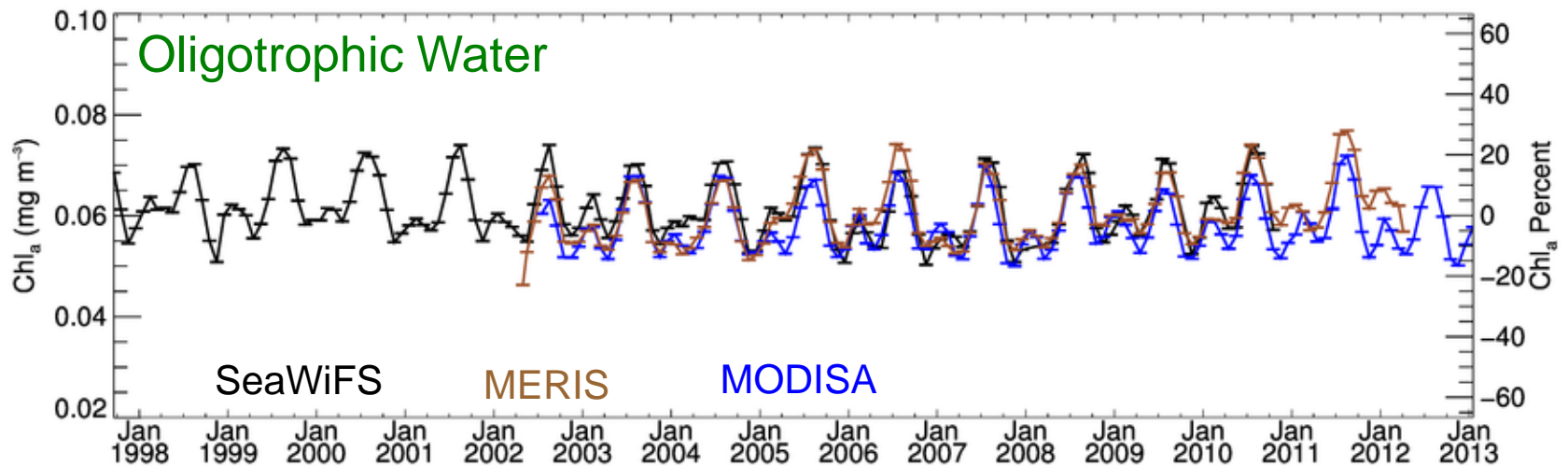
Multi-mission Chlorophyll Record



Multi-mission Chlorophyll Record

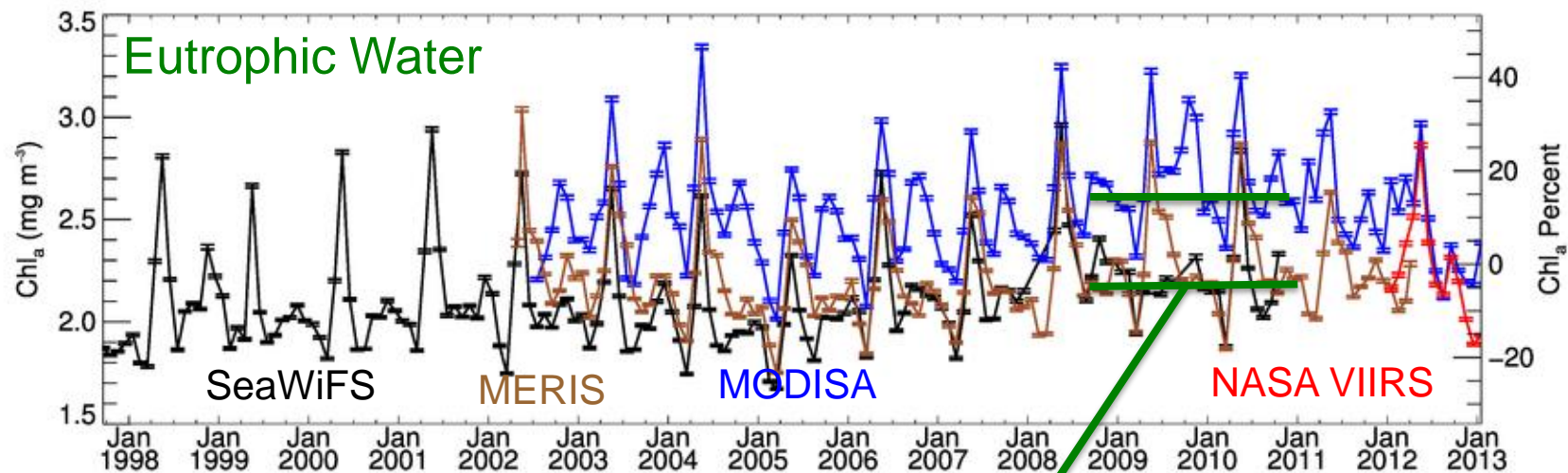
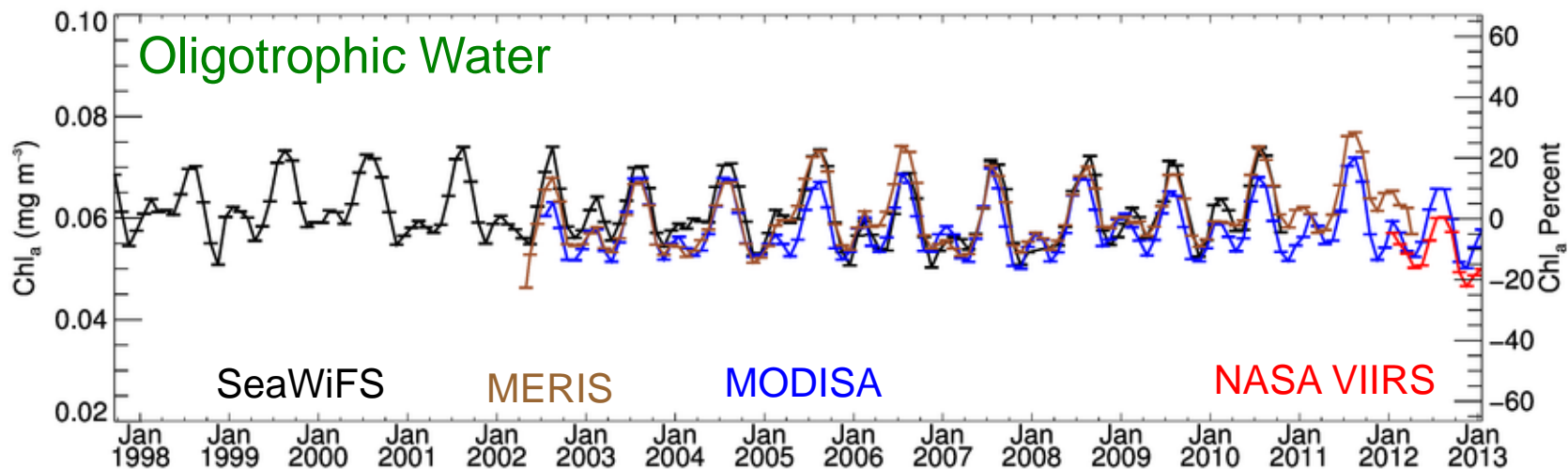


Multi-mission Chlorophyll Record



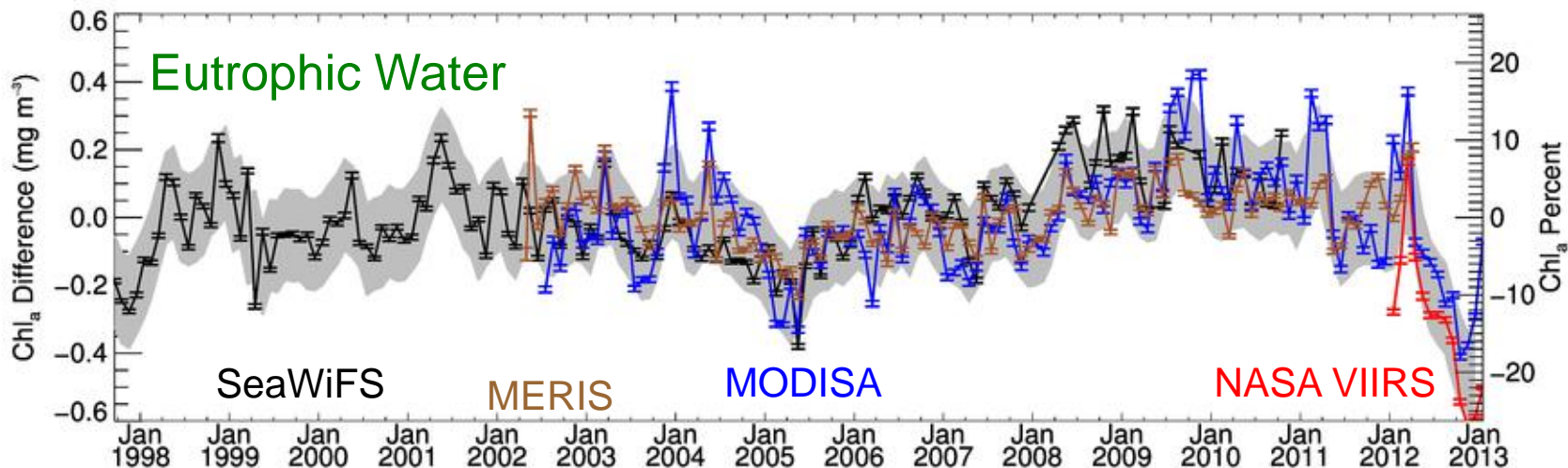
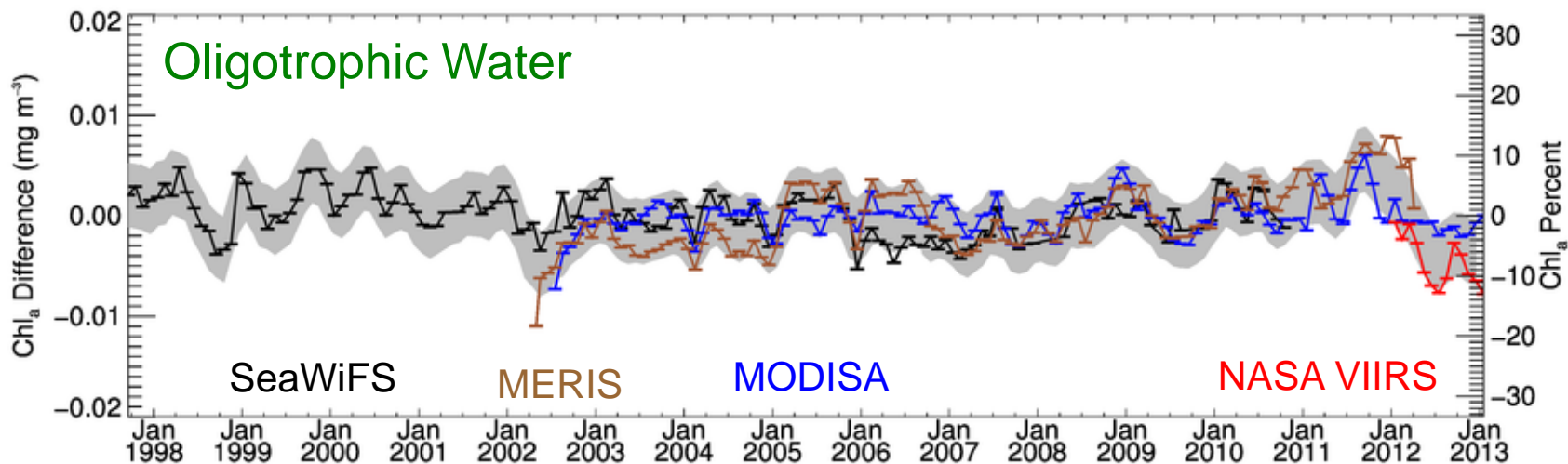
10%-20% difference (OC4 vs OC3 algorithm?)

Multi-mission Chlorophyll Record



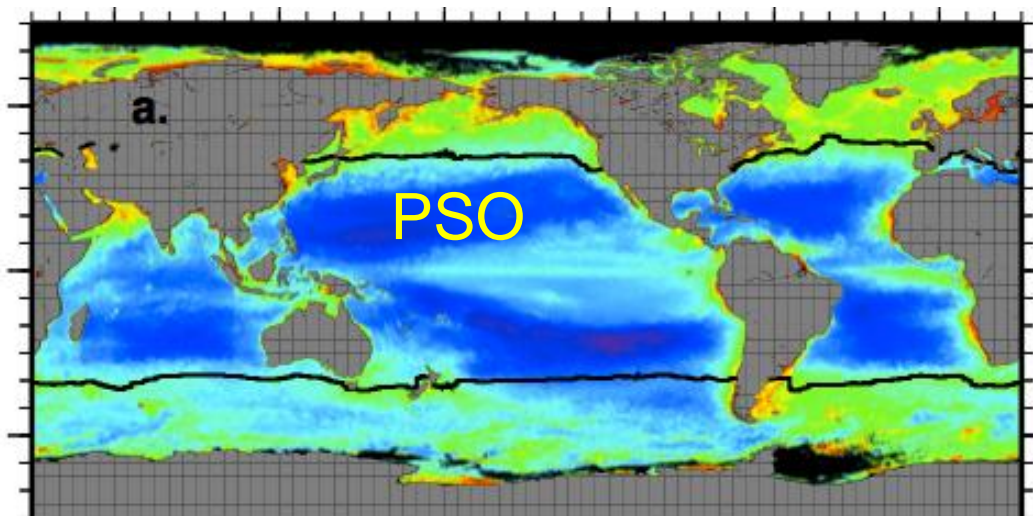
10%-20% difference (OC4 vs OC3 algorithm?)

Multi-mission Chlorophyll Anomaly Record

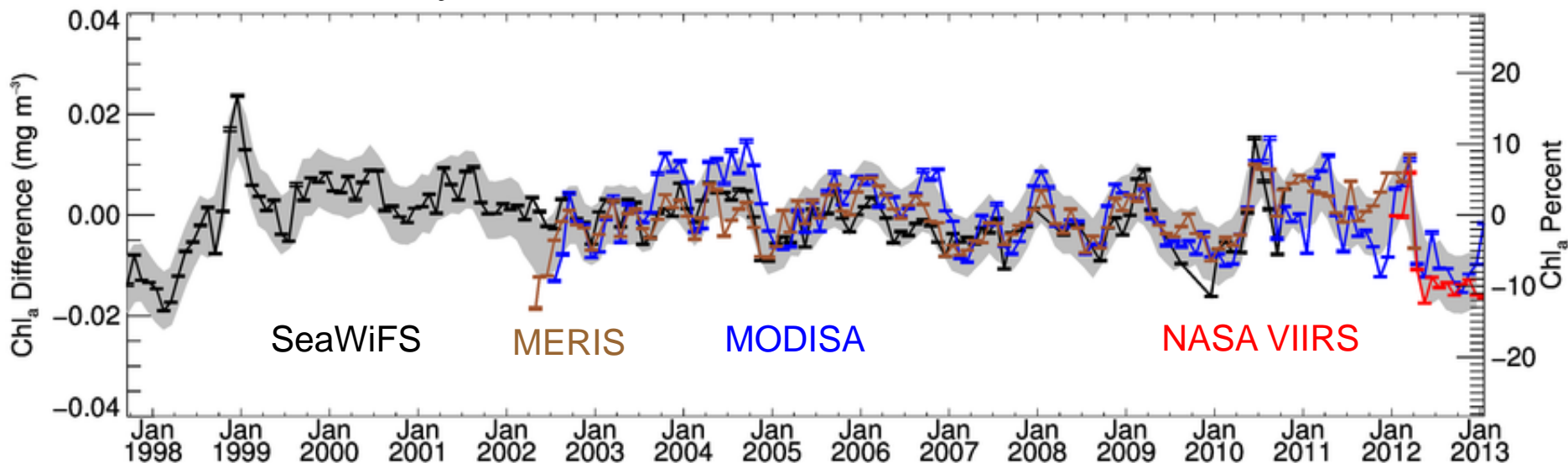


Multi-mission Chlorophyll Anomaly Record

Following
Berenfeld et al. 2006
Mean SST > 15C



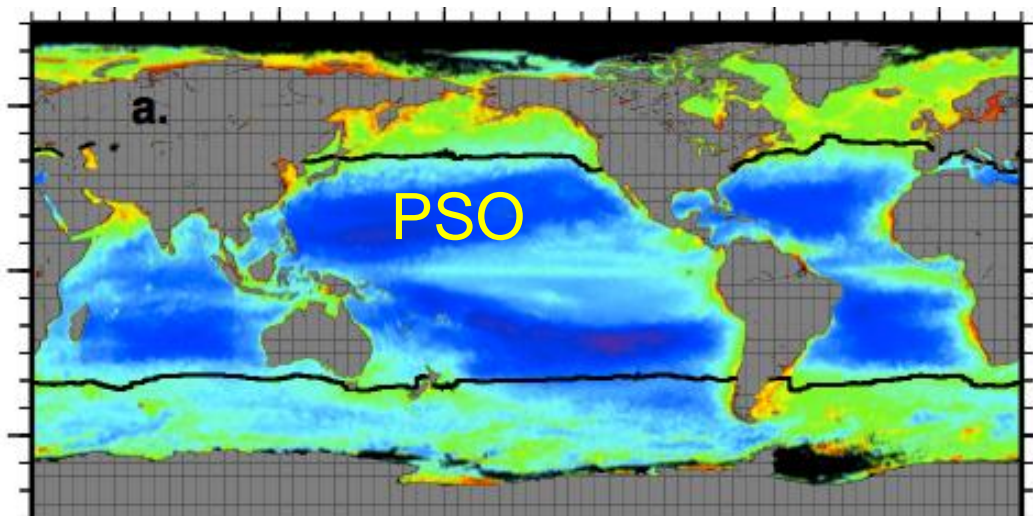
PSO Anomaly



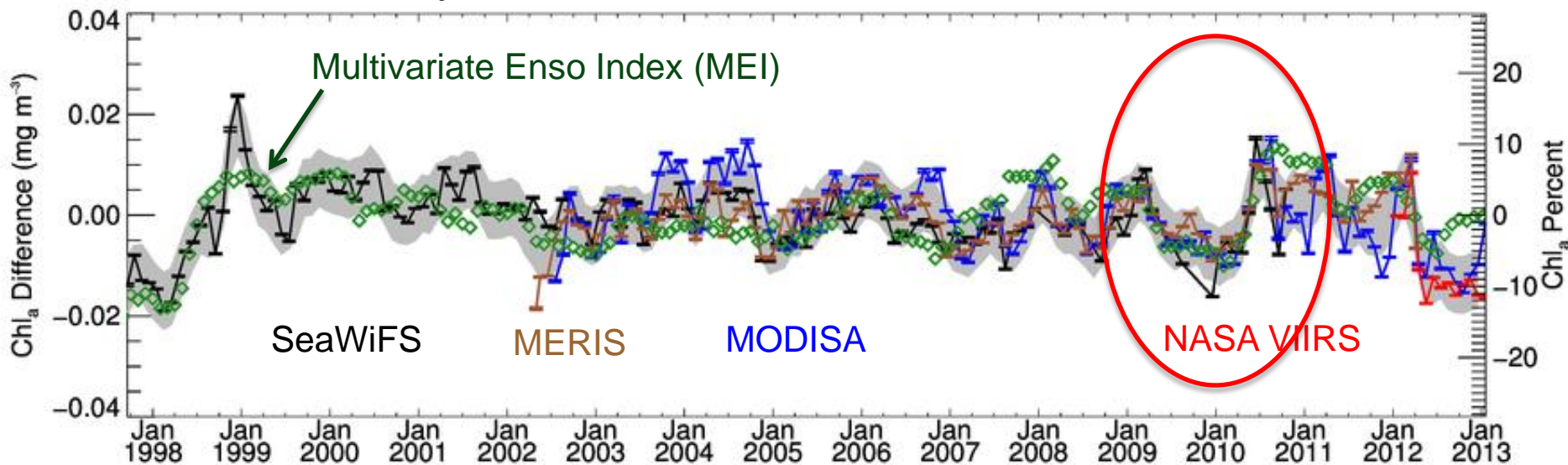
Franz, B.A., D.A. Siegel, M.J. Behrenfeld, P.J. Werdell (2013). Global ocean phytoplankton [in State of the Climate in 2012]. Bulletin of the American Meteorological Society (submitted)

Multi-mission Chlorophyll Anomaly Record

Following
Berenfeld et al. 2006
Mean SST > 15C



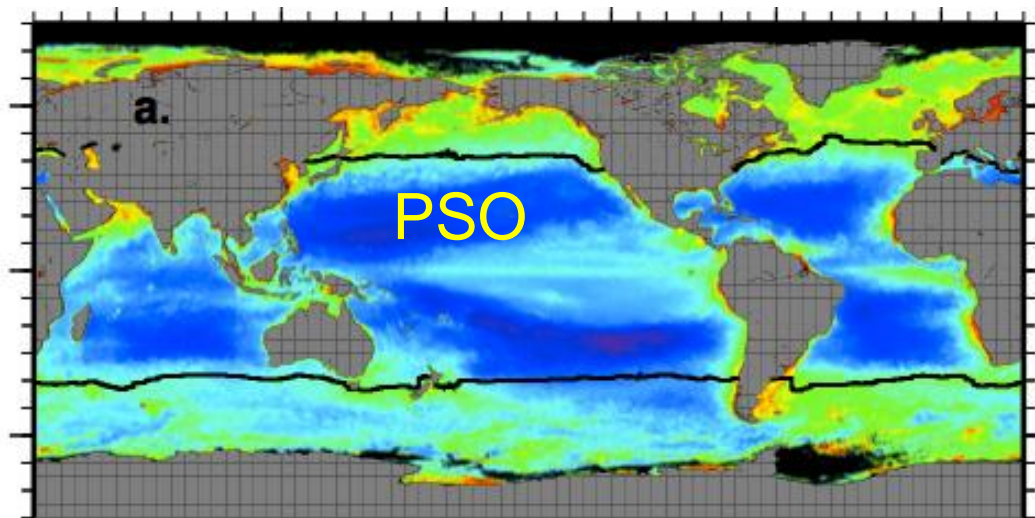
PSO Anomaly



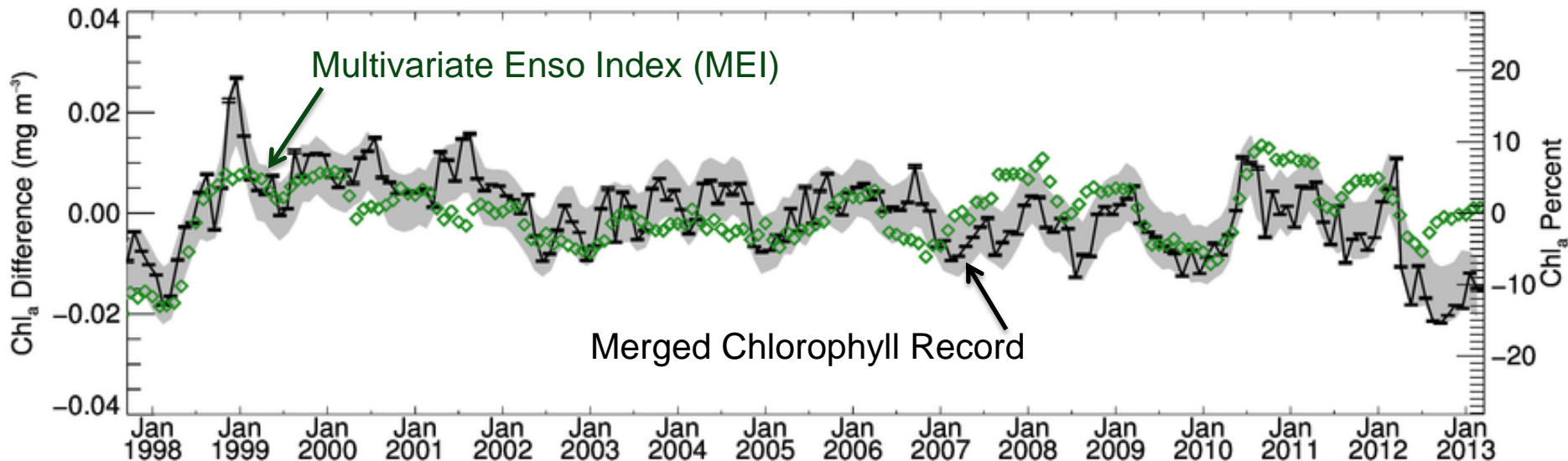
Franz, B.A., D.A. Siegel, M.J. Behrenfeld, P.J. Werdell (2013). Global ocean phytoplankton [in State of the Climate in 2012]. Bulletin of the American Meteorological Society (submitted)

Multi-mission Chlorophyll Anomaly Record

Following
Berenfeld et al. 2006
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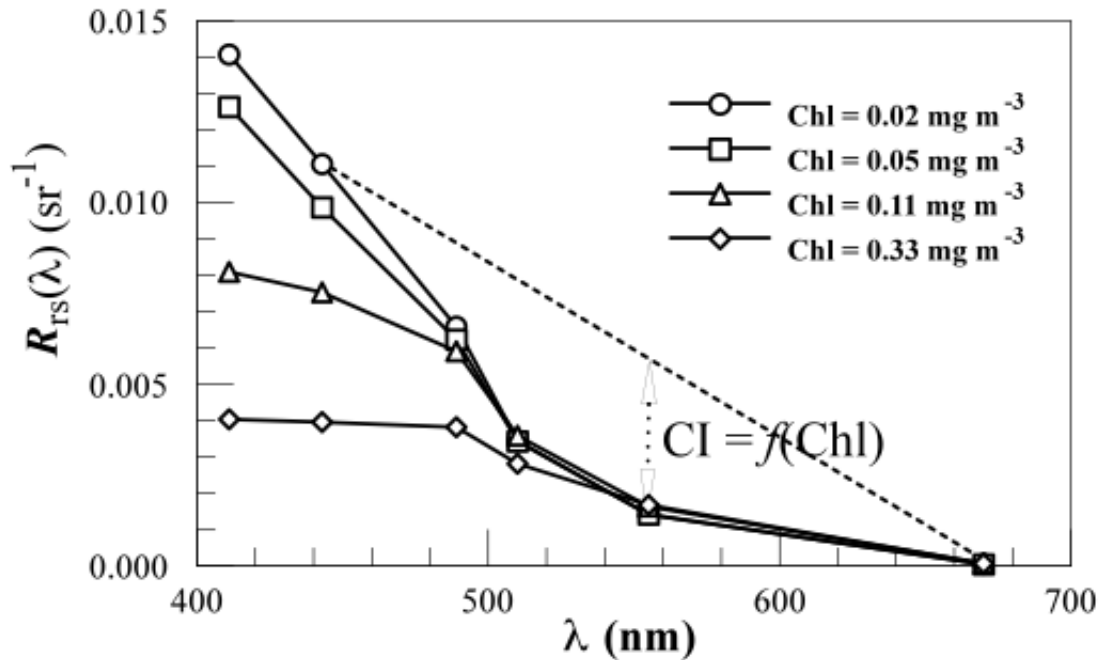
PSO Anomaly



Chlorophyll Algorithm Refinement

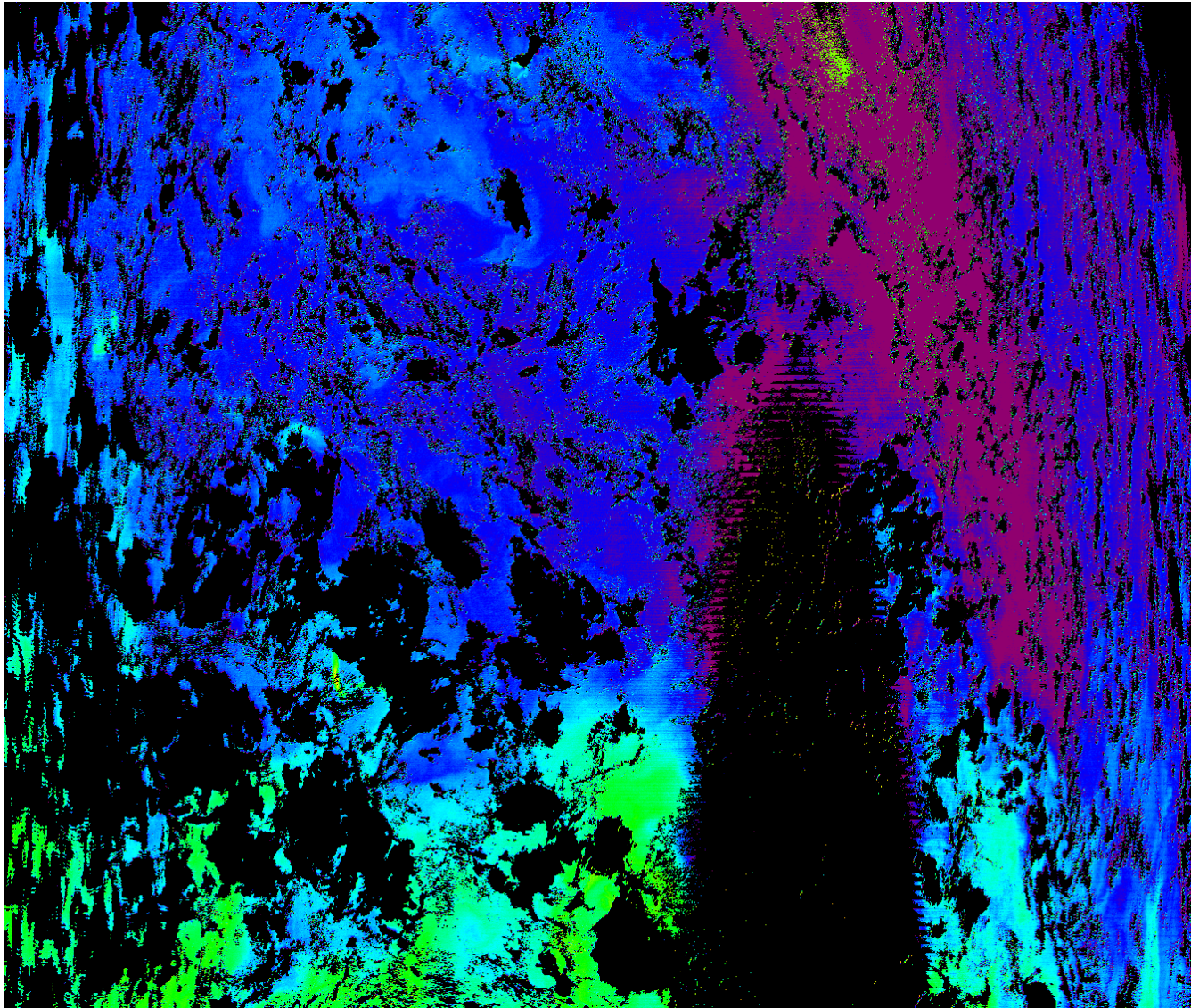
Chlorophyll Algorithm Refinement (OCI) for low-chlorophyll water only

OCI algorithm: Line height algorithm for chlorophyll $< 0.25 \text{ mg m}^{-3}$, merged with OC3/OC4 max band ratio algorithm for chlorophyll $> 0.3 \text{ mg m}^{-3}$.

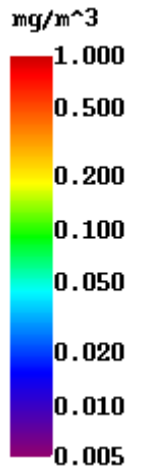


Hu, C., Z. Lee, and B.A. Franz (2012). Chlorophyll-a algorithms for oligotrophic oceans: A novel approach based on three-band reflectance difference, *J. Geophys. Res.*, 117, C01011, doi:10.1029/2011JC007395.

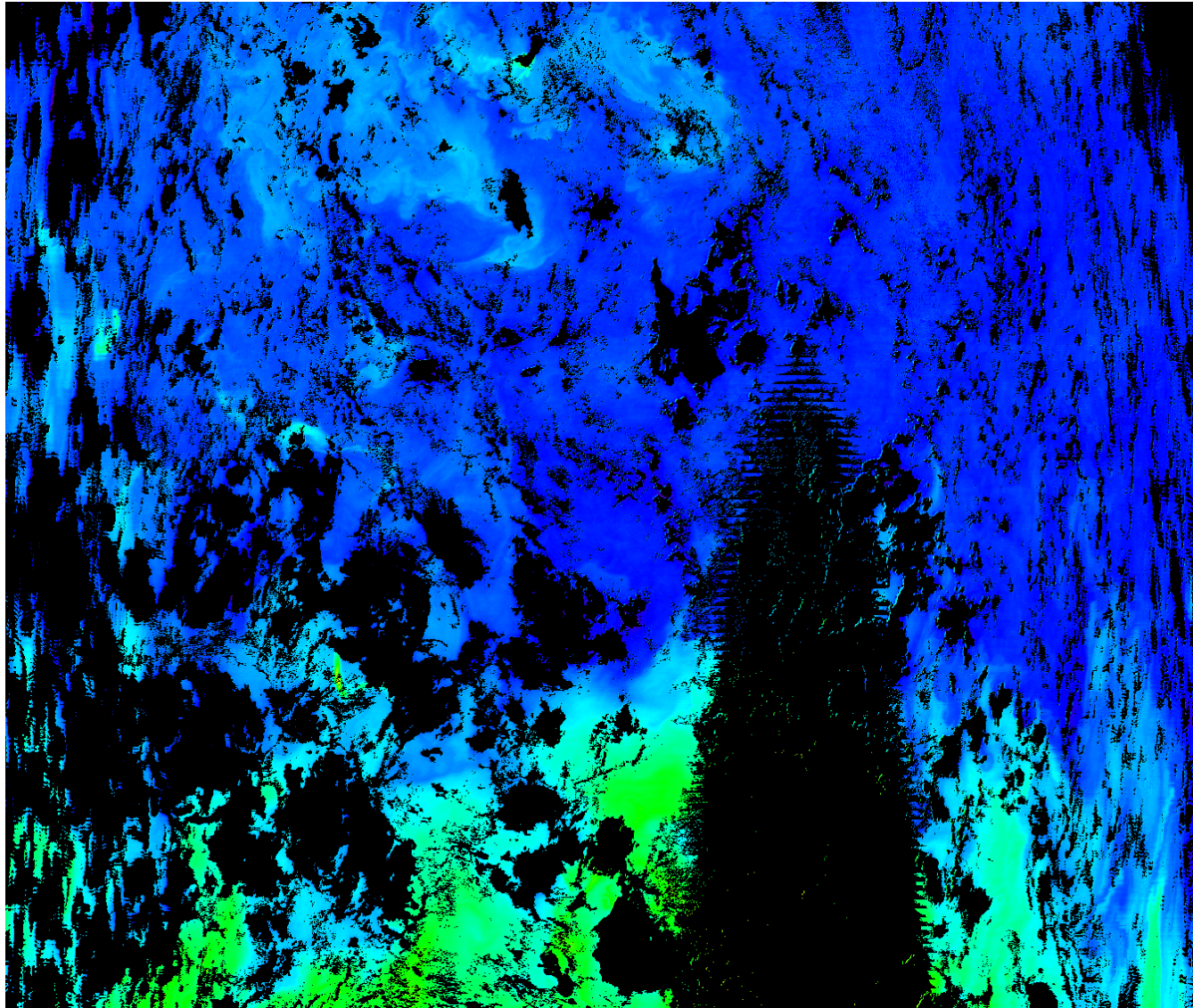
MODISA Standard OC3 Chlorophyll



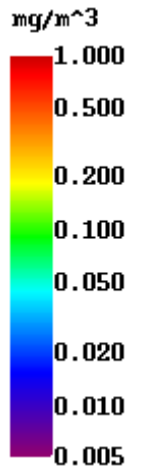
Chl_{OC3}
Flags off



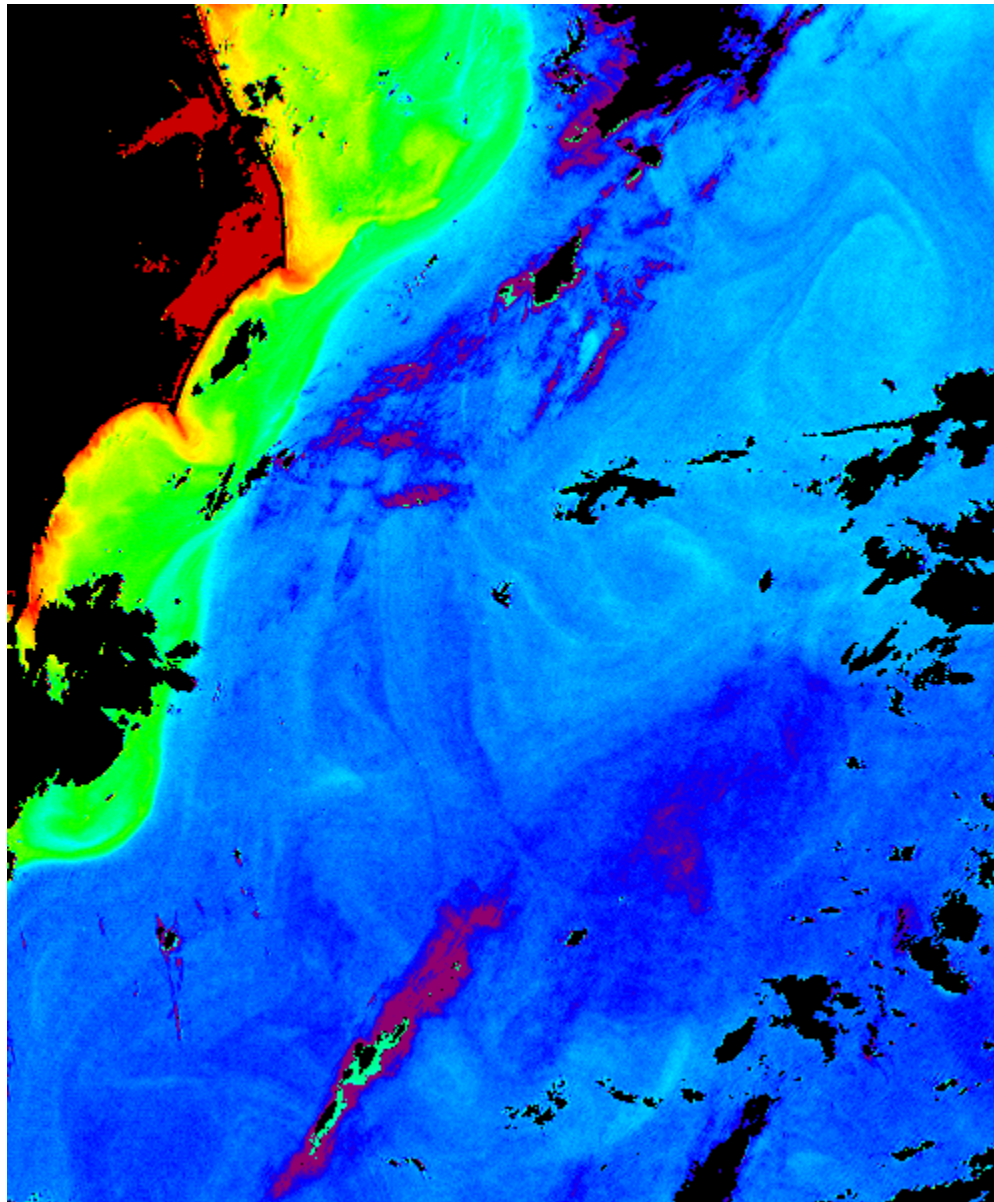
MODISA Evaluation OCI Chlorophyll



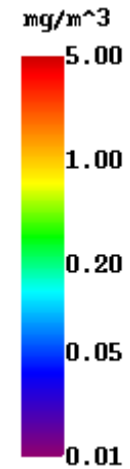
Chl_{CI}
Flags off



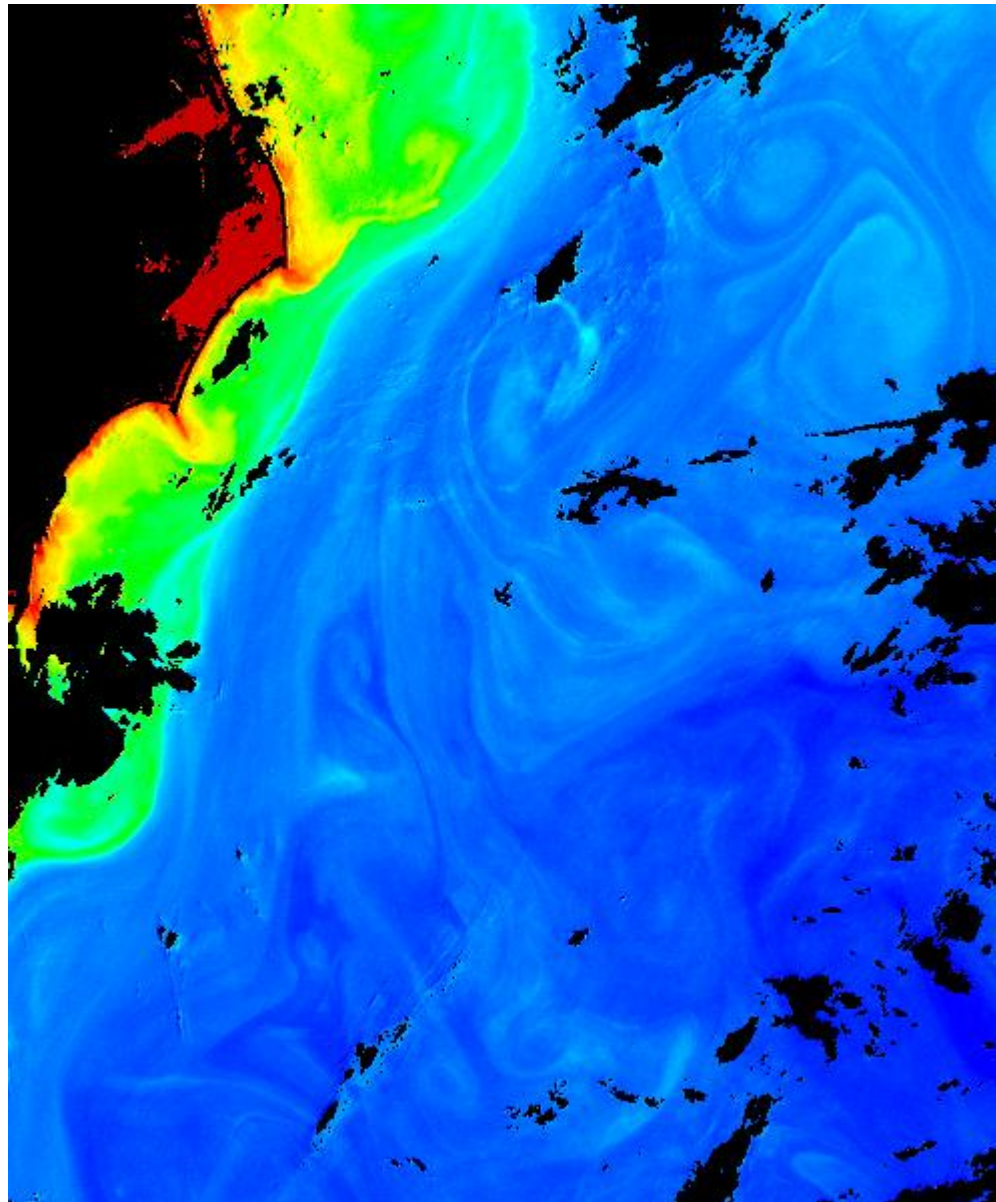
SeaWiFS Standard OC4 Chlorophyll



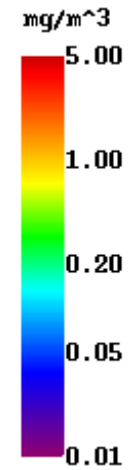
Chl_{OC4}



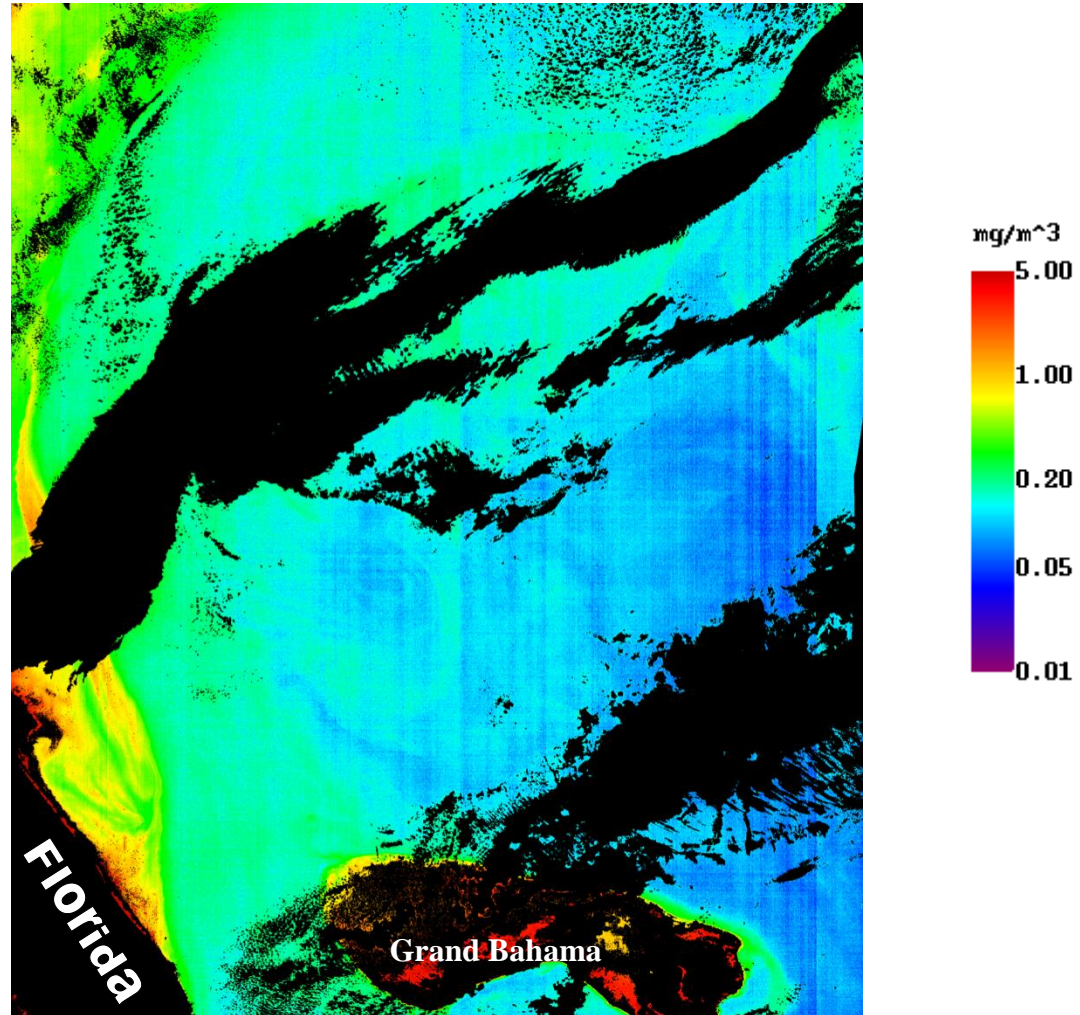
SeaWiFS Evaluation OCI Chlorophyll



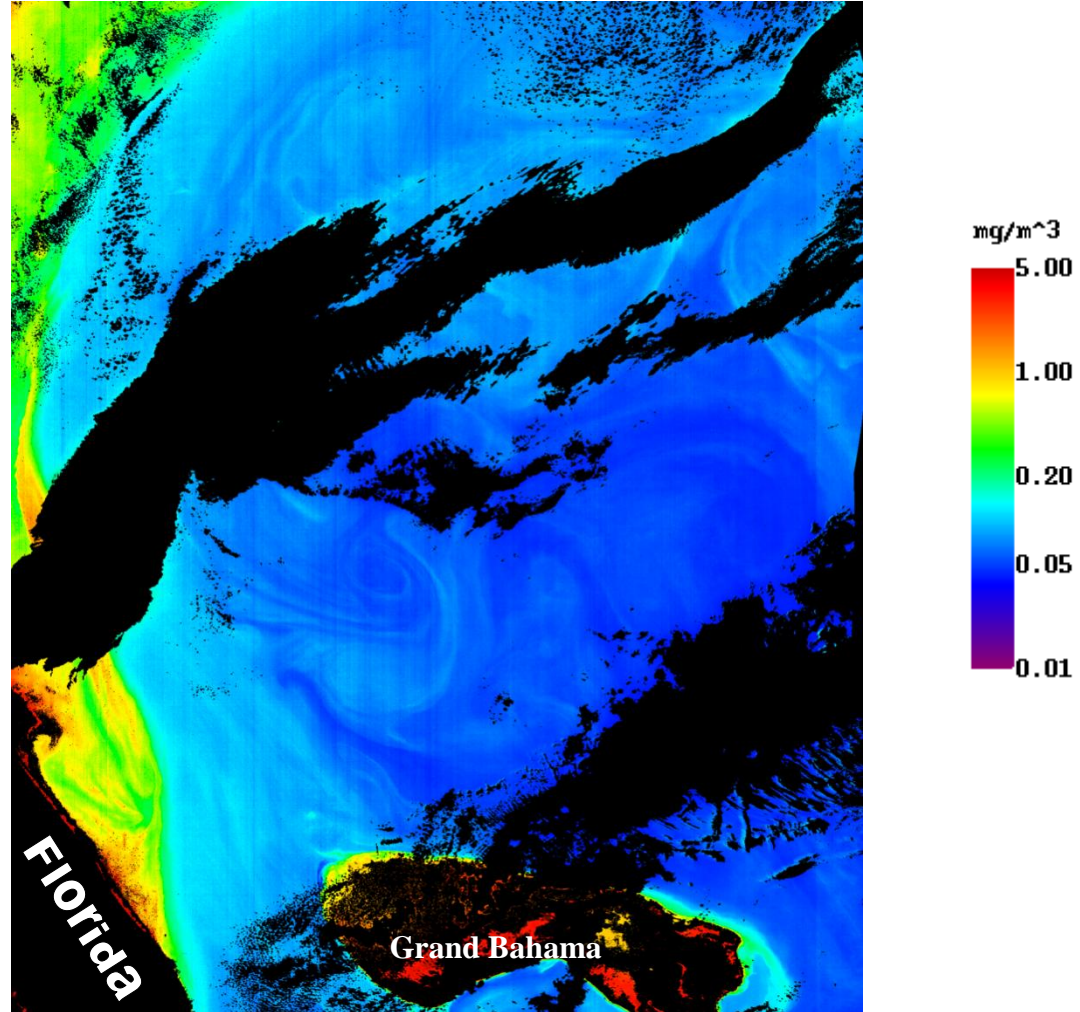
Chl_{OCI}



MERIS Standard OC4 Chlorophyll



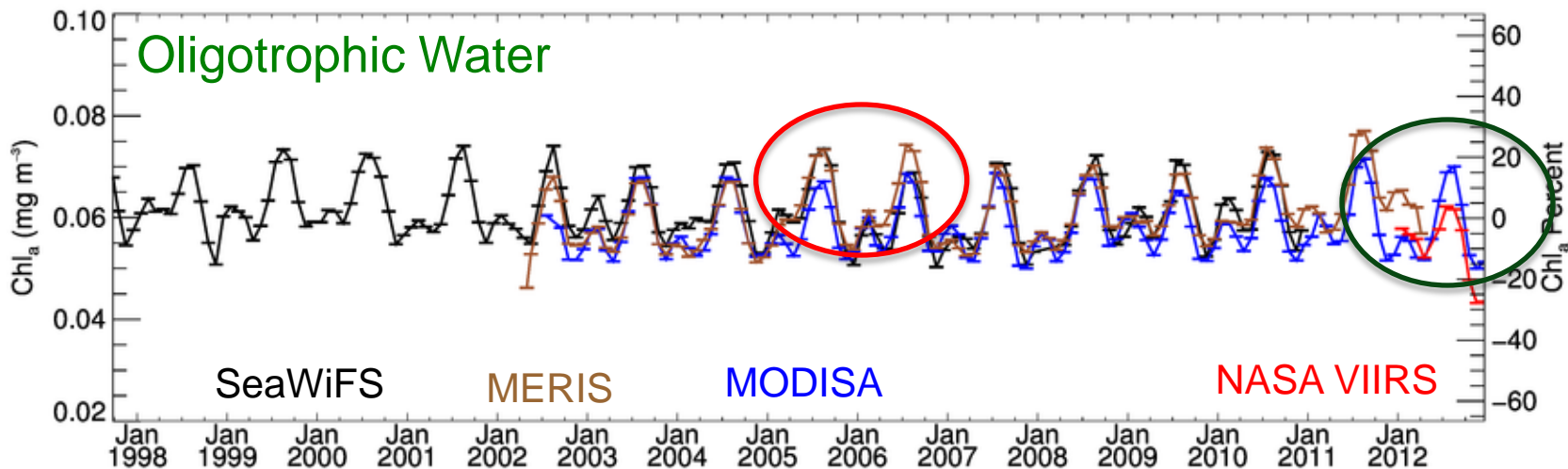
MERIS Evaluation OCI Chlorophyll



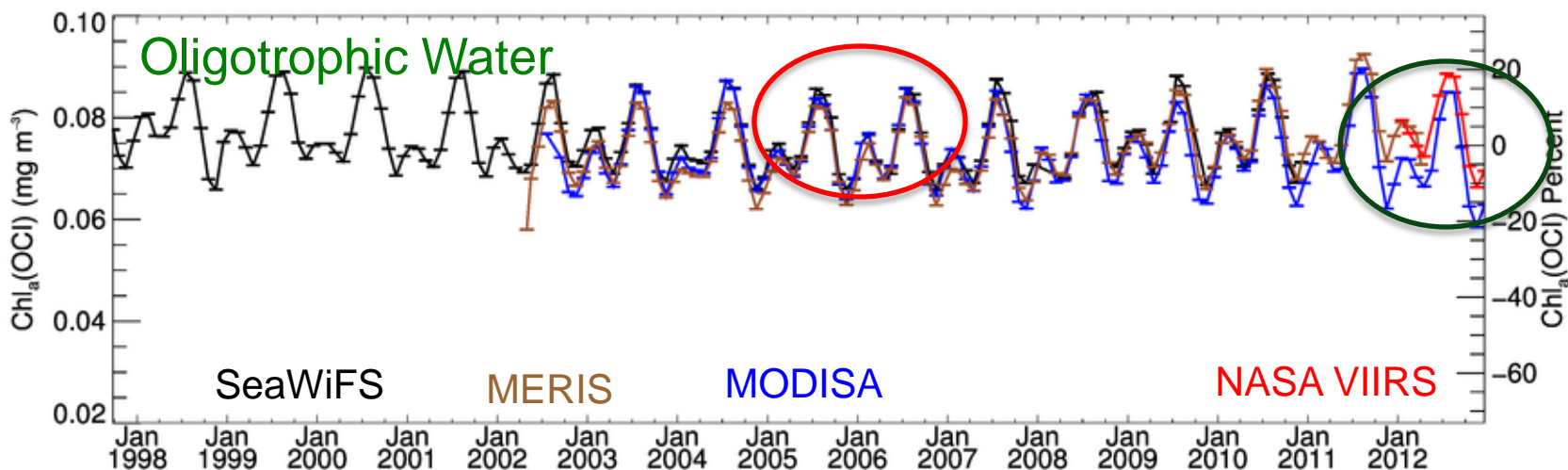
Chlorophyll Algorithm Refinement

improved agreement between sensors in clear water

OC3 & OC4



OCI



Future Plans

Next multi-mission reprocessing anticipated 2013-2014

Incorporate algorithm refinements

- advancements in atmospheric correction

- new chlorophyll algorithm likely

- updates to PIC algorithm

- updates to PAR algorithm

Expand standard product suite

- IOP products (algorithm TBD)

- Uncertainties (method TBD)

Change data formats

- moving to CF-compliant netCDF4

Splinter 11

Conclusions

A high degree of consistency has been achieved between SeaWiFS, MODIS, MERIS (and VIIRS).

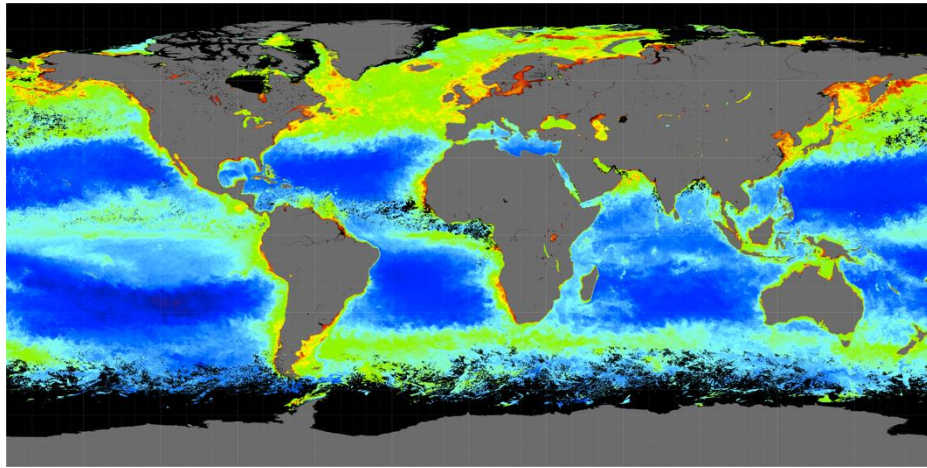
Multiple overlapping missions, consistently processed and calibrated, provide insight into trend uncertainty and truth.

We do chlorophyll pretty well (and we can still do it better), but chlorophyll is a rough proxy for phytoplankton abundance.

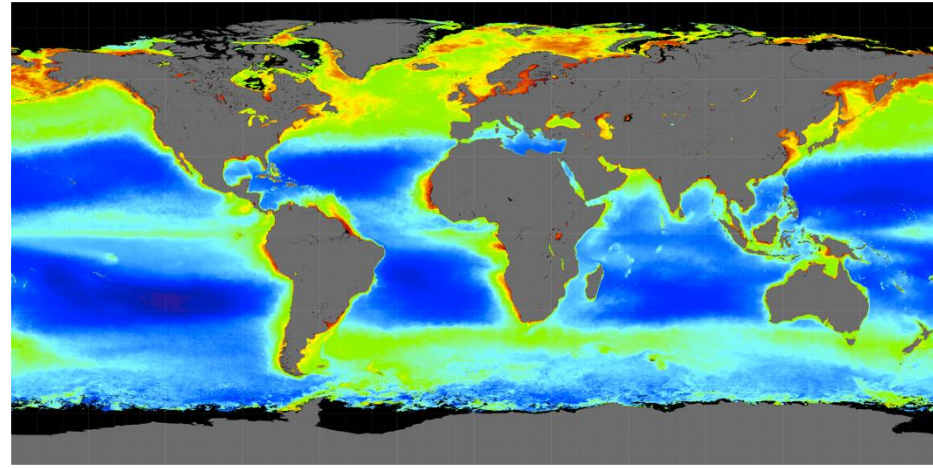
We need to focus equivalent effort on IOP trends (separation of CDOM from chlorophyll) and push into phytoplankton community structure,

... leading to requirements for global hyperspectral (PACE Mission)

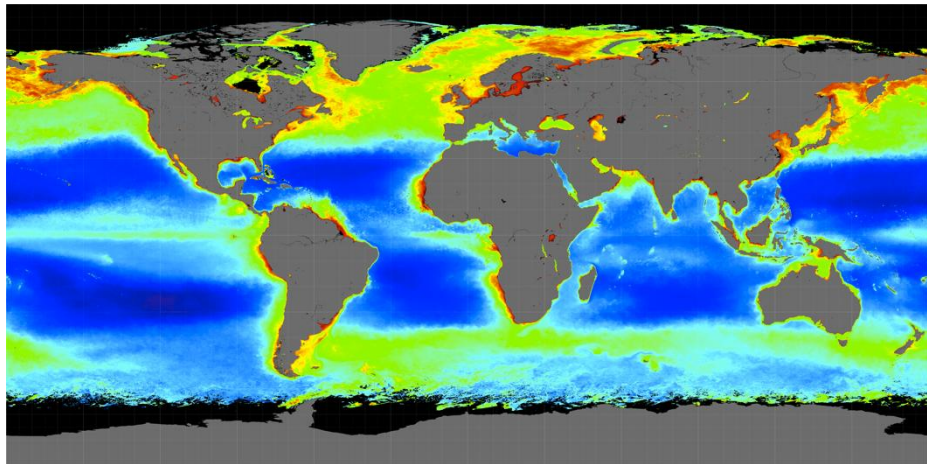
Questions?



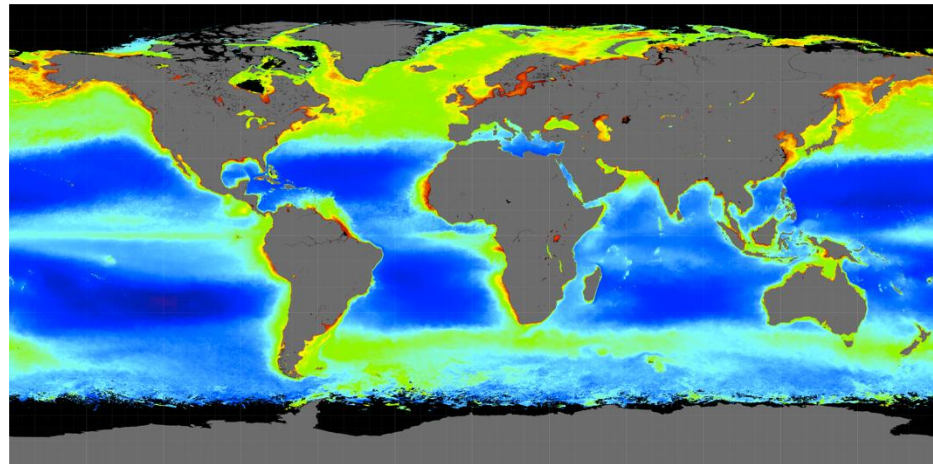
Spring 2012 - VIIRS



Spring Climatology - SeaWiFS

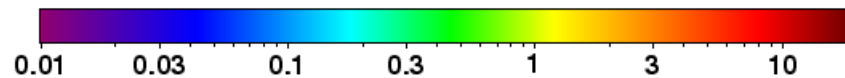


Spring Climatology - Aqua/MODIS



Spring Climatology - Terra/MODIS

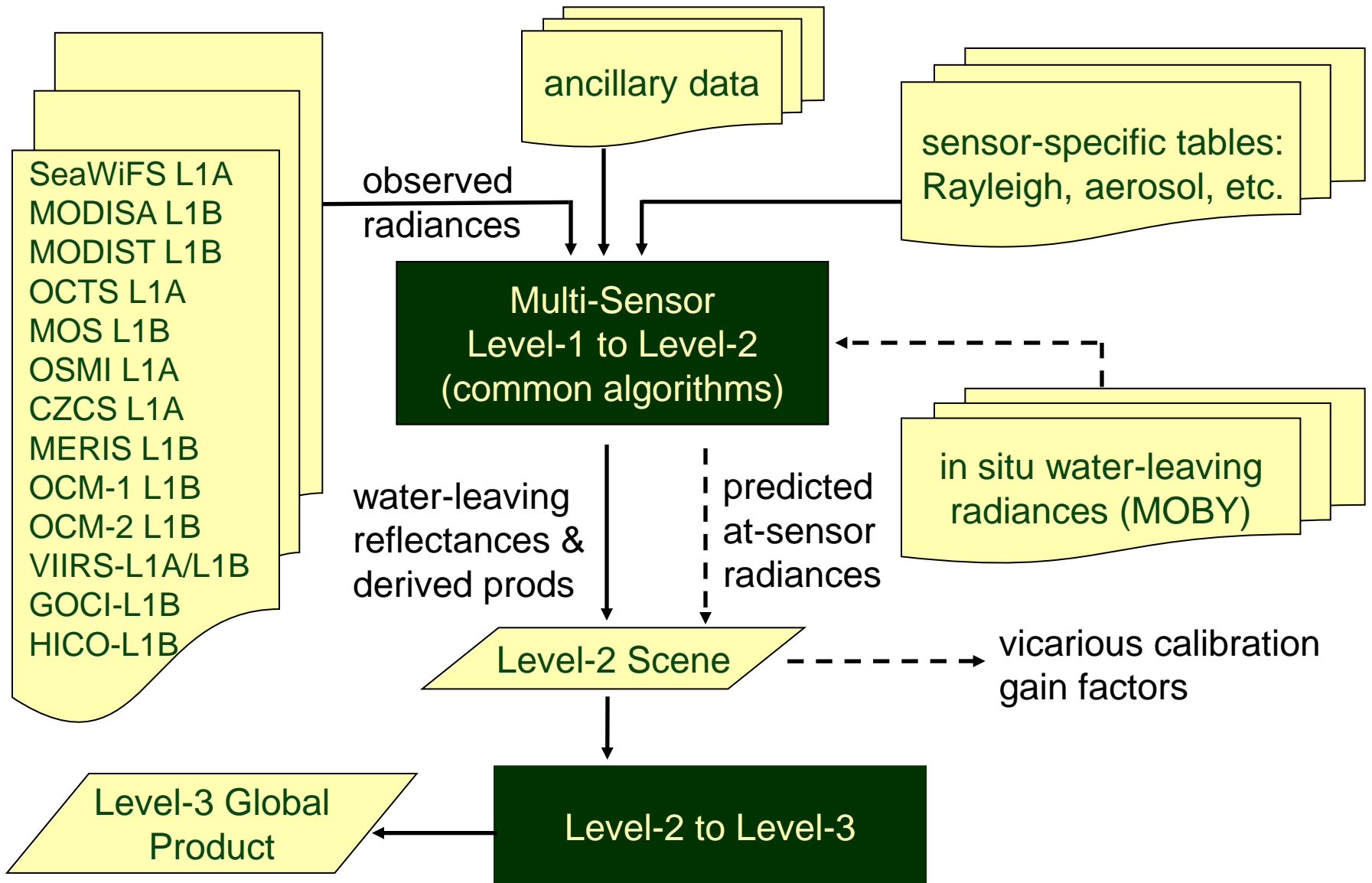
Chlorophyll a concentration (mg / m³)





Thank You

Common Processing Approach



Recent Ocean Color Reprocessings

Multi-Mission Reprocessing (2010-2011)

R2010.0 all missions with consistent algorithms and calibration approach
MODISA, MODIST, SeaWiFS, OCTS, CZCS

MODISA Calibration Updates (2012 & 2013)

R2012.0 full-mission revised instrument temporal calibration

R2013.0 partial-mission instrument calibration update (2011-2013)

VIIRS Ingest and Reprocessing (2011-2013)

R2013.0 latest version of VIIRS processing with consistent algorithms and
MOBY vicarious calibration (NASA VIIRS)

MERIS RR Ingest and Reprocessing (2012-2013)

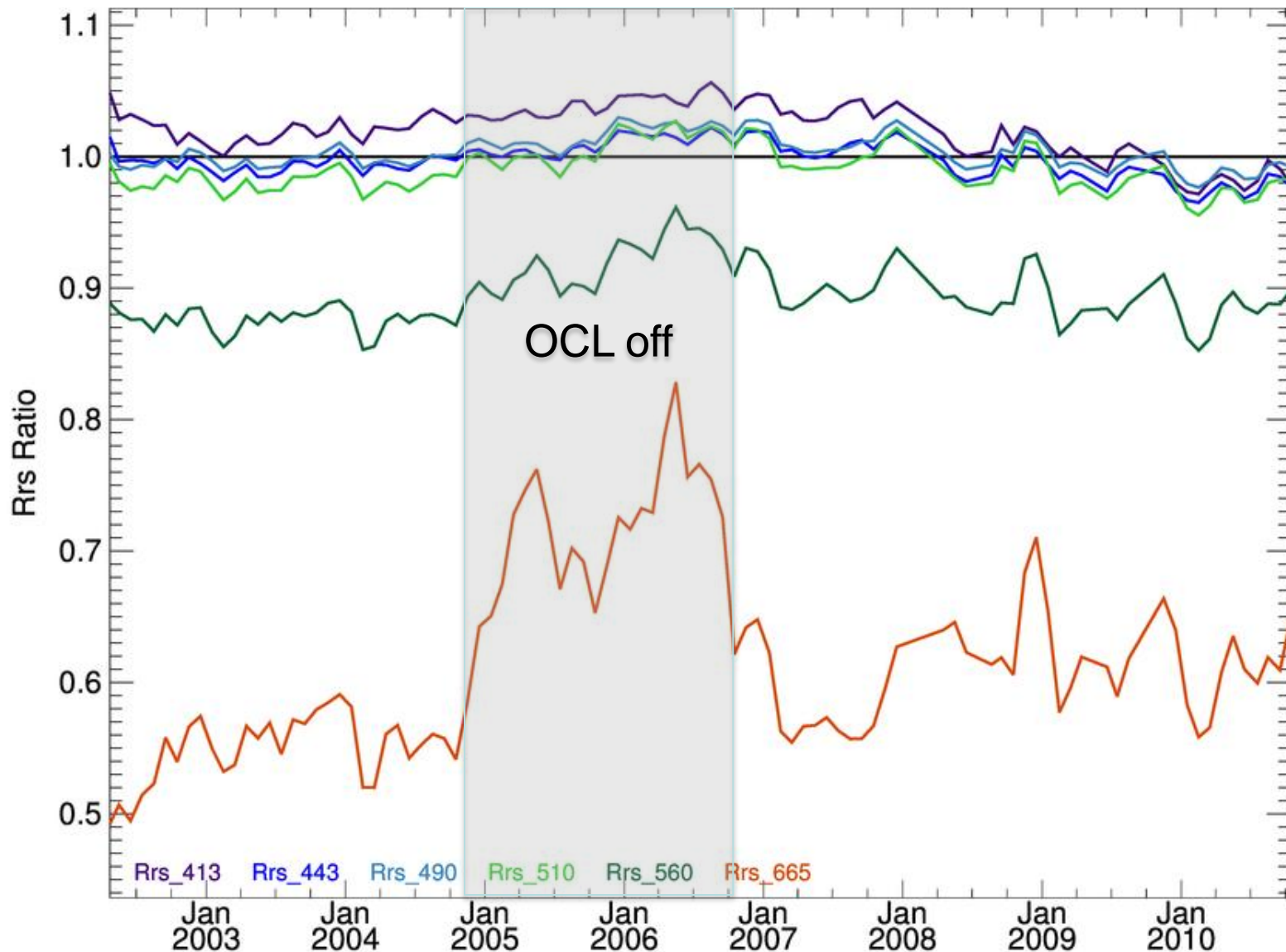
R2012.1 full mission reprocessing with consistent algorithms and MOBY
vicarious calibration

MODIST Calibration Update (expected May 2013)

<http://oceancolor.gsfc.nasa.gov/WIKI/OCReproc.html>

MERIS/SeaWiFS Rrs Ratios

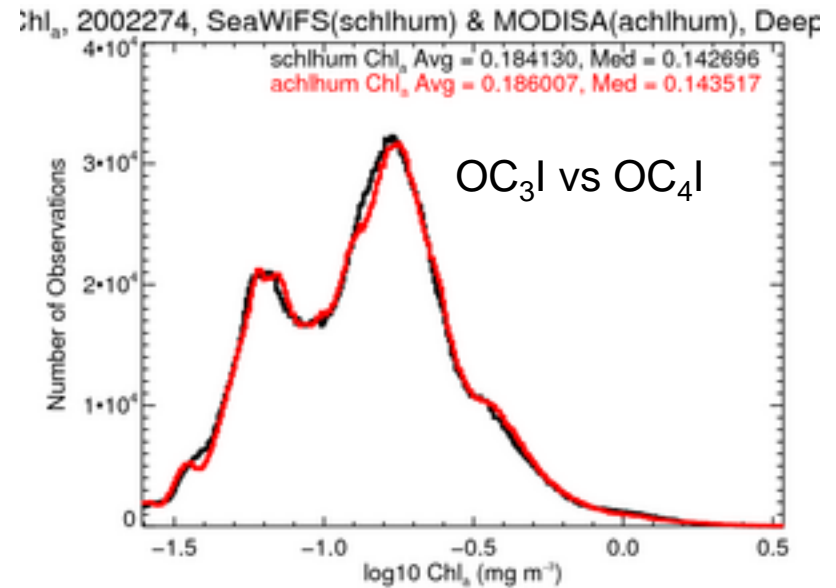
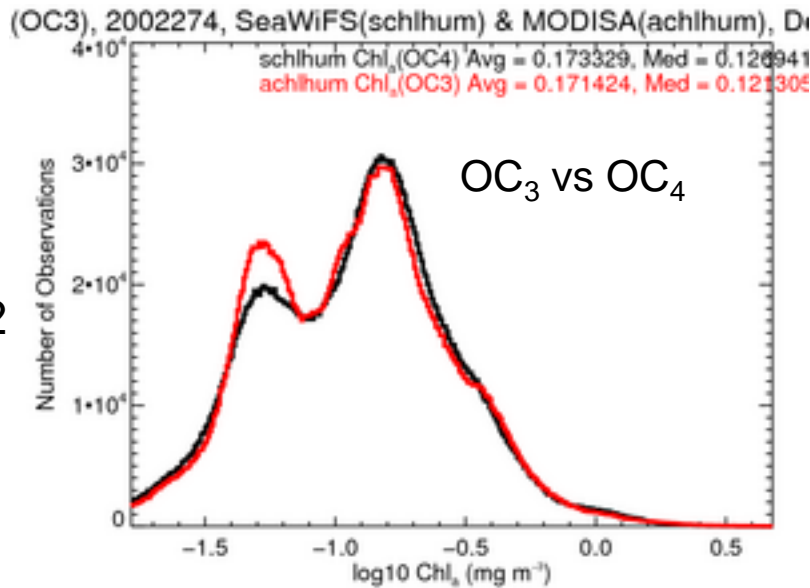
Deep-Water



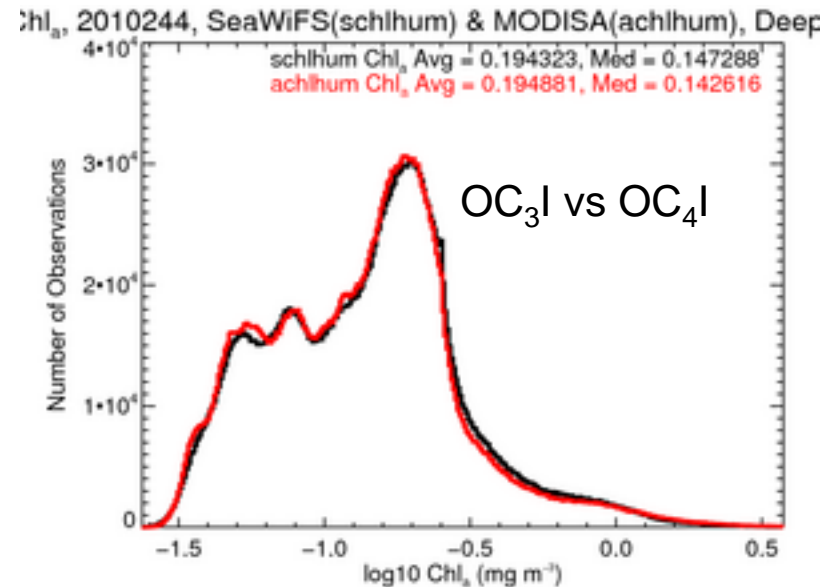
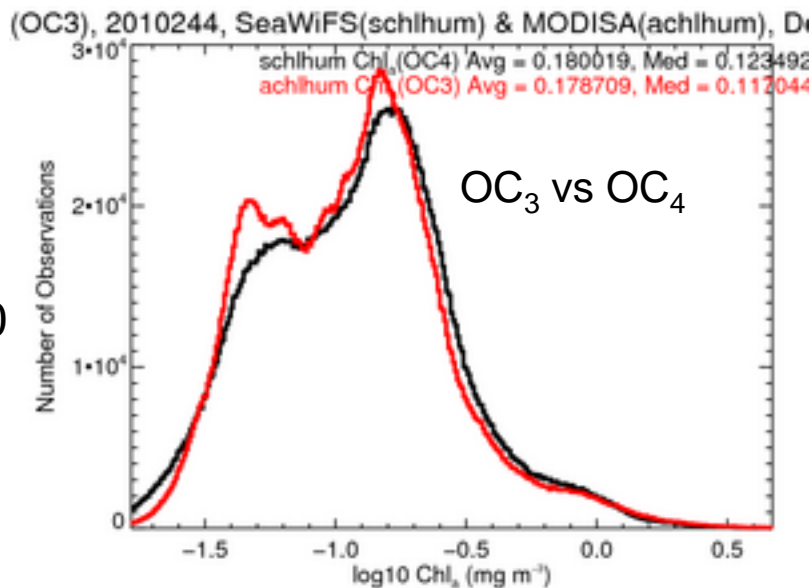
Improved Agreement in Chl Distribution

Deep-Water Monthly Mean, MODISA (red) & SeaWiFS (black)

Fall
2002



Fall
2010



VIIRS

Generating Continuity Products

MODISA L2	NASA VIIRS L2	NOAA VIIRS EDR
1. $R_{rs}(\lambda)$	$R_{rs}(\lambda)$	nLw(λ)
2. Ångstrom	Ångstrom	
3. AOT	AOT	
4. Chlorophyll <i>a</i>	Chlorophyll <i>a</i>	Chlorophyll <i>a</i>
5. $K_d(490)$	$K_d(490)$	
6. POC	POC	
7. PIC	PIC	
8. PAR	PAR	
9. iPAR		
10. nFLH		

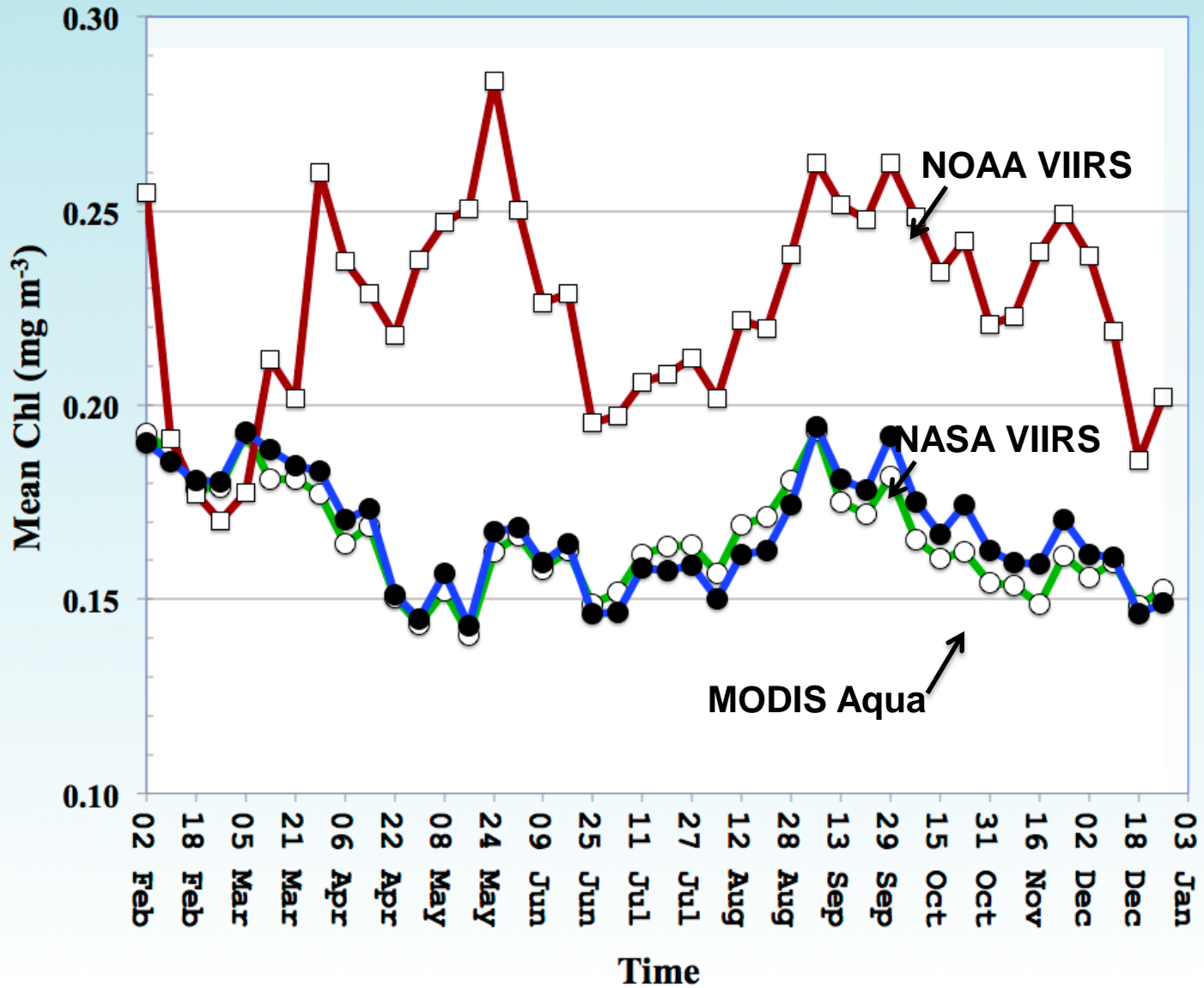
VIIRS lacks fluorescence capability

Chlorophyll Bands

λ (nm)	SeaWiFS	412	443	490	510	555	670
	MODIS	412	443	488		531	547 667 678
	VIIRS	412	443	486		555	671

VIIRS and MODIS lack 510 nm band for high Chla case

8-Day Composite Deep-Water Chl *a* Concentration Mean



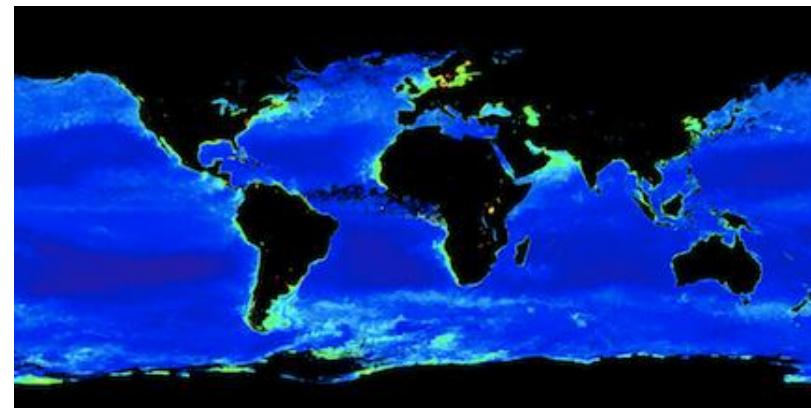
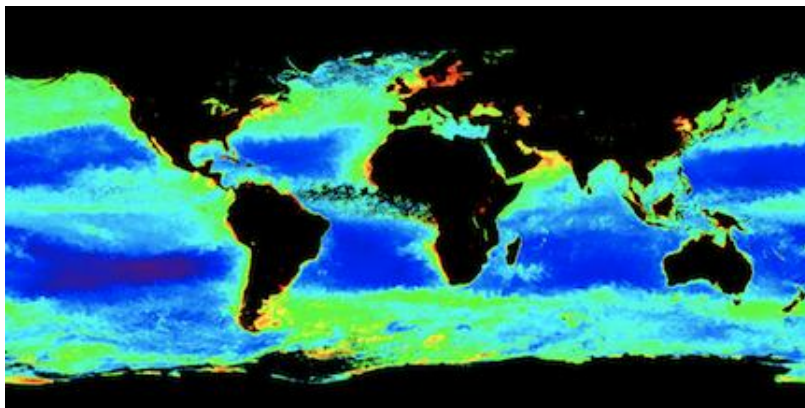
VIIRS & MODISA Winter 2012

NASA/OBPG Calibration & Processing

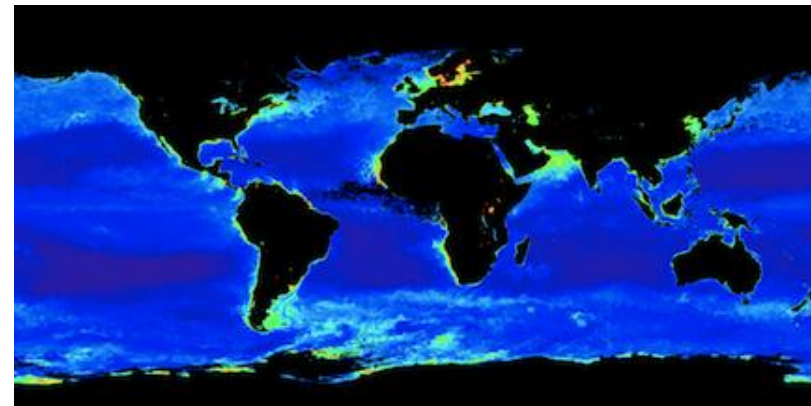
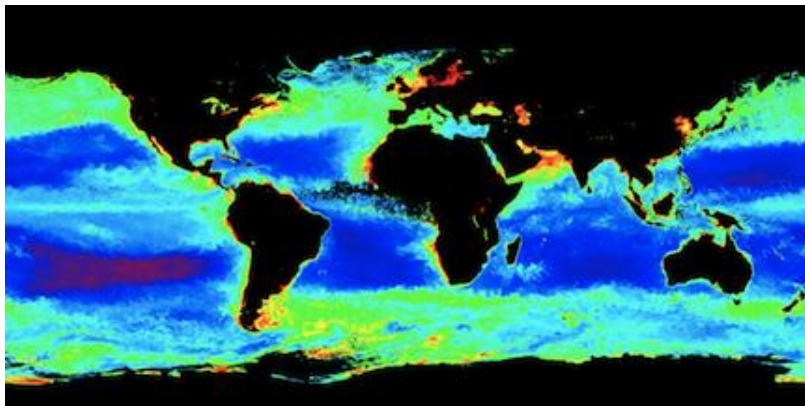
Chlorophyll

Kd(490) Diffuse Attenuation

VIIRS



MODISA



Chlorophyll a concentration (mg / m³)

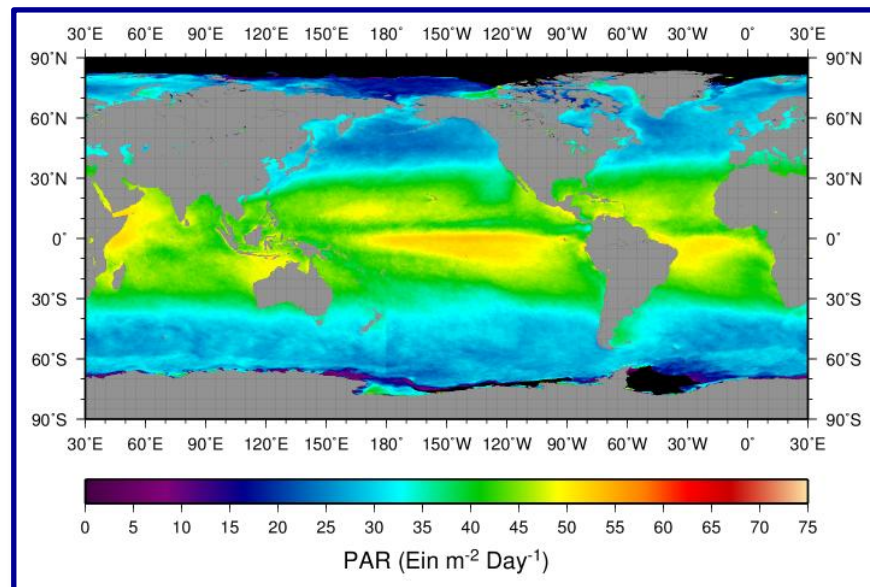
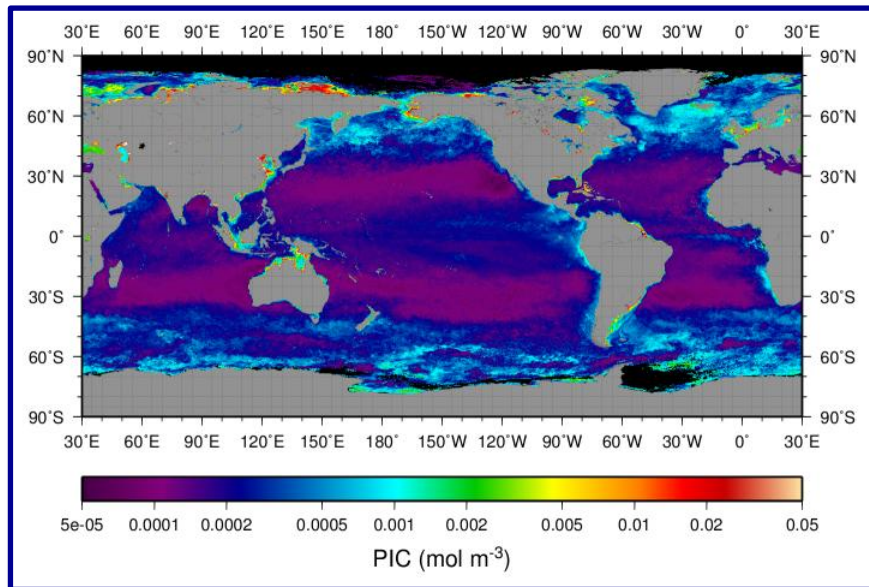
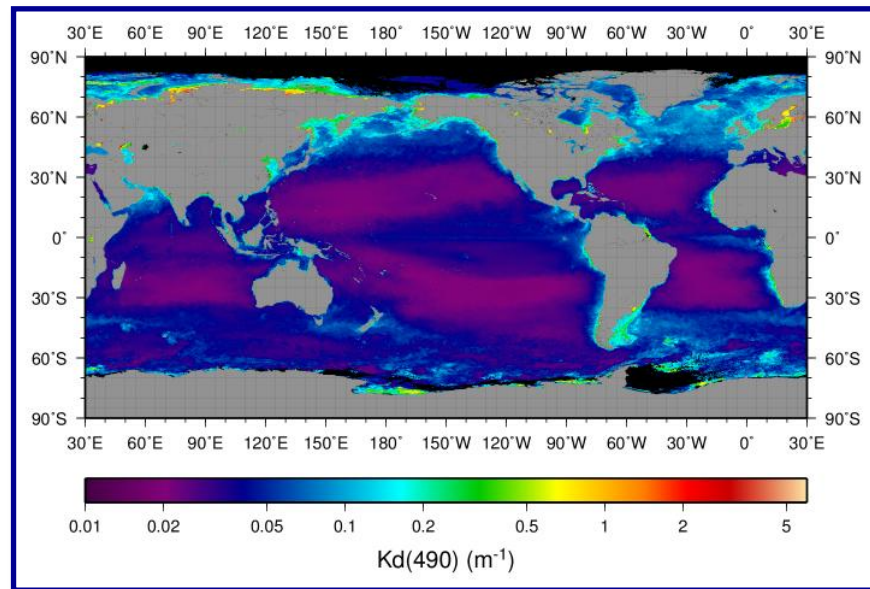
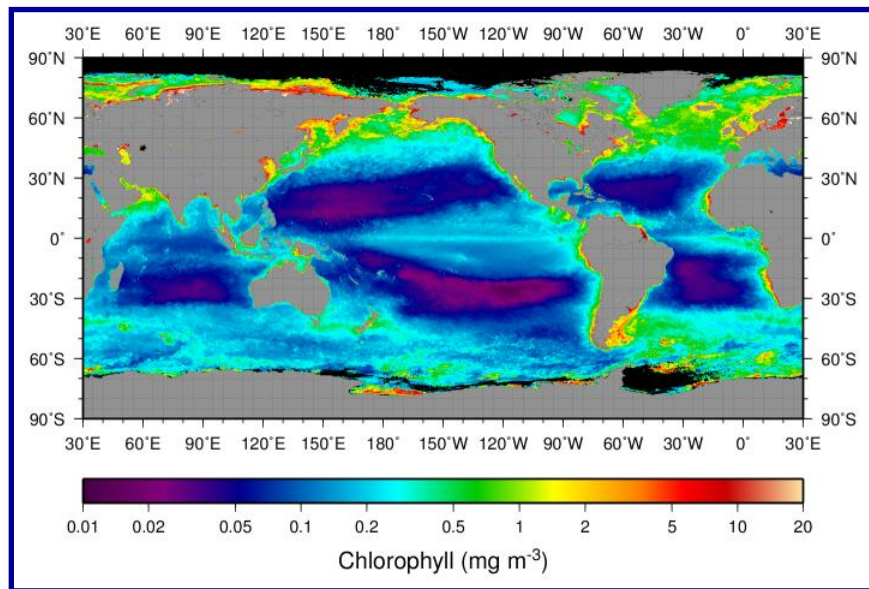
Diffuse attenuation coefficient at 490 nm (m⁻¹)

43

0.01 0.03 0.1 0.3 1 3 10

0.01 0.02 0.05 0.1 0.2 0.5 1 2 5

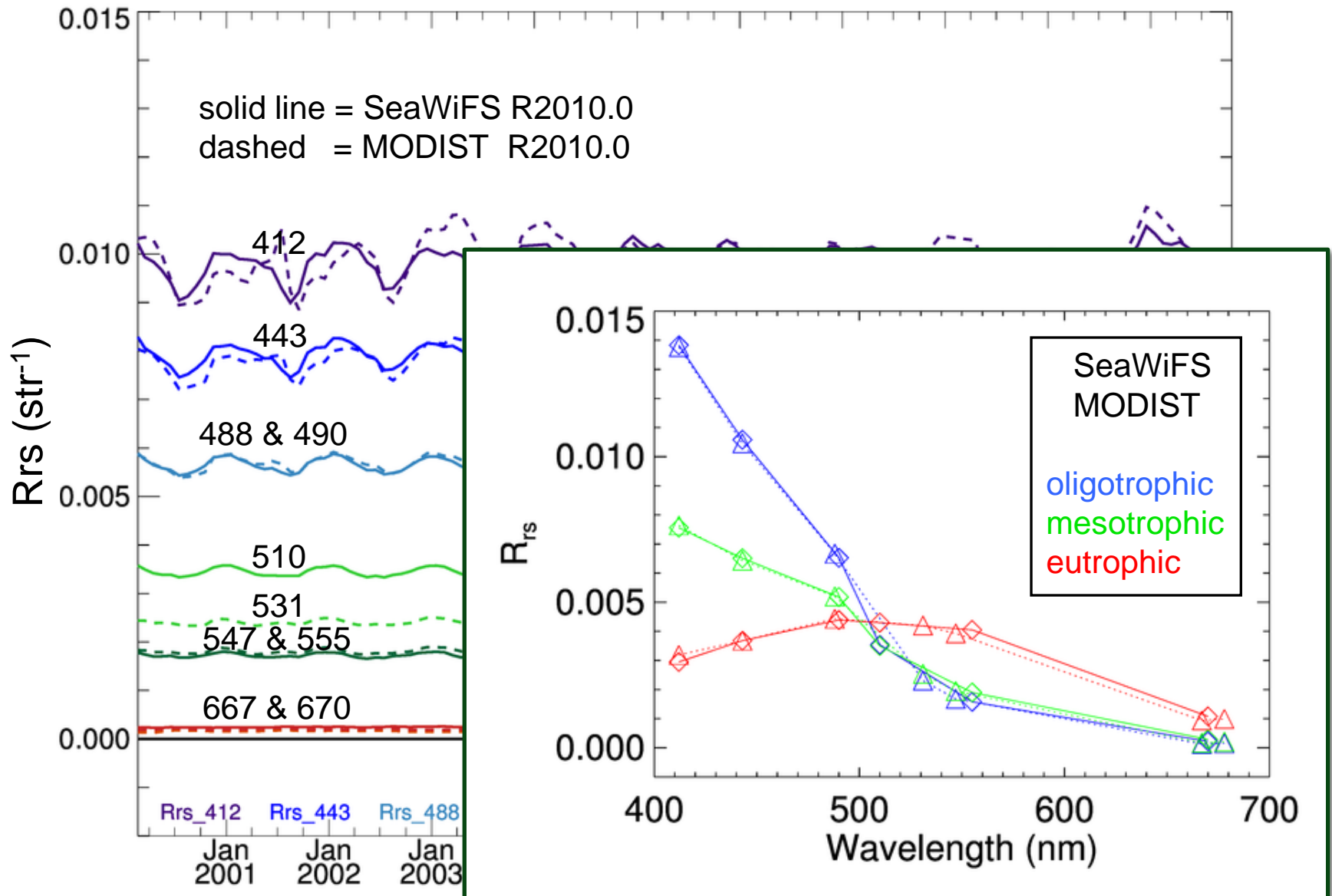
Generating Continuity Products



MODIST

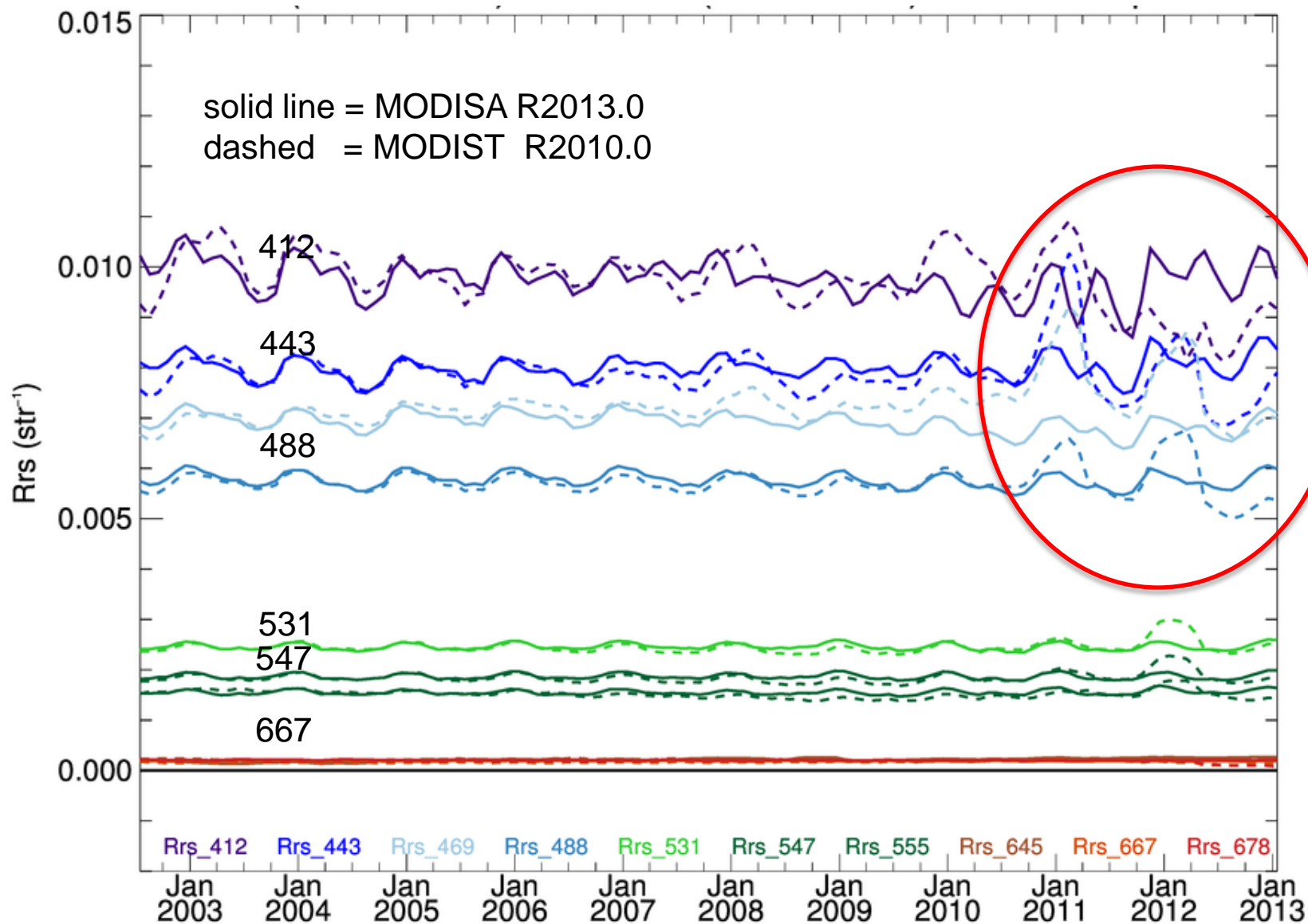
Radiometric Consistency of MODIST & SeaWiFS

Deep-Water



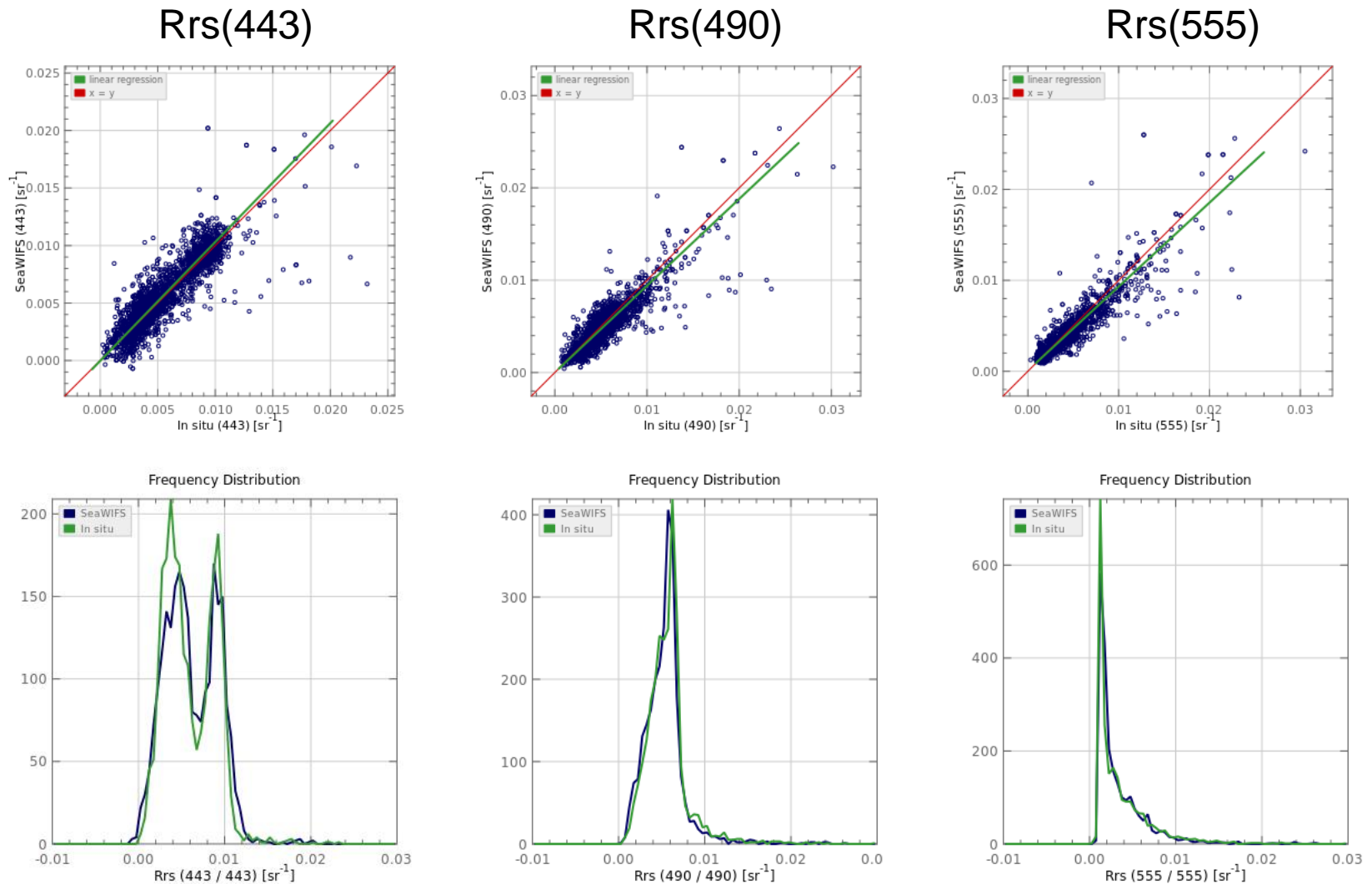
Degrading Radiometric Stability of MODIST

Deep-Water



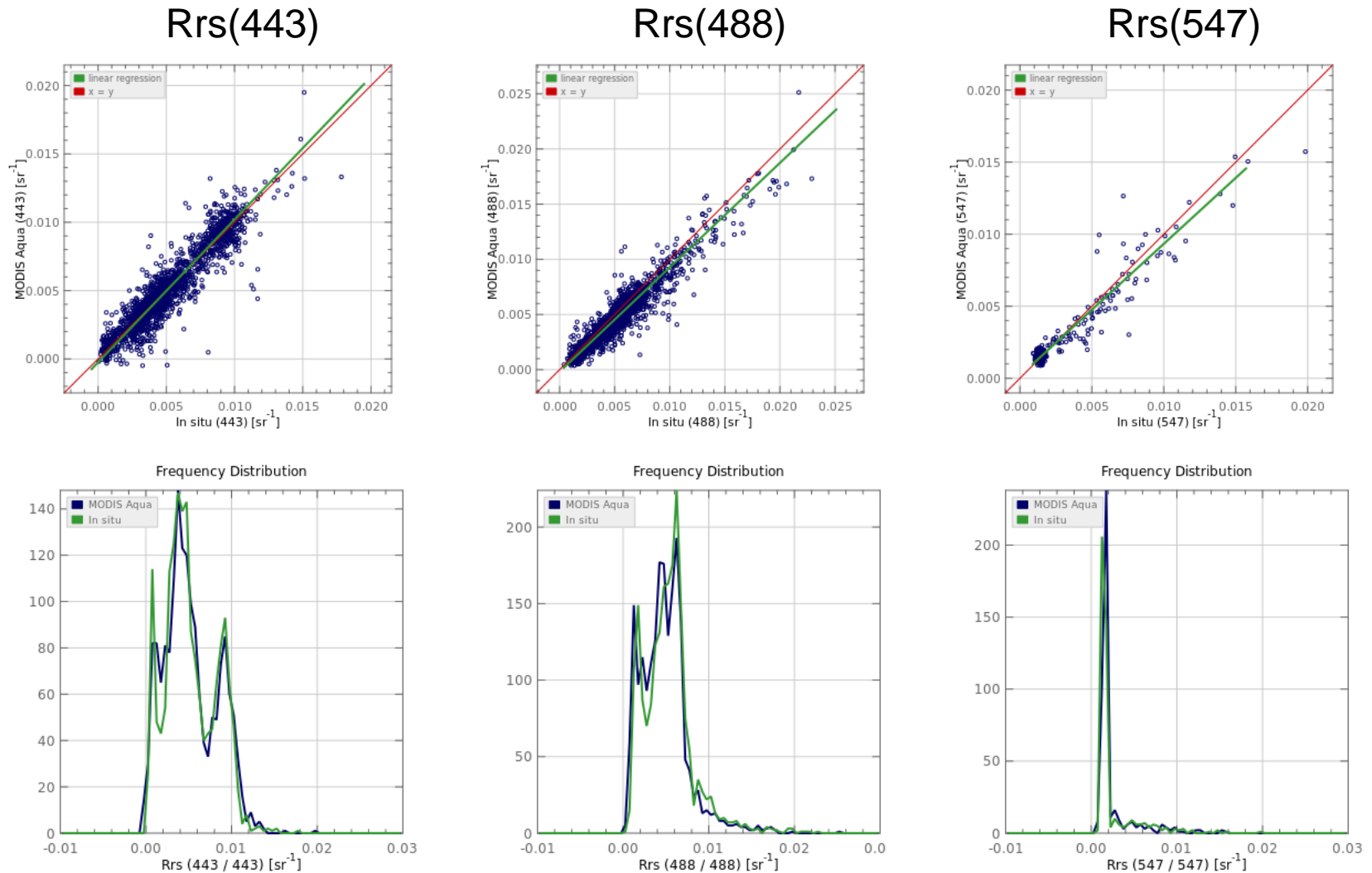
In situ Validation

SeaWiFS (R2010.0) Rrs vs Field Measurements



Mean APD < 14%, Mean Bias < 6%, R² > 0.8

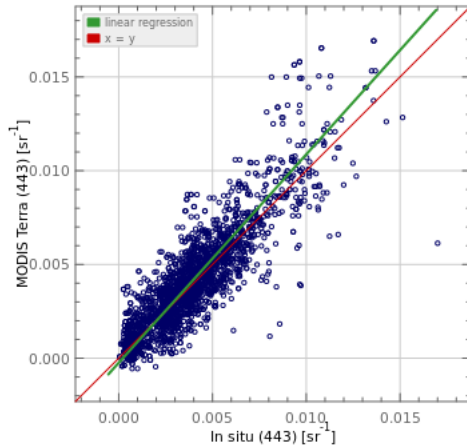
MODISA (R2013.0) Rrs vs Field Measurements



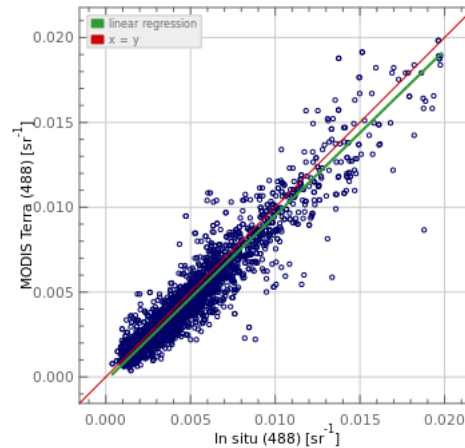
Mean APD < 13%, Mean Bias < 10%, $R^2 > 0.9$

MODIST (R2010.0) Rrs vs Field Measurements

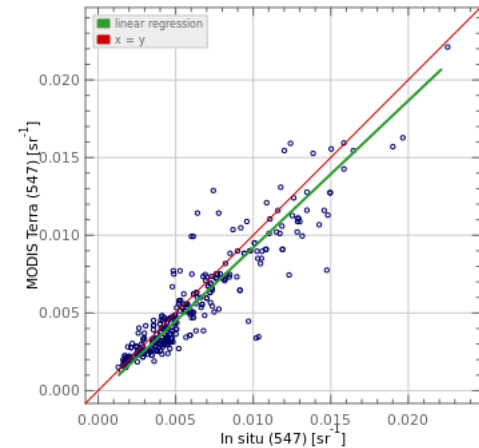
Rrs(443)



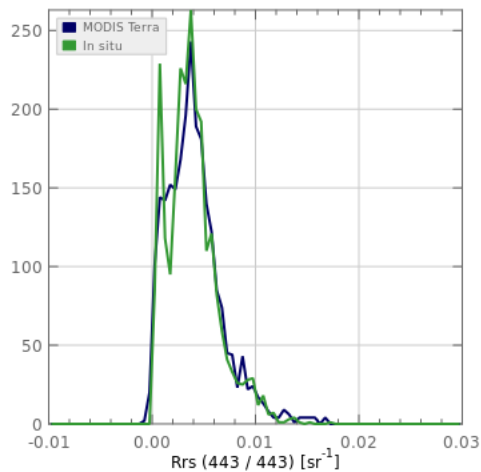
Rrs(488)



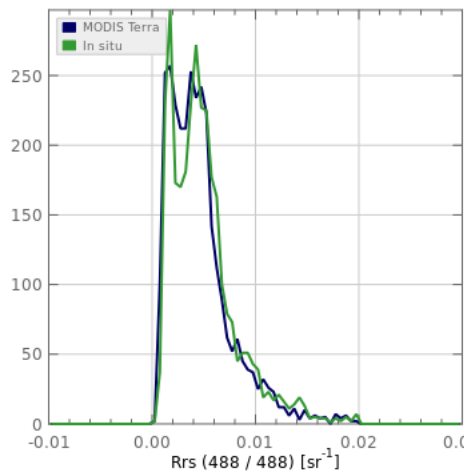
Rrs(547)



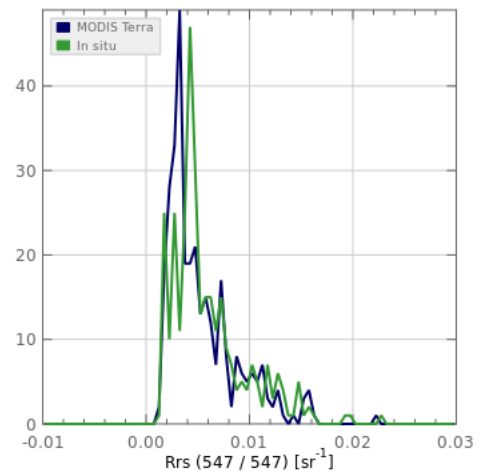
Frequency Distribution



Frequency Distribution



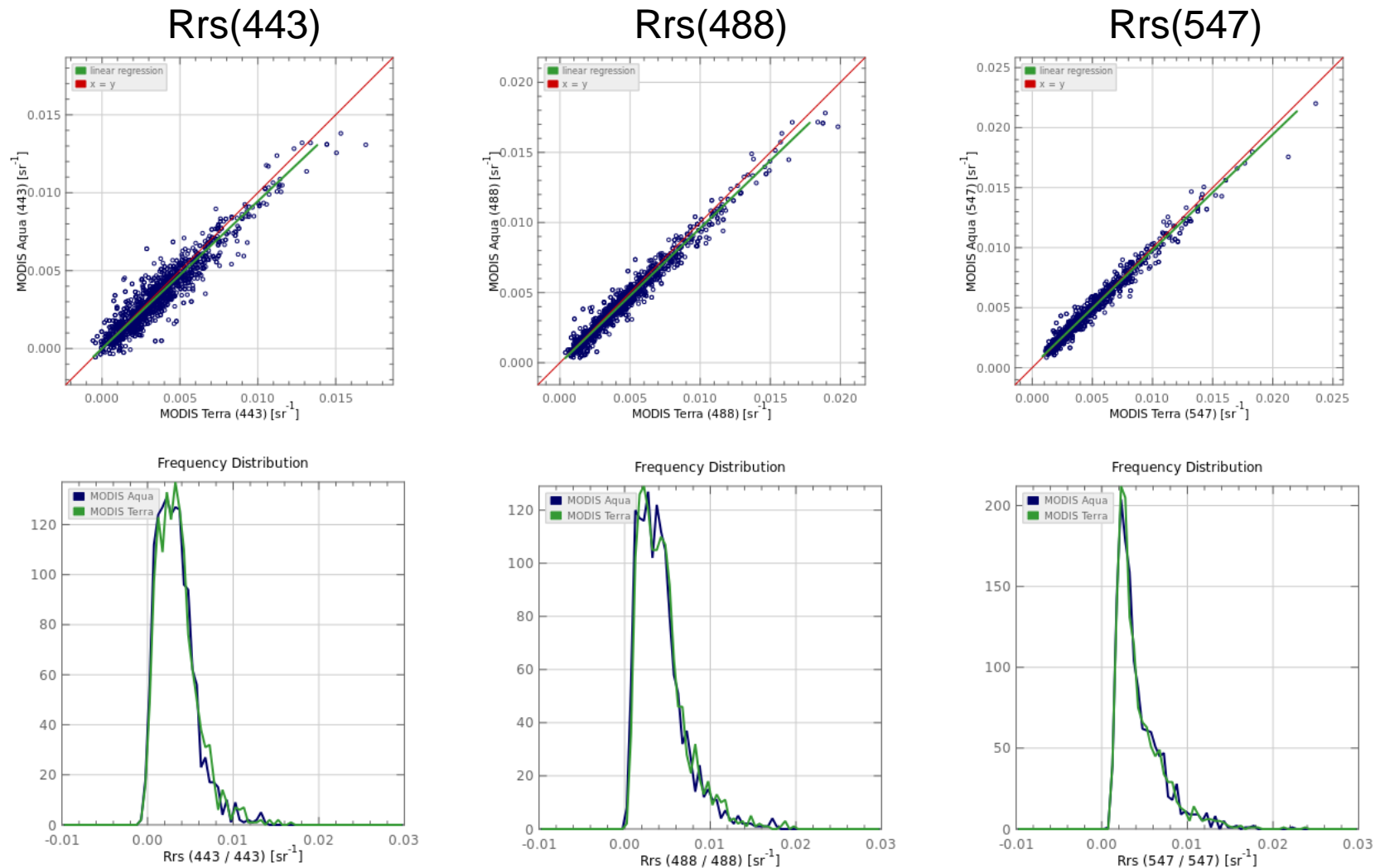
Frequency Distribution



Mean APD 14-21%, Mean Bias < 11%, $R^2 > 0.8$

MODIST (R2010.0) vs MODISA (R2013.0)

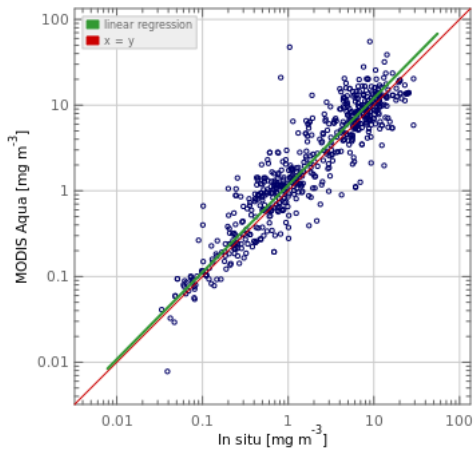
common in situ match-up locations



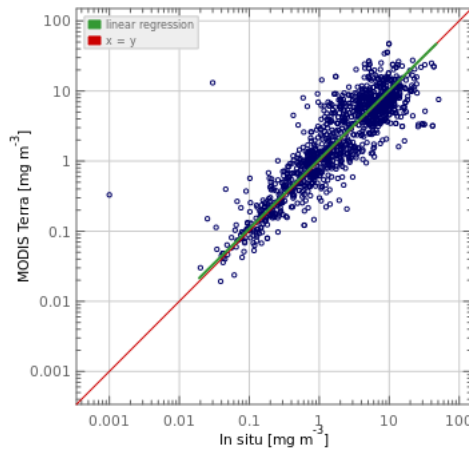
MODISA to MODIST scatter 1/2 the MODIS to in situ scatter!

Chl_a in Good Agreement with Field Measurement

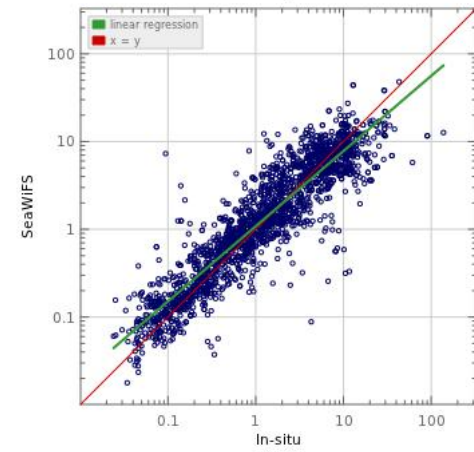
MODISA



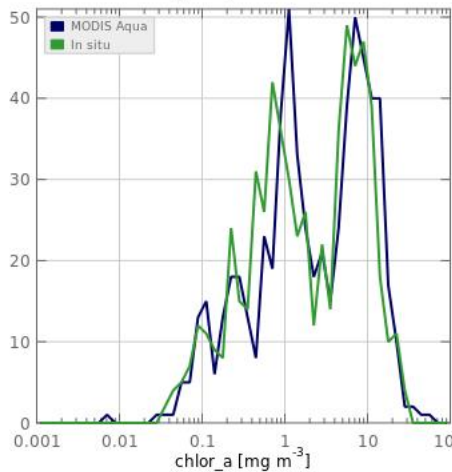
MODIST



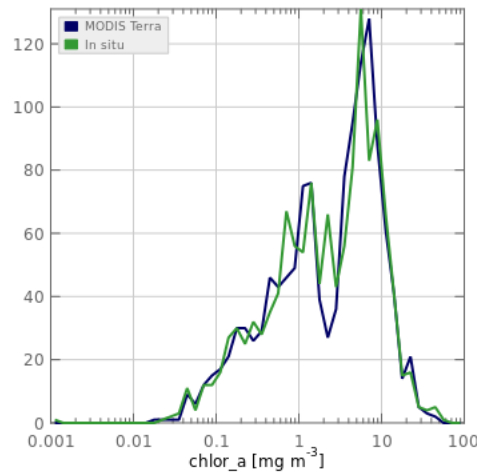
SeaWiFS



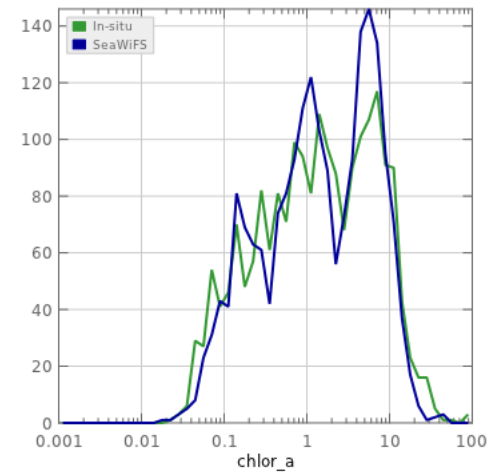
Frequency Distribution*



Frequency Distribution*



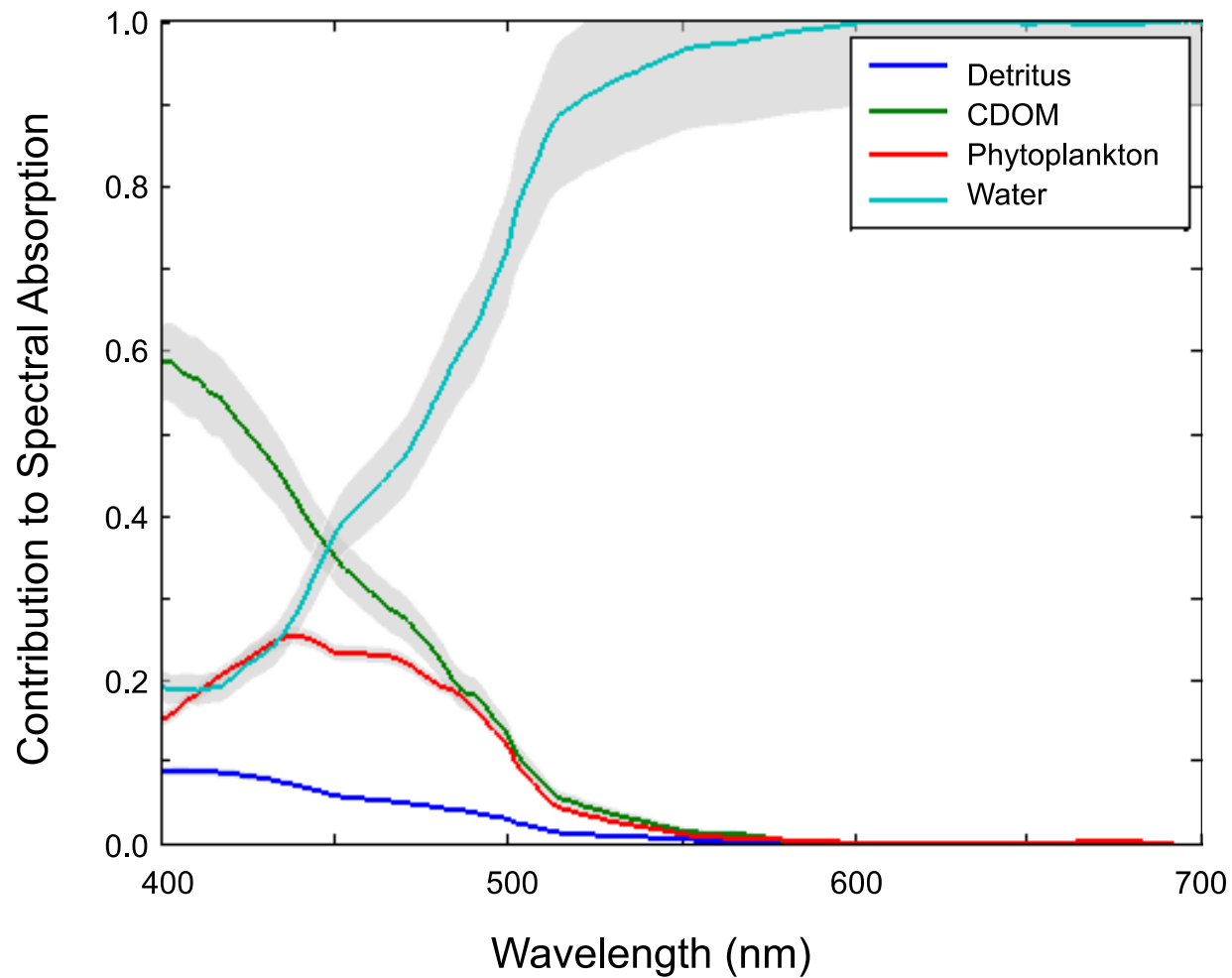
Frequency Distribution*



Mean APD 35%, Mean Bias < 15%, R² > 0.8

IOPs

Beyond Chlorophyll

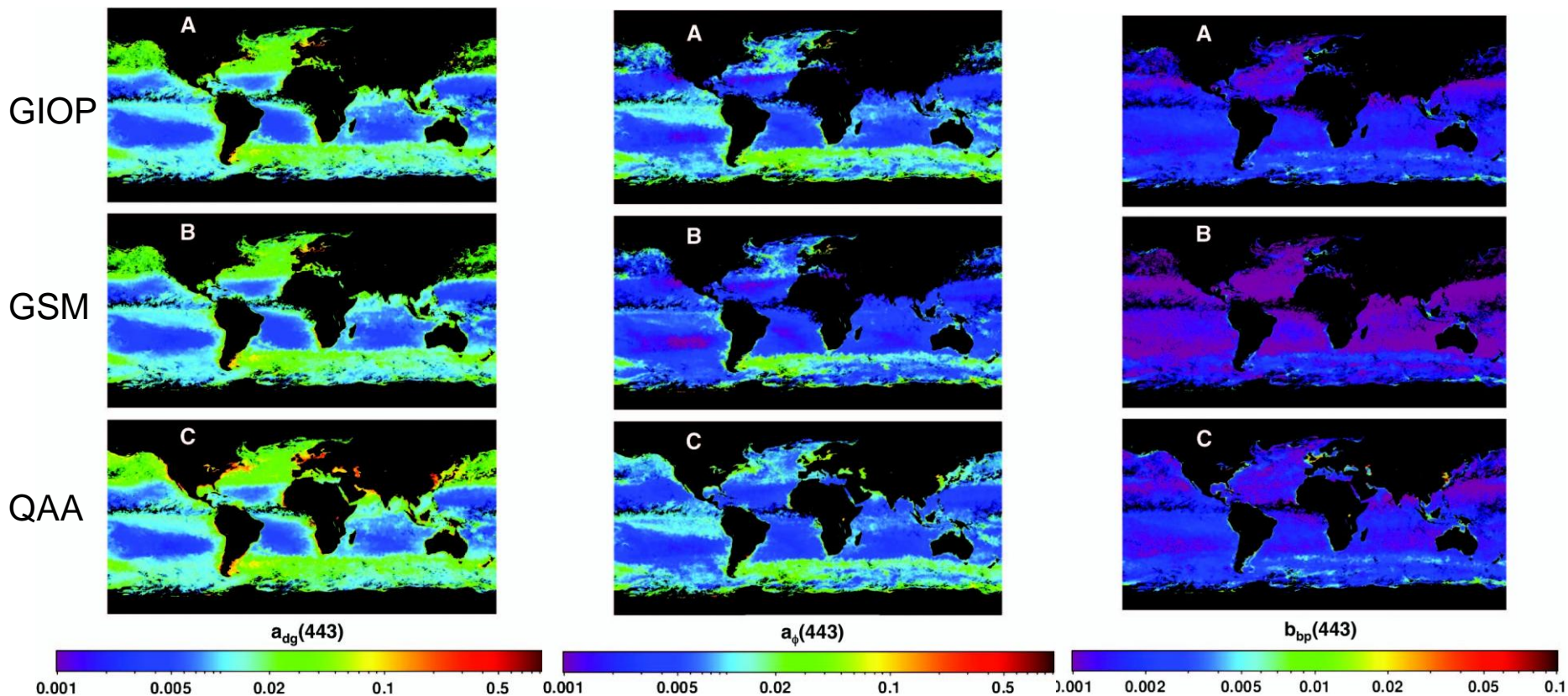


Separation of Constituent Absorption

CDOM & detritus

Phytoplankton

Particle Backscatter



Werdell, P.J., B.A. Franz, S.W. Bailey, G.C. Feldman and 15 co-authors (2013). Generalized ocean color inversion model for retrieving marine inherent optical properties, *Applied Optics* 52, 2019-2037.

Beyond Chlorophyll

