Satellite Ocean Color Validation Activities at STAR

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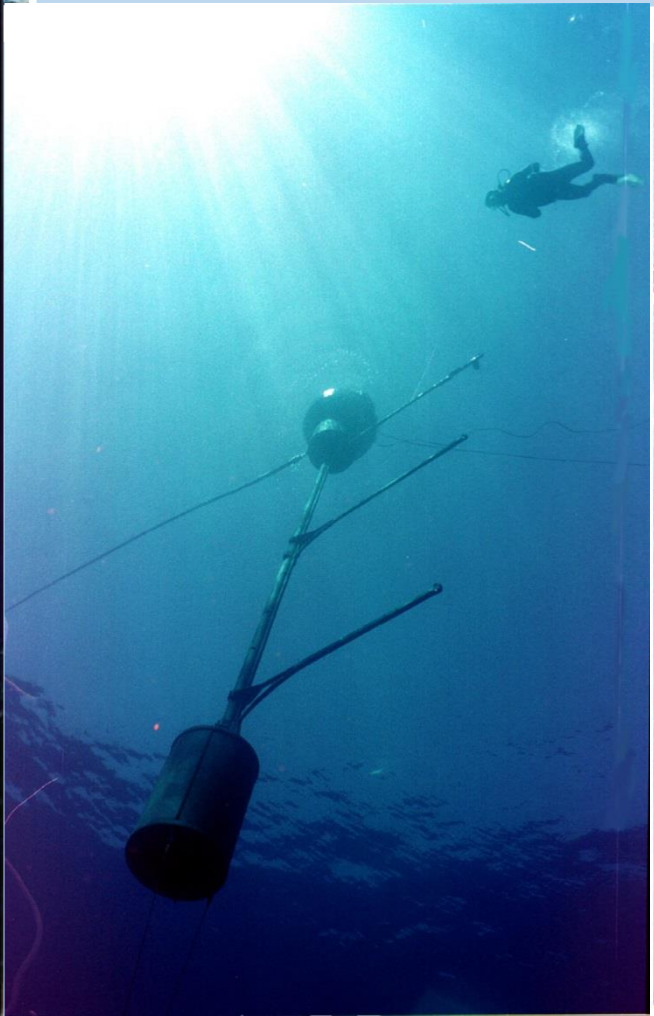
4/24/2019

NOCCG Seminar

NESDIS STAR/ORA has been conducting shipboard validation measurements since the CZCS days (Dennis Clark, NASA Funded).

May 5, 1942 - September 14, 2014

Marine Optical BuoY (MOBY) – Primary ocean color vicarious calibration source from 1997 to present.

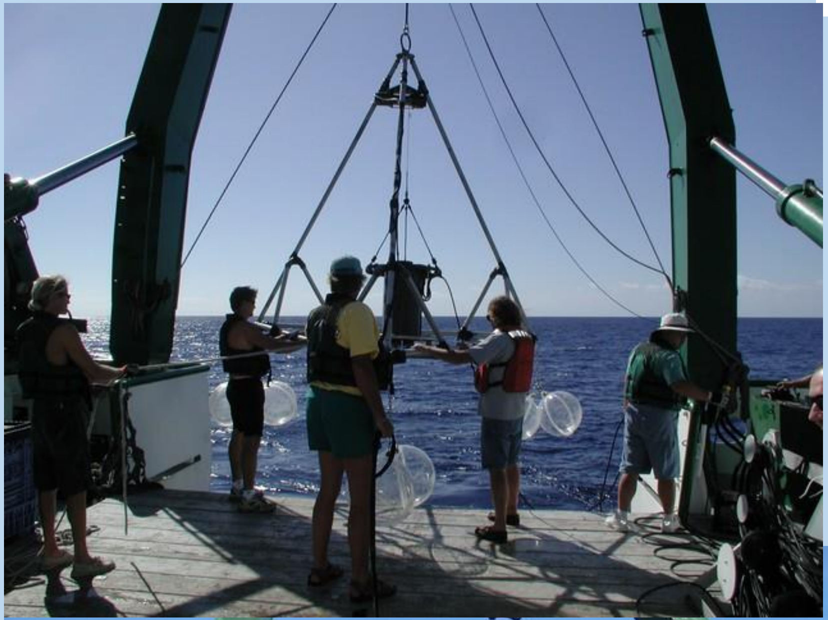


Early systems such as the Bio-Optical Profiling System (BOPS) left and Marine Optical System (MOS) right, were bulky, had to be deployed with a crane and had ship and instrument shadowing problems.

Figure 1. Photograph of the Bio-Optical Profiling System underwater unit.

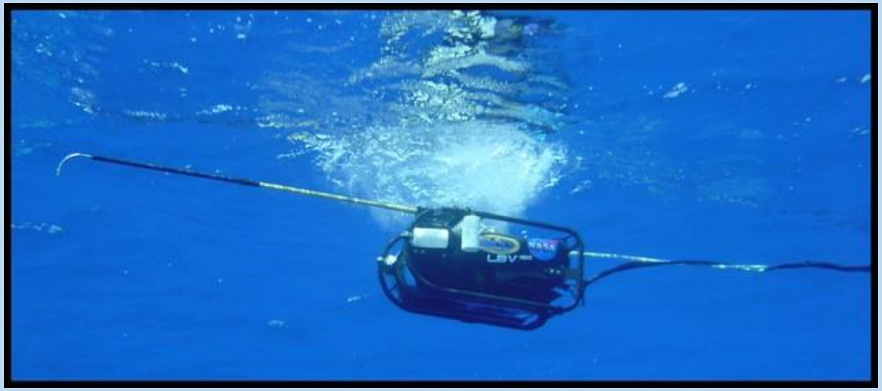
From Smith et al., 1997

Early efforts to reduce ship shadows included floating the instruments away from the ship



Improvements included profiling the MOS or attaching fiber-optics to an ROV

MOCE ROV with tethered fiber optic attached to MOS



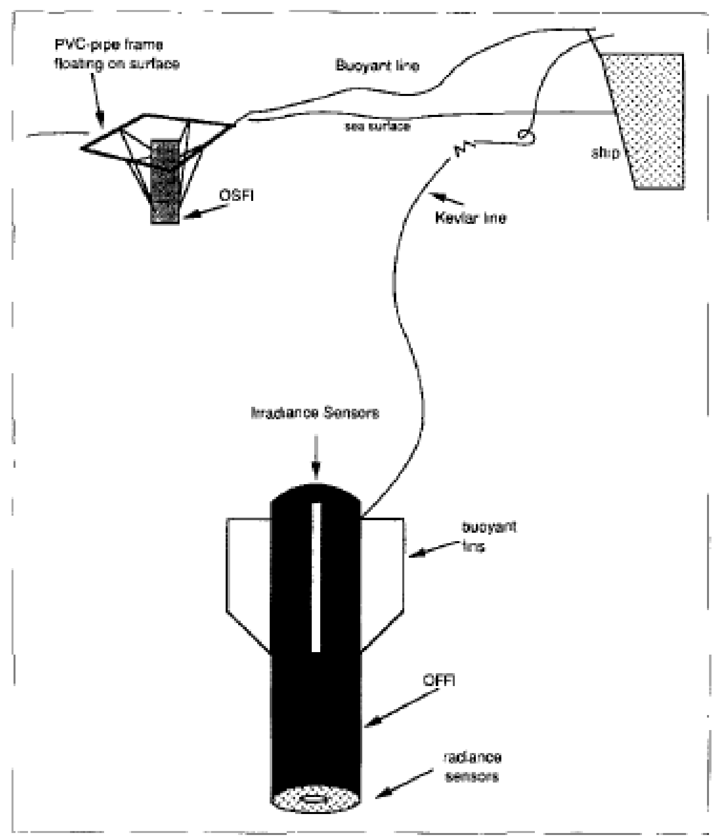


Fig. 1: Cartoon of OFFI and OSFI instruments as deployed.

From: Avoiding Ship-induced Light-Field Perturbation in the Determination of Oceanic Optical Properties. Waters et al., Oceanography 1990

During SeaWiFS there were several dedicated validation cruises and many tied to the Marine Optical Buoy Operations. When Dennis Clark retired in 2004, funding was not available for utilizing MOBY/MOCE team for routine validation, especially in other water types, especially the coastal US.

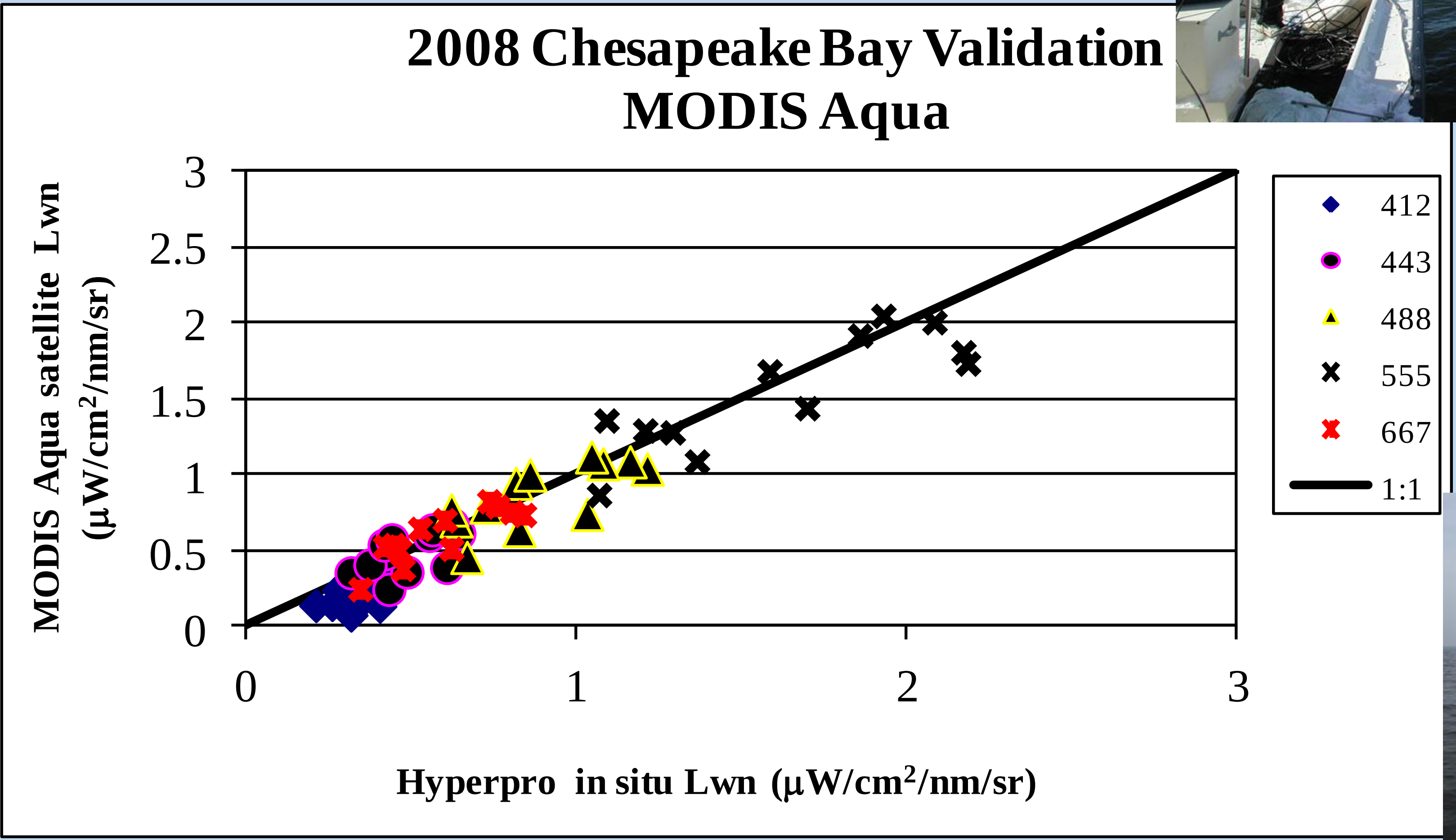
Validation of satellite ocean color sensors :

- Requires accurate and traceable in situ measurements
- Hyperspectral to match all sensors
- Many matchups and water types

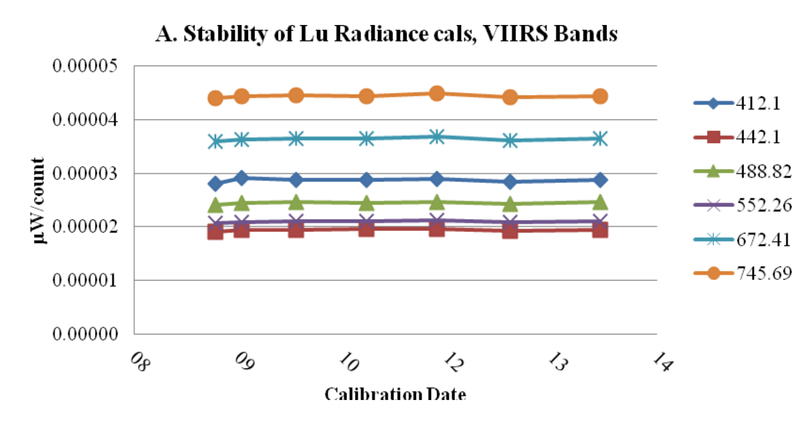
Satlantic Profiler II (Hyperpro) in-water radiometer:

- Hyperspectral
- Profiling
- Lu, Ed, and Es

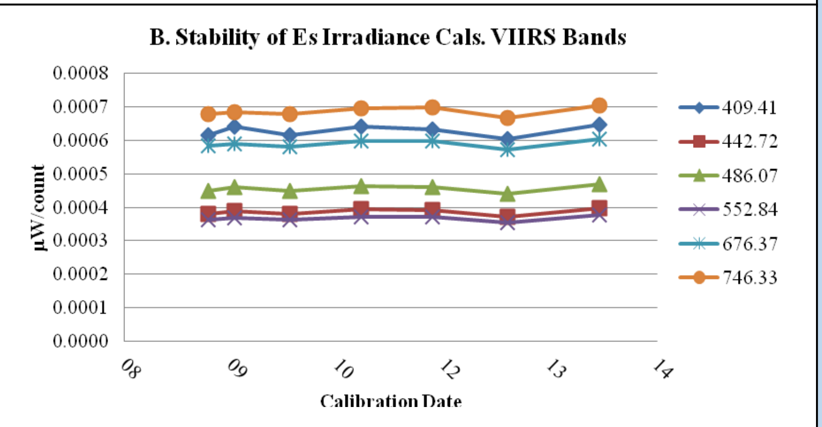
NOAA has been using a Hyperpro in-water radiometer to validate ocean color sensors and algorithm development since 2006



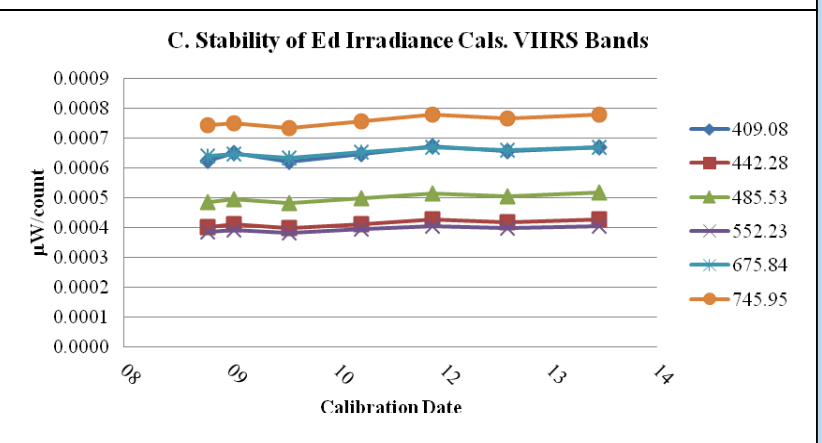
CALIBRATION STABILITY



A. Lu	412.1	442.1	488.82	552.26	672.41	745.69
3/19/2009	0. 0281	0. 0191	0. 0240	0. 0207	0.0359	0. 0440
7/22/2009	0. 0291	0. 0195	0. 0245	0. 0209	0. 0363	0. 0443
4/7/2010	0. 0288	0. 0195	0. 0246	0. 0211	0. 0365	0. 0445
3/9/2011	0. 0289	0. 0196	0. 0246	0. 0210	0. 0364	0. 0443
2/9/2012	0. 0289	0. 0196	0. 0247	0. 0212	0. 0368	0. 0449
1/24/2013	0. 0284	0. 0193	0. 0242	0. 0208	0. 0361	0. 0441
3/31/2014	0. 0288	0. 0196	0. 0246	0. 0210	0. 0364	0. 0443
Average	0. 0287	0. 0194	0. 0245	0. 0210	0. 0364	0. 0443
Std Dev.	0. 0003	0. 0002	0. 0002	0. 0002	0. 0003	0. 0003

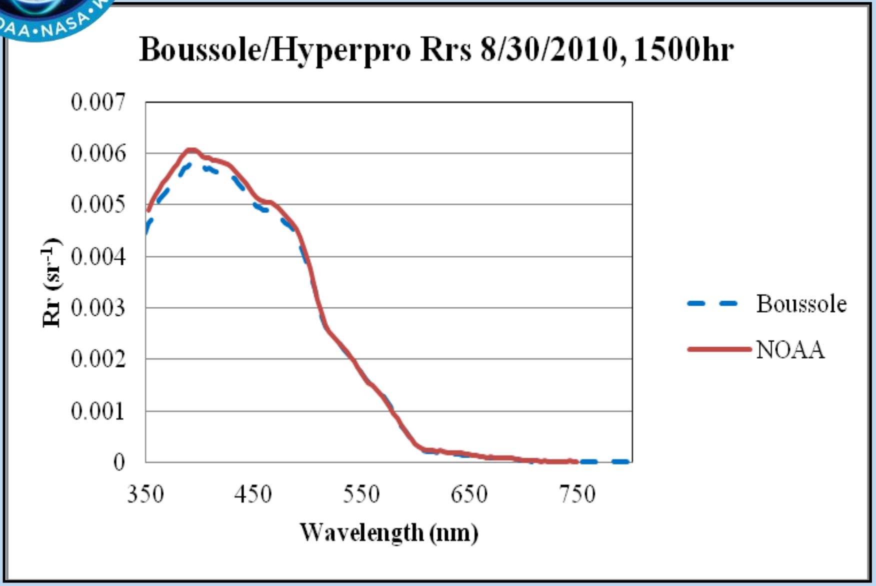


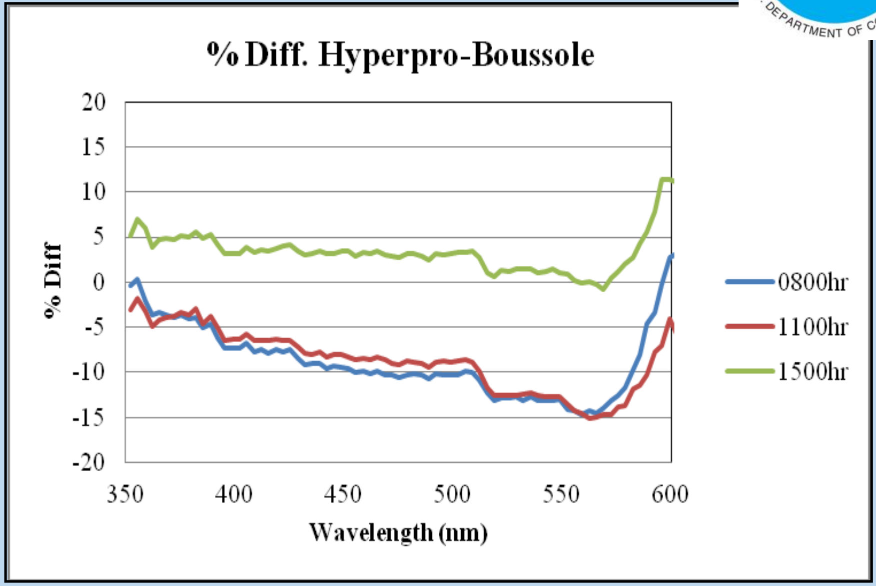
B. Es	409.41	442.72	486.07	552.84	676.37	746.33
3/19/2009	0. 616	0. 381	0. 450	0. 364	0. 583	0. 679
7/22/2009	0. 640	0. 390	0. 459	0. 368	0. 590	0. 685
4/7/2010	0. 614	0. 380	0. 450	0. 363	0. 581	0. 679
3/9/2011	0. 639	0. 393	0. 463	0. 372	0. 597	0. 694
2/9/2012	0. 632	0. 391	0. 461	0. 372	0. 598	0. 699
1/24/2013	0. 605	0. 373	0. 441	0. 355	0. 571	0. 667
3/31/2014	0. 647	0. 398	0.470	0. 377	0. 603	0. 703
Average	0. 628	0. 387	0. 456	0. 367	0. 589	0. 686
Std Dev.	0. 016	0. 009	0. 010	0. 007	0. 011	0. 013



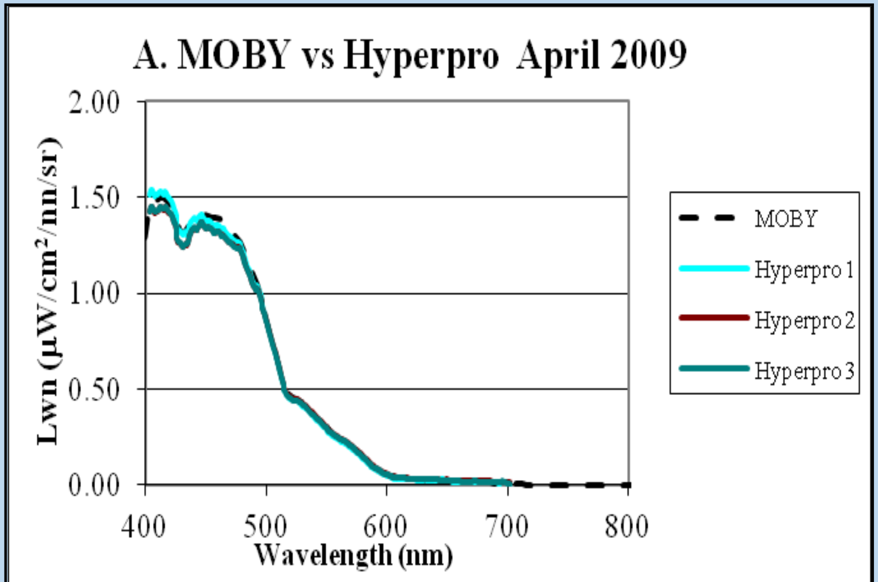
C. Ed	409.08	442.28	485.53	552.23	675.84	745.95
3/19/2009	0. 623	0. 400	0. 486	0. 386	0. 640	0. 744
7/22/2009	0. 649	0. 409	0. 496	0. 390	0. 647	0. 749
4/7/2010	0. 620	0. 397	0. 483	0. 383	0. 632	0. 735
3/9/2011	0. 646	0. 412	0. 499	0. 394	0. 653	0. 757
2/9/2012	0. 672	0. 426	0. 515	0. 405	0. 670	0. 779
1/24/2013	0. 655	0. 416	0. 504	0. 397	0. 659	0. 766
3/31/2014	0. 669	0. 426	0. 516	0. 405	0. 670	0. 777
Average	0. 644	0. 410	0. 497	0. 392	0. 648	0. 755
Std Dev.	0. 018	0. 010	0. 011	0. 008	0. 014	0. 016

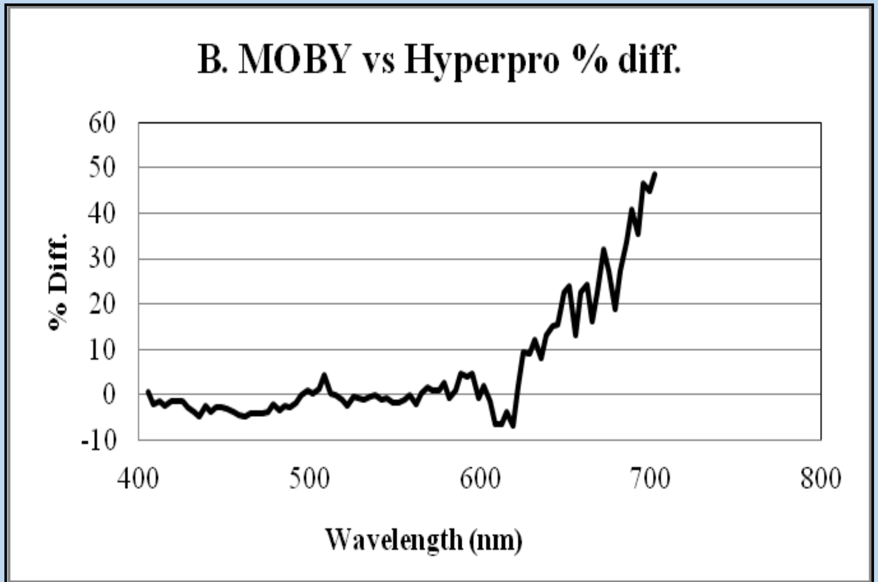
Remote Sensing Reflectances from simultanious NOAA Hyperpro and Boussole Buoy measured during NATO Cruise, August 30, 2010



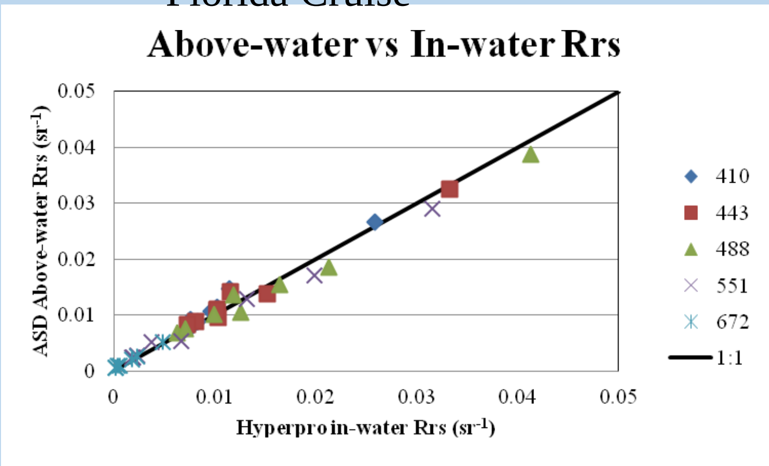


Normalized Water-Leaving Radiances and percent differences from simultaneous NOAA Hyperpro and MOBY Buoy measured during an April 2009 MOBY swapout cruise.

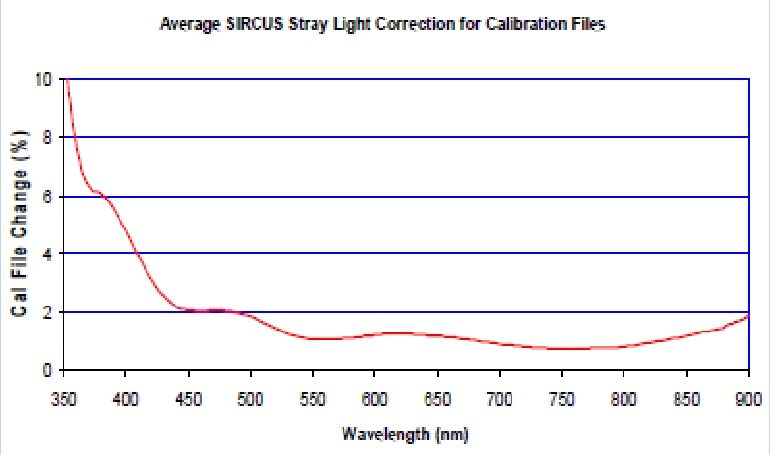




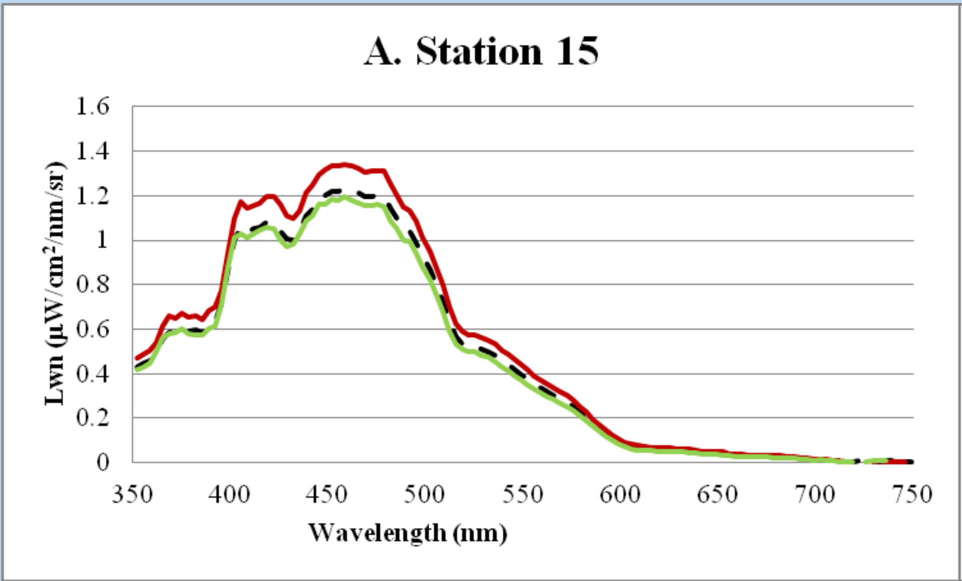
Remote Sensing Reflectance Comparison Between NOAA Hyperpro Profiler and ASD Handheld II above-water radiometer during March 2012 Florida Cruise

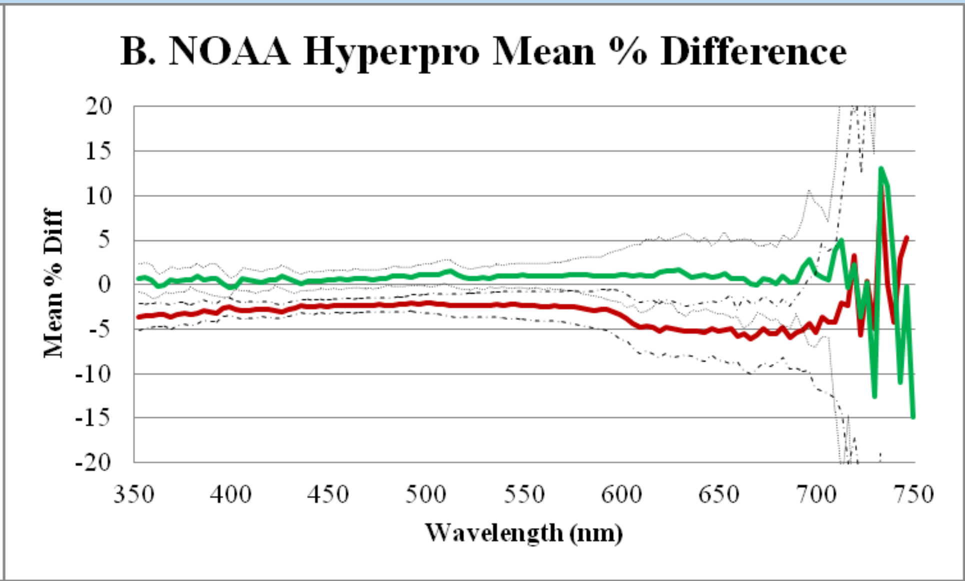


Conducted straylight characterization at NIST

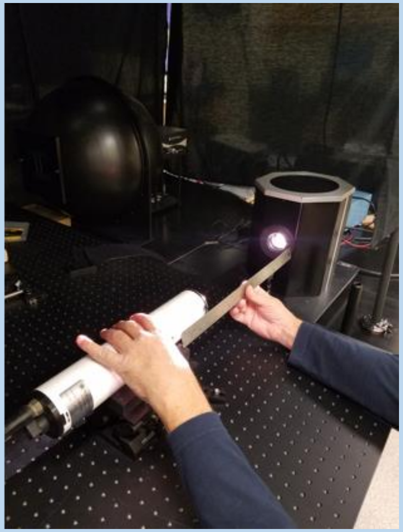


Consistency between Hyperpros, August, 2010 NATO Cruise, 41 Stations with 3 Simultaneous Hyperpro cast to asses variability between instruments.

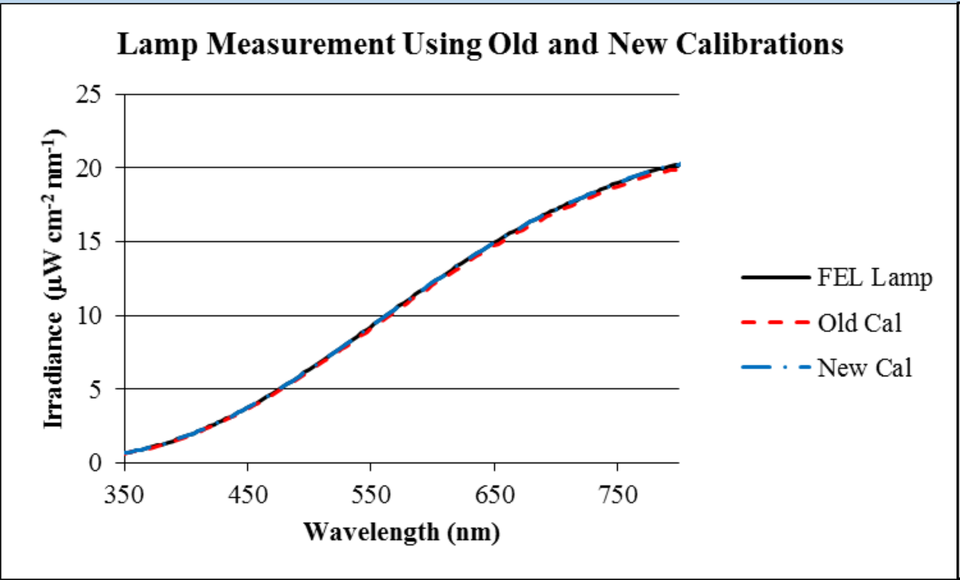


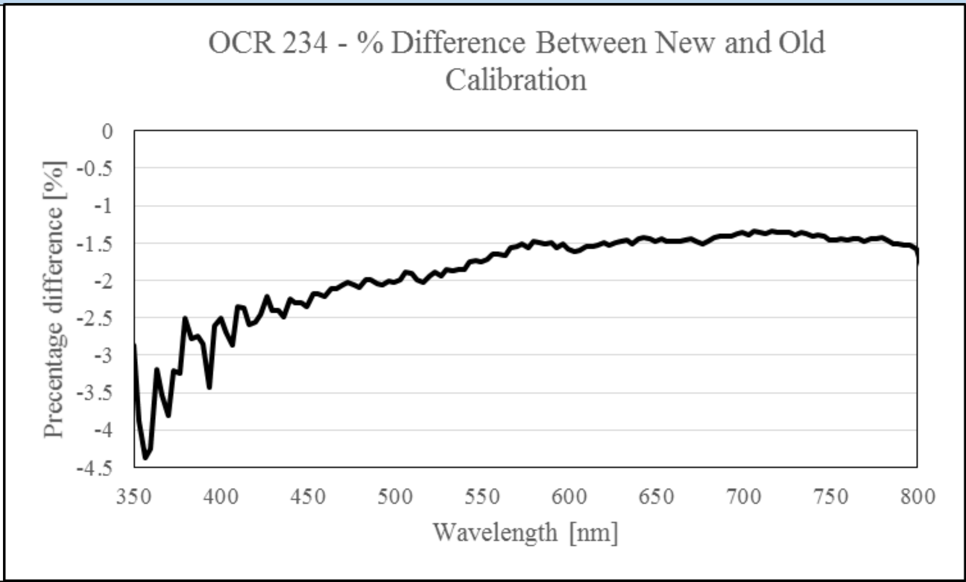


Calibration Facility at the NOAA/STAR Optical Laboratory



Pre and Post-cruise calibration for radiance and irradiance for all cruises

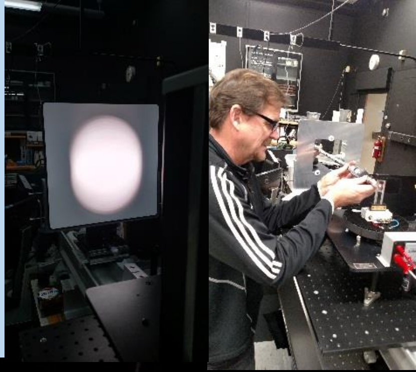


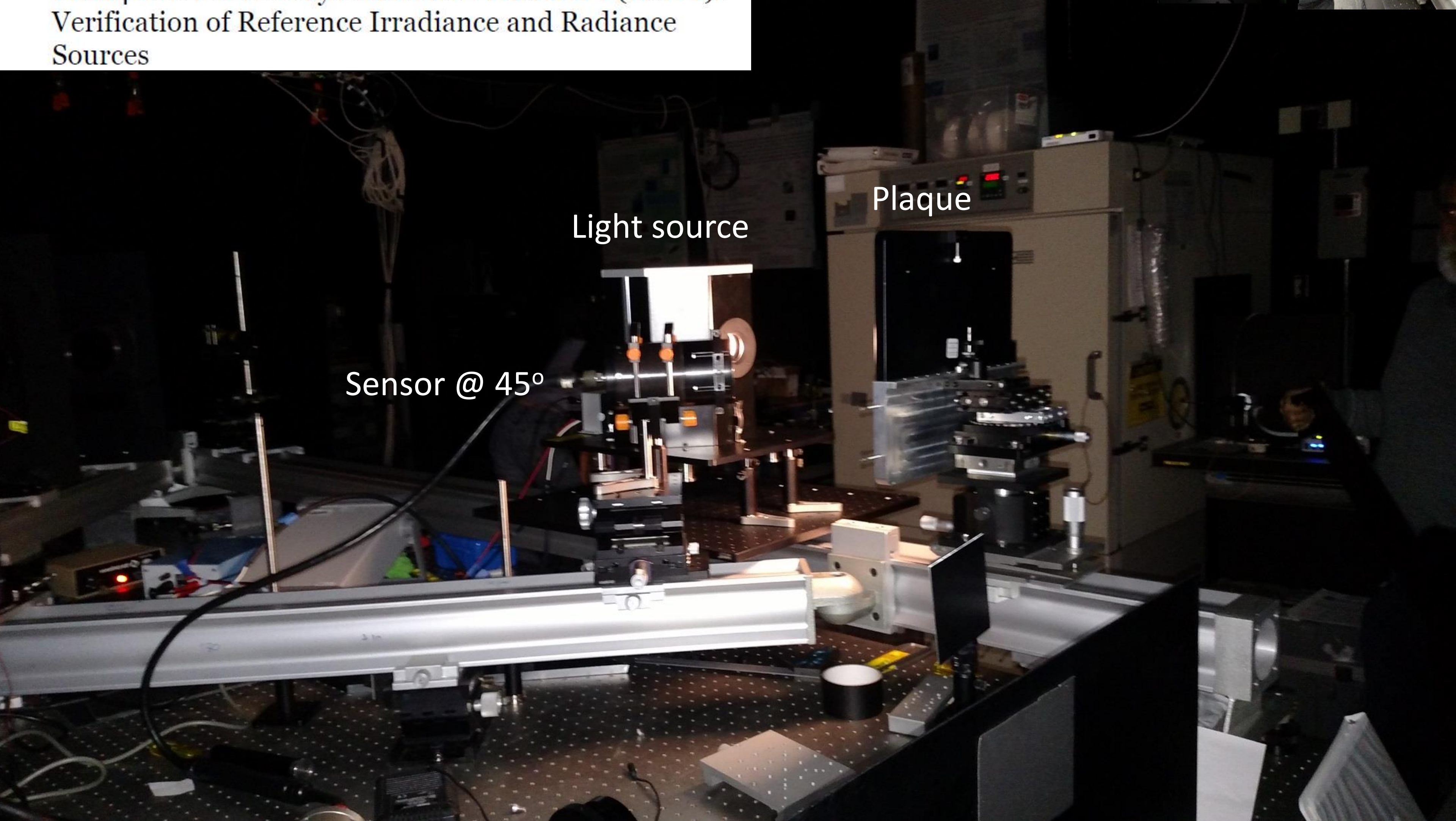


fiducial reference measurements for satellite ocean colour

FRM4SOC Laboratory Calibration Exercise 1 (LCE-1): Verification of Reference Irradiance and Radiance Sources

Irradiance cal at NOAA March, 2017 and London, April 2017
Radiance cal at NOAA 1/29/18 and NIST 1/24/18 and 1/25/18





- **More recently, up until 2014, our team and most other ocean color investigators were conducting Cal/Val measurements aboard cruise of opportunity.**

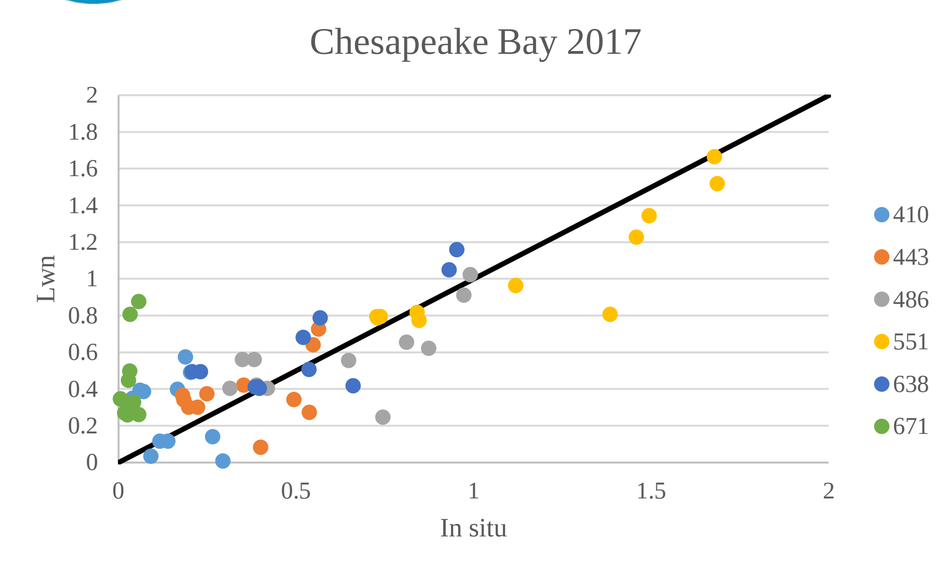
- **NOAA Office of Marine and Aviation Operations Ship-time requests have resulted in the use of NOAA ships for dedicated validation cruises in FY 2015, 2016, 2017, 2018 and coming up in Sept 2019.**

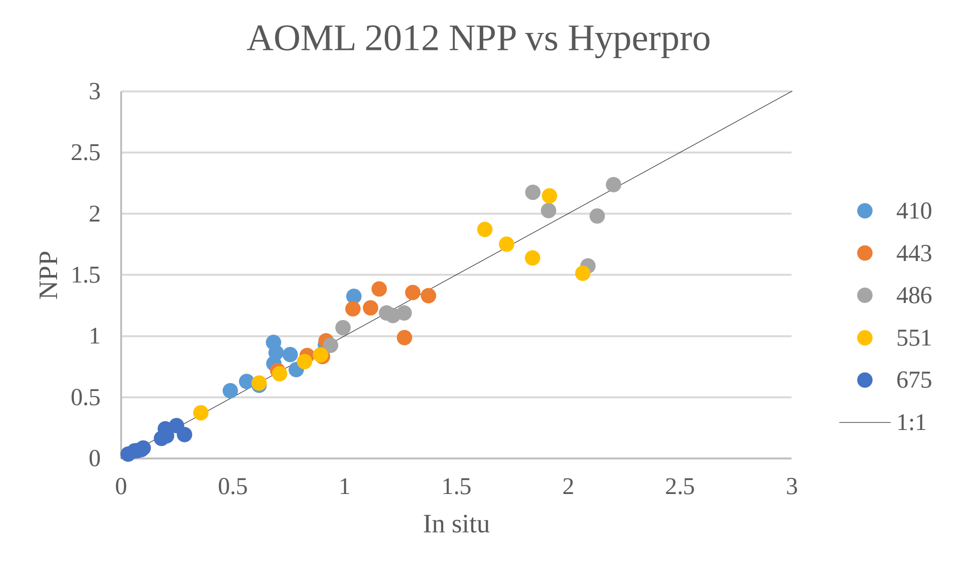
Validation measurements conducted since the launch of VIIRS

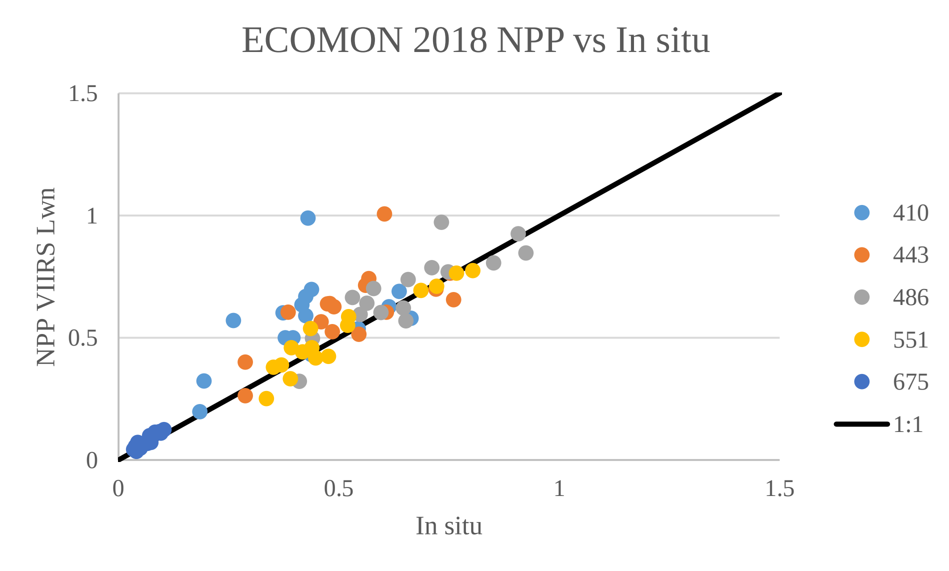
Location	Season	Year	Stations	Status	To NOAA	Seabass Format	
Ches. Bay GEOCAPE	July	2011	57	Processed	Yes	Yes	NASA GEOCAPE
Chesapeake Bay 2011		2011	6				
VIIRS Launch							
Chesapeake Bay 2012	Dec	2011	2	Processed	Yes	No	First VIIRS validation
South Florida	Mar	2012	17	Processed	Yes	No	First good validation, lots of matchups.
Oahu, HI	September	2012	21	Processed	Yes	Yes	Many good matchups
Chesapeake Bay 2013	All Year	2013	37	Processed	Yes	No	Many good matchups and Red Tide and Mabel overflight
CUNY Ches. Bay Exp.	Aug	2013	42	Processed	Yes	No	Some matchups, Good closure experiment
GOM GEOCAPE	September	2013	67	Processed	Yes	Yes	Many good matchups in lots of conditions
Chesapeake Bay 2014	All Year	2014	27	Processed	Yes	Yes	Many good matchups and Red Tide and JOEYS
Puerto Rico	May	2014	15	Processed	Yes	Yes	Many good matchups
Hawaii/MOBY	May	2014	12	Processed	Yes	Yes	Good matchups with VIIRS and MOBY
VIIRS Cal/Val	Nov	2014	23	Processed	Yes	Yes	Many good matchups
Chesapeake Bay 2015	All Year	2015	7	Processed	Yes	Yes	Many good matchups
Puerto Rico	Mar	2015	15	Processed	Yes	Yes	Many good matchups
East Coast Ocean Acidificati	Jun/July	2015	74	Processed	Yes	Yes	Many good matchups
VIIRS Cal/Val	Dec	2015	27	Processed	Yes	Yes	Many good matchups
Chesapeake Bay 2016	All Year	2016	6+	Processed	No	No	Landsat validation
KORUS OC	May/June	2016	35	Processed	Yes	Yes	Many good matchups
West Coast Ocean Acidifica	May/June	2016	35	Processed	Yes	Yes	lots of clouds some good matches
Fiji to Australia	Jun/July	2016	24	Processed	Yes	Yes	Several Matchups
CORAL PRISM	Oct	2016	37	Processed	Yes	Yes	Hurricane Matthew
VIIRS Cal/Val	Oct	2016	12	Processed	Yes	No	Several Matchups
P18 South Pacific	Jan/Feb	2017	45	Processed	Yes	Yes	includes south pacific gyre low chl H2O
JOEYS	March	2017	12	Processed	Yes	No	With UMD
Chesapeake Bay 2017	All Year	2017	15	Processed	Yes	No	Red tides
AOML 1801	Jan	2018	17	Processed	Yes	No	Many Good matchups
AOML_1803	March	2018	12	Processed	Yes	Yes	Many good matchups
VIIRS_18	May	2018	22	Processed	Yes	Yes	Many good matchups
ECOMON_1806	May/June	2018	21	Processed	Yes	Yes	Some matchups
ECOA_18_1	June/July	2018	30	Processed	Yes	Yes	Northern east coast
ECOA_18_2	July	2018	20	Processed	Yes	Yes	Southern east coast
RNG	August	2018	4	Processed	Yes	Yes	transect north
ECOMON_1808	August	2018	17	Processed	Yes	Yes	Some matches Northeast
AOML_1810	October	2018	21	Processed	Yes	Yes	Hab sampling
ECOMON_1810	November	2018	5	Processed	Yes	Yes	Some matchups
Chesapeake Bay 2018	All Year	2018	10	No	No	No	Runoff
Total since VIIRS			**780**				

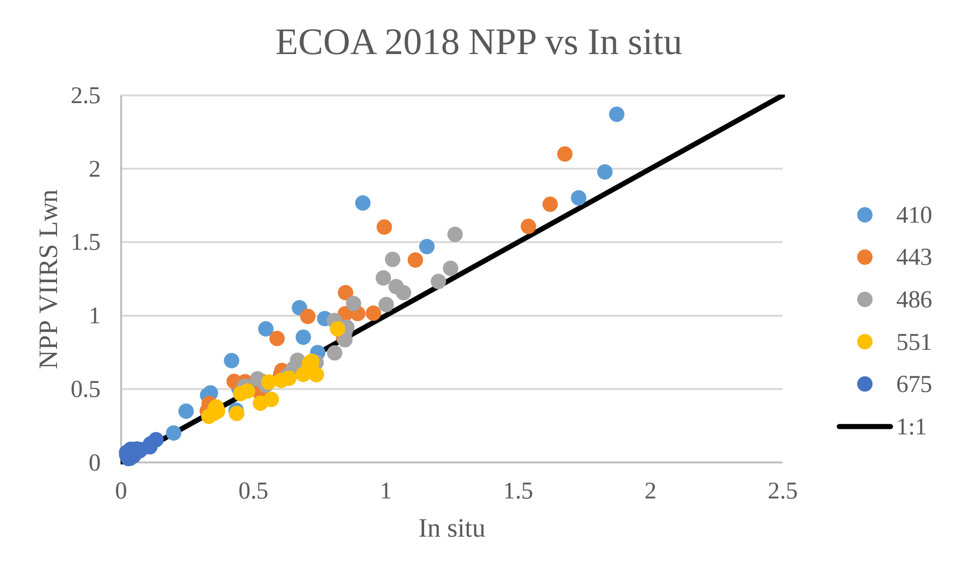
Ocean Acidification, AOML, ECOMON, VIIRS Cal/Val, Chesapeake Bay, Puerto Rico, and GEOCAPE Cruises

Examples of Cross plots of North American Validations

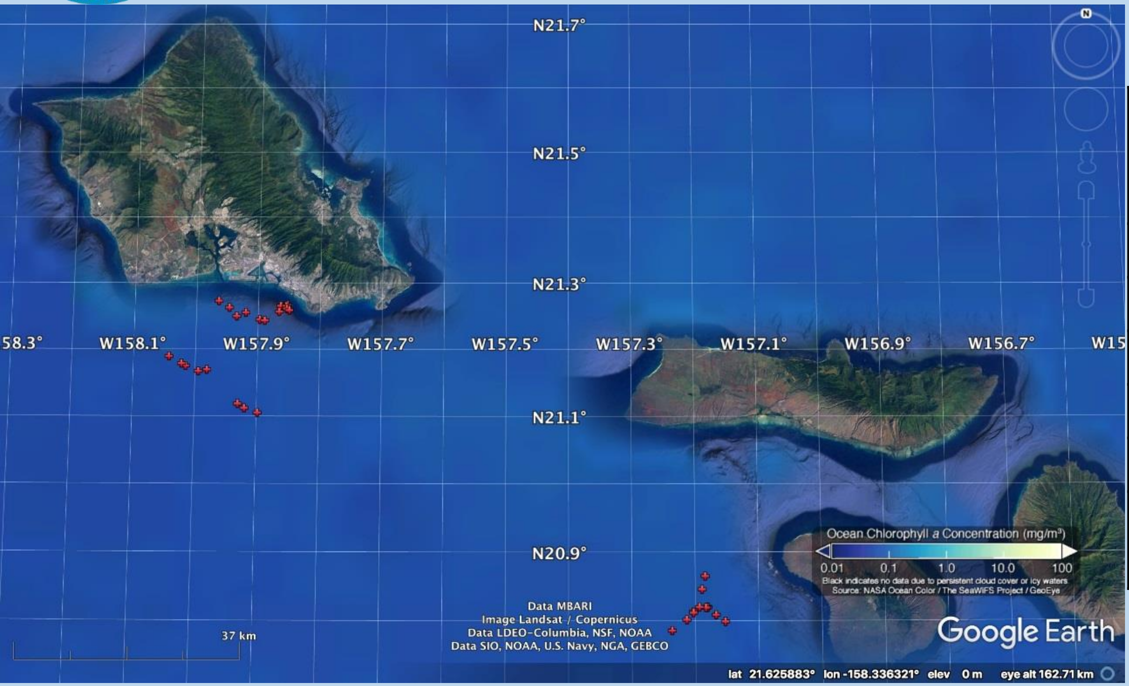




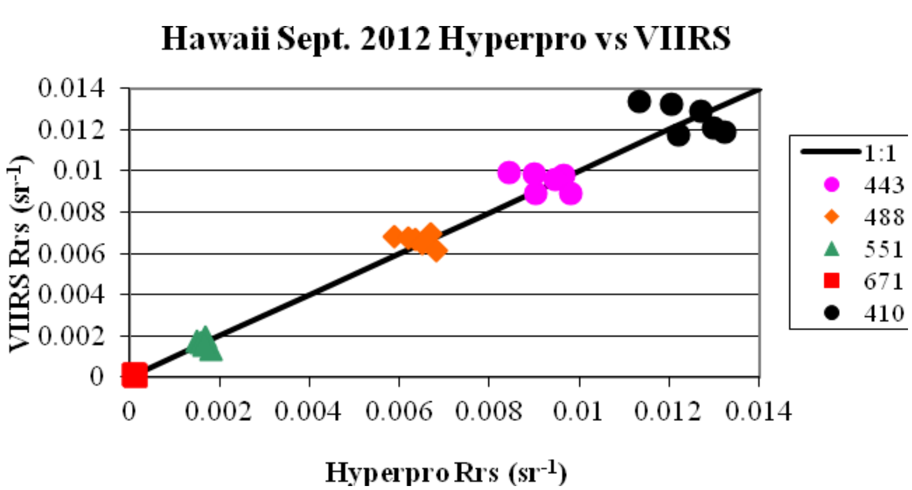


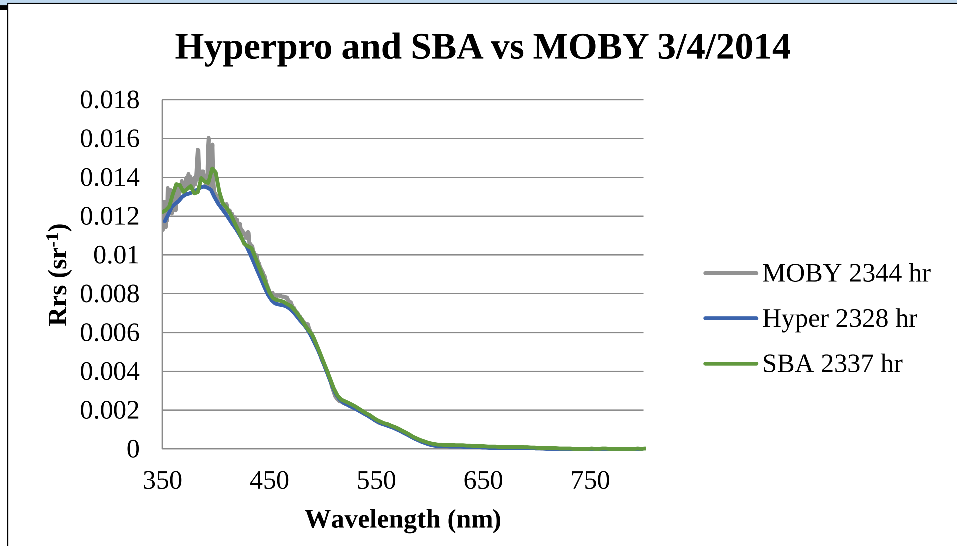


VIIRS validation using in situ Hyperpro measurements off Oahu, Hawaii collected in September, 2012 and at MOBY in 2014. 33 matchup stations.



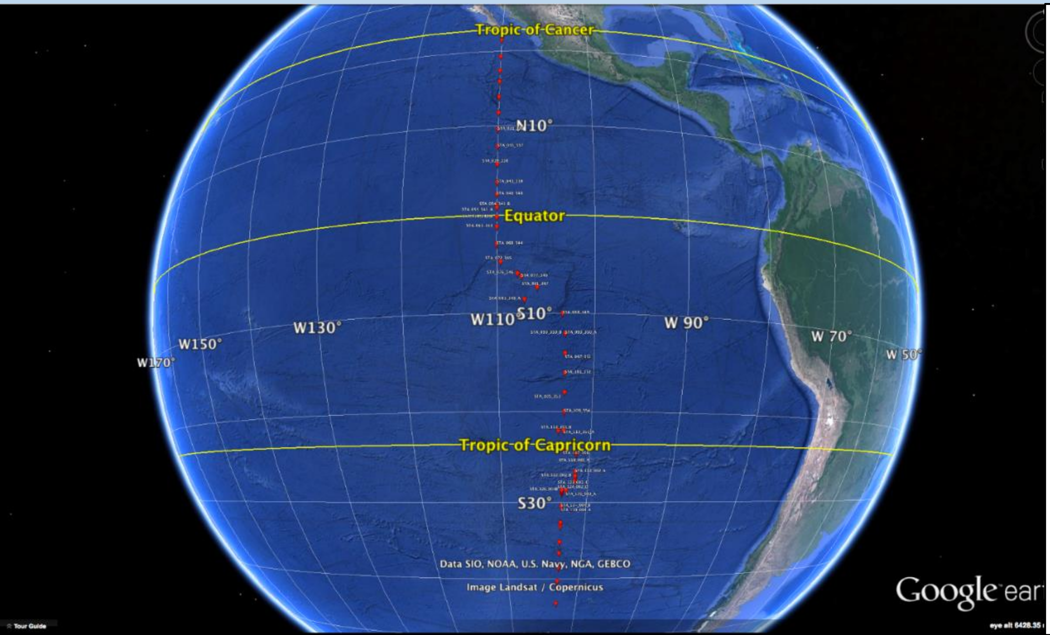
Band	% Diff Hyperpro – VIIRS	Std Dev of % Diff Hyperpro
410	1.50	3.48
443	3.18	1.05
488	3.93	3.38
551	1.40	36.27
671	-8.81	158.79
Average 410 to 551	2.50	11.05

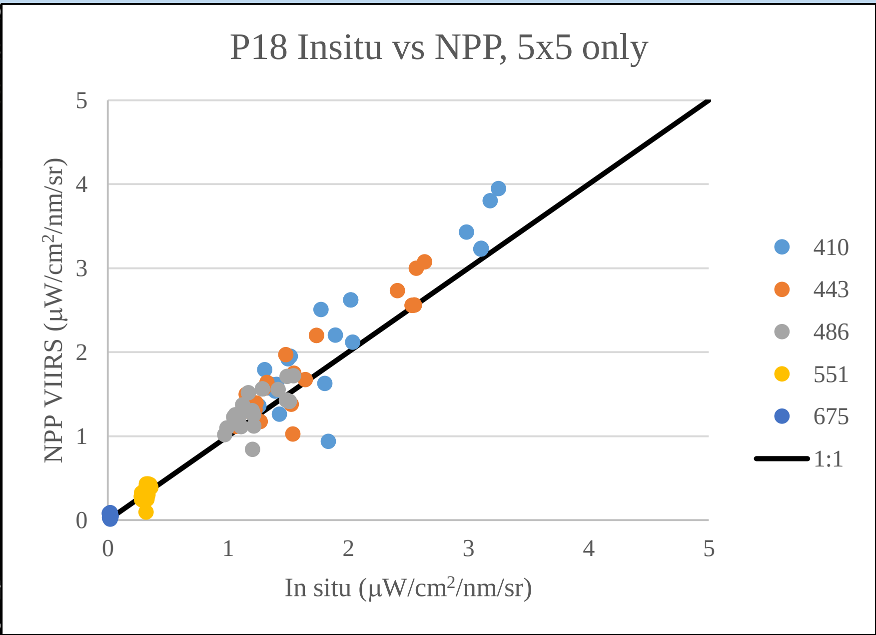




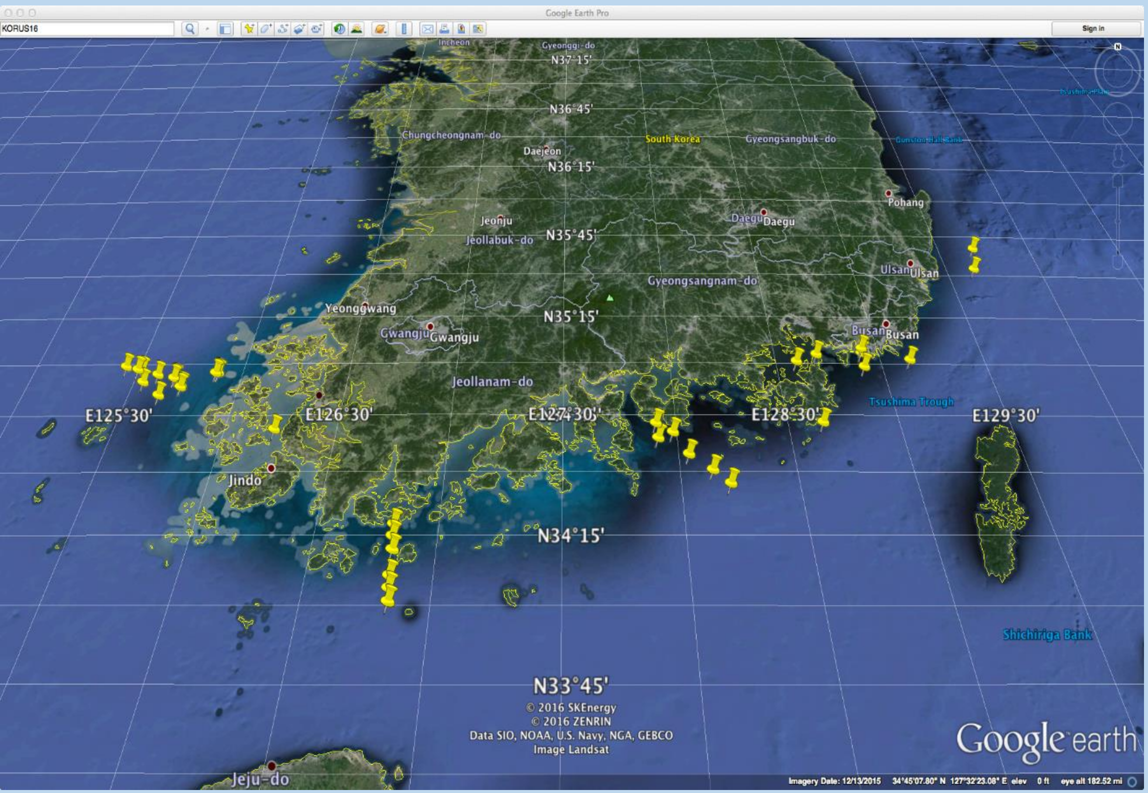
P18 GO-SHIP/CO2 Repeat Hydro long term changes and variability in marine biogeochemical and physical processes in response to natural and human-induced forcing. transports of CO2, heat, and freshwater in the ocean. Continue decadal observations of JGOFS, WOCE and CLIVAR.

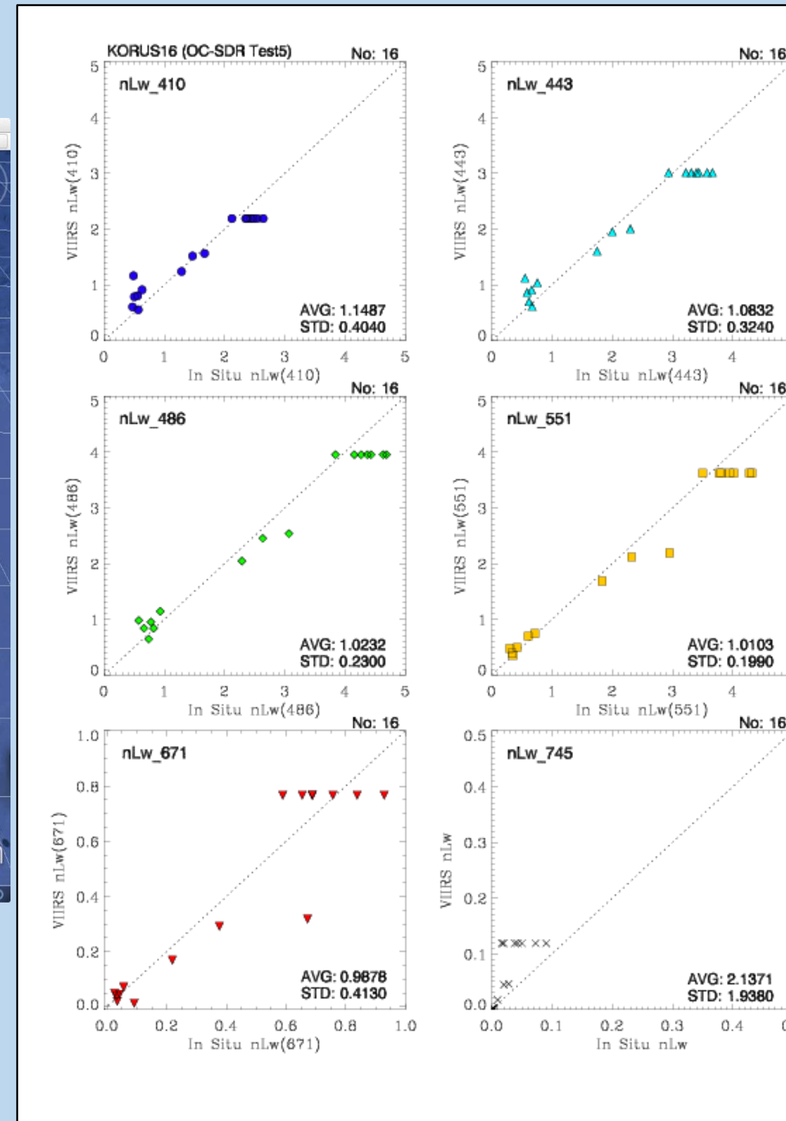
DEP: 11/2/2016 San Diego, CA, Leg 1
ARR: 12/8/2016 Easter Island, Chile
DEP: 12/13/2016 Easter Island, Chile, Leg 2
ARR: 1/19/2017 Punta Arenas, Chile



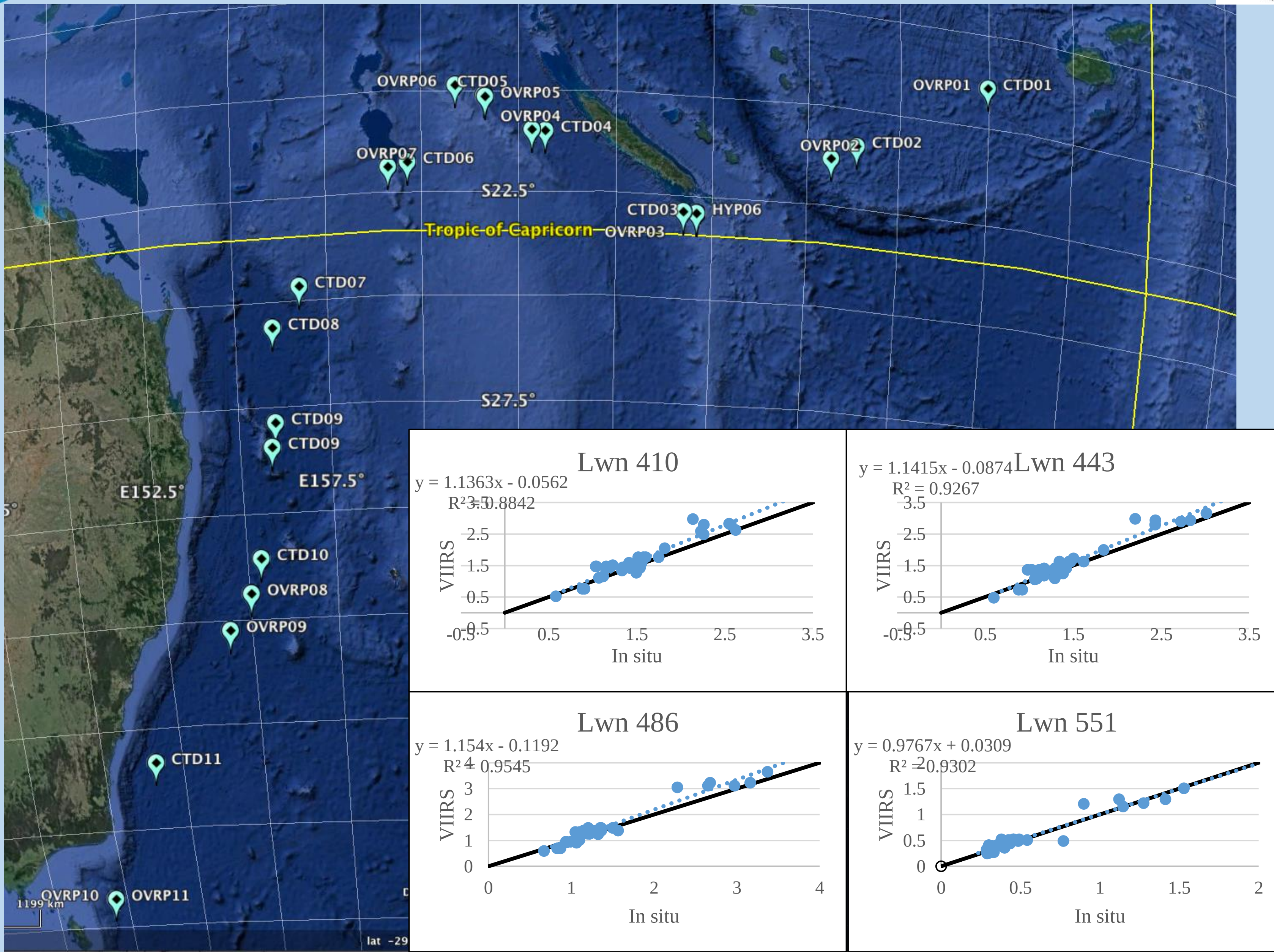


KORUS 2016- off the coast of South Korea from May 20th to June 5th 2016, Janmok conducted 35 stations. We measured Hyperpro, NURADS, Microtops, ASD Handheld II. Other groups measured pigments, IOPs and other relevant parameters.





June – July 2016 CSIRO cruise – Fiji to Tasmania – 24 HyperPro II Stations with Microtops & ancillary chemistry & IOPs, Crossplots vs in situ vs NPP.



International, Interagency and Academic Collaborations

US Agencies

- NOAA/NESDIS/STAR (NOAA)
- Naval Research Laboratory, Stennis Space Center (NRL)
- NASA/Goddard Space Flight Center (NASA)
- National Institute of Standards and Technology (NIST)

Foreign Agencies

- Joint Research Center of the European Commission (JRC)
- Korea Institute of Ocean Science and Technology (KIOST).
- Australian (CSIRO)
- European Space Agency (ESA)

Universities

- City University of New York, Long Island; Crest
- Lamont-Doherty Earth Observatory, Columbia University
- University of Massachusetts, Boston
- University of Miami
- University of South Florida
- University of Southern Mississippi
- Florida Atlantic University
- University of New Hampshire
- Curtin University

All these collaborators are utilizing same and/or different instruments at different locations all over the world. These are the data used in SeaBASS, MERMAID and NOAA's in situ database.

Since these are used to validate the ocean color satellites, we need to know what is the uncertainty of a validation measurement of any investigator taking any instrument at any locations .

To address this question and to provide validation for JPSS VIIRS ocean color sensors, NOAA has provided annual shiptime aboard NOAA research vessels.

Cal/Val cruise PIs and participants.

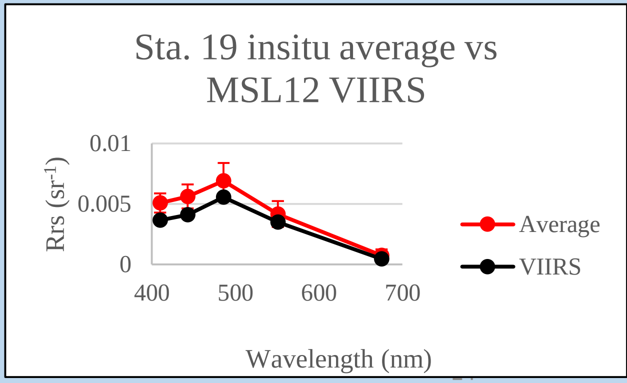
Michael Ondrusek, Eric Stengel, Charle Kovach, Bob Arnone, Zhongping Lee, Sherwin Ladner, Scott Freeman, Wesley Goode, Chuanmin Hu, David English, Jianwei Wei, Junfang Lin, Alex Gilerson, Sam Ahmed, Ahmed El-Habashi, Robert Foster, Nick Tufillaro, Curt Davis, Matteo Ottaviani, Michael Twardowski, Carlos Carrizo, Eder Herrera, Giuseppe Zabordi, Yingjun Zhang, Xialolong Yu, Zhehai Shang, Chih-Wei, Carol Johnson, Ivan Lalovic, Laura Zoffoli, Shaojie Sun, Nicole Stockley, Scott Freeman, Guoqing Wang, Joaquin Chaves, Ryan Vandermeulen, Amir Ibrahim, Marco Talone, Aimee Neeley, Ken Voss, Veronica Lance, Menghua Wang.

Science Objectives for the Cruise

Goals

1) Validation of VIIRS JPSS Satellite Ocean Color products
- Ground truth ocean color sensors and product

- **Occupied optical stations over four cruises to collect the best in situ matchups with VIIRS and other ocean color sensors used by NOAA.**
- **Water-Leaving Radiance** - HyperPro, HyperTSRB, C-OPS, GER, Spectral Evolution, SBA, HyperSAS, ASD Handheld 2.
- **Conducted pre- and post-cruise inter-cals**
- **Chlorophyll** - HPLC, Fluorometric, (in situ and extracted)
- **Absorption** - ACS, AC9, Spectrophotometric, flowthrough and profile
- **Backscatter** - BB9, BB7, BB3, ECO Puck, flowthrough and profile
- **Phytoplankton Physiology and Functional Types -** Imaging Flowcytobot, FlowCam, ALF
- **Carbon** – POC, DOC, and CDOM
- **Total Suspended Matter** - Gravimetric
- **Aerosol Optical Depth** - Microtops
- **Bi-directional radiance distribution** - NURADS

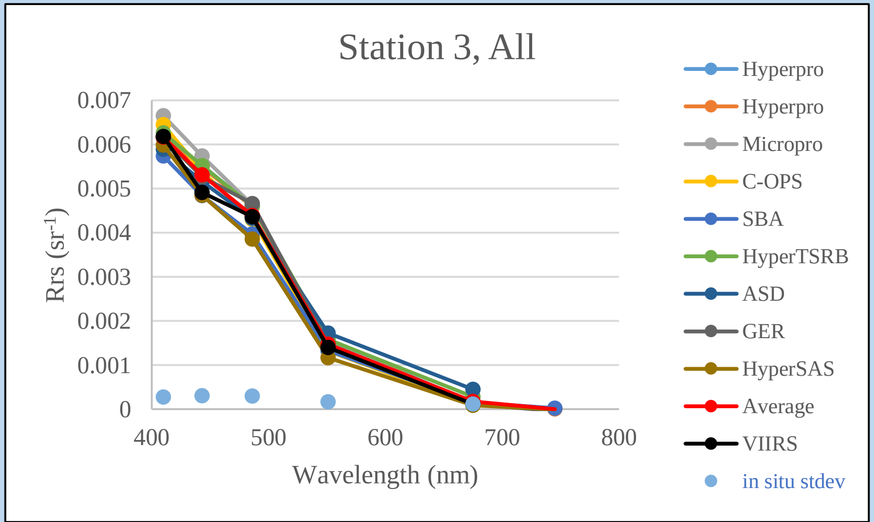


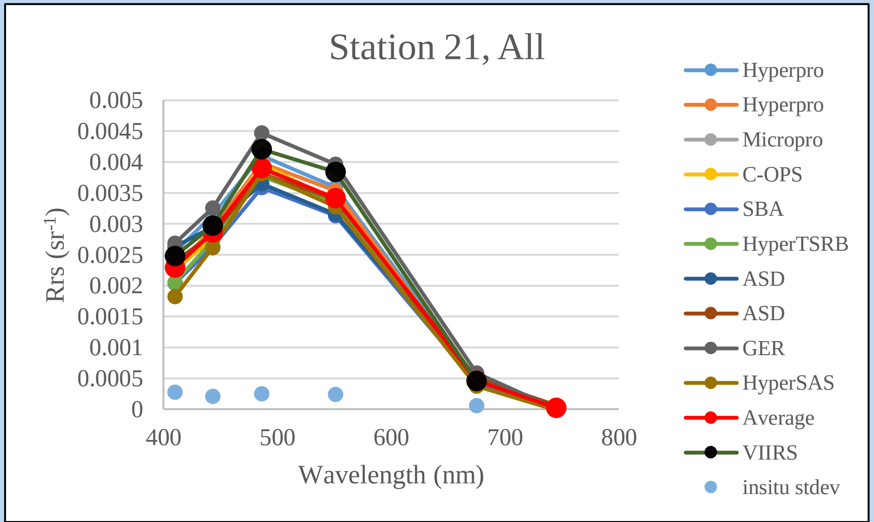
Science Objectives for the Cruise

Goals (cont.)

2) Characterization of uncertainties among the in situ ocean color measurements

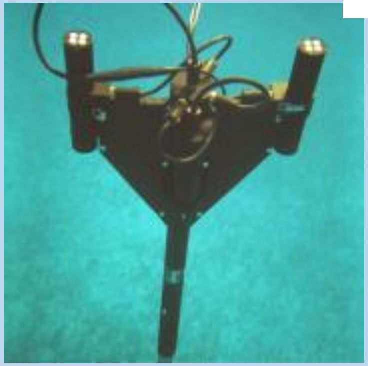
a) replicate observations from multiple identical (same model) instruments deployed in parallel;
b) observations of the same in situ parameters but using different types of instruments;
c) different deployment protocols for sample collection;
d) different post-processing methods for the in situ data; and
e) spatial and temporal variability of the ocean waters.
f) Protocol analysis and recommendations.





Instruments used to measure Remote Sensing Reflectance

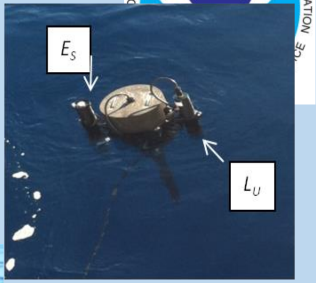
Profilers



Hyperpro (Satlantic) – Hyperpro free-falling hyperspectral optical profiler. 10 nm bands sampled every 3 nm. Radiance FOV 8.5 degrees. Calibrated from 350 to 800 nm.

C-OPS (Biospherical Instruments, Inc.) – compact multispectral optical profiling system. a spectral range from 300 nm to 900 nm, with 19 wavebands wavelengths each: 305 nm, 320 nm, 340 nm, 380 nm, 395 nm, 412 nm, 443 nm, 465 nm, 490 nm, 510 nm, 532 nm, 555 nm, 565 nm, 625 nm, 665 nm, 683 nm, 710 nm, 780 nm, and 875 nm.

Instruments used to measure Remote Sensing Reflectance



Surface

Float (Satlantic) – HyperTSRB. Same instrument as hyperpro but collared to float at surface.

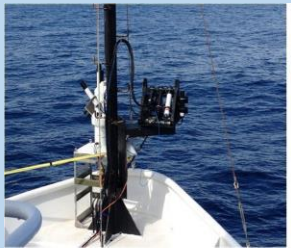
SBA (Satlantic) – Sky- Blocking Apparatus (SBA) radiometer package composed of one HyperOCR radiance sensor and one irradiance sensor. directly measures the water-leaving radiance Lw while blocking out sky-light (Lee et al., 2013).

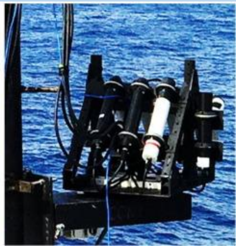
Above-water

ASD Analytical Spectral Device (PANalytical) – Handheld 2 above-water spectrometer. Spectral range of 325 to 1075 nm. Spectral Resolution <3.0 nm, FOV 10 degrees. 2nd asd has 7 degrees FOV.

GER (Spectra Vista Corporation) – The GER 1500, Field Portable hand-held Spectroradiometer. Wavelengths from 350 nm to 1050 nm at 3 nm resolution with 4° nominal field of view (FOV).

Spec-Evo – Spectral Evolution above water radiometer.





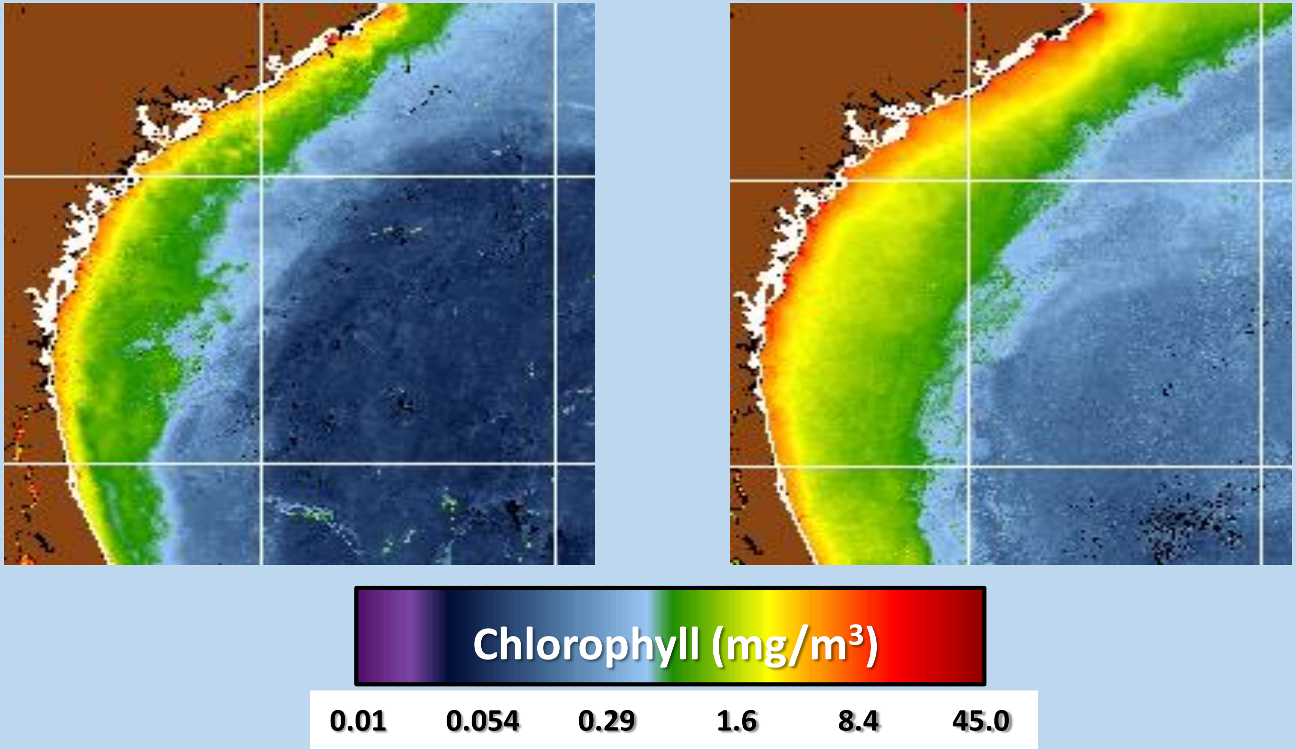
HyperSAS (Satlantic) – Autonomous above-water OCR’s with narrow FOV of 3 degrees. Also set up to measure polarization

Science Objectives for Cal/Val Cruises

Goals (cont.)

3) Optical characterization of oceanic processes (i.e. coastal, near-shore, cross-shelf, eddies, fronts, filaments, blue water)

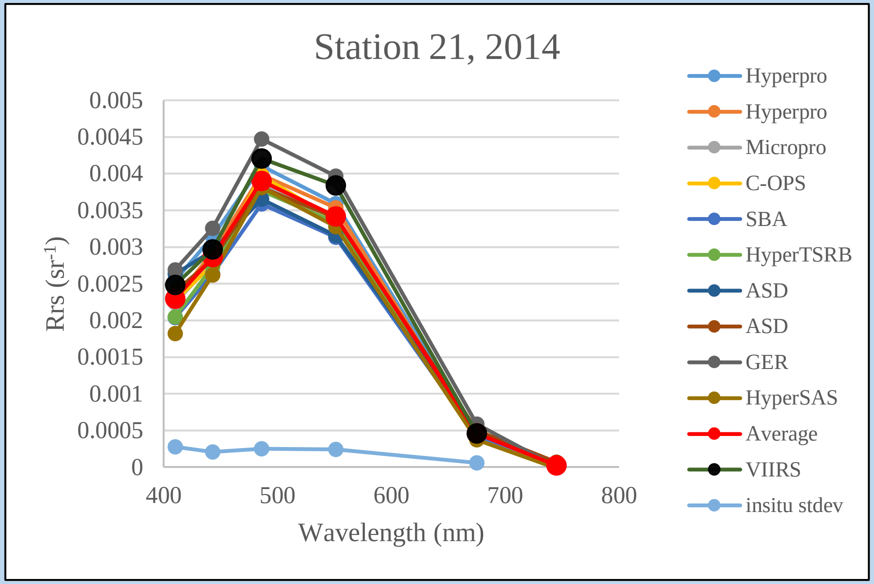
Influence of Hurricane Matthew on the Coastal waters

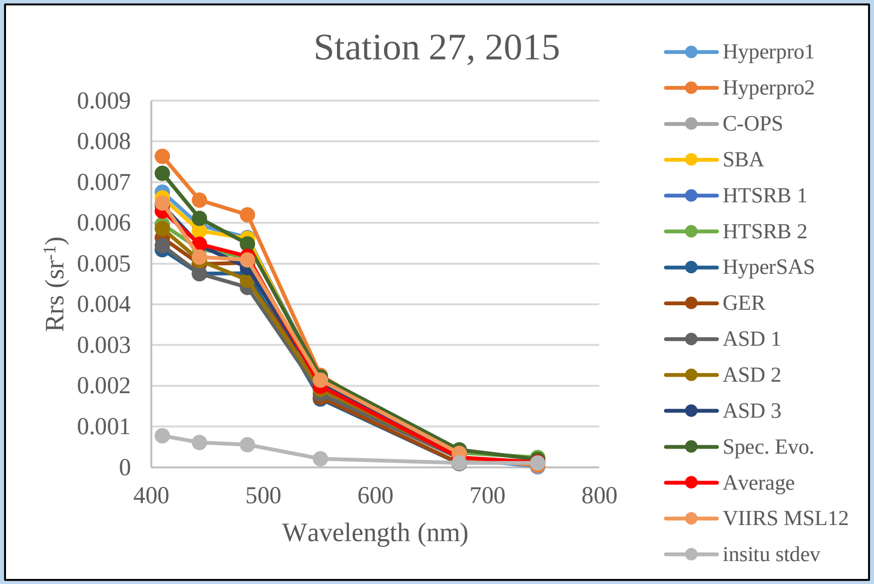


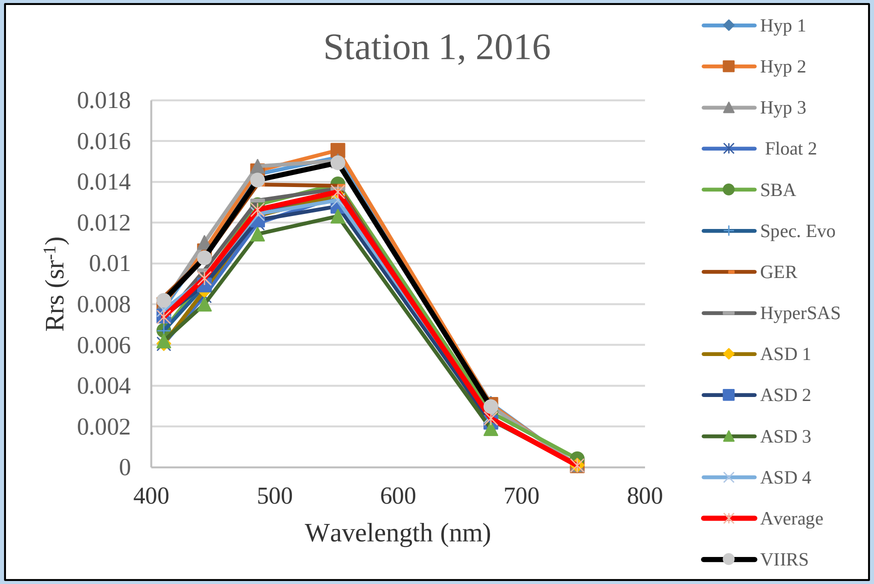
-Can water mass characterization of the representing different bio-physical processes be defined using VIIRS bio-optical products in the a dynamic system?

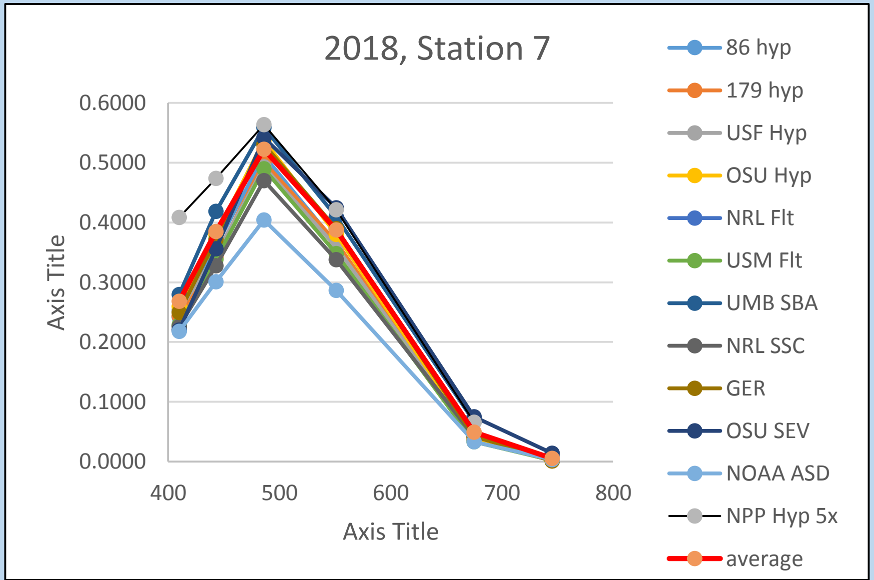
Annual JPSS Cal/Val Cruises, FY15 to FY18

Examples of station inter-comparison from each cruise

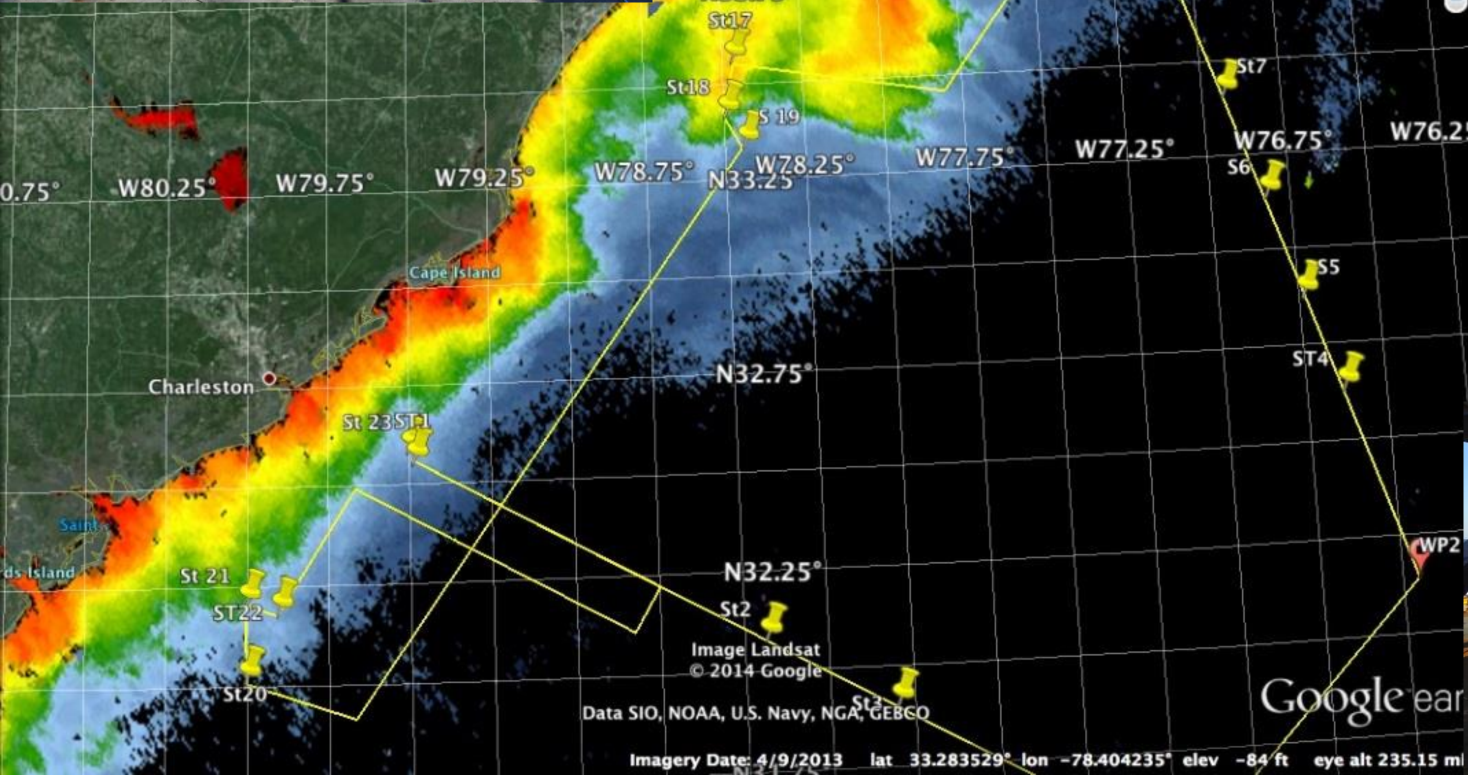








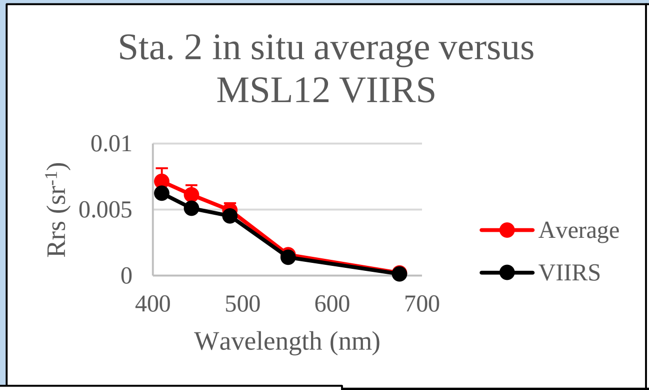
The FY15 cruise (Nov. 10-20, 2014) went in and out of Charleston SC aboard the Nancy Foster. In 10 days occupied 24 stations resulting in 9 good matchups with VIIRS

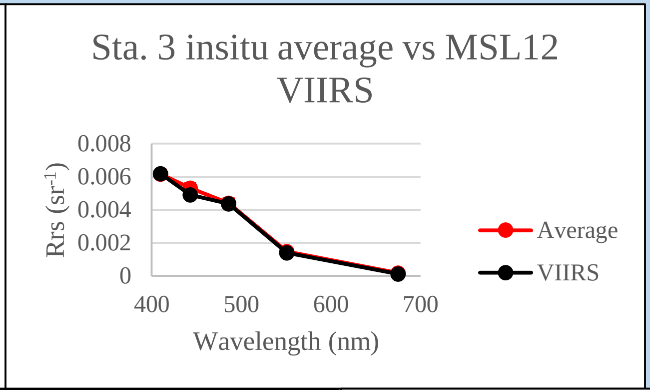


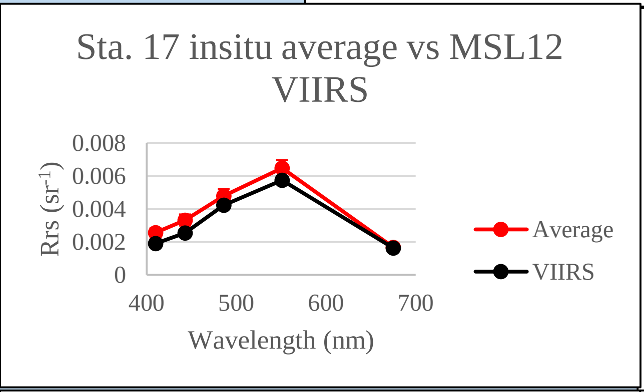
2014 MSL12 VIIRS 5x5 avg vs avg of all Rrs measurements

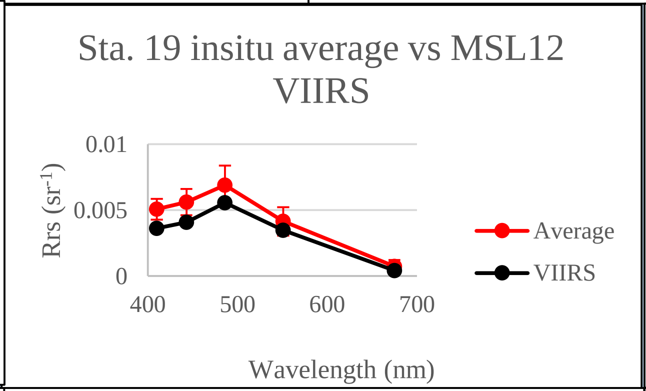
(error bars are +/- 1 stdev)

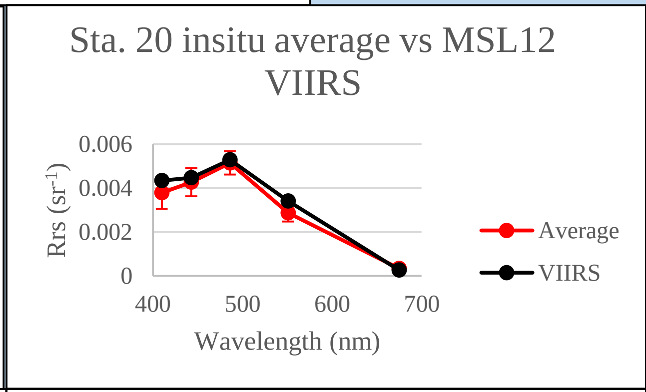
For Satellite used Ocview NIR-SCI 5x5 pixel average with outliers (+/- 1.5 Stdev) removed (Wang et al., 2009).

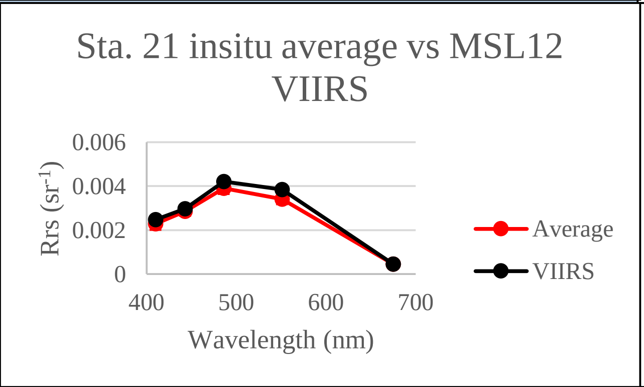


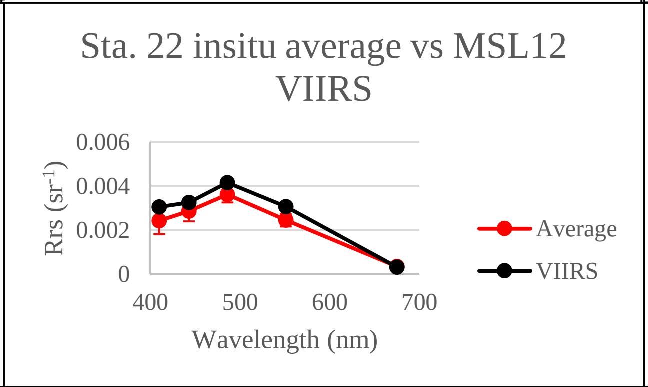


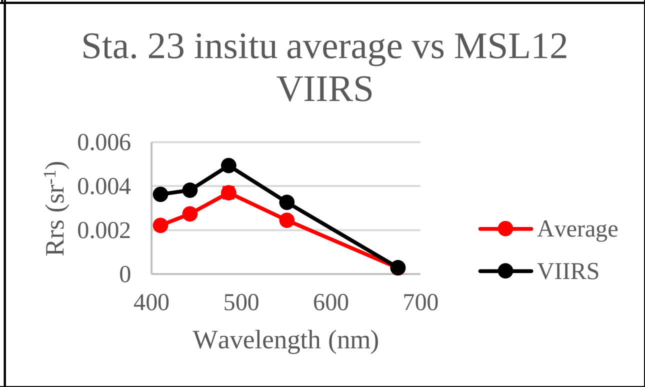




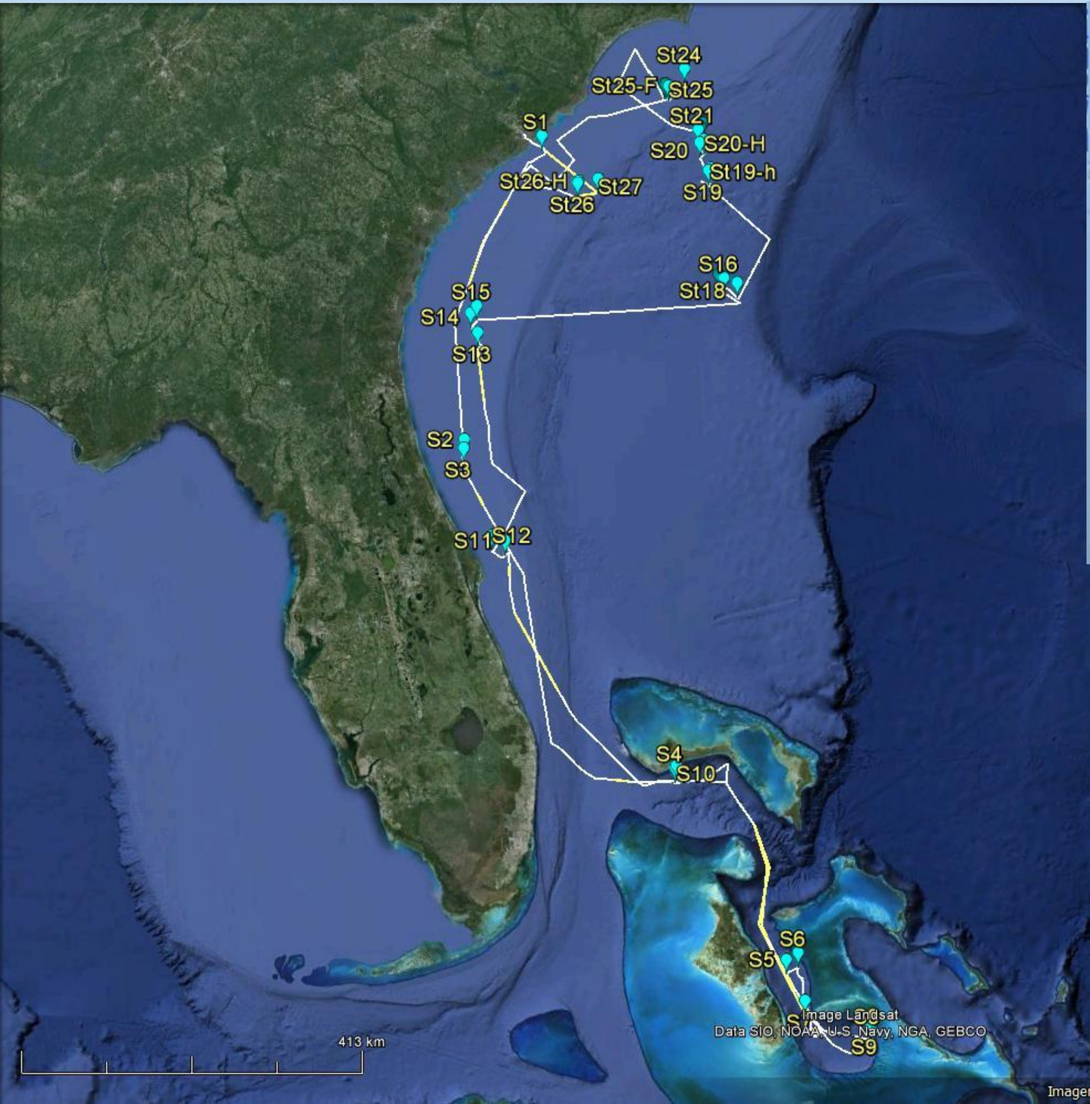


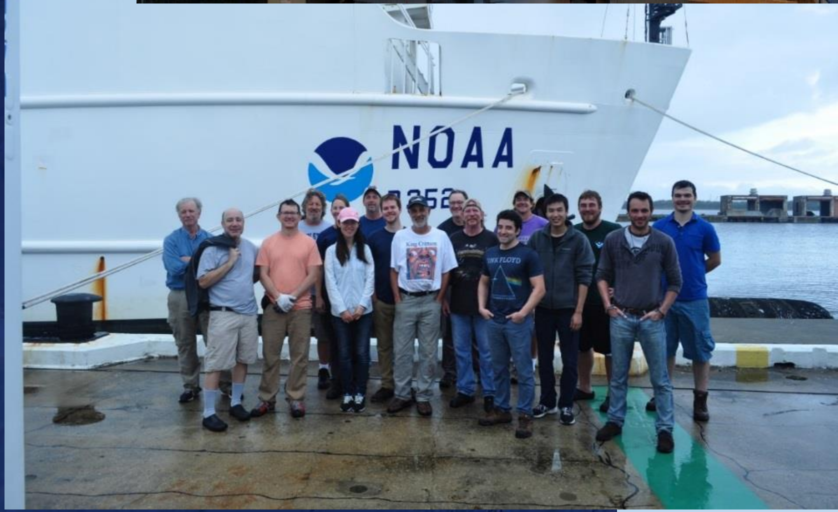




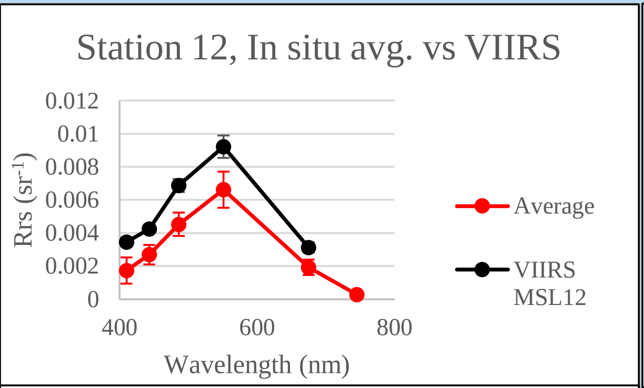


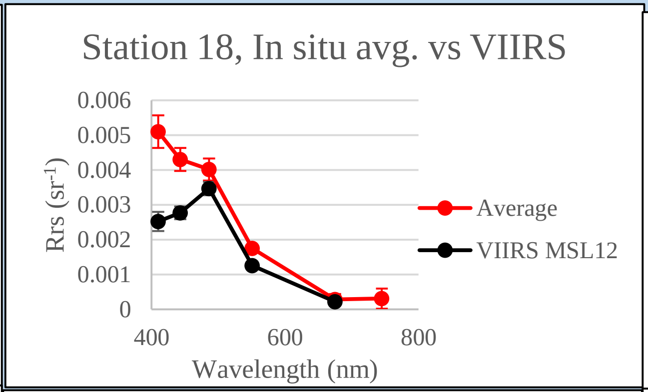
The FY16 cruise (Dec. 2-13, 2015) went in and out of Charleston SC aboard the Nancy Foster. In 12 days occupied 27 stations resulting in 9 good matchups with VIIRS

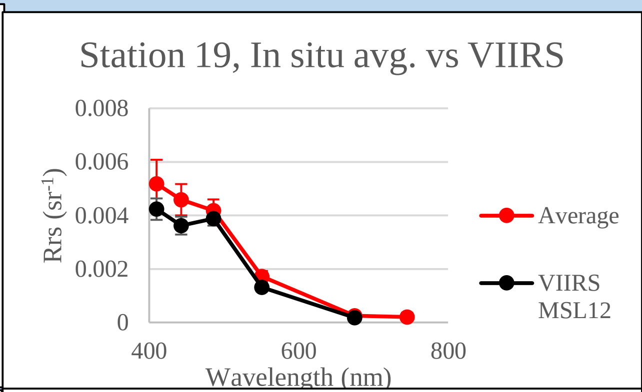


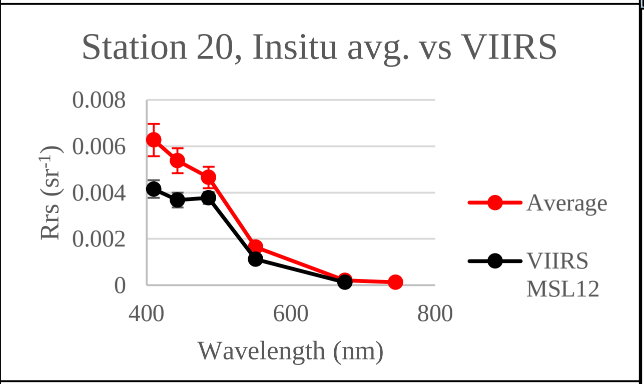


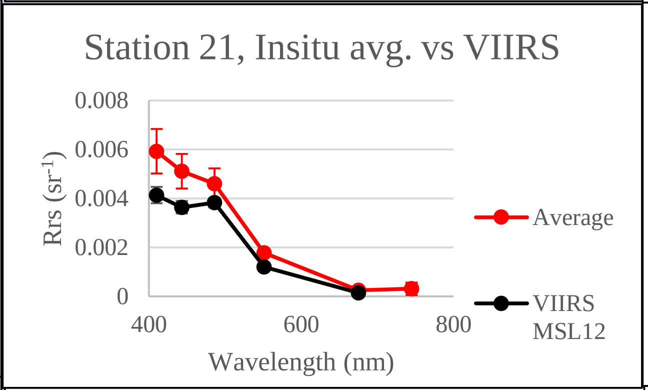
2015 MSL12 VIIRS 5x5 avg vs avg of all Rrs measurements

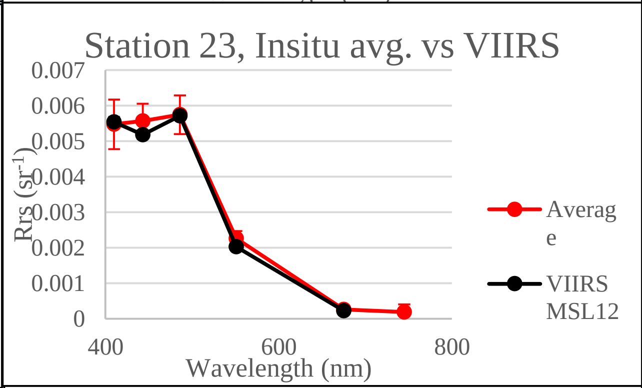


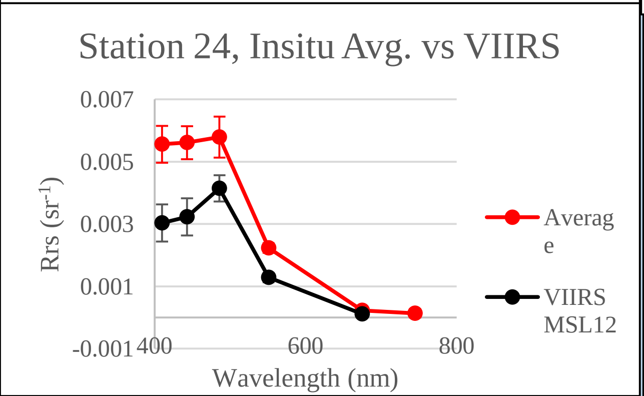


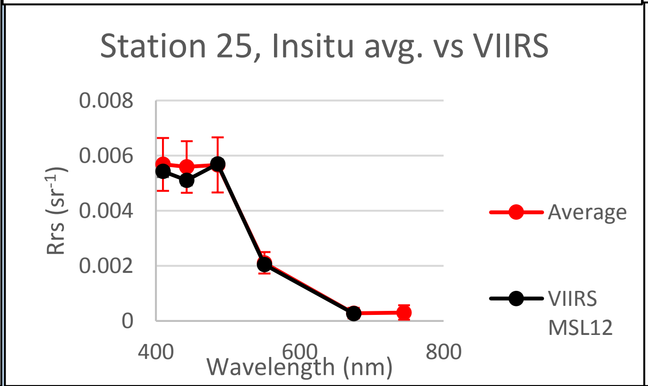


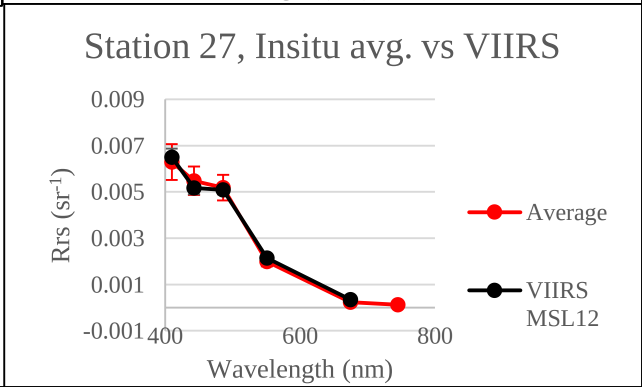




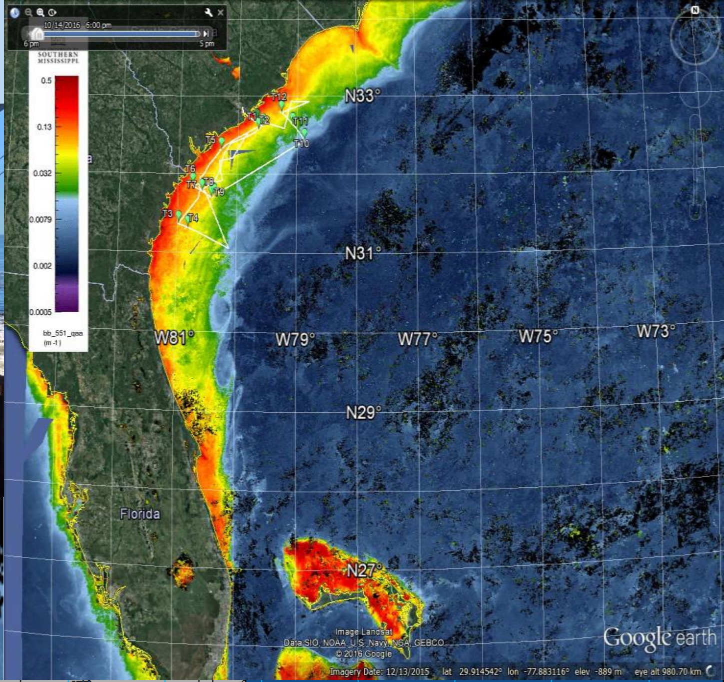


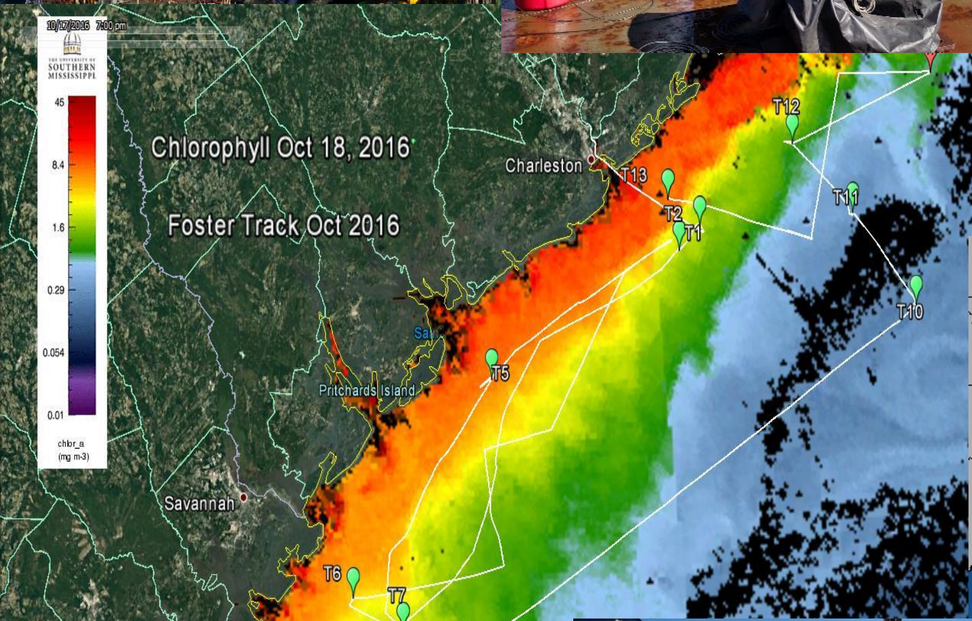


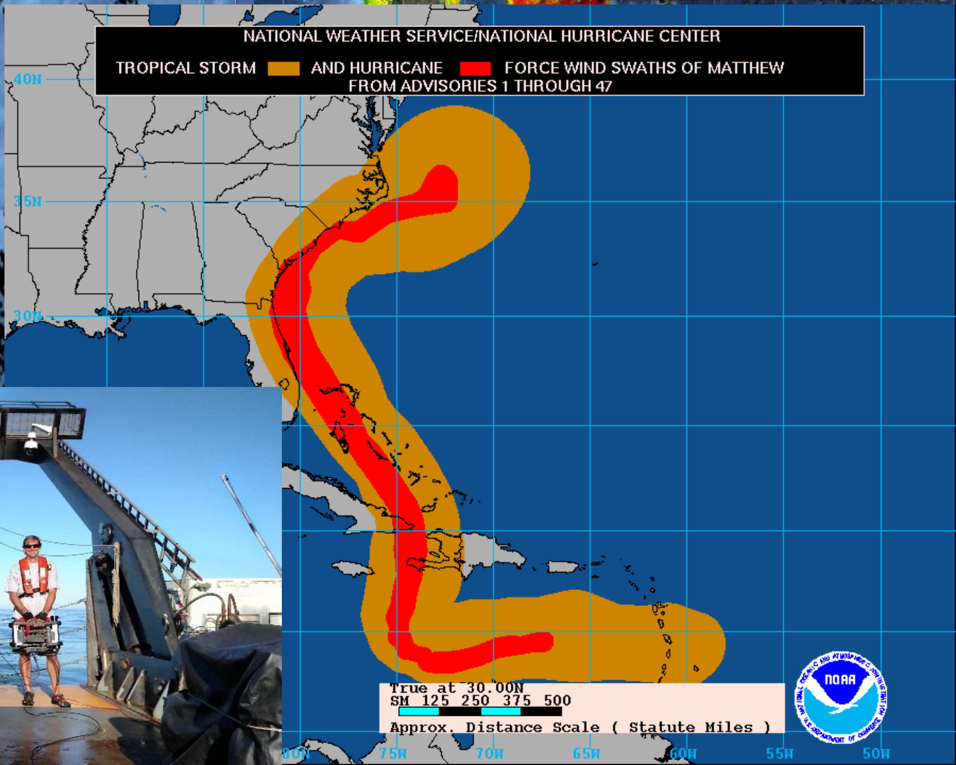


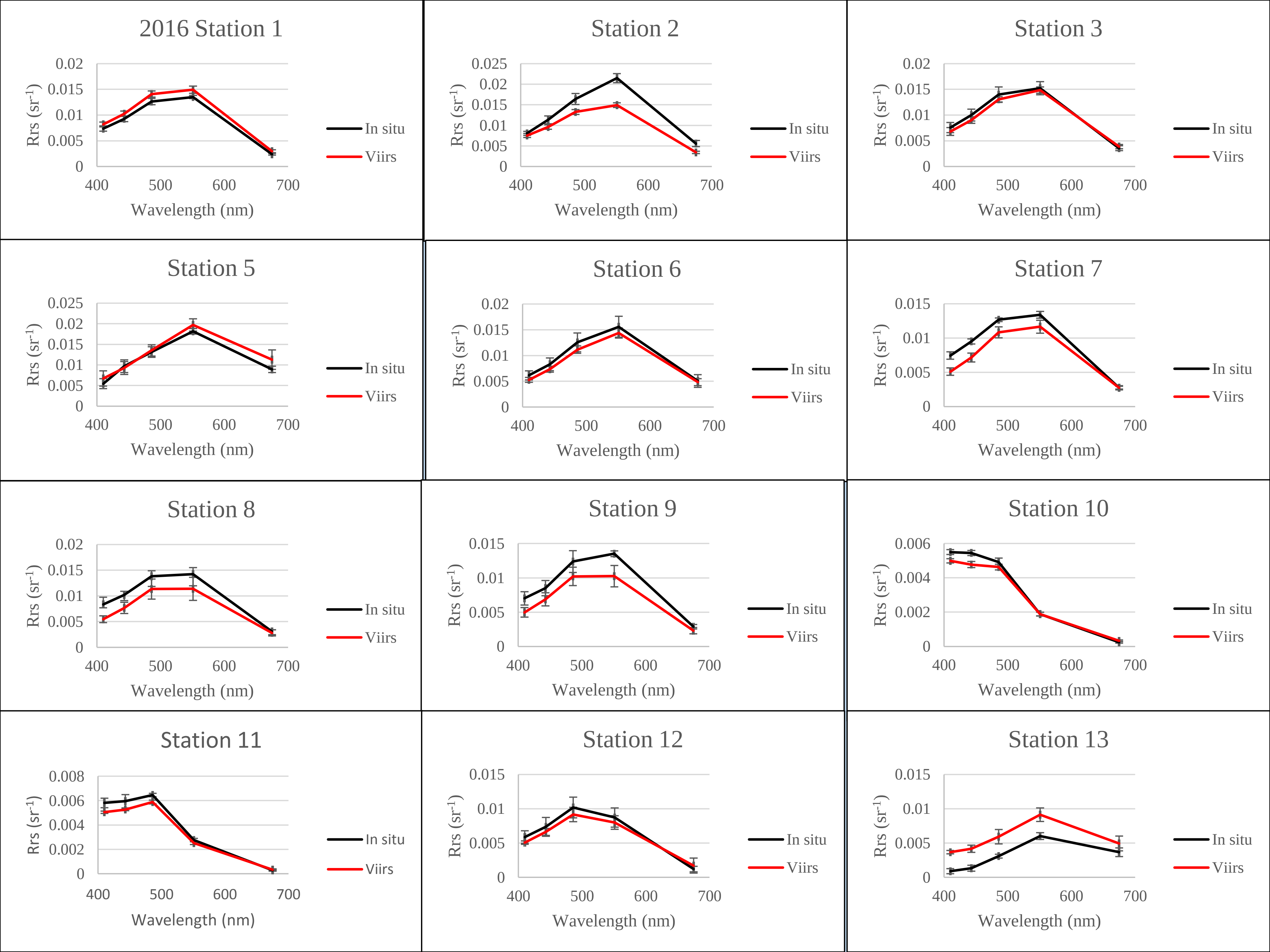


FY 17 VIIRS Cal/Val Cruise III (NF-16-08), October 13 to 18, 2016 aboard the NOAA Vessel Nancy Foster. In and out of Charleston, SC. 13 st.



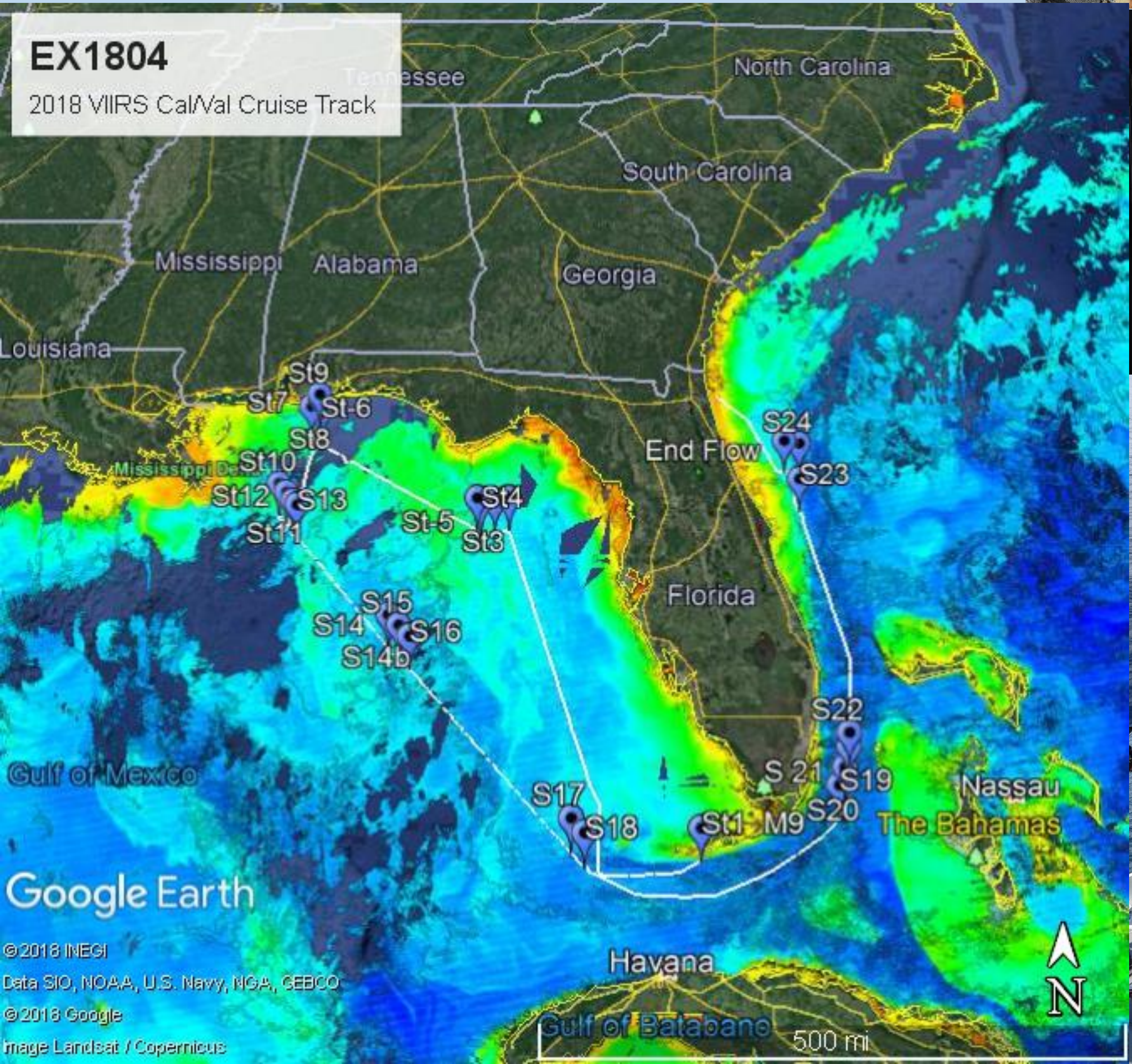


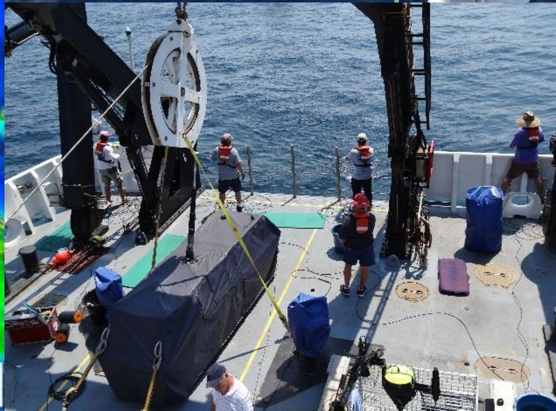


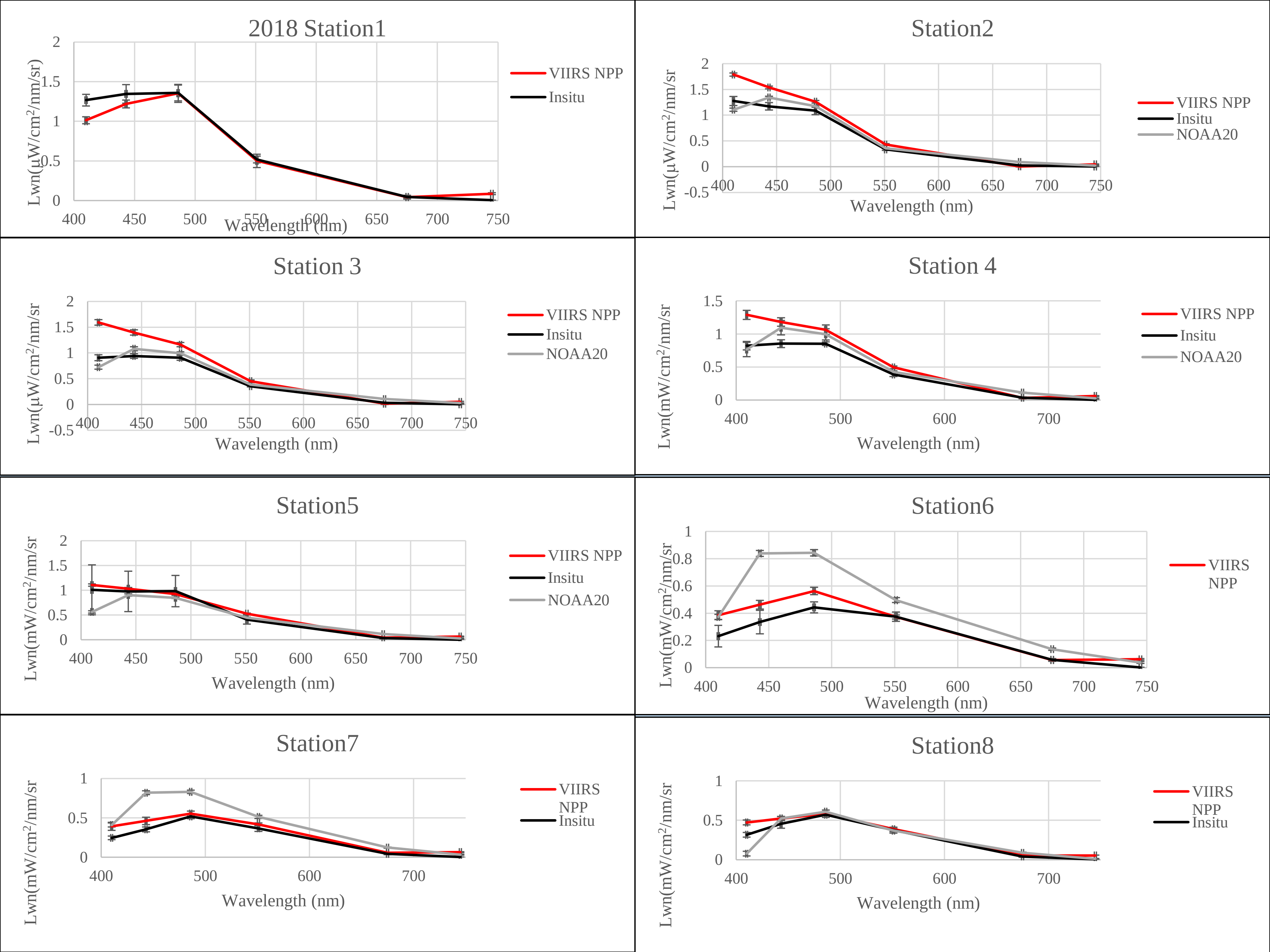


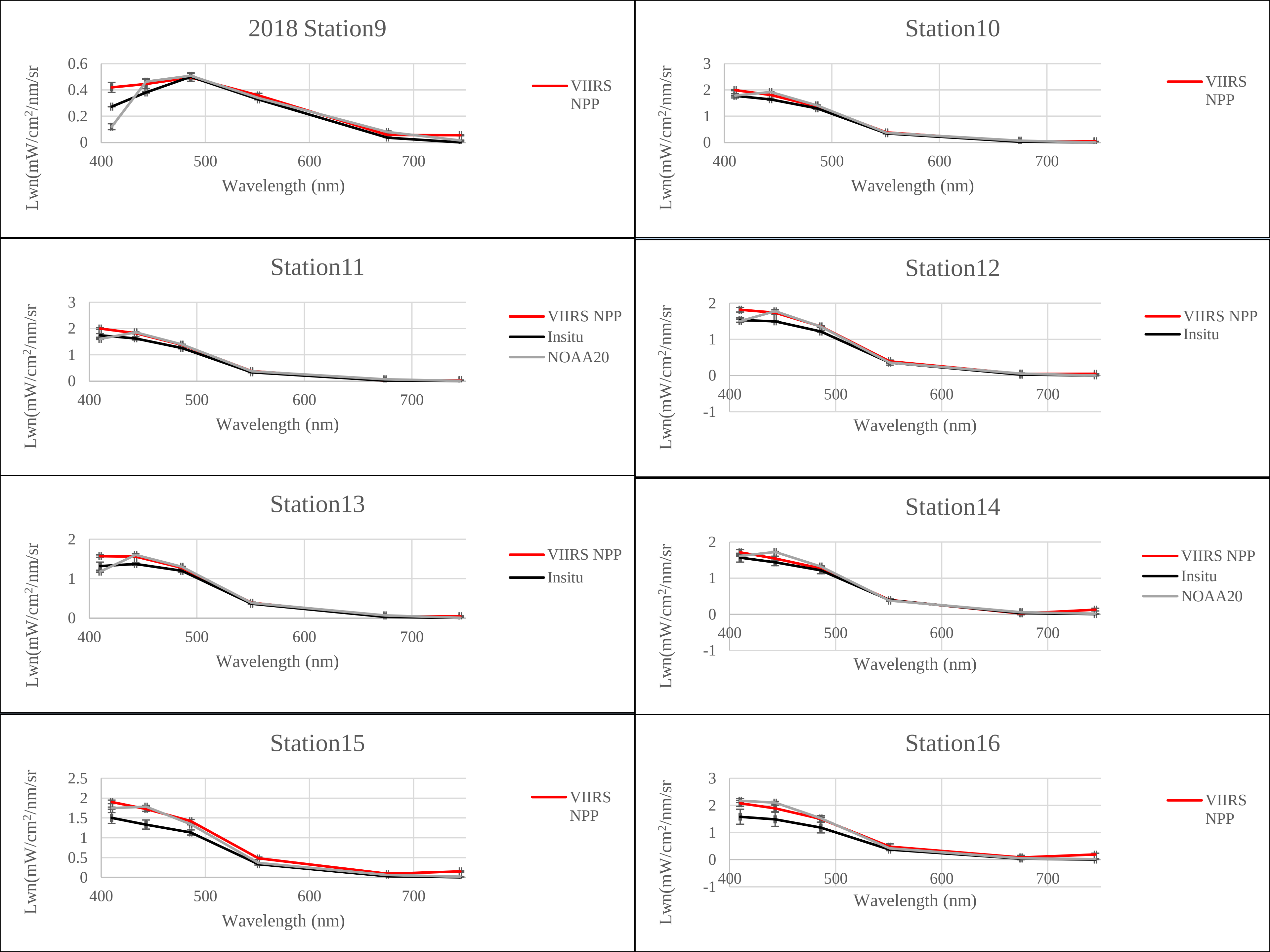
2016 Station 1
Station 2
Station 3
Station 5
Station 6
Station 7
Station 8
Station 9
Station 10
Station 11
Station 12
Station 13
Rrs (sr-1)
Wavelength (nm)
In situ
Viirs

FY18 Cal/Val cruise. May 9 – 18, 2018. NOAA Ship Okeanos Explorer. Key West to Jacksonville. 24 stations, 18 matches.






2018 Station1
Lwn(μW/cm2/nm/sr)
Wavelength (nm)
VIIRS NPP
Insitu
Station2
Lwn(μW/cm2/nm/sr
Wavelength (nm)
VIIRS NPP
Insitu
NOAA20
Station 3
Lwn(μW/cm2/nm/sr
Wavelength (nm)
VIIRS NPP
Insitu
NOAA20
Station 4
Lwn(mW/cm2/nm/sr
Wavelength (nm)
VIIRS NPP
Insitu
NOAA20
Station5
Lwn(mW/cm2/nm/sr
Wavelength (nm)
VIIRS NPP
Insitu
NOAA20
Station6
Lwn(mW/cm2/nm/sr
Wavelength (nm)
VIIRS NPP
Station7
Lwn(mW/cm2/nm/sr
Wavelength (nm)
VIIRS NPP
Insitu
Station8
Lwn(mW/cm2/nm/sr
Wavelength (nm)
VIIRS NPP
Insitu


2018 Station9
Lwn(mW/cm2/nm/sr
Wavelength (nm)
0.6
0.4
0.2
0
400
500
600
700
VIIRS NPP
Station10
Lwn(mW/cm2/nm/sr
Wavelength (nm)
3
2
1
0
400
500
600
700
VIIRS NPP
Station11
Lwn(mW/cm2/nm/sr
Wavelength (nm)
3
2
1
0
400
500
600
700
VIIRS NPP
Insitu
NOAA20
Station12
Lwn(mW/cm2/nm/sr
Wavelength (nm)
2
1
0
-1
400
500
600
700
VIIRS NPP
Insitu
Station13
Lwn(mW/cm2/nm/sr
Wavelength (nm)
2
1
0
400
500
600
700
VIIRS NPP
Insitu
Station14
Lwn(mW/cm2/nm/sr
Wavelength (nm)
2
1
0
-1
400
500
600
700
VIIRS NPP
Insitu
NOAA20
Station15
Lwn(mW/cm2/nm/sr
Wavelength (nm)
2.5
2
1.5
1
0.5
0
400
500
600
700
VIIRS NPP
Station16
Lwn(mW/cm2/nm/sr
Wavelength (nm)
3
2
1
0
-1
400
500
600
700
VIIRS NPP

MSL12 VIIRS Percent difference relative to in situ (average for all stations)

2014 VIIRS Cal/Val Cruise

Band	Hyperpro	Hyperpro	Micropro	C-OPS	SBA	HyperTSRB	ASD	ASD	GER	HyperSAS	Average
410	-6.73	-3.36	-5.39	-2.15	10.31	1.57	-8.17	-8.73	3.33	3.85	**-3.79**
443	-13.15	-10.87	-7.45	-3.93	4.15	-7.42	-8.53	-9.38	-8.44	-3.90	**-8.31**
486	-6.49	-5.70	-1.44	0.45	11.28	-2.84	3.67	-2.83	-8.83	0.35	**-2.30**
551	-3.58	-2.71	4.05	10.21	14.65	-2.89	2.89	3.18	-2.82	5.52	**1.17**
675	-10.37	-0.44	1.06	1.70	-3.34	-28.45	-25.91	-9.02	-22.89	-4.94	**-17.04**
All	-8.07	-4.62	-1.83	1.26	7.41	-8.01	-7.21	-5.36	-7.93	0.18	**-6.05**

2015 VIIRS Cal/Val Cruise

Band	Hyperpro	Hyperpro	Spec Evo	SBA	HTSRB	HTSRB	ASD 1	ASD 2	ASD 3	GER	HyperSAS	Average
410	-10.71	-33.17	-32.44	0.69	-17.95	-2.30	-5.63	-13.05	-6.59	11.00	33.56	**-6.96**
443	-18.16	-31.21	-29.54	-8.79	-22.38	-11.47	-4.18	-11.97	-8.68	-4.17	-4.42	**-14.09**
486	-10.39	-19.94	-14.26	-0.97	-12.37	-5.97	13.50	4.83	4.68	-2.64	-2.58	**-4.19**
551	-20.75	-24.85	-24.76	-7.82	-24.11	-18.53	-0.83	-12.52	-11.21	-6.12	-7.59	**-14.46**
675	-5.97	-7.69	1.95	82.36	-45.75	-40.02	0.21	-15.49	-9.78	82.26	56.15	**8.93**
Average	-13.20	-23.37	-19.81	13.09	-24.51	-15.66	0.62	-9.64	-6.32	16.07	15.02	**-6.16**

For Satellite used Ocview NIR-SCI 5x5 pixel average with outliers (+/- 1.5 Stdev) removed (Wang et al., 2009).

MSL12 VIIRS Percent difference relative to in situ

2016 VIIRS Cal/Val Cruise

Band	Hyp 1	Hyp 2	Hyp 3	Float 1	Float 2	SBA	Spec. Ev	GER	HyperSA	ASD 1	ASD 2	ASD 3	ASD 4	Average
410	-21.14	-13.02	-14.58	-8.70	-10.17	-5.17	-17.35	9.41	-13.09	-9.54	-13.75	-15.73	-14.53	-11.33
443	-23.64	-18.25	-16.39	-9.11	-12.20	-9.33	-13.49	-6.53	-10.05	-9.60	-6.38	-4.69	-12.33	-11.69
486	-19.98	-19.42	-10.79	-8.22	-5.89	-8.39	-12.21	-8.70	-9.25	-3.90	-0.04	-8.70	-4.42	-9.22
551	-20.50	-16.07	-14.42	-5.46	-10.17	-12.97	-13.57	-4.52	-7.59	-5.08	-7.38	0.55	-1.78	-9.15
675	-9.04	23.98	8.34	8.54	6.38	-10.03	10.62	13.27	12.94	30.51	11.00	18.10	0.30	9.61
avg all	-18.86	-8.56	-9.57	-4.59	-6.41	-9.18	-9.20	0.59	-5.41	0.48	-3.31	-2.09	-6.55	-6.36

2018 VIIRS Cal/Val Cruise

Band	Hyp 1	Hyp 2	Hyp 3	Hyp4	Float 1	Float 2	SBA	SEV1	SEV2	GER	SEV3	SVC	ASD	NPP
410	33.49	30.10	33.29	32.90	21.01	32.80	31.68	29.28	29.13	25.28	31.80	39.59	36.77	31.32
443	21.33	20.45	23.23	20.58	17.71	20.66	16.60	21.49	22.32	15.18	6.65	8.98	21.21	18.18
486	10.73	11.12	14.43	7.90	10.21	13.11	11.98	14.48	13.82	6.03	5.55	1.37	7.98	9.90
551	13.54	12.84	14.05	8.92	15.38	14.76	15.75	-2.45	14.56	10.93	5.17	18.85	13.58	11.99
675	154.41	134.69	79.59	91.86	158.29	121.57	138.91	131.78	116.91	114.39	89.91	323.46	110.10	135.84
avg all	46.70	41.84	32.92	32.43	44.52	40.58	42.99	38.92	39.35	34.36	27.82	78.45	37.93	41.45
vg 410-55	19.77	18.63	21.25	17.58	16.08	20.33	19.00	15.70	19.95	14.36	12.29	17.20	19.89	17.85

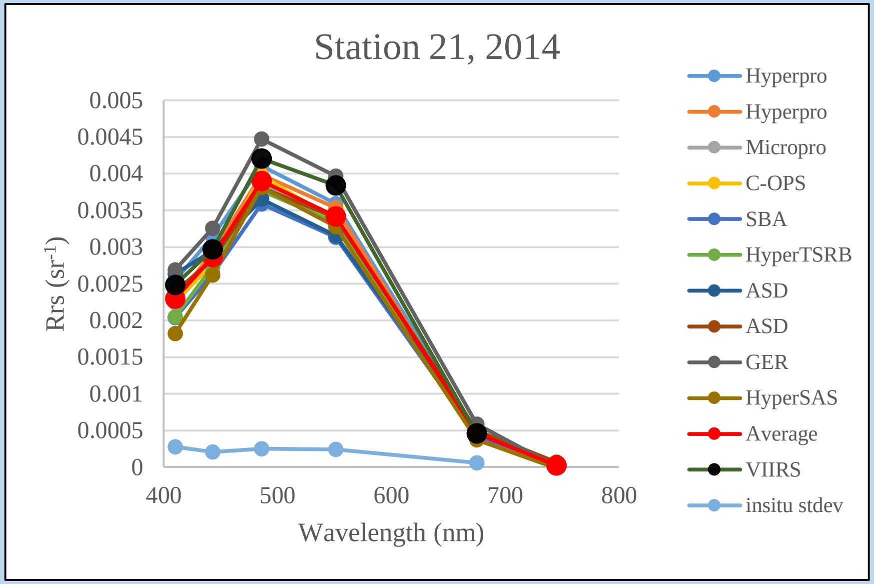
VIIRS percent difference relative to average of all instruments

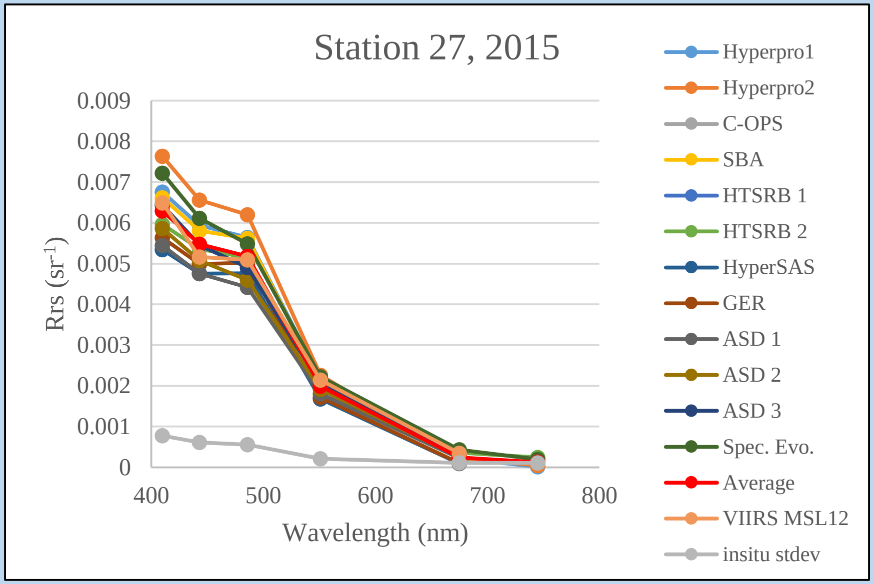
Band	2014	2015	2016	Avg. All
410	-4	-7	-11	-7
443	-8	-14	-12	-11
486	-2	-4	-9	-5
551	1	-14	-9	-7
675	-17	9	10	1
Average	-6	-6	-6	**-6**

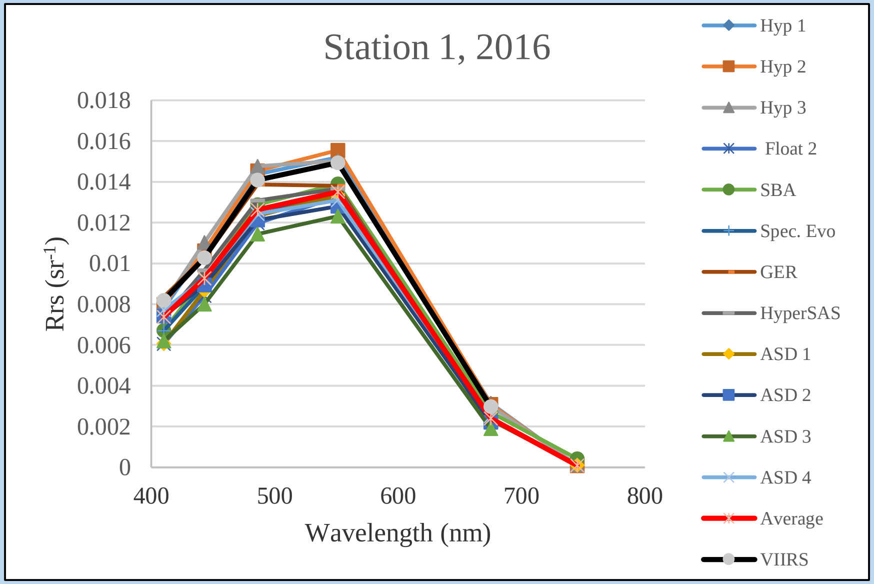
VIIRS matchups to in-water validation measurements averaged 6% lower from 410 to 550 nm.

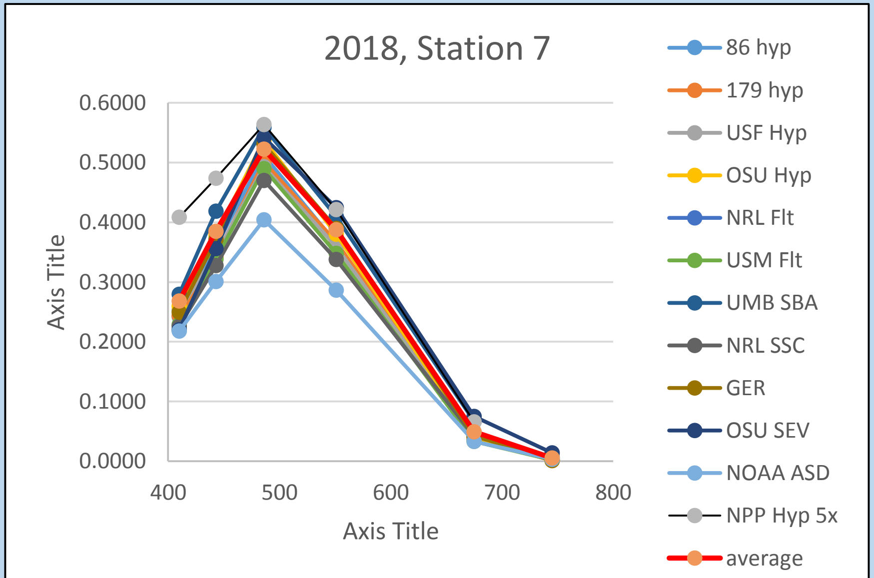
Annual JPSS Cal/Val Cruises, FY14 to FY18

Examples of station inter-comparison from each cruise









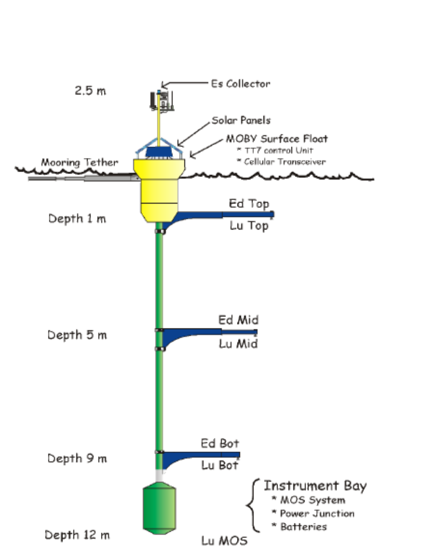
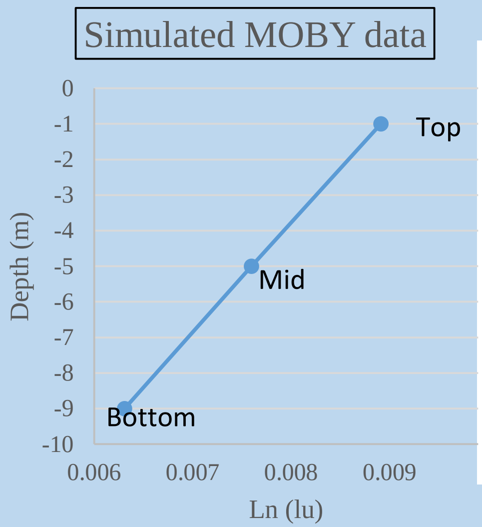
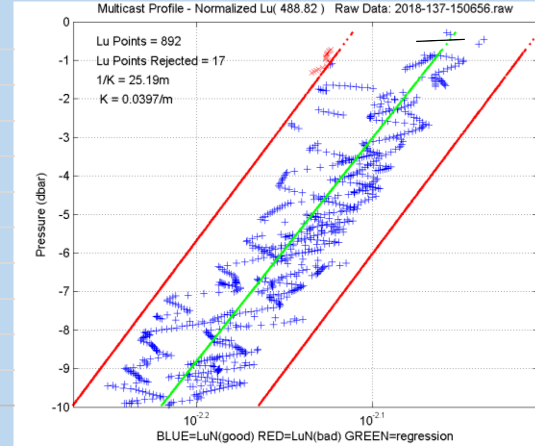


Fig. 1. Schematic diagram of MOBY.

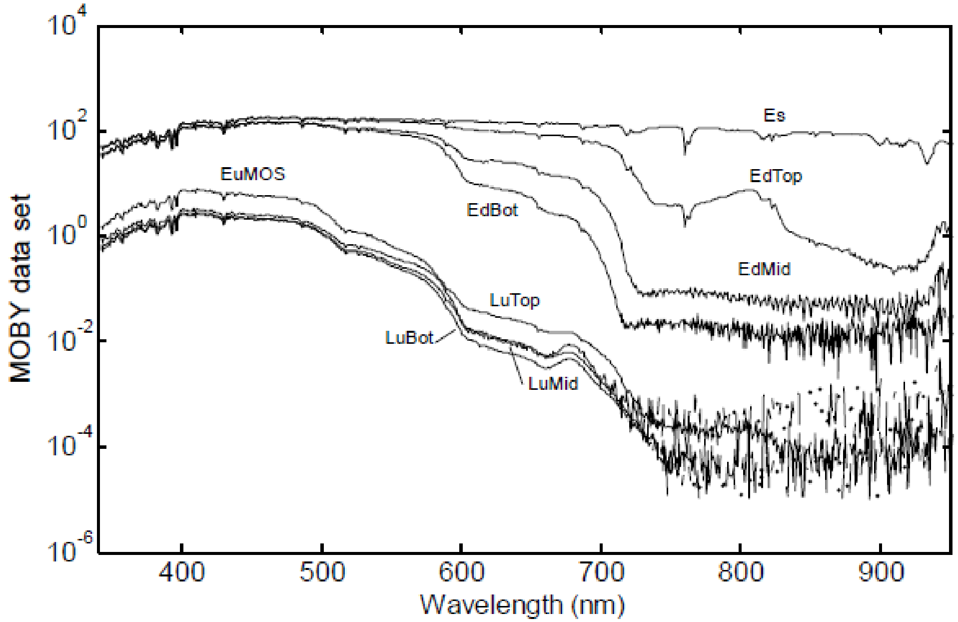


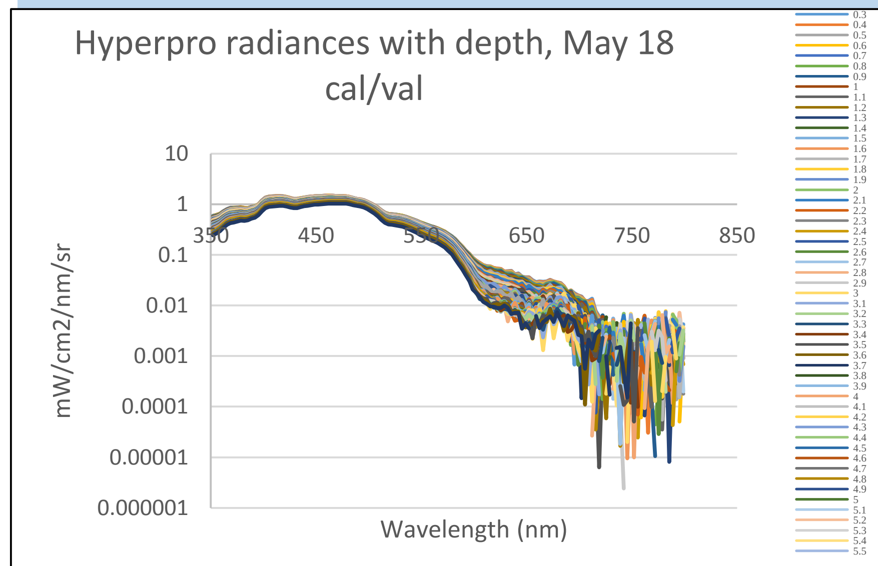


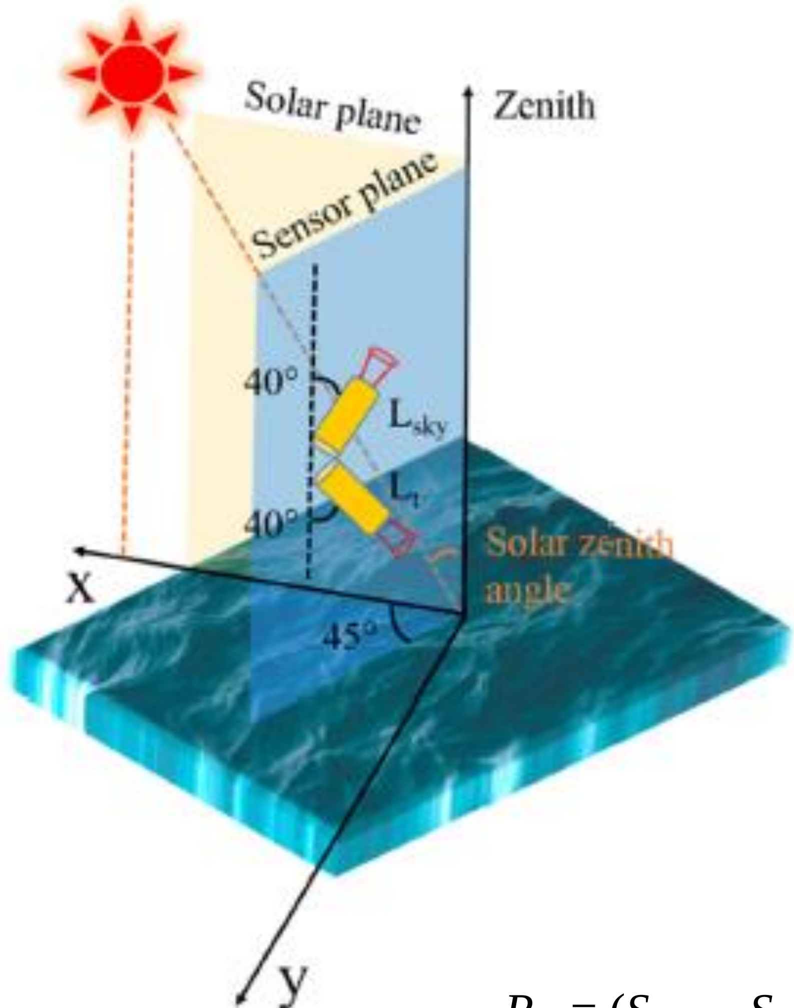
$$L_w(0^+, \lambda) = L_u(0^-, \lambda) * [(1-\rho(\lambda, \theta))/n_w(\lambda)^2]$$

$$nL_w(\lambda) = L_w(\lambda, 0^+) * F_0(\lambda)/E_s(\lambda)$$

From: Brown et al. 2007







$$R_{rs} = (S_{w+s} - S_{sky}\,\rho(\theta))/(\,\pi S_p/refl)$$

Fig. 1. Schematic diagram showing the typical experimental setup for above-water water-leaving radiance measurements. As a convention, the sun is always placed in the X-Z plane.

From Zhang et al., 2017 Optics Express

Skylight Blocking Apparatus.

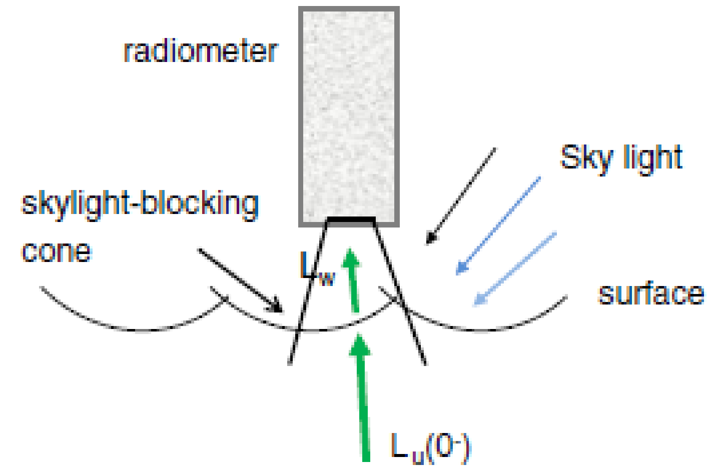


Fig. 1. (Color online) Schematic draw to show the concept of measuring L_w directly in the field. The cone is integrated with a radiometer to block surface-reflected light, with its open end inserted just below (~5 cm) the surface when measuring L_w.

From Lee et al., 2013 Applied Optics

Instrument Percent difference relative to average of all instruments at that station

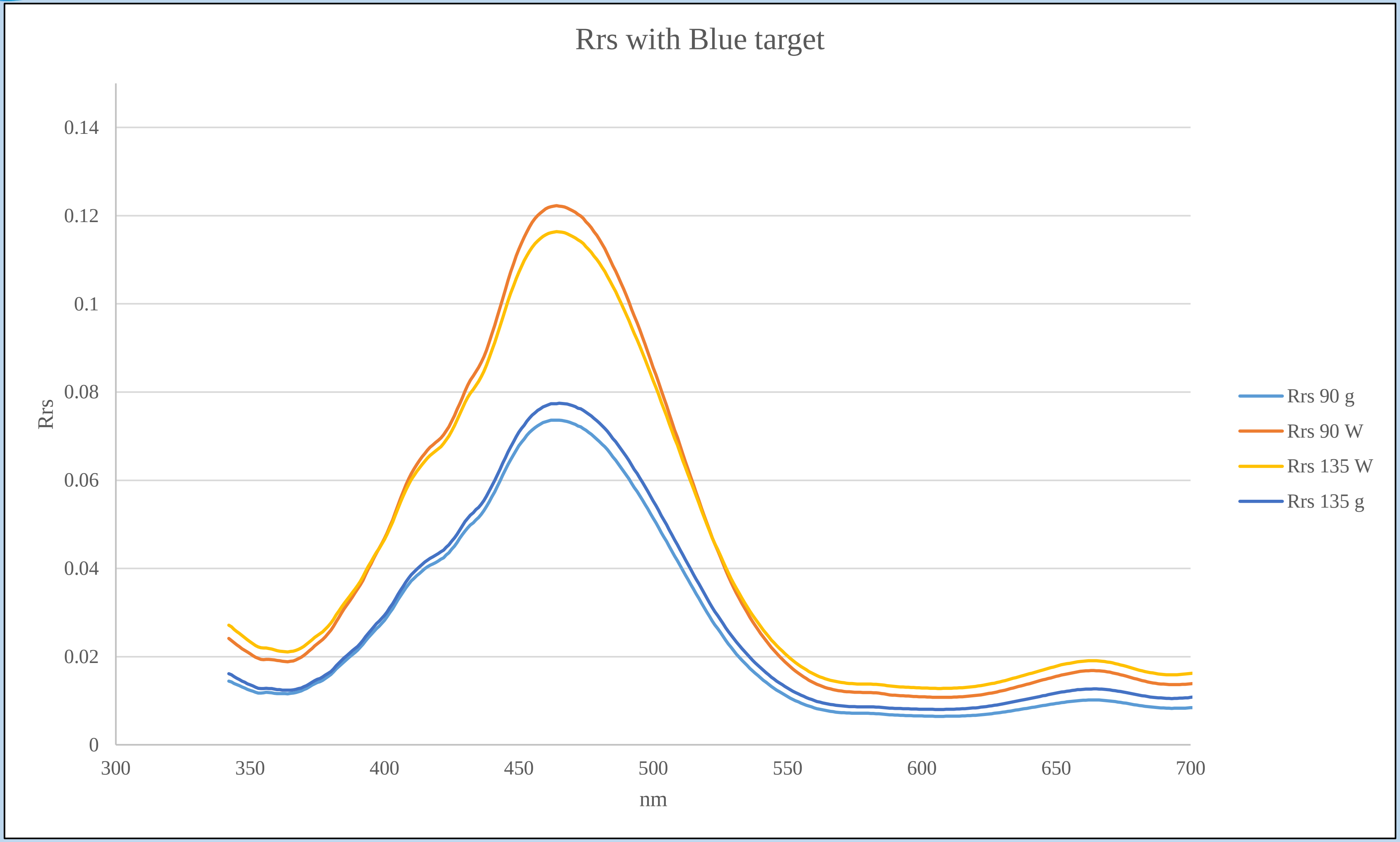
2014 VIIRS Validation Cruise

Band	Hyperpro	Hyperpro	Micropro	C-OPS	SBA	HyperTSRB	ASD	ASD	GER	HyperSAS
410	5	0	2	-1	-9	-4	6	-2	4	-1
443	7	3	0	-4	-9	0	1	-3	6	-1
486	5	4	0	-2	-10	1	-5	-2	10	-1
551	5	4	-2	-7	-9	6	0	-5	9	-1
675	-9	-14	-15	-17	-9	36	38	0	5	-11
All	3	-1	-3	-6	-9	8	8	-2	7	-3

2015 VIIRS Validation Cruise

Band	Hyperpro	Hyperpro	Spec Evo	SBA	HTSRB 1	HTSRB 2	ASD 1	ASD 2	ASD 3	GER	HyperSAS
410	4	13	14	-1	-1	-2	-6	2	-12	-7	-17
443	5	10	10	0	-1	0	-11	-3	-13	-5	-5
486	6	10	5	1	-2	3	-15	-9	-14	1	1
551	7	3	6	-3	-2	6	-11	-2	-9	-6	-4
675	-5	-17	-4	-33	51	72	-5	9	-7	-44	-35
Average	3	4	6	-7	9	16	-10	-1	-11	-12	-12

Field plaque experiment from 11/17



Instrument Percent difference relative to average of all instruments at that station

2016 VIIRS Validation Cruise

Band	Hyp 1	Hyp 2	Hyp 3	Float 1	Float 2	SBA	Spec. Evo	GER	HyperSAS	ASD 1	ASD 2	ASD 3	ASD 4
410	7	8	17	-21	-9	-5	14	-16	12	-10	-3	-6	3
443	9	9	18	-10	-5	-2	9	-10	5	-7	-7	-8	-3
486	10	10	16	-5	-2	0	6	-6	3	-4	-9	-10	-7
551	11	10	15	-3	2	4	6	-5	1	-8	-9	-12	-7
675	14	5	23	18	12	31	-3	-7	-7	-25	-4	-40	5
avg all	10	9	18	-4	0	6	6	-9	3	-11	-6	-15	-2

2018 VIIRS Validation Cruise

Band	Hyp 1	Hyp 2	Hyp 3	Hyp4	Float 1	Float 2	SBA	SEV1	SEV2	GER	SEV3	SVC	ASD
410	-5	-2	-6	-2	1	-3	-13	10	1	-1	8	-14	26
443	-6	-4	-8	-2	-4	-6	-8	2	-3	-3	10	12	22
486	-3	-2	-8	0	-3	-4	-8	1	-3	-1	11	0	22
551	-5	-5	-10	-3	-6	-8	-11	-15	-2	-7	18	26	30
675	-18	-21	-20	-20	-20	-18	-20	-27	15	-15	53	30	86
avg all	-7	-7	-10	-5	-6	-8	-12	-6	1	-5	20	11	37
vg 410-55	-5	-3	-8	-2	-3	-5	-10	0	-2	-3	12	6	25

Average of all station's instrument percent difference relative to avg. of all instruments at each station

All Stations where good VIIRS matchups

Band	All	Profiler	Floater	Above	Hyperpro	SBA	HTSRB	Hypersas	GER	Spec Ev	ASD	NOAA Hyp	Average All
410	0	2	-5	1	2	-5	-3	-1	-6	12	-2	1	0
443	0	2	-3	0	3	-3	-2	0	-3	9	-5	3	0
486	0	3	-1	-1	3	-3	0	1	7	1	-8	4	0
551	0	2	-1	-1	3	-3	2	-1	8	2	-7	4	0
675	0	-6	12	-5	-5	-6	24	-17	-7	1	-3	-4	0
Avg 410-551	0	2	-2	0	3	-4	-1	0	1	6	-6	3	0

Best All Stations where good VIIRS matchups, clear skies and winds < 10kts.

Band	All	Profiler	Floater	Above	Hyperpro	SBA	HTSRB	Hypersas	GER	Spec Ev	ASD	NOAA Hyp	Average All
410	0	3	-3	-1	3	-1	-1	-2	-3	9	-6	2	0
443	0	2	-3	0	3	-3	-2	0	-3	9	-5	3	0
486	0	3	-1	-1	3	-3	0	1	7	1	-8	4	0
551	0	2	-1	-1	3	-3	2	-1	8	2	-7	4	0
675	0	-6	12	-5	-5	-6	24	-17	-7	1	-3	-4	0
Avg 410-551	0	3	-2	-1	3	-3	0	-1	2	5	-7	3	0

Blue water - All Stations where good VIIRS matchups and chlorophyll < 0.1 mg/m^3

Band	All	Profiler	Floater	Above	Hyperpro	SBA	HTSRB	Hypersas	GER	Spec Ev	ASD	NOAA Hyp	Average All
410	0	1	1	-2	1	4	4	-7	1	5	-10	0	0
443	0	2	-3	0	3	-3	-2	0	-3	9	-5	3	0
486	0	3	-1	-1	3	-3	0	1	7	1	-8	4	0
551	0	2	-1	-1	3	-3	2	-1	8	2	-7	4	0
675	0	-6	12	-5	-5	-6	24	-17	-7	1	-3	-4	0
Avg 410-551	0	2	-1	-1	3	-1	1	-2	3	4	-8	3	0

STDEV of the instrument percent difference to the average of all instruments at each station

All Stations where good VIIRS matchups

Band	All	Profiler	Floater	Above	Hyperpro	SBA	HTSRB	Hypersas	GER	Spec Ev	ASD	NOAA Hyp	Average All
410	16	9	12	21	9	11	13	16	15	23	21	8	15
443	12	8	9	15	9	11	10	10	11	17	14	7	11
486	11	8	9	13	8	11	8	8	16	8	10	7	10
551	11	9	9	15	8	12	8	9	22	9	11	7	11
675	41	19	44	40	20	38	46	20	39	31	48	19	34
Avg 410-551	13	9	10	16	9	11	10	11	16	14	14	7	12

Best - All Stations where good VIIRS matchups, clear skies and winds < 10kts.

Band	All	Profiler	Floater	Above	Hyperpro	SBA	HTSRB	Hypersas	GER	Spec Ev	ASD	NOAA Hyp	Average All
410	14	8	11	17	8	10	12	12	15	21	14	7	12
443	12	8	9	15	9	11	10	10	11	17	14	7	11
486	11	8	9	13	8	11	8	8	16	8	10	7	10
551	11	9	9	15	8	12	8	9	22	9	11	7	11
675	41	19	44	40	20	38	46	20	39	31	48	19	34
Avg 410-551	12	8	10	15	8	11	10	10	16	14	12	7	11

Blue - All Stations where good VIIRS matchups and chlorophyll < 0.1 mg/m^3.

Band	All	Profiler	Floater	Above	Hyperpro	SBA	HTSRB	Hypersas	GER	Spec Ev	ASD	NOAA Hyp	Average All
410	12	5	8	13	5	9	8	10	11	13	9	4	5
443	12	8	9	15	9	11	10	10	11	17	14	7	11
486	11	8	9	13	8	11	8	8	16	8	10	7	10
551	11	9	9	15	8	12	8	9	22	9	11	7	11
675	41	19	44	40	20	38	46	20	39	31	48	19	34
Avg 410-551	12	7	9	14	7	11	9	9	15	12	11	6	10

											BEST	
Station 2	out liers remove:		+/- 1 standard deviation								**ESTIMATE**	
	USF H	NOAA H	JRC Mic	NASA CC	UMB SBA	NRL FL	USM ASD	USF ASD	CUNY GER	CUNY SAS	**New Avg**	**New STDEV**
410.0000		0.0067	0.0076	0.0071	0.0071	0.0067		0.0068		0.0074	**0.0070**	**0.0004**
443.0000	0.0057	0.0059		0.0062	0.0060	0.0058		0.0059		0.0061	**0.0059**	**0.0002**
486.0000	0.0047	0.0049	0.0052	0.0049	0.0049	0.0048		0.0048		0.0048	**0.0049**	**0.0002**
551.0000	0.0015	0.0016	0.0016		0.0016	0.0016	0.0015			0.0015	**0.0016**	**0.0000**
675.0000	0.0001	0.0001	0.0002	0.0001	0.0002			0.0002	0.0002	0.0002	**0.0002**	**0.0000**
745.0000	0.0000	0.0000			0.0000					0.0000	**0.0000**	**0.0000**
Sta 3		Sta 3	Sta 3		Sta 3	Sta 3	Sta 3		Sta 3	Sta 3		
	USF H	NOAA H	JRC Mic	NASA CC	UMB SBA	NRL FL	USM ASD	USF ASD	CUNY GER	CUNY SAS	**Average**	
410.0000	0.0062	0.0062				0.0063	0.0059		0.0062	0.0060	**0.0061**	**0.0001**
443.0000	0.0055	0.0055		0.0054		0.0055	0.0052		0.0053		**0.0054**	**0.0002**
486.0000	0.0046	0.0046	0.0046	0.0043		0.0046	0.0043		0.0047		**0.0045**	**0.0001**
551.0000	0.0016	0.0016	0.0015	0.0013	0.0013	0.0016			0.0015	0.0012	**0.0014**	**0.0001**
675.0000	0.0001	0.0001	0.0001	0.0001	0.0002	0.0003			0.0001	0.0001	**0.0001**	**0.0001**
745.0000	0.0000	0.0000									**0.0000**	**0.0000**
Sta 17		noaa										
	USF H	NOAA H	JRC Mic	NASA CC	UMB SBA	NRL FL	USM ASD	USF ASD	CUNY GER	CUNY SAS	**Average**	
410.0000		0.0028	0.0026	0.0024			0.0022	0.0024			**0.0025**	**0.0002**
443.0000			0.0033	0.0031		0.0030	0.0030	0.0032	0.0036	0.0034	**0.0032**	**0.0002**
486.0000			0.0047	0.0048		0.0045	0.0044	0.0048	0.0049	0.0048	**0.0047**	**0.0002**
551.0000			0.0064	0.0067		0.0063	0.0060	0.0064	0.0063	0.0064	**0.0064**	**0.0002**
675.0000			0.0017	0.0015	0.0015	0.0014		0.0016		0.0015	**0.0015**	**0.0001**
745.0000	0.0001	0.0000			0.0002				0.0000		**0.0001**	**0.0001**
Sta 18												
	USF H	NOAA H	JRC Mic	NASA CC	UMB SBA	NRL FL	USM ASD	USF ASD	CUNY GER	CUNY SAS	**Average**	
410.0000		0.0029		0.0027		0.0028	0.0026				**0.0027**	**0.0001**
443.0000			0.0035	0.0032	0.0032	0.0036	0.0032				**0.0033**	**0.0002**
486.0000		0.0049	0.0047	0.0045	0.0044						**0.0046**	**0.0002**
551.0000		0.0052	0.0050	0.0048	0.0047						**0.0049**	**0.0002**
675.0000		0.0009	0.0010	0.0008	0.0009						**0.0009**	**0.0001**
745.0000		0.0000			0.0001						**0.0001**	**0.0000**
Sta 19												
	USF H	NOAA H	JRC Mic	NASA CC	UMB SBA	NRL FL	USM ASD	USF ASD	CUNY GER	CUNY SAS	**Average**	
410.0000	0.0049	0.0045	0.0048	0.0048		0.0055			0.0056		**0.0050**	**0.0005**
443.0000	0.0055	0.0052	0.0048	0.0050		0.0062					**0.0053**	**0.0006**
486.0000	0.0065	0.0064	0.0059	0.0060		0.0076					**0.0065**	**0.0007**
551.0000	0.0039	0.0037	0.0034	0.0032							**0.0035**	**0.0003**
675.0000	0.0004	0.0004	0.0003	0.0005			0.0006		0.0009	0.0010	**0.0006**	**0.0003**
745.0000	0.0000	0.0000									**0.0000**	**0.0000**
Sta 20												
	USF H	NOAA H	JRC Mic	NASA CC	UMB SBA	NRL FL	USM ASD	USF ASD	CUNY GER	CUNY SAS	**Average**	
410.0000	0.0039	0.0036	0.0037	0.0035	0.0034	0.0033			0.0034	0.0036	**0.0035**	**0.0002**
443.0000	0.0046	0.0042	0.0041	0.0038	0.0039	0.0039			0.0039	0.0040	**0.0041**	**0.0002**
486.0000	0.0055	0.0052	0.0051	0.0048	0.0047	0.0048			0.0049	0.0048	**0.0050**	**0.0003**
551.0000	0.0032	0.0030	0.0027	0.0025	0.0027	0.0028			0.0026	0.0026	**0.0028**	**0.0002**
675.0000	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003			0.0003	0.0003	**0.0003**	**0.0000**
745.0000	0.0000	0.0000								0.0000	**0.0000**	**0.0000**
Sta 21												
	USF H	NOAA H	JRC Mic	NASA CC	UMB SBA	NRL FL	USM ASD	USF ASD	CUNY GER	CUNY SAS	**Average**	
410.0000	0.0025	0.0023	0.0022	0.0023	0.0020	0.0020		0.0024			**0.0023**	**0.0002**
443.0000		0.0029	0.0028	0.0028		0.0027	0.0029	0.0028			**0.0028**	**0.0001**
486.0000	0.0041	0.0040	0.0039	0.0040	0.0036	0.0038	0.0037	0.0038		0.0038	**0.0038**	**0.0002**
551.0000	0.0036	0.0035	0.0034	0.0034		0.0033		0.0034		0.0033	**0.0034**	**0.0001**
675.0000	0.0005	0.0004	0.0004	0.0004	0.0004	0.0004	0.0005	0.0005			**0.0005**	**0.0000**
745.0000	0.0000	0.0000			0.0000				0.0000		**0.0000**	**0.0000**
Sta 22												
	USF H	NOAA H	JRC Mic	NASA CC	UMB SBA	NRL FL	USM ASD	USF ASD	CUNY GER	CUNY SAS	**Average**	
410.0000	0.0028	0.0026	0.0025	0.0025	0.0021	0.0023				0.0019	**0.0024**	**0.0003**
443.0000		0.0032	0.0028	0.0028	0.0024	0.0029				0.0025	**0.0028**	**0.0003**
486.0000			0.0036	0.0036		0.0037	0.0039		0.0033	0.0034	**0.0036**	**0.0002**
551.0000			0.0024	0.0023		0.0026	0.0026		0.0022	0.0024	**0.0024**	**0.0002**
675.0000	0.0004	0.0004	0.0003	0.0003		0.0004			0.0003	0.0003	**0.0003**	**0.0000**
745.0000	0.0000	0.0000			0.0000						**0.0000**	**0.0000**
Sta 23												
	USF H	NOAA H	JRC Mic	NASA CC	UMB SBA	NRL FL	USM ASD	USF ASD	CUNY GER	CUNY SAS	**Average**	
410.0000		0.0022	0.0023	0.0022				0.0022			**0.0022**	**0.0000**
443.0000		0.0028	0.0028	0.0027				0.0026			**0.0027**	**0.0001**
486.0000	0.0039	0.0039	0.0038	0.0038				0.0035			**0.0038**	**0.0002**
551.0000	0.0026	0.0026	0.0025	0.0024							**0.0025**	**0.0001**
675.0000	0.0003	0.0003	0.0003	0.0003	0.0003			0.0003			**0.0003**	**0.0000**
745.0000	0.0000	0.0000			0.0000						**0.0000**	**0.0000**

To compare the methods we will look at the variability of the measurements by looking at the standard deviation and coefficient of variation between method replicates

Then compare accuracy by looking at percent difference to references (Hyperpro and station averages)

Every effort was taken to make data consistent.

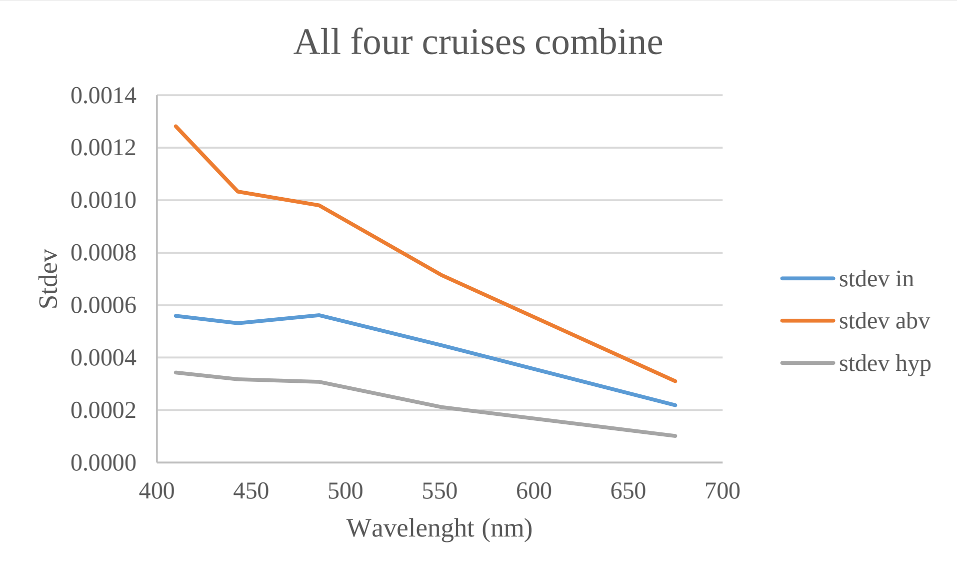
All data is hyperspectral and spectrally weighted to VIIRS NPP Bands.

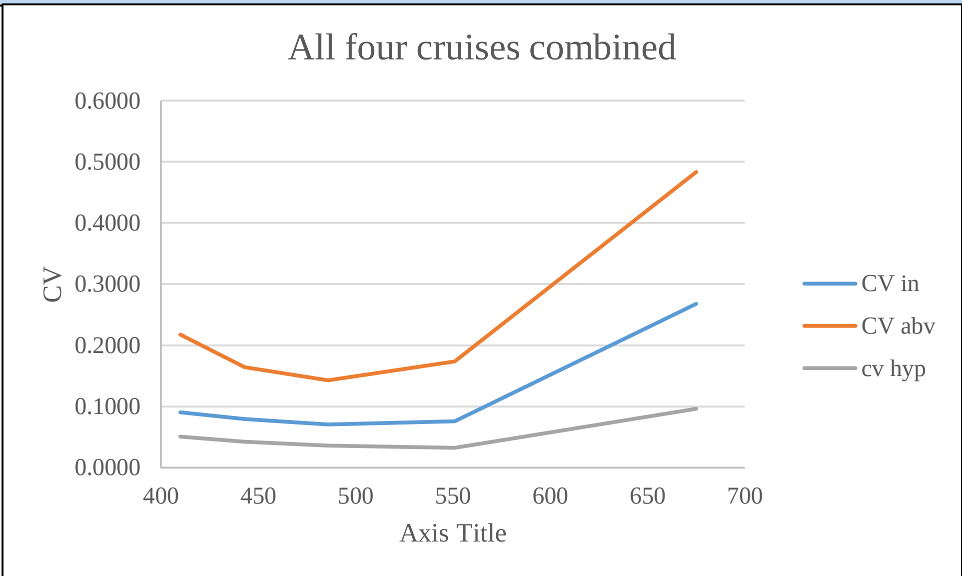
Only stations that have good VIIRS matchups are used in the analysis. These stations must have at least half of the pixels in a 5x5 pixel box after outliers > or < than 1.5 standard deviation are removed.

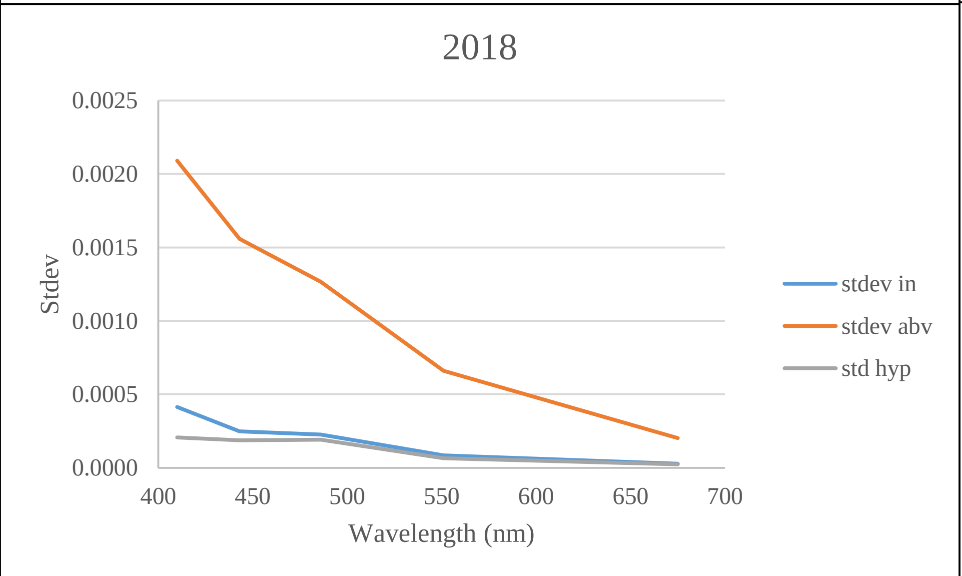
2014 – 9 stations
2015 – 10 stations
2016 – 11 stations
2018 – 17 stations
Total – 47 stations

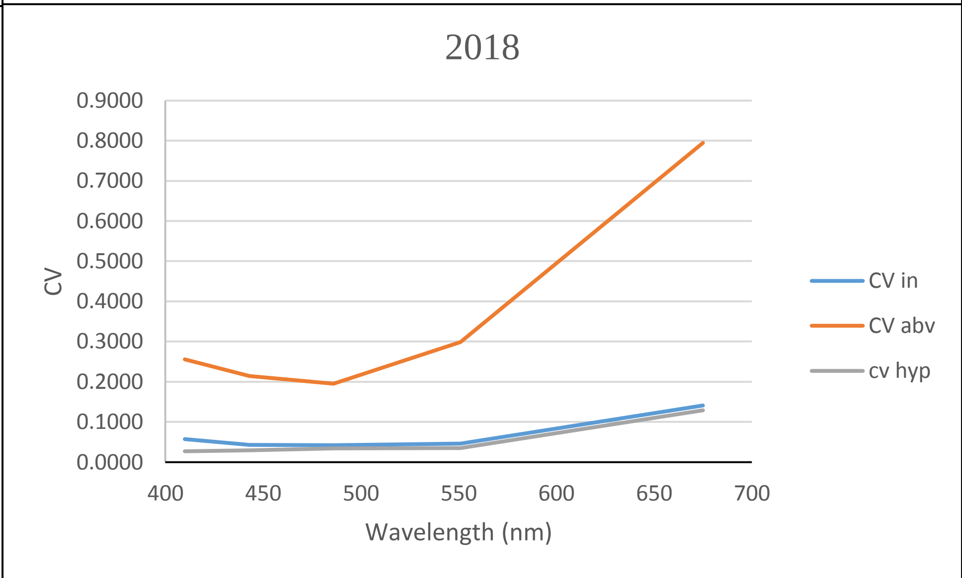
Standard deviation and Coefficeint of variation for all the inwater (in), above-water (abv), and hyperpro (hyp) Rrs for each cruise. SBA is part of inwater..

Standard deviation and Coefficeint of variation for all the inwater (in), above-water (abv), and hyperpro (hyp) Rrs measurements for each cruise and all combined (on top). SBA is part of inwater. Both above-water Stdev and CV are consistently double in-water measurements which are double hyperpro measurements.

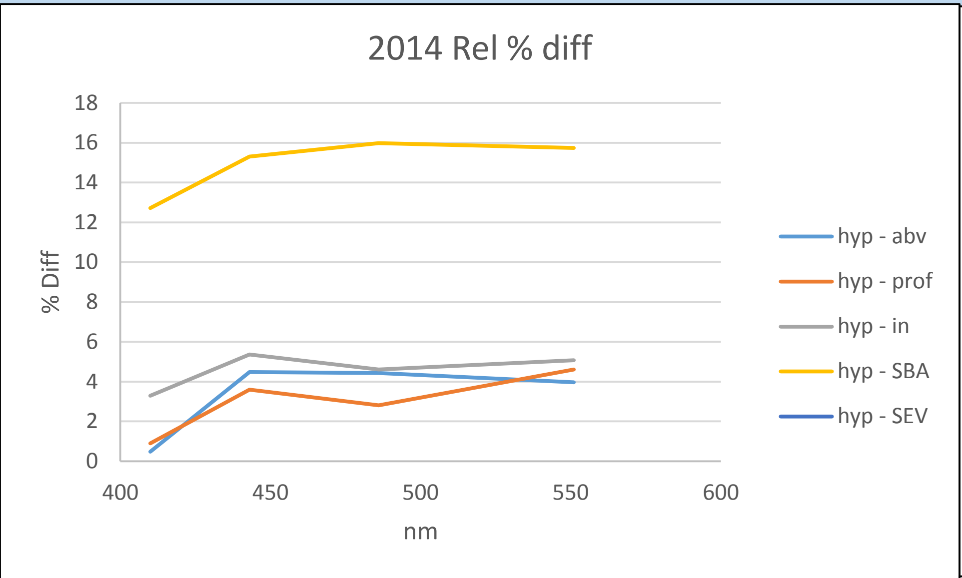


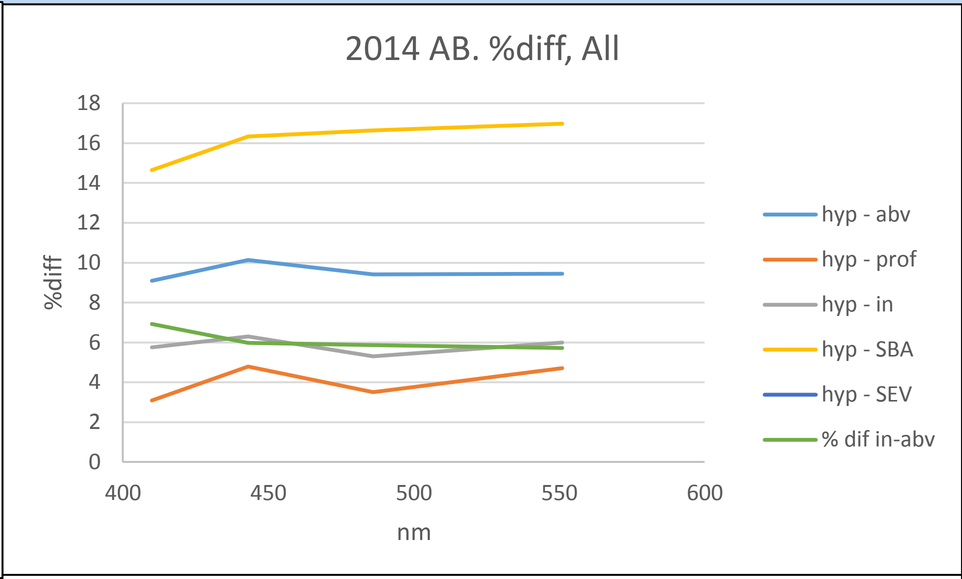


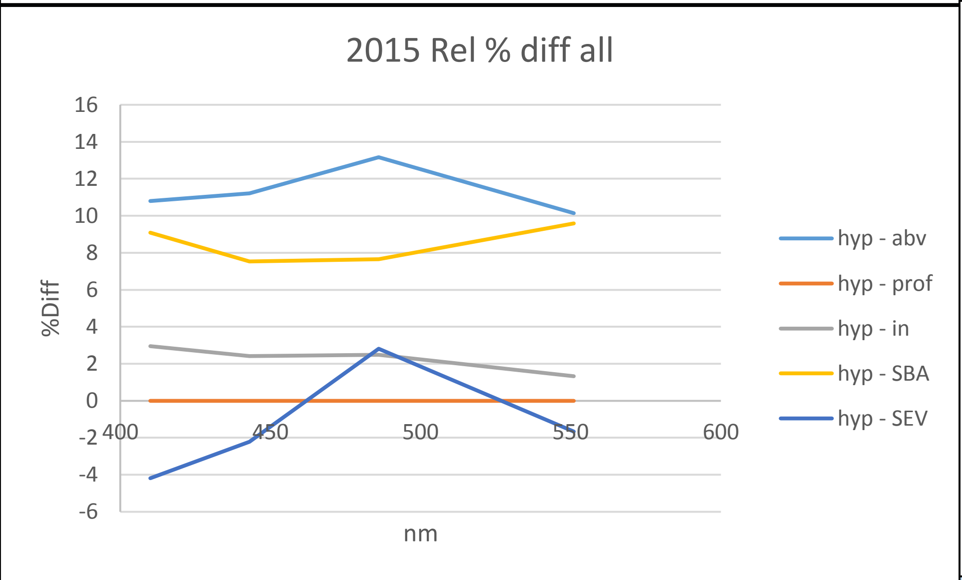


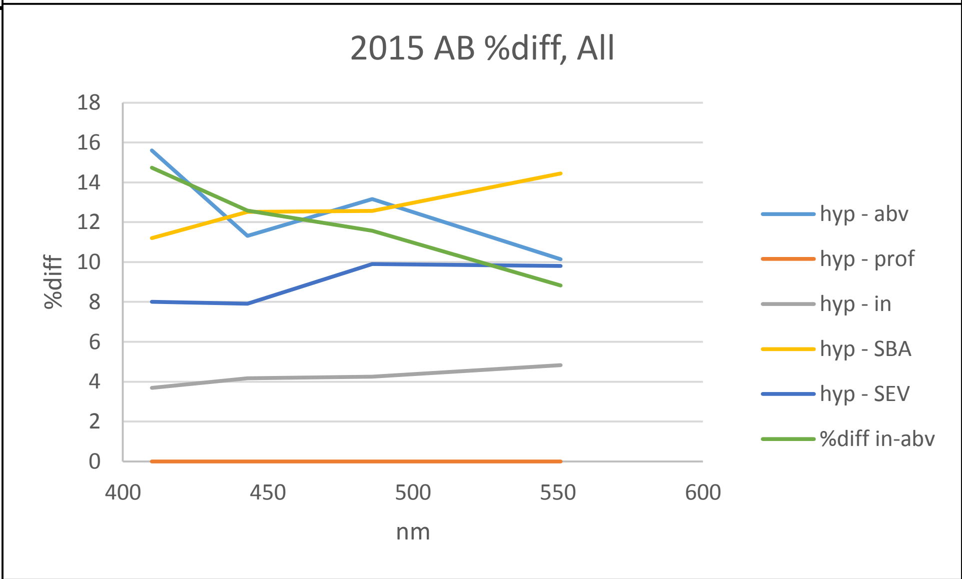


2014 Relative and Absolute Percent Difference to average of all Hyperpro measurements (hyp)
Abv – average of all above-water measurements. Prof – average of all hyperpros, C-ops, and micropro
In – average of all profilers, floaters and SBA. SBA – UMB Skylight Blocking Apparatus
SEV – OSU Spectral Evolution
Top - all stations with good VIIRS matchups. Bottom – Best stations with wind ≤ 10 kts and clouds , 10%

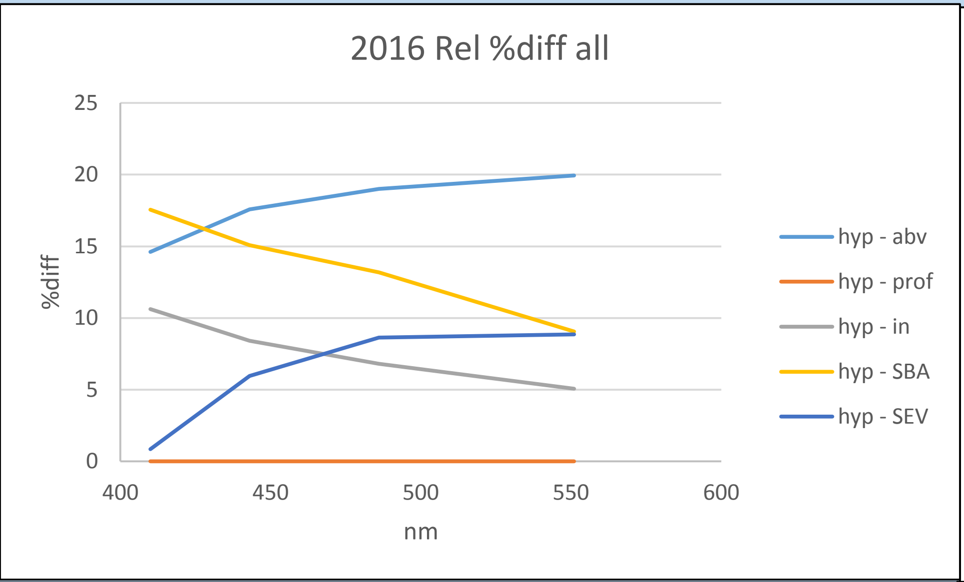


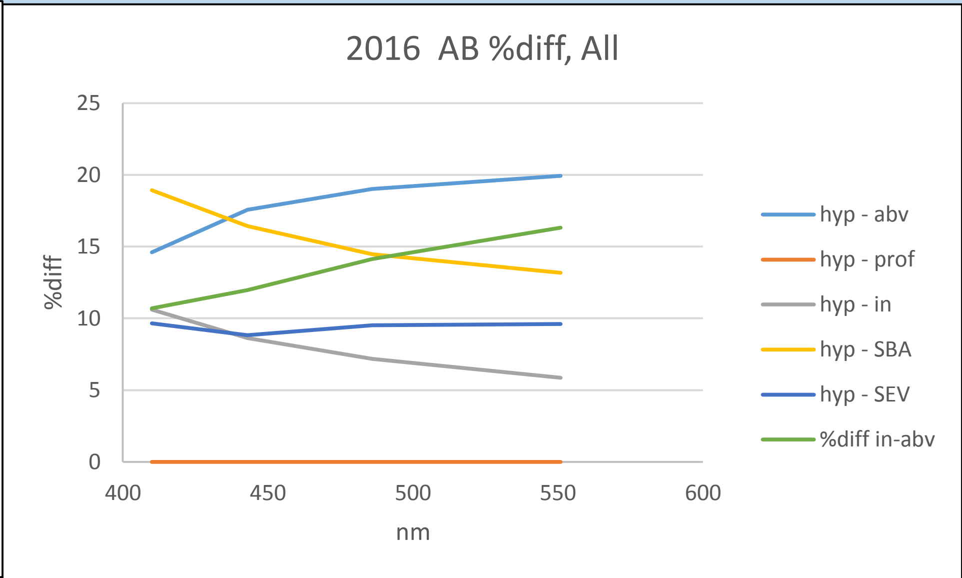


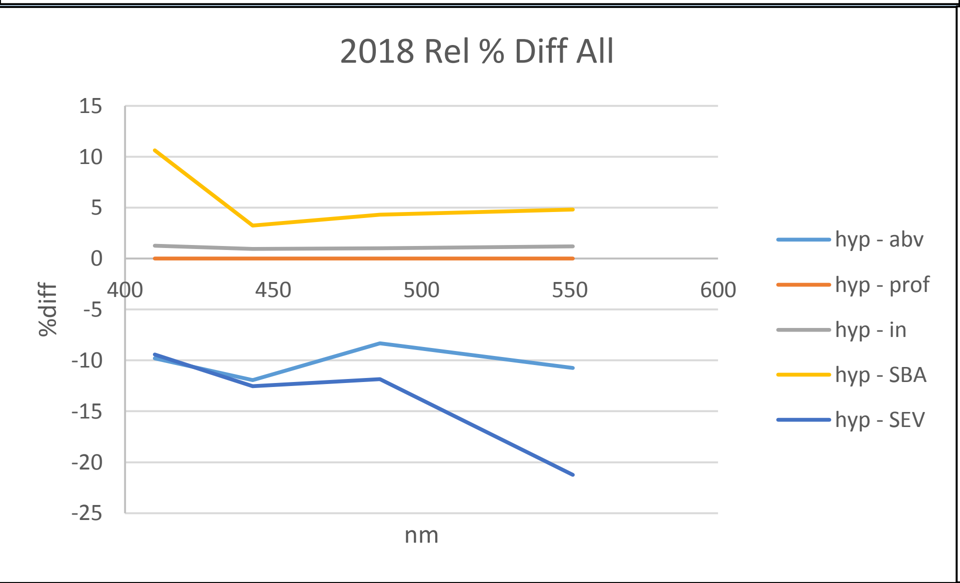


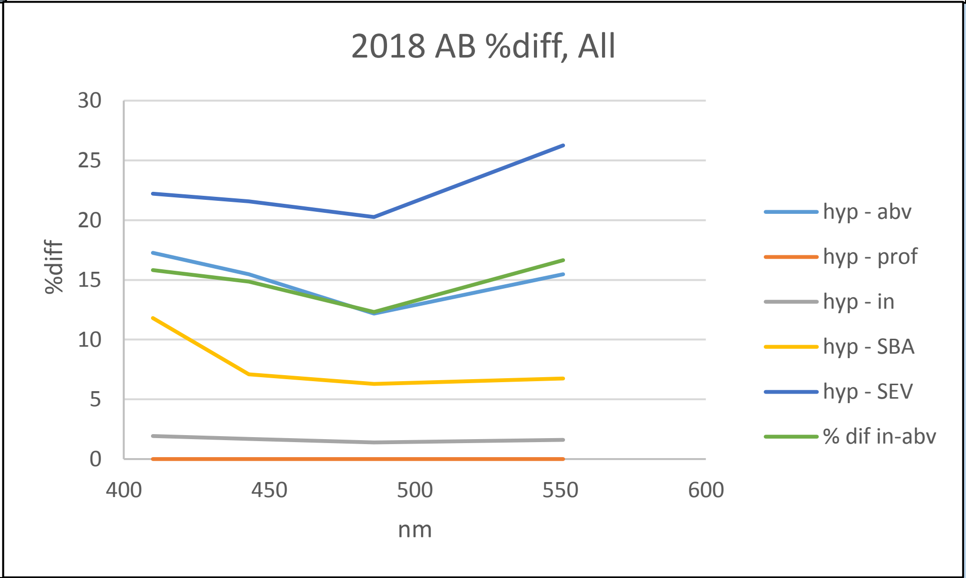


2016 Relative and Absolute Percent Difference to average of all Hyperpro measurements (hyp)
Abv – average of all above-water measurements. Prof – average of all hyperpros, C-ops, and micropro
In – average of all profilers, floaters and SBA. SBA – UMB Skylight Blocking Apparatus
SEV – OSU Spectral Evolution
Top - all stations with good VIIRS matchups. Bottom – Best stations with wind ≤ 10 kts and clouds , 10%

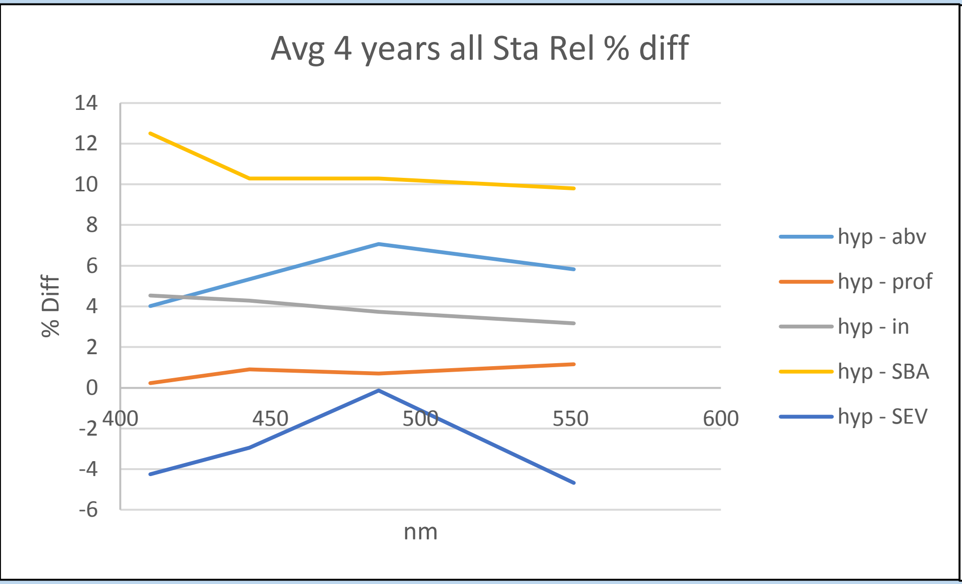


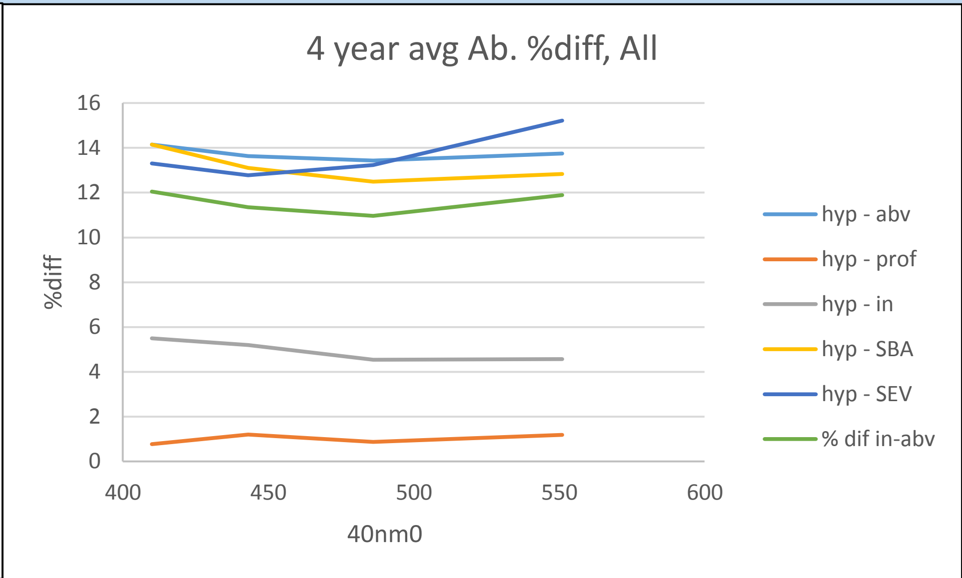






All years Relative and Absolute Percent Difference to average of all Hyperpro measurements
Hyp – average of all hyperpros. Abv – average of all above-water measurements.
Prof – average of all hyperpros, C-ops, and micropro.In – average of all profilers, floaters and SBA.
SBA – UMB Skylight Blocking Apparatus. SEV – OSU Spectral Evolution
Top - all stations with good VIIRS matchups. Bottom – Best stations with wind < 10 kts and clouds , 10%





Conclusions

1. Variability between in-water measurements is less than above-water measurements
2. Hyperpros are most consistent between replicates,
 -due to simultaneous cast and identical instruments and methods
3. Consistency between 10 to 13 independent measurements of water-leaving radiance is generally within 6 % from 410 to 551nm (mean % diff., slide 19).
4. Assuming that the average of the multiple in situ measurements is truth, the accuracy of making a single validation measurement with any calibrated instrument in any water type is within 11% (Stdev, Slide 20). Worst Case.

Summary:

- Bring together JPSS ocean color cal/val team investigators from many agencies and universities to test the consistency in validation measurements being provided to processing centers.

- In four Cal/Val cruises we have occupied 88 stations with 48 matchup stations.

- Provided best in situ validation data to NOAA and other agencies responsible for ocean color processing and quality control.

- Identified sampling uncertainties and problems areas and are constantly working to lower the uncertainties and resolve sampling errors.

- Will continue annual validation cruises. Next expedition is in Sept 2019 aboard the NOAA Gordon Gunter along the east coast or Gulf of Mexico (TBD).

- More information and complete list of measurements can be found in the Cruise Reports-
  - FY2015 - NOAA Technical Report NESDIS 146, DOI:10.7289/V52B8W0Z
  - FY2016 - NOAA Technical Report NESDIS 148, DOI:10.7289/V5/TR-NESDIS-148
  - FY2017 - NOAA Technical Report NESDIS 151, DOI: 10.7289/V5/TR-NESDIS-151