The Importance of FRM in Ocean Color Satellite Data Validation for NOAA

Menghua Wang &

Ocean Color EDR and Cal/Val Teams

NOAA/NESDIS Center for Satellite Applications and Research (STAR)
E/RA3, 5830 University Research Ct.
College Park, MD 20740, USA

The FRM4SOC Workshop
National Physical Laboratory, London, UK, October 4-5, 2018

Website for VIIRS ocean color images and Cal/Val:
http://www.star.nesdis.noaa.gov/sod/mecb/color/

1

VIIRS Ocean Color EDR & Cal/Val Teams

EDR	Name	Organization	Funding Agency	Task
Lead	**Menghua Wang (OC EDR & Cal/Val Lead),** L. Jiang, X. Liu, W. Shi, S. Son, L. Tan, X. Wang, J. Sun, K. Mikelsons, M. Chu, V. Lance, **M. Ondrusek,** E. Stengel, C. Kovach	NOAA/NESDIS/STAR	JPSS/NJO	Leads – Ocean Color EDR Team & Cal/Val Team OC products, algorithms, SDR, EDR, Cal/Val, vicarious cal., refinements, data processing, reprocessing, algorithm improvements, software updates, data validations and analyses
Ocean Color	**Robert Arnone** Sherwin Ladner, Adam Lawson, Jen Bowers	U. Southern MS, NRL, QinetiQ Corp., SDSU	JPSS/NJO	Satellite matchup tool (SAVANT) – Golden Regions, Cruise participation and support WAVE_CIS (AERONET-OC site) operation
	Carol Johnson	NIST	JPSS/NJO	Traceability, AERONET Uncertainty
	Nicholas Tufillaro, Curt Davis	OSU	JPSS/NJO	Ocean color validation, Cruise data matchup West Coast
	Burt Jones, Matthew Ragan	USC	JPSS/NJO	Eureka (AERONET Site)
	Alex Gilerson, Sam Ahmed	CUNY	JPSS/NJO	LISCO (AERONET site), Cruise data and matchup
	Chuanmin Hu	USF	JPSS/NJO	NOAA data continuity, OC data validation
	Ken Voss & **MOBY** team	Miami	JPSS/NJO	Marine Optical Buoy (MOBY)
	Zhongping Lee, Jianwei Wei	UMB	JPSS/NJO	Ocean color IOP data validation and evaluation Ocean color optics matchup

Working with: **NOAA CoastWatch**, VIIRS SDR team, DPA/DPE, Raytheon, NOAA OC Working Group, NOAA various line-office reps, NOAA NCEI, NOAA OCPOP, IOCCG, NASA, ESA, EUMETSAT, etc.

Collaborators: D. Antoine (BOUSSOLE), B. Holben (NASA-GSFC), G. Zibordi (JRC-Italy), R. Frouin (for PAR), and many others.

Summary of VIIRS Ocean Color EDR Products (Updates)

- **Inputs**:
  - VIIRS M1-M7, I1, and the **SWIR** M8, M10, and M11 bands SDR data
  - Terrain-corrected geo-location file
  - Ancillary meteorology and ozone data
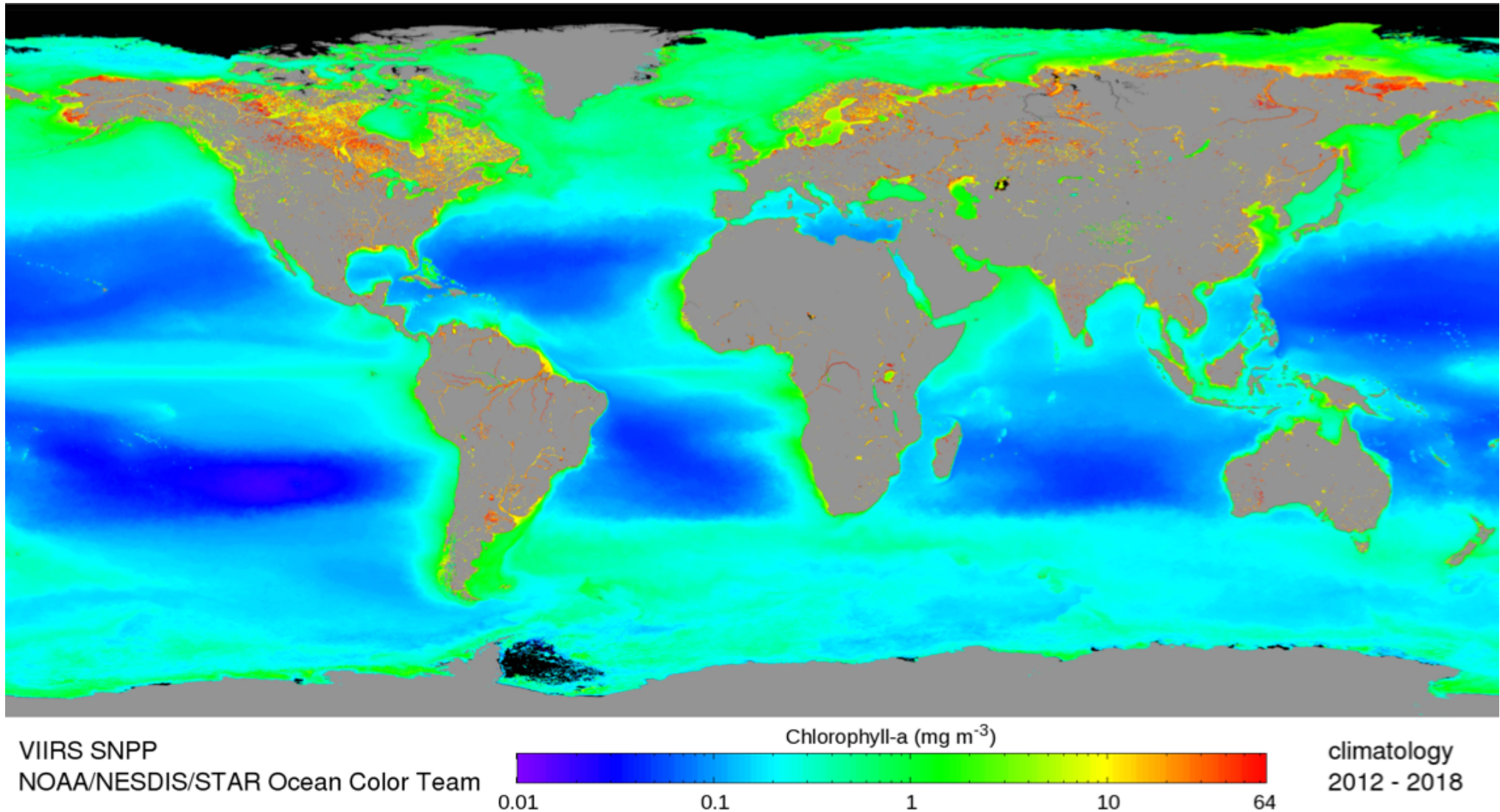- **Operational (Standard) Products (10)**:
  - Normalized water-leaving radiance (nL_w's) at VIIRS visible bands M1-M5, and **I1 (638 nm)**
  - Chlorophyll-a (Chl-a) concentration
  - Diffuse attenuation coefficient for the downwelling spectral irradiance at the wavelength of 490 nm, $K_d(490)$
  - Diffuse attenuation coefficient of the downwelling photosynthetically available radiation (PAR), $K_d(PAR)$
  - **QA Score** for data quality ($nL_w(\lambda)$ spectra) (*Wei et al.*, 2016)
  - Level-2 quality flags
- **Experimental Products (29):**
  - Inherent Optical Properties (IOP-a, IOP-a_{ph}, IOP-a_{dg}, IOP-b_b, IOP-b_{bp}) at VIIRS M2 or other visible bands (M1-M5) from the Quasi-Analytical Algorithm (QAA) (*Lee et al.*, 2002)
  - Photosynthetically Available Radiation (PAR) (*R. Frouin*)
  - Chl-a from ocean color index (OCI) method (*Hu et al.*, 2012; *Wang and Son*, 2016)
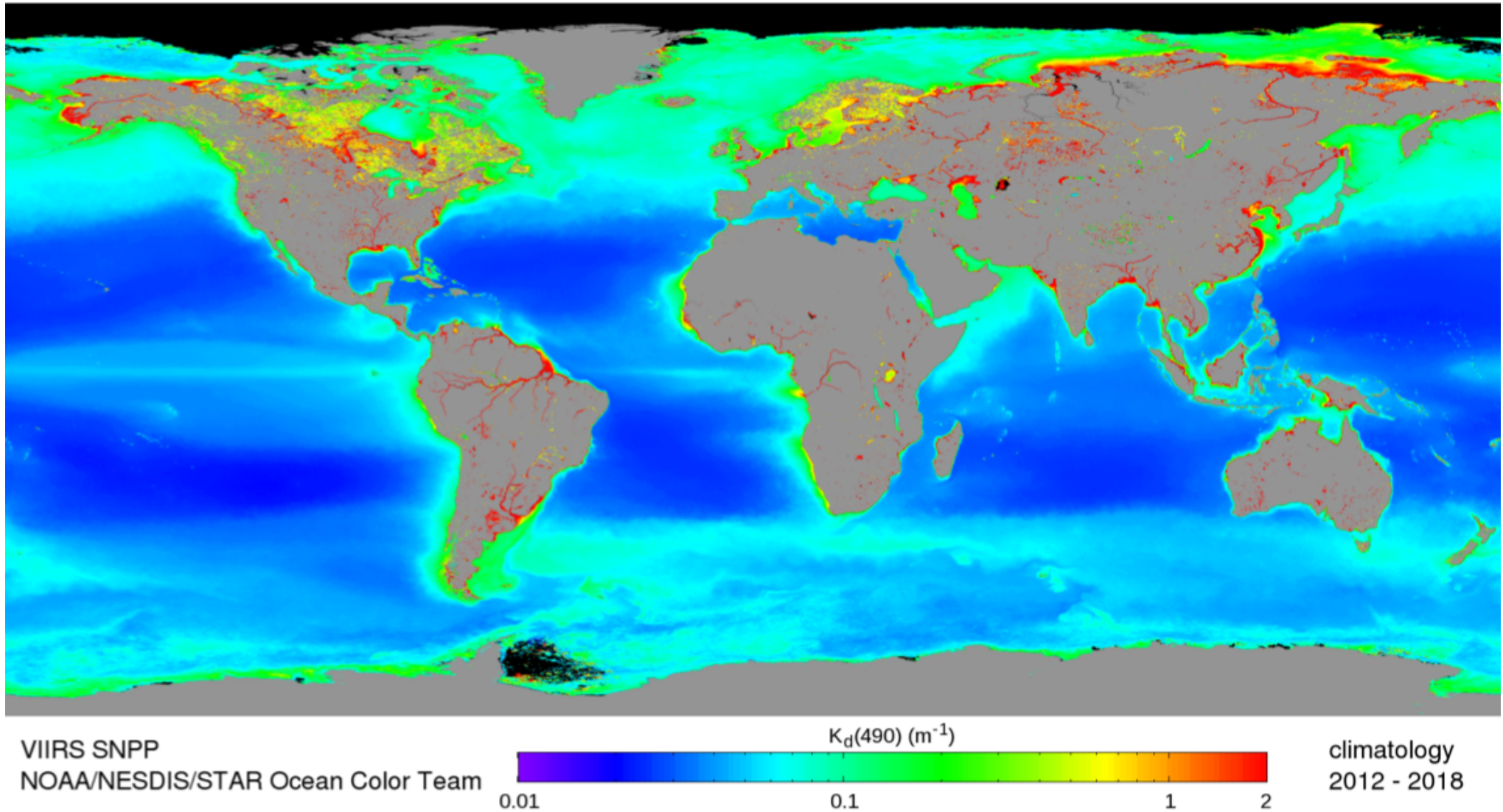 - Others, e.g., user specific products (e.g., **Chl-a anomaly** and **Chl-a anomaly ratio**)

> Data quality of ocean color EDR are extremely sensitive to the SDR quality. It requires **~0.1%** data accuracy (degradation, band-to-band accuracy…)!

VIIRS Climatology Ocean Color Product: Chl-a
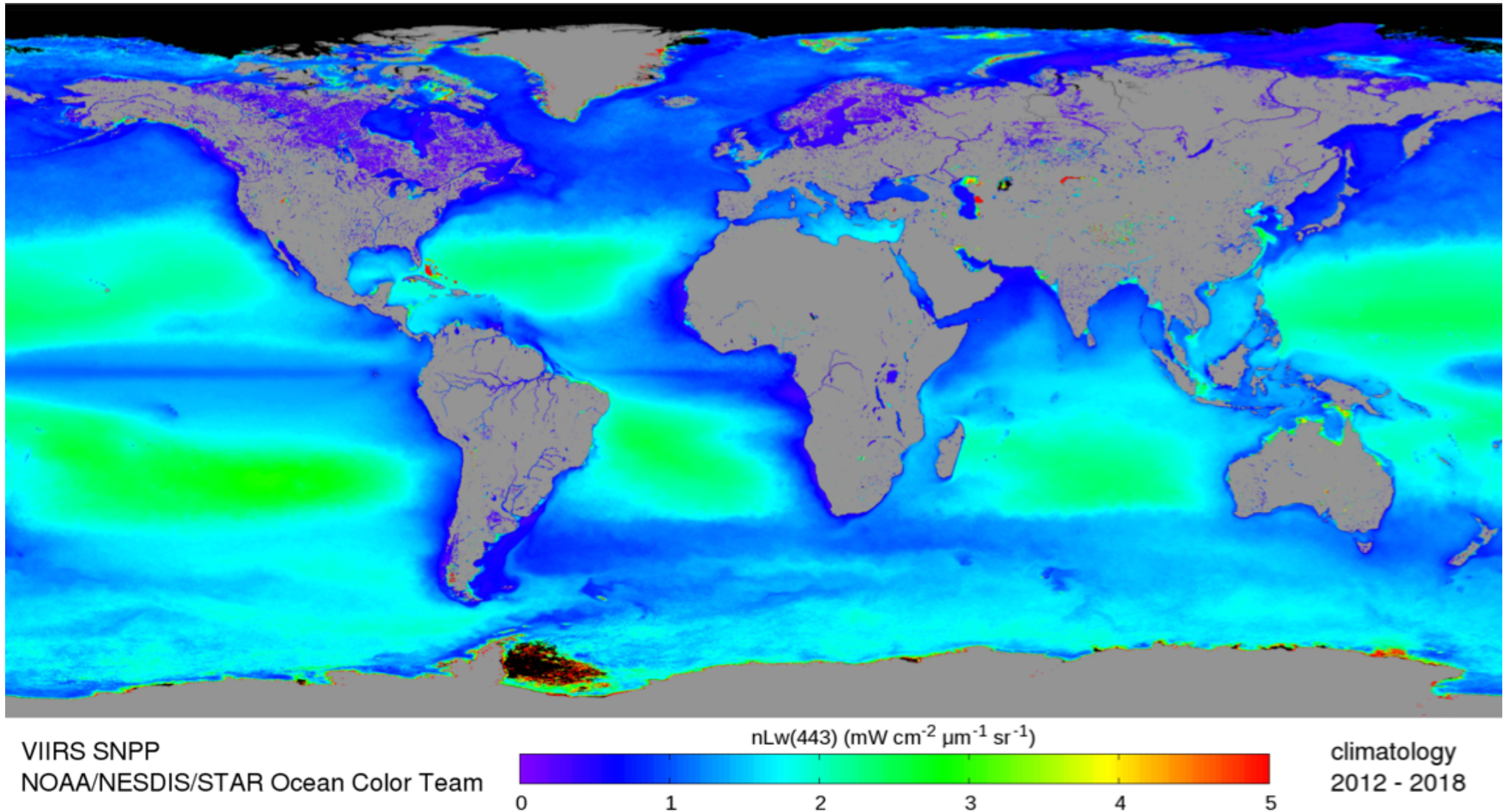## SNPP (2012–2018)

VIIRS SNPP
NOAA/NESDIS/STAR Ocean Color Team

Chlorophyll-a (mg m^{-3})

0.01   0.1   1   10   64

climatology
2012 - 2018

MSL12 with the NIR-SWIR data processing system is used for VIIRS

Menghua Wang, NOAA/NESDIS/STAR

VIIRS Climatology Ocean Color Product: K_d(490) SNPP (2012–2018)

VIIRS SNPP
NOAA/NESDIS/STAR Ocean Color Team

K_d(490) (m^{-1})

0.01   0.1   1   2

climatology 2012 - 2018

MSL12 with the NIR-SWIR data processing system is used for VIIRS

Menghua Wang, NOAA/NESDIS/STAR

VIIRS Climatology Ocean Color Product: nL_w(443) SNPP (2012–2018)

VIIRS SNPP
NOAA/NESDIS/STAR Ocean Color Team

nLw(443) (mW cm^{-2} µm^{-1} sr^{-1})

climatology 2012 - 2018

0   1   2   3   4   5

MSL12 with the NIR-SWIR data processing system is used for VIIRS

Menghua Wang, NOAA/NESDIS/STAR

VIIRS Climatology Ocean Color Product: nL_w(551) SNPP (2012–2018)

VIIRS SNPP
NOAA/NESDIS/STAR Ocean Color Team

nLw(551) (mW cm^{-2} μm^{-1} sr^{-1})

0   0.5   1   1.5   2   2.5   3

climatology 2012 - 2018

MSL12 with the NIR-SWIR data processing system is used for VIIRS

Menghua Wang, NOAA/NESDIS/STAR
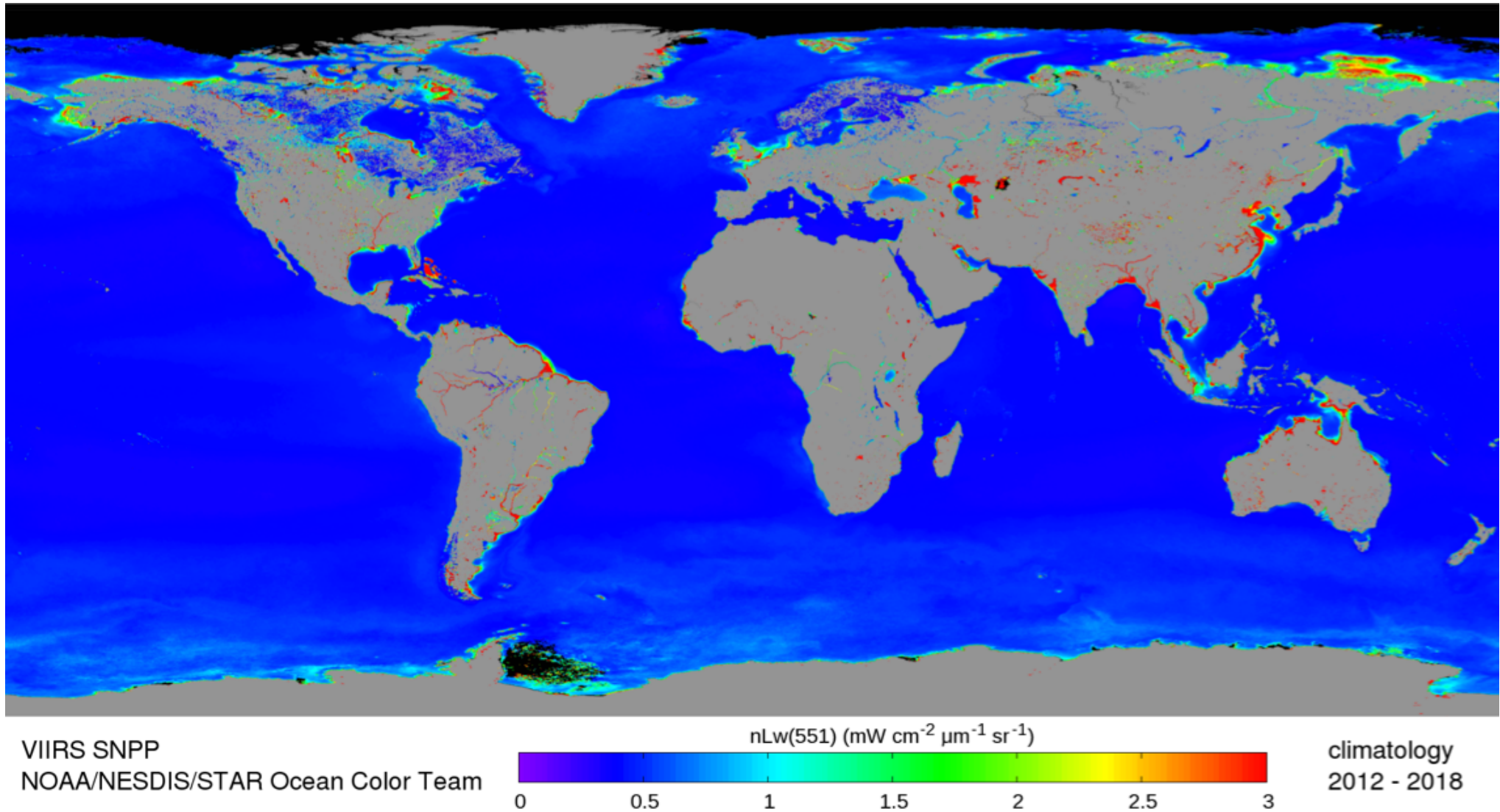
VIIRS Climatology QA Score Image
SNPP (2012–2017)

Climatology from 2012/02 to 2017/06

Atlantic Ocean

Med Sea

Some Coastal Regions

QA score
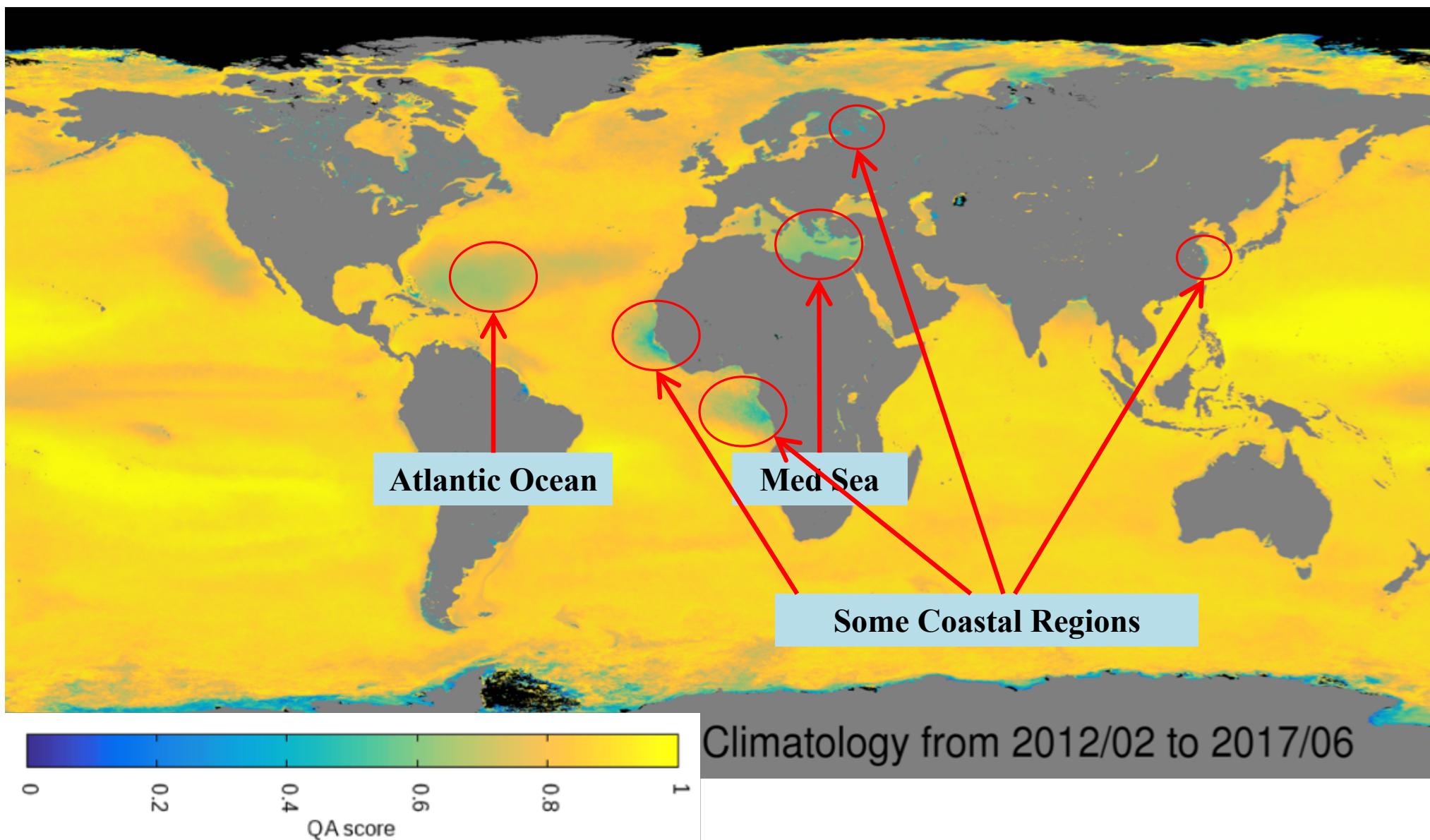
Wei, J., Z. Lee, and S. Shang (2016), "A system to measure the data quality of spectral remote-sensing reflectance of aquatic environments", *J. Geophys. Res., Oceans*, 121, 8189-8207, doi:10.1002/2016JC012126.

Menghua Wang, NOAA/NESDIS/STAR

VIIRS-SNPP Chl-a Anomaly
(July 26, 2018)

West Coast of Florida

Chlorophyll-a anomaly (mg m^{-3})

-2   -1.5   -1   -0.5   0   0.5   1   1.5   2
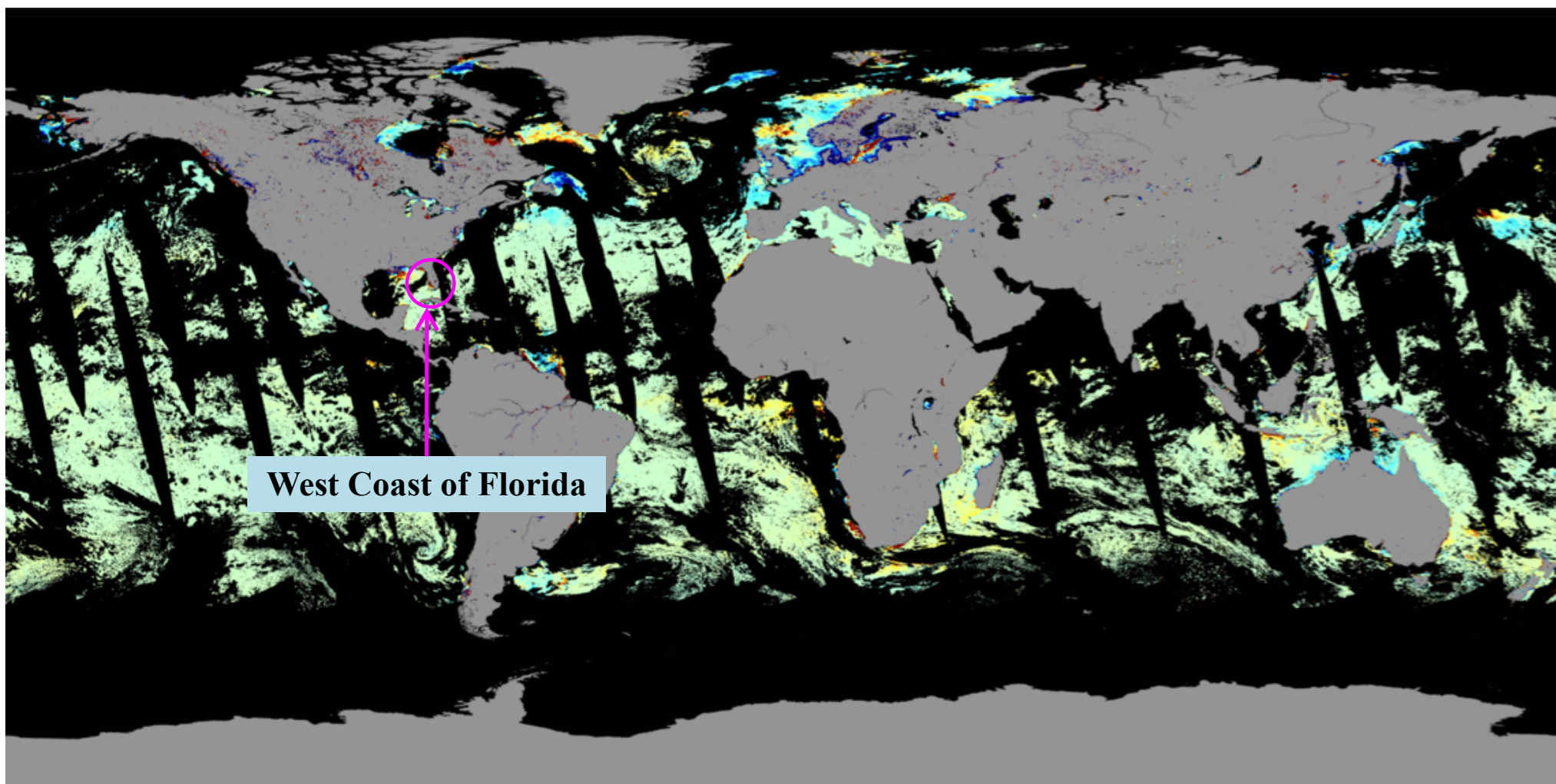
STAR Ocean Color
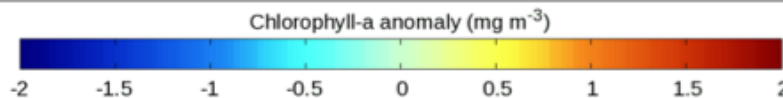
2018-07-26

Global daily NRT Chl-a anomaly and anomaly ratio are Routinely produced

Menghua Wang, NOAA/NESDIS/STAR

High Chl-a Anomaly Linked to HAB in the West Coast of Florida (July 26, 2018)
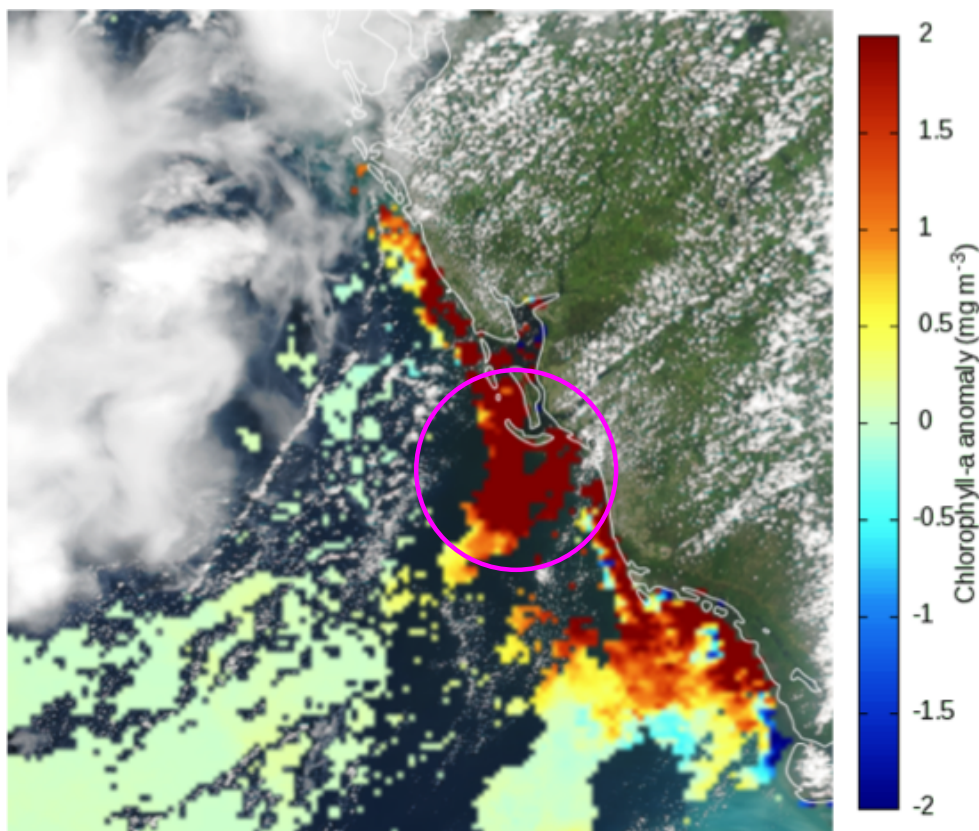
Chl-a Anomaly
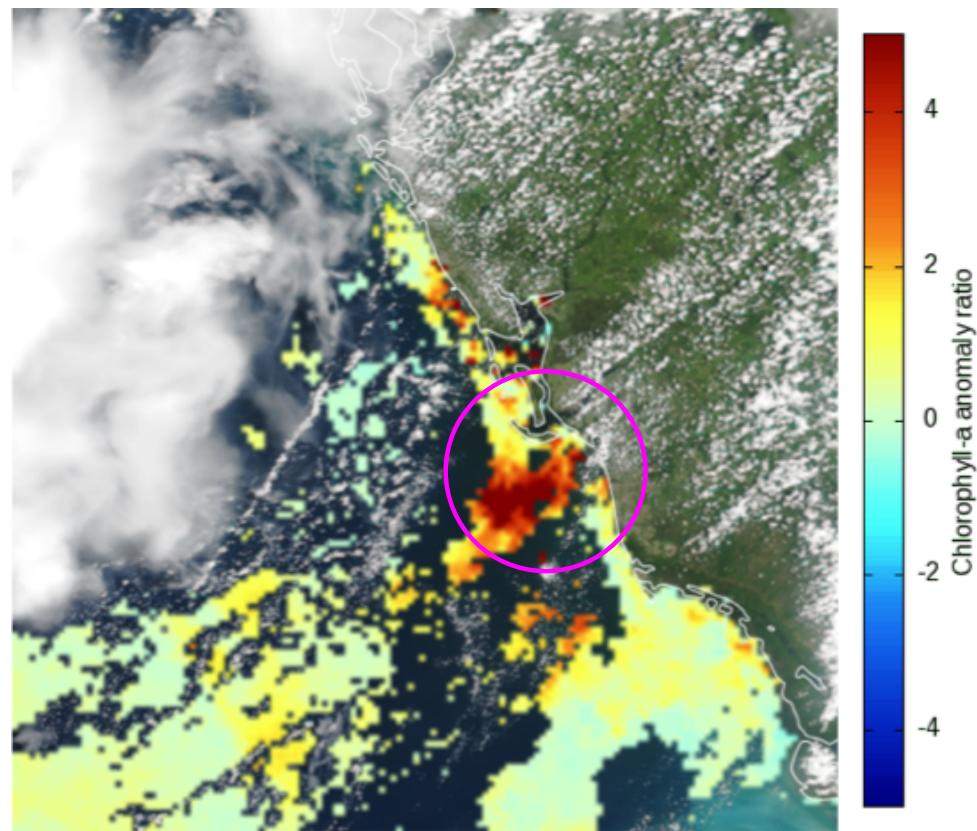
Chl-a Anomaly Ratio
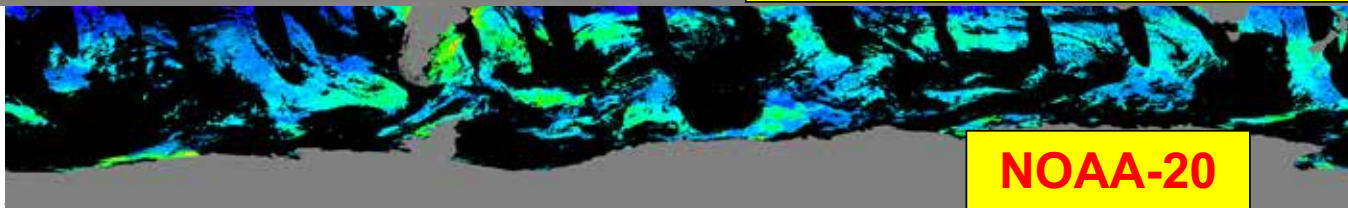
Global NRT Chl-a anomaly and anomaly ratio are routinely produced

Menghua Wang, NOAA/NESDIS/STAR

VIIRS-SNPP and NOAA-20 Chl-a Images
(January 6, 2018)

SNPP

NOAA-20

Menghua Wang, NOAA/NESDIS/STAR

VIIRS-SNPP and NOAA-20 Chl-a Images
(January 6, 2018)

SNPP & NOAA-20 Merged

NOAA-20

Menghua Wang, NOAA/NESDIS/STAR
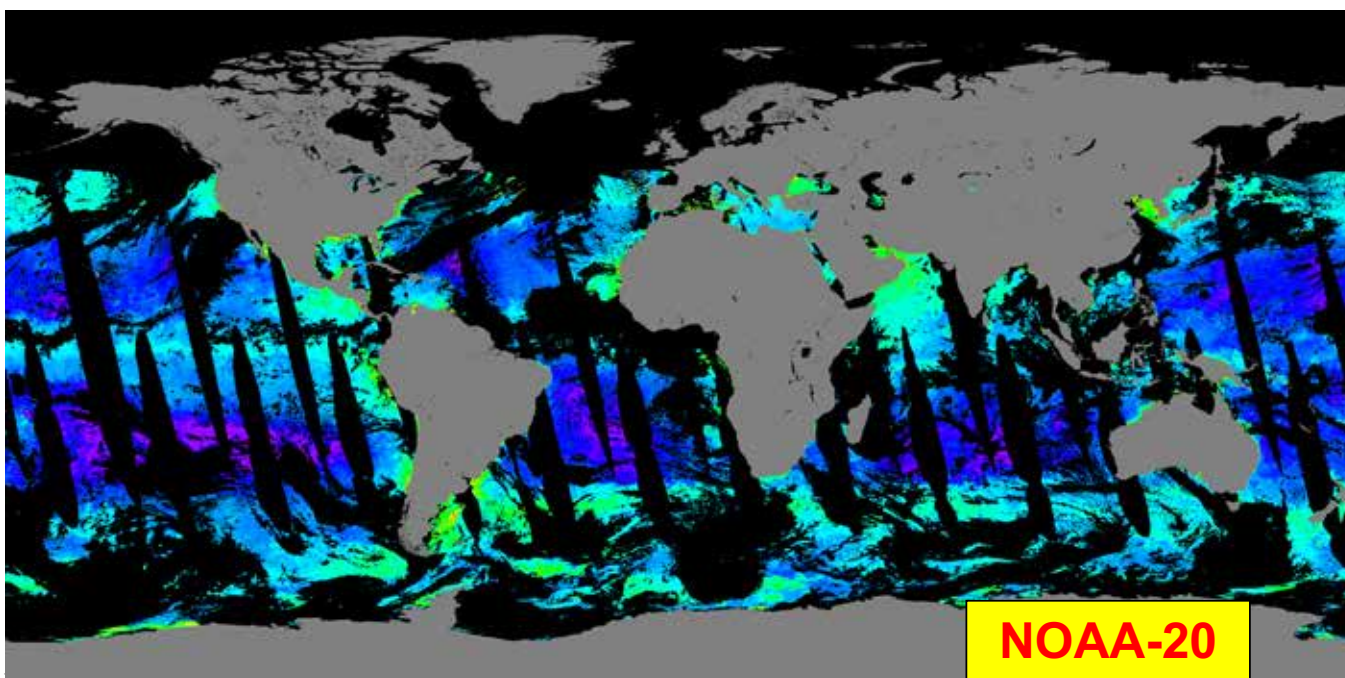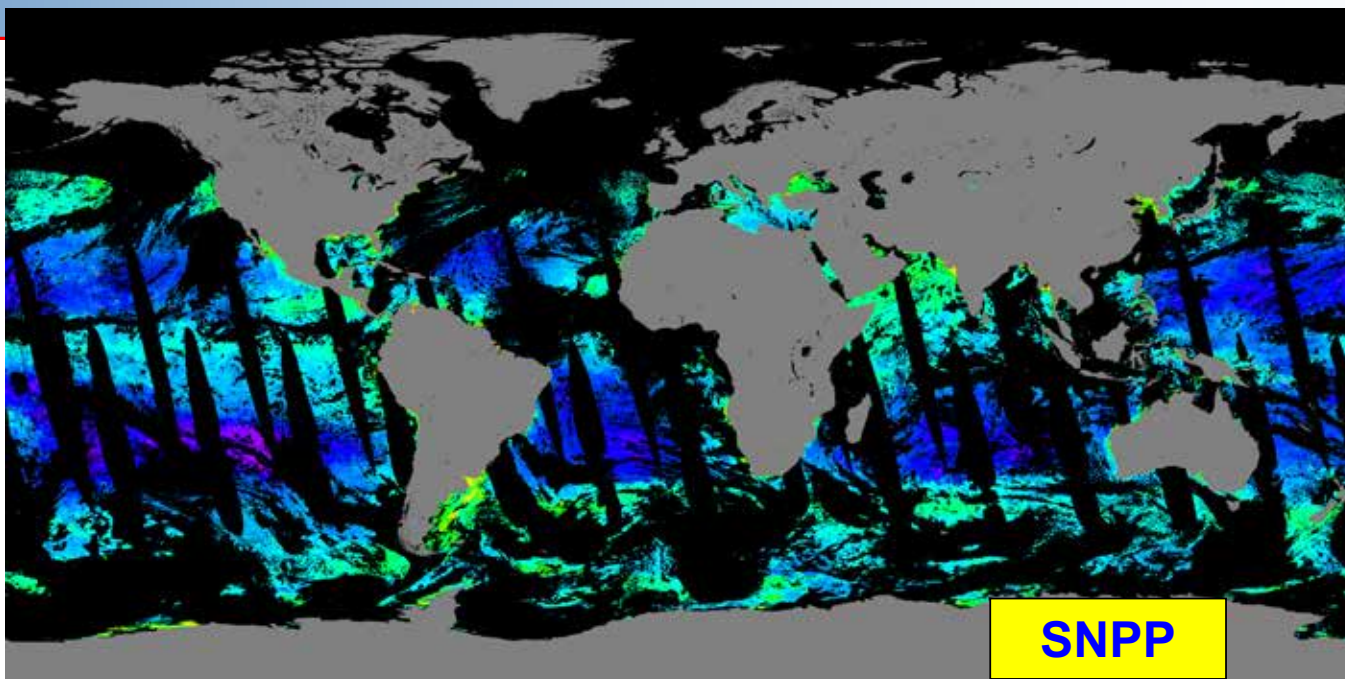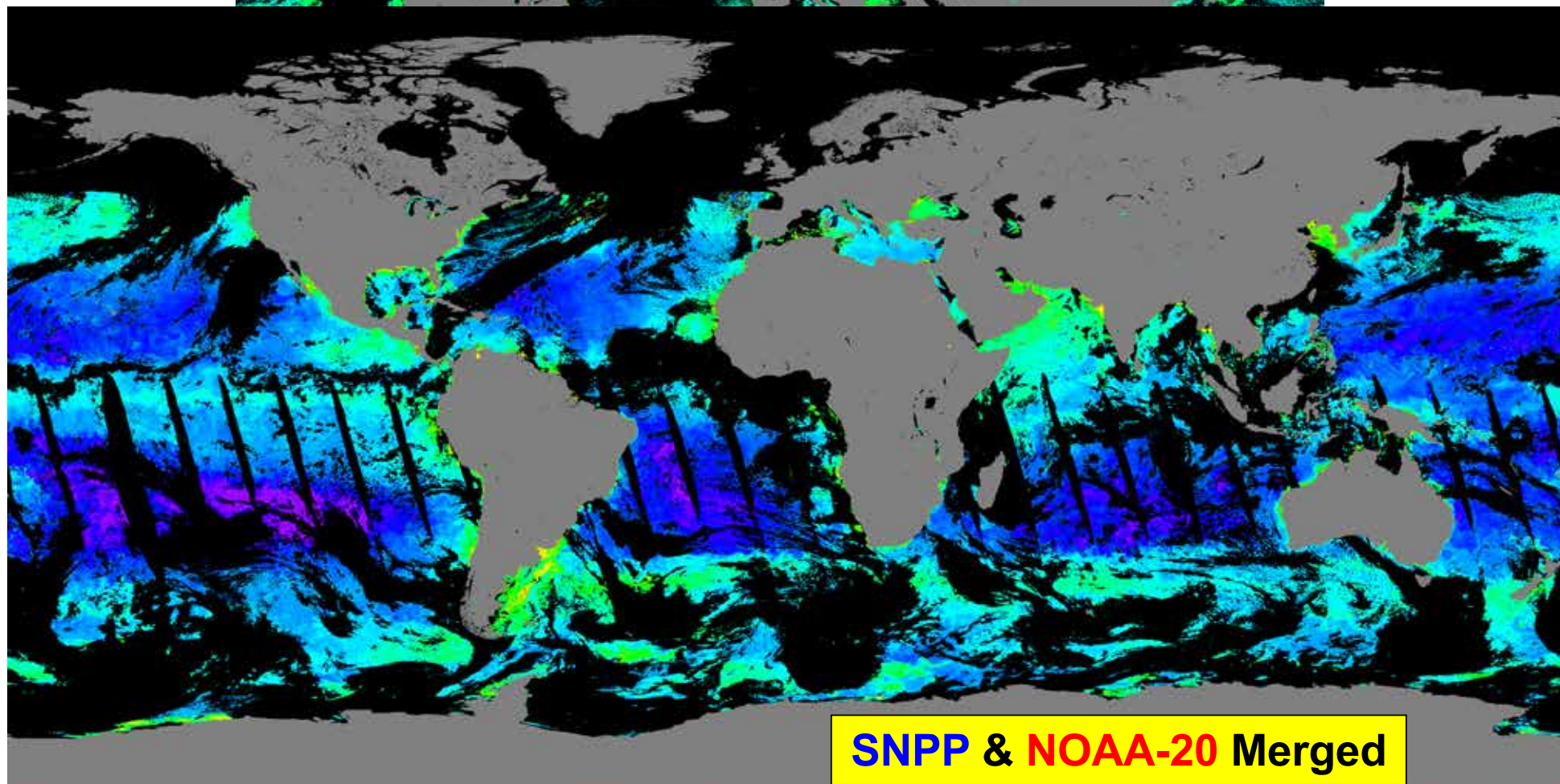
Two Data Streams for VIIRS Ocean Color EDR

To meet requirements from **All** users (operational, research, modeling, etc.), we have been routinely producing VIIRS global ocean color products in **two data streams**: Near-Real-Time (NRT) and Delayed Science-Quality data.

Attribute	Near-Real Time (NRT)	Delayed Science-Quality
Latency:	Best effort, as soon as possible (~12-24h)	Best effort, on 1-2-week delay
Processing System:	MSL12	MSL12
SDR:	IDPS Operational SDR	OC-Improved SDR
Ancillary Data:	Global Forecast System (GFS) Model	Science quality (assimilated; GDAS) from NCEP
Coverage:	May have gaps due to various issues	Complete global coverage
Processed by:	NOAA CoastWatch, transferring to OSPO (operational)	NOAA/STAR
Distributed by:	NOAA CoastWatch, OSPO	NOAA CoastWatch, NCEI
Archive Plans:	Yes, from OSPO to NCEI	Yes, from CoastWatch to NCEI
Full Mission Reprocessing:	No	Yes, every ~2-3 years or as needed

NOAA Capability:
End-to-End Ocean Color Data Processing

➤ NOAA Ocean Color Team has been developing/building the capability for the **End-to-End** satellite ocean color data processing including:

- Level-0 (or Raw Data Records (RDR)) to Level-1B (or Sensor Data Records (SDR)).
- **Level-1B (SDR) to ocean color Level-2 (Environmental Data Records (EDR) using the Multi-Sensor Level-1 to Level-2 (MSL12) ocean color data processing.**
- Level-2 to global Level-3 (routine daily, 8-day, monthly, and climatology data/images).
- Validation of satellite ocean color products (in situ data and data analysis capability).

➤ Support of in situ data collections for VIIRS Cal/Val activities, e.g., **MOBY**, **AERONET-OC** sites (3 sites operation, added **Lake Erie site**), **NOAA dedicated Cal/Val cruises** (2014, 2015, 2016, **2018, 2019** ….,)

➤ **On-orbit instrument calibration (solar and lunar) for ocean color data processing:**

- J. Sun and M. Wang, "Radiometric calibration of the VIIRS reflective solar bands with robust characterizations and hybrid calibration coefficients," Appl. Opt., 54, 9331–9342, 2015.

➤ **On-orbit vicarious calibration using MOBY in situ data:**

- M. Wang, W. Shi, L. Jiang, and K. Voss, "NIR- and SWIR-based on-orbit vicarious calibrations for satellite ocean color sensors," *Opt. Express*, **24**, 20437-20453, 2016.

➤ **RDR (Level-0) to SDR (Level-1B) data processing** (efficient RDR to SDR processing)**:**

- Sun, J., M. Wang, L. Tan, and L. Jiang, "An efficient approach for VIIRS RDR to SDR data processing," *IEEE Geosci. Remote Sens. Lett.*, **11**, 2037–2041, 2014.

➤ **Ocean Color Viewer (OCView)**—Online display and monitoring of ocean color product imagery.

➤ **Ocean Color Data Analysis and Processing System (OCDAPS)**—IDL-based VIIRS ocean color data visualization and processing package

- Wang, X., X. Liu, L. Jiang, M. Wang, and J. Sun, "VIIRS ocean color data visualization and processing with IDL-based NOAA-SeaDAS", *Proc. SPIE 9261*, 8 Nov. 2014.

➤ **Work with users to meet their requirements.**

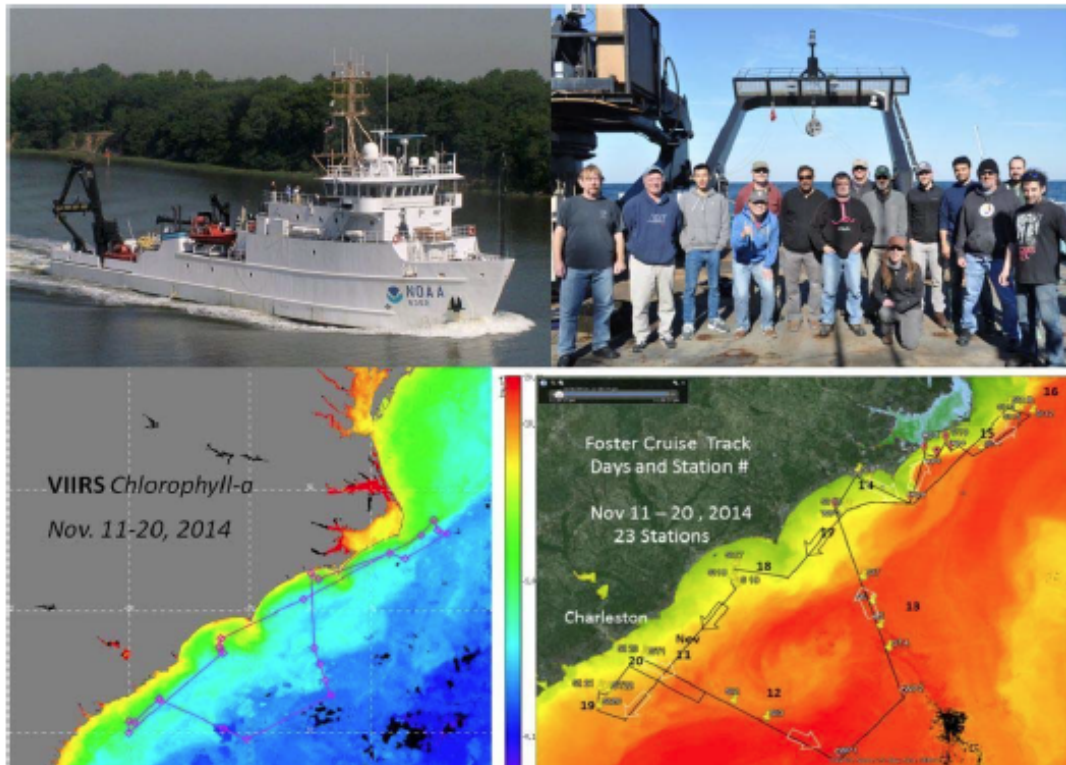# Report for the 2014 NOAA dedicated Cal/Val cruise has been published!

NOAA Technical Report NESDIS 146

DOI: 10.7289/V52B8W0Z

Report for Dedicated JPSS VIIRS Ocean Color Calibration/Validation Cruise

Dedicated VIIRS Cal/Val Cruises

VIIRS Chlorophyll-a
Nov. 11-20, 2014

Foster Cruise Track
Days and Station #

Nov 11 – 20 , 2014
23 Stations

Charleston

Ondrusek, M., E. Stengel, V. P. Lance, M. Wang, K. J. Voss, G. Zibordi, M. Talone, Z. P. Lee, J. Wei, J. Lin, C. Hu, D. English, C. Kovach, J. Cannizzaro, A. Gilerson, S. Ahmed, A. Ibrahim, A. El-Habashi, R. Foster, R. Arnone, R. Vandermeulen, S. Ladner, W. Goode, J. I. Goes, H. Gomes, A. Chekalyuk, K. McKee, S. Freeman, A. Neeley, and B. C. Johnson, "Report for Dedicated JPSS VIIRS Ocean Color Calibration/Validation Cruise," *NOAA Technical Report NESDIS 146*, V. P. Lance (ed.), NOAA National Environmental Satellite, Data, and Information Service, Silver Spring, Maryland, 2015. http://dx.doi.org/10.7289/V52B8W0Z
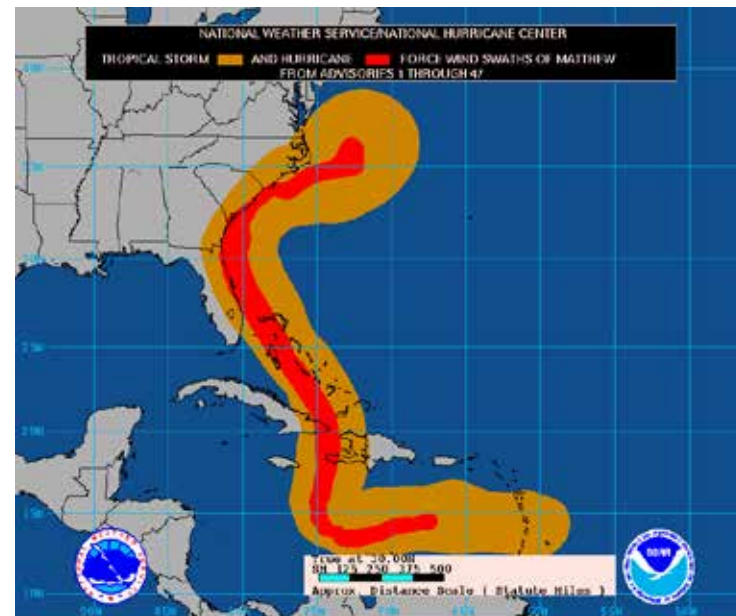
NOAA Technical Report NESDIS 148

Report for
Dedicated JPSS VIIRS Ocean Color
## Calibration/Validation Cruise
December 2015
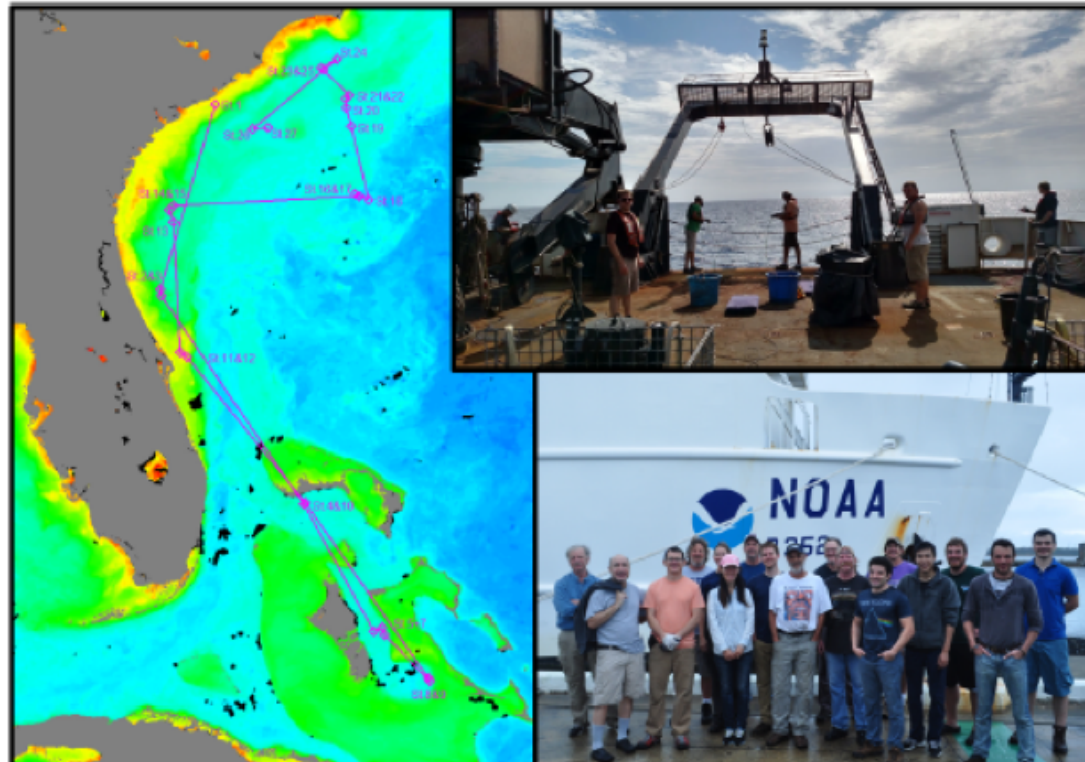
Report for the 2015 NOAA dedicated Cal/Val cruise has been published!

Ondrusek, M., V. P. Lance, E. Stengel, M. Wang, R. Arnone, S. Ladner, W. Goode, R. Vandermeulen, S. Freeman, J. E. Chaves, A. Mannino, A. Gilerson, S. Ahmed, C. Carrizo, A. El-Habashi, R. Foster, M. Ottaviani, J. I. Goes, H. Gomes, K. McKee, C. Hu, C. Kovach, D. English, J. Cannizzaro, B. C. Johnson, Z. P. Lee, J. Wei, Q. Wang, J. Lin, N. Tufillaro, J. Nahorniak, C. O. Davis, and K. J. Voss, "Report for Dedicated JPSS VIIRS Ocean Color Calibration/Validation Cruise December 2015," *NOAA Technical Report NESDIS 148*, V. P. Lance (ed.), NOAA National Environmental Satellite, Data, and Information Service, Silver Spring, Maryland, 2016. http://dx.doi.org/10.7289/V5/TR-NESDIS-148

NOAA Technical Report NESDIS 148

**Report for
Dedicated JPSS VIIRS Ocean Color
Calibration/Validation Cruise
December 2015**
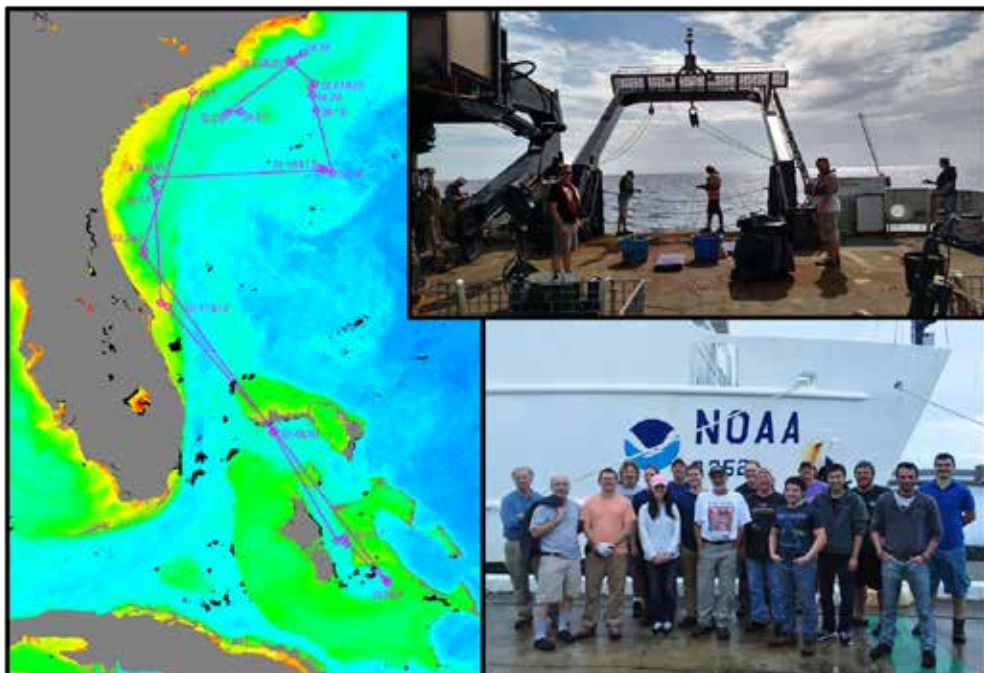
Washington, D.C.
October 2016

**Report for
Dedicated JPSS VIIRS
Ocean Color Cal/Val
cruise has been published!**

Ondrusek, M., V. P. Lance, M. Wang, E. Stengel, C. Kovach, R. Arnone, S. Ladner, W. Goode, A. Gilerson, S. Ahmed, A. El-Habashi, R. Foster, M. Ottaviani, J. I. Goes, H. Gomes, K. McKee, J. W. Kang, C. Hu, J. Cannizzaro, S. Sun, D. English, B. C. Johnson, Z. P. Lee, L. Zoffoli, J. Lin, N. Tufillaro, I. Lalovic, J. Nahorniak, C. O. Davis, M. Twardowski, N. Stockley, and K. J. Voss, "Report for Dedicated JPSS VIIRS Ocean Color Calibration/Validation Cruise October 2016," *NOAA Technical Report NESDIS 151*, V. P. Lance (ed.), NOAA National Environmental Satellite, Data, and Information Service, Silver Spring, Maryland, 2017. http://dx.doi.org/10.7289/V5/TR-NESDIS-151
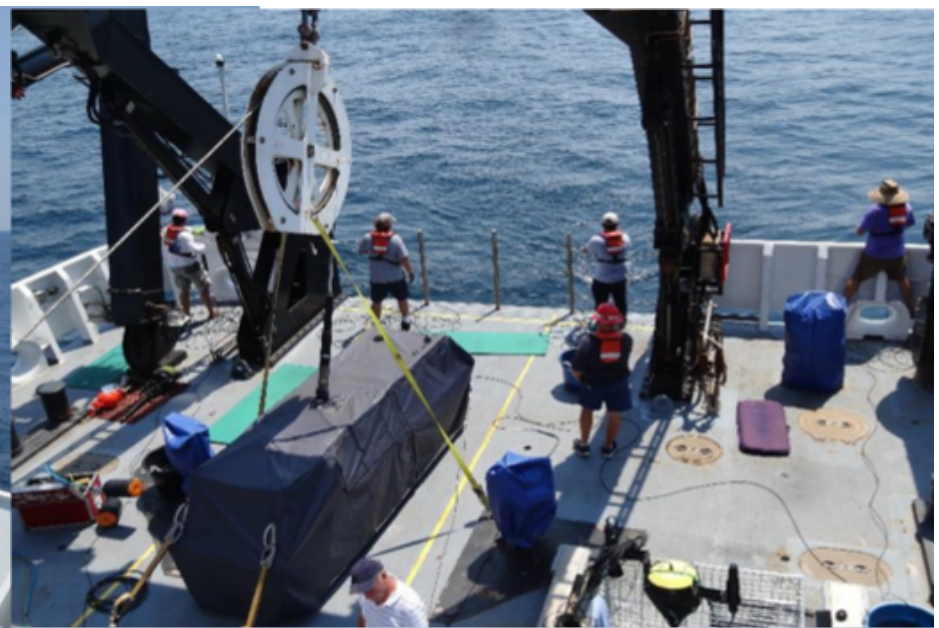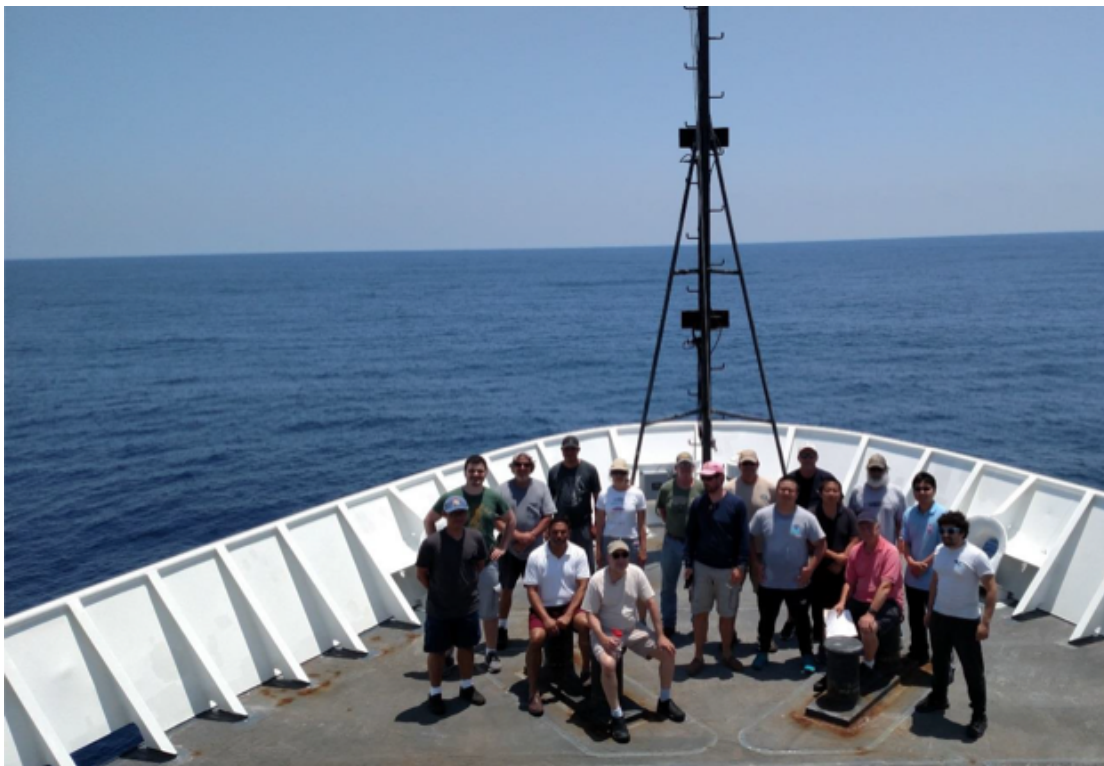
Dedicated VIIRS Cal/Val Cruise IV
NOAA Ship *Okeanos Explorer*
9-18 May 2018

Cal/Val cruise report will be published early next year!
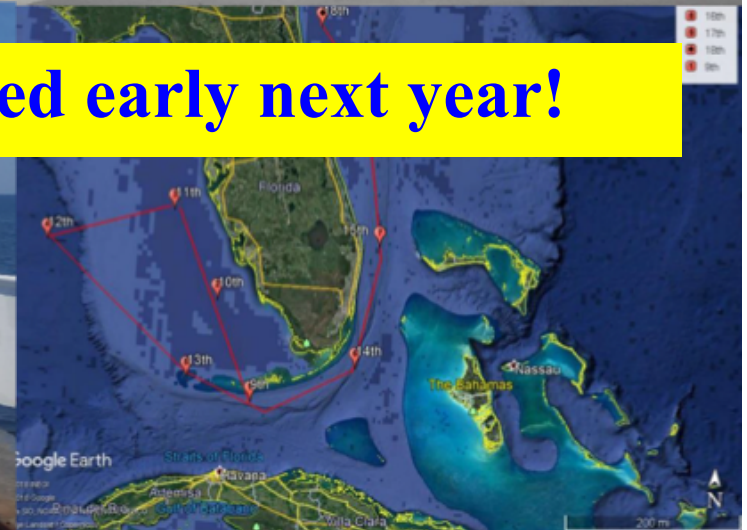
➢ The three secondary lamps and the Gamma Scientific 5000 housing were shipped to the NPL in April 2017. One lamp was damaged during transit.

➢ Measurements conducted by NPL personnel.

➢ NOAA lamp measurements agree well with the NPL scale and other systems
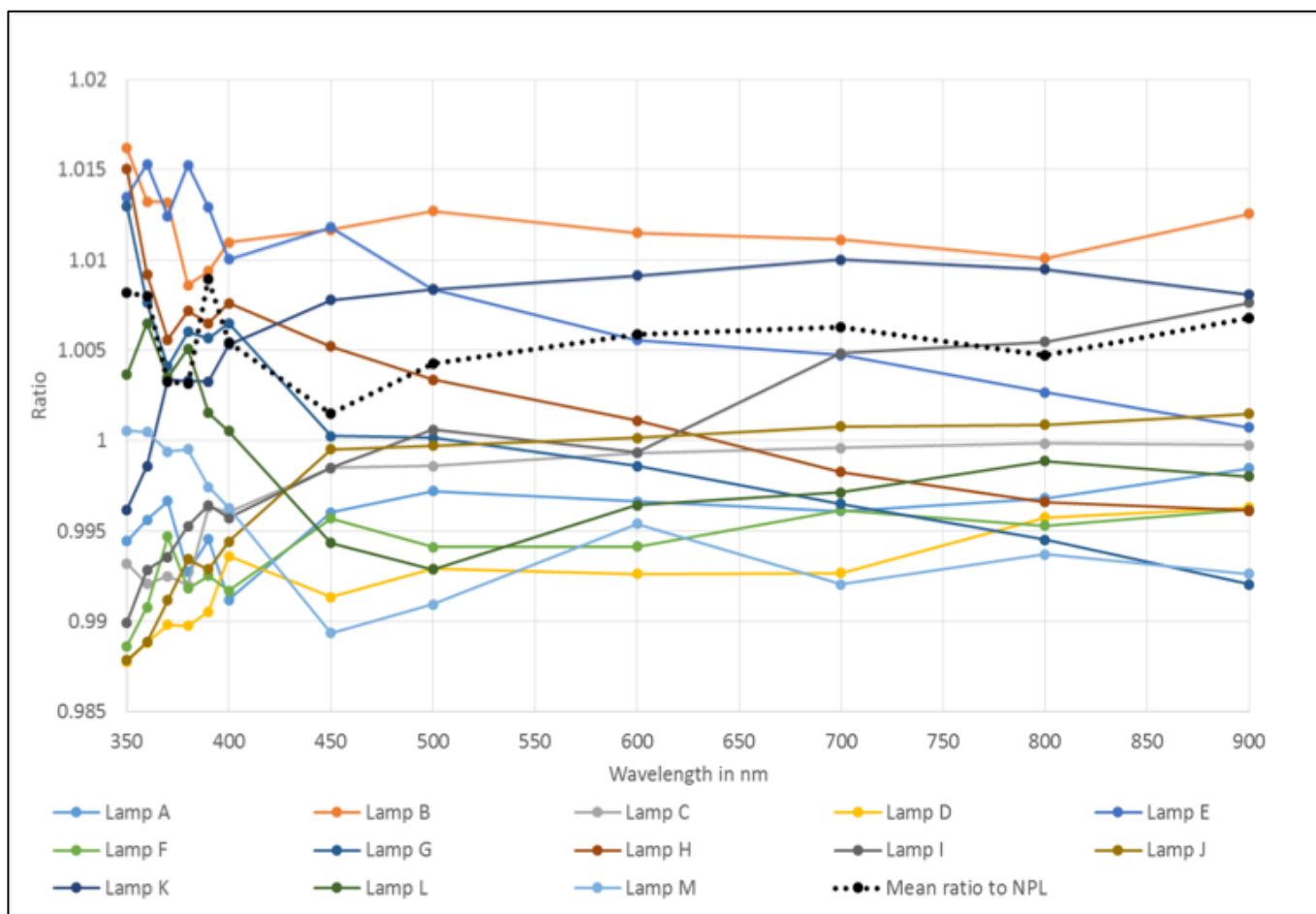

Ratio to NPL measurements

From **Michael Ondrusek**

**Verify the Performance of Reference Radiance Sources used by Fiducial Reference Measurement (FRM) Ocean Color Radiometers for Satellite Validation**

➢ On 1/24/2018 and 1/25/2018, conducted radiance source calibration exercise. Conducted measurements of **NPL** supplied radiometers 110 and 051 using prescribed protocols.

➢ Data supplied to **NPL** on September 10, 2018. Inter-comparison results pending.

➢ Measurements of **NPL** supplied radiometers conducted using same Gamma Scientific 5000 lamp holder and same Gamma Scientific lamp utilized in irradiance calibration exercise.
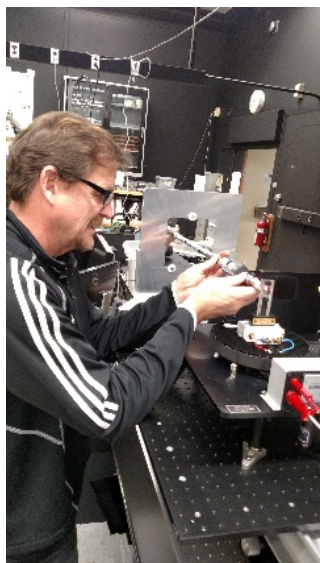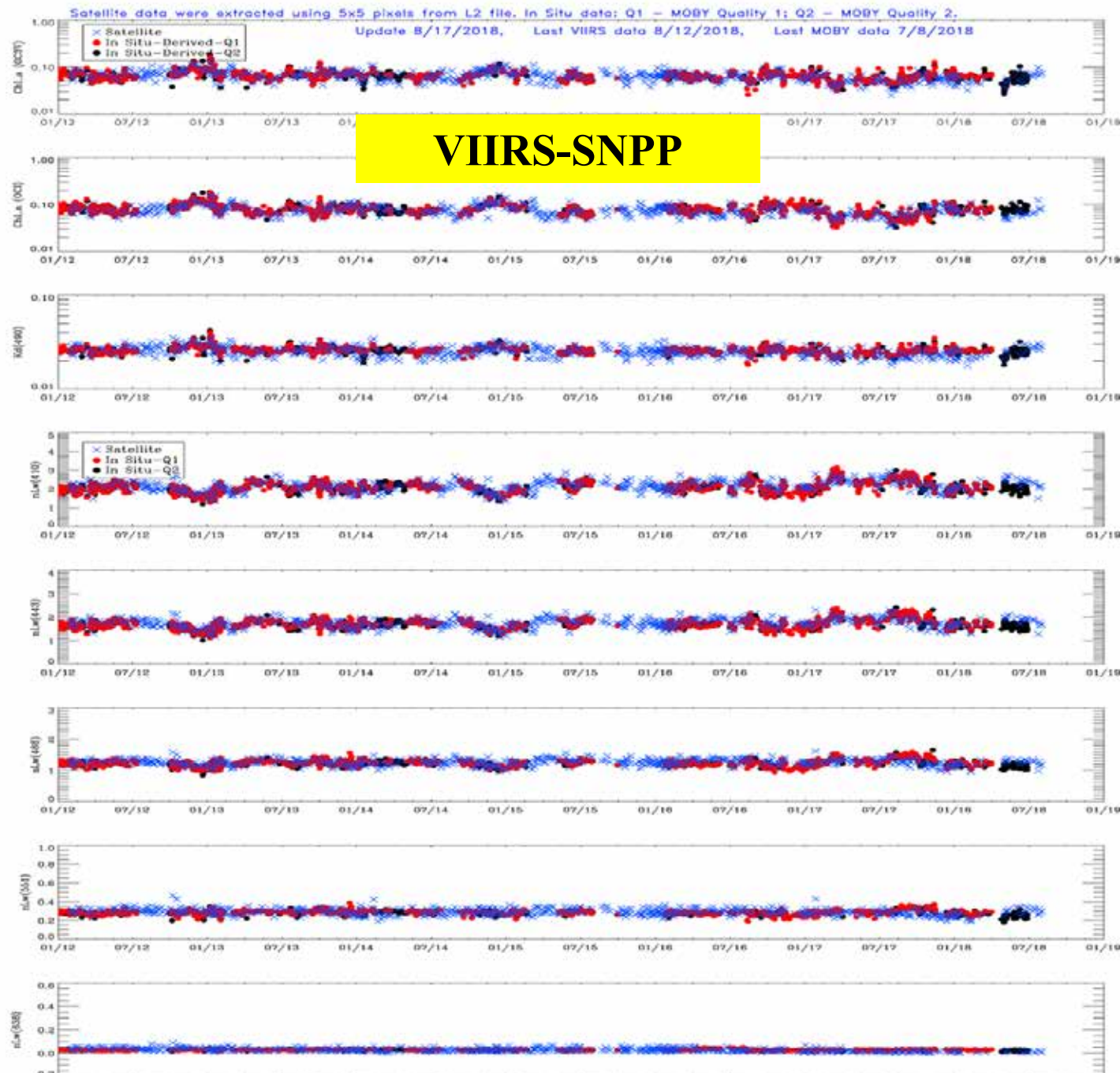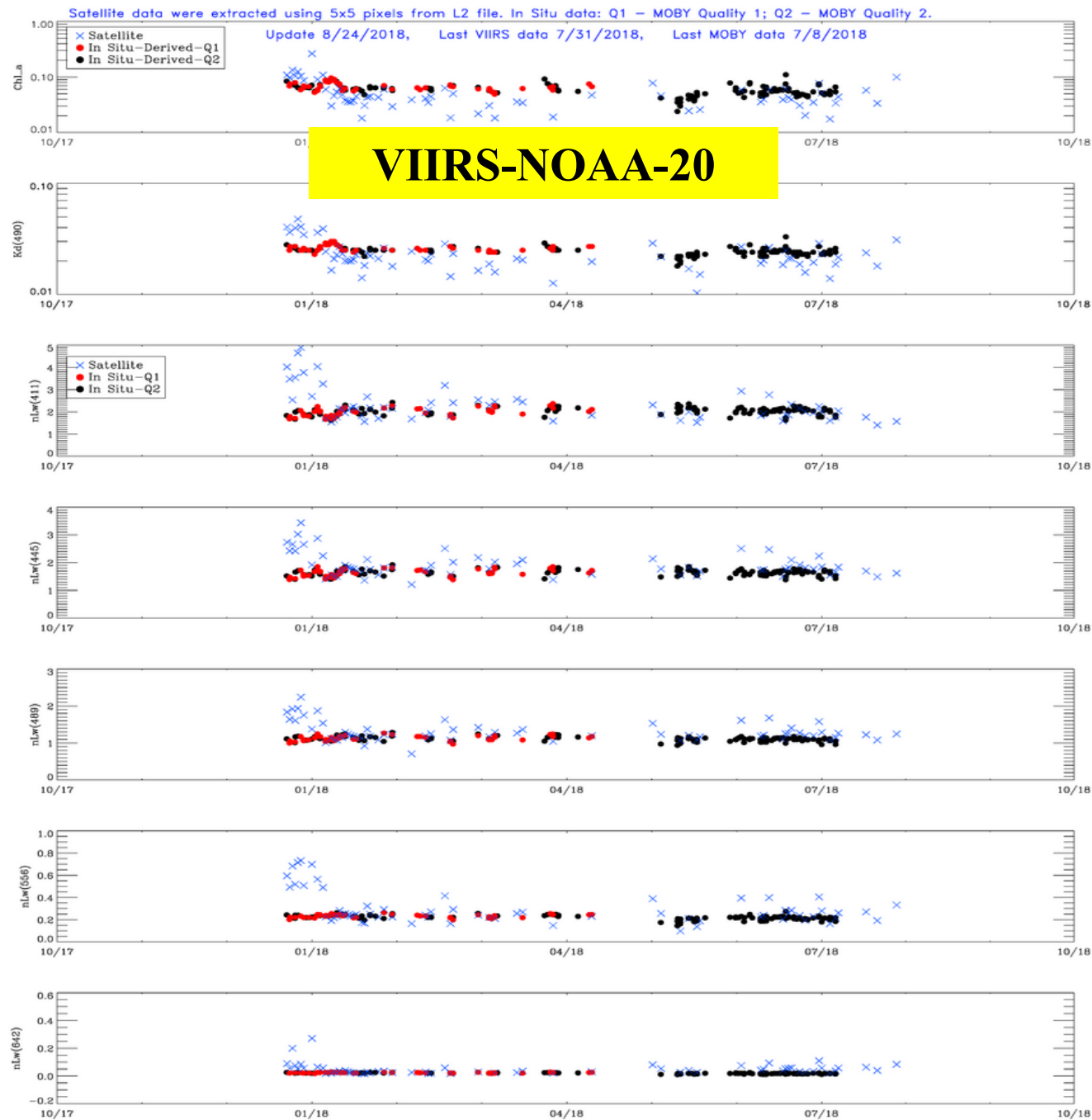

From **Michael Ondrusek**
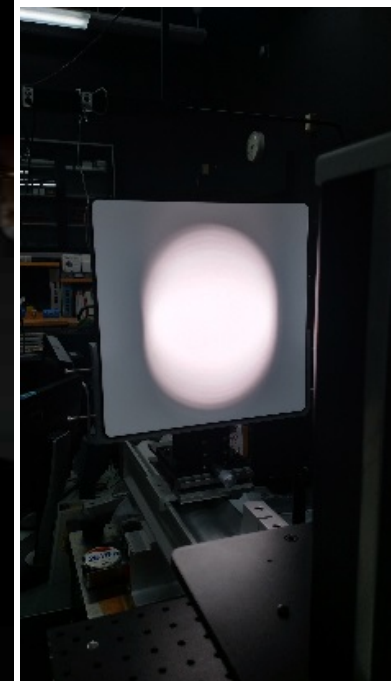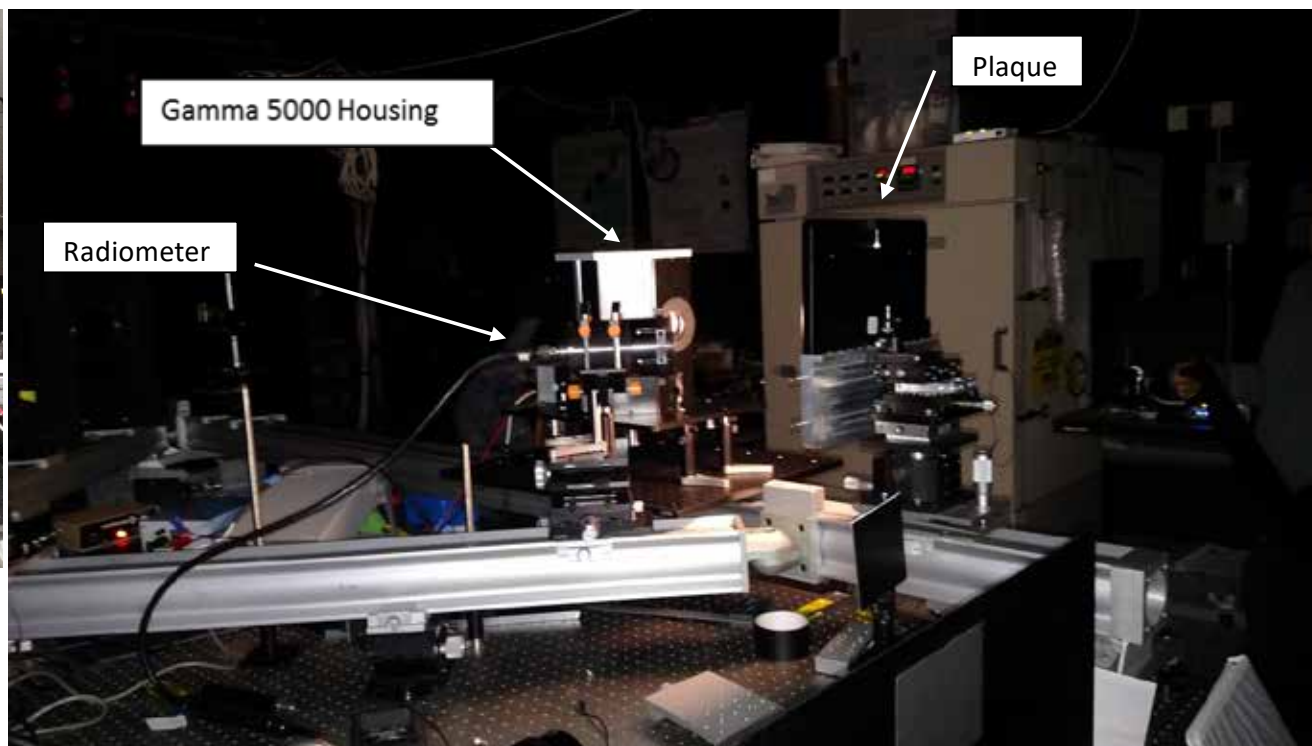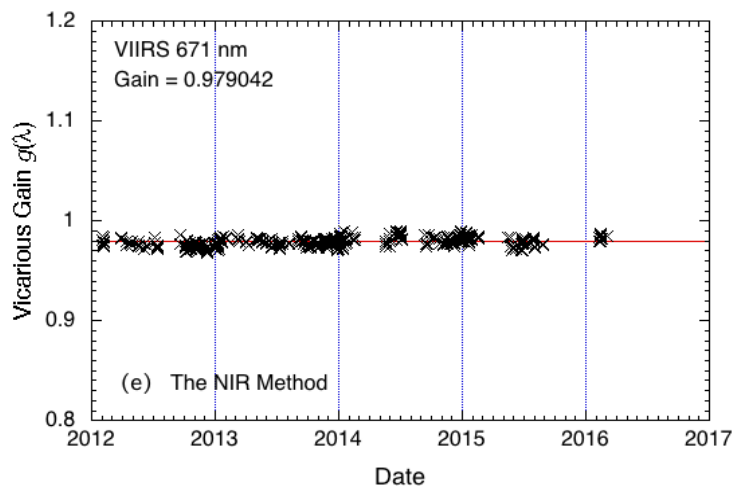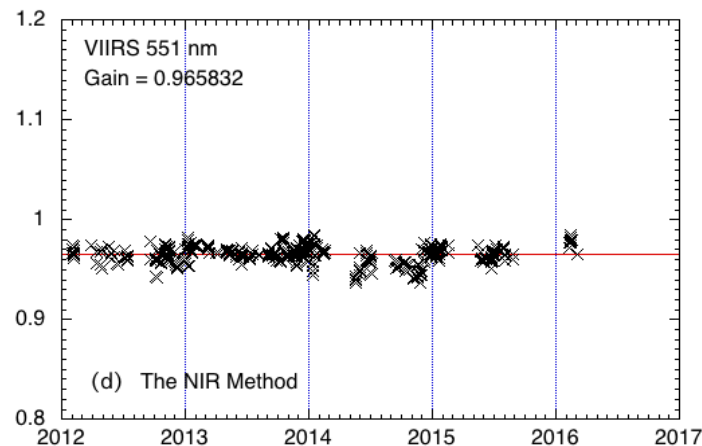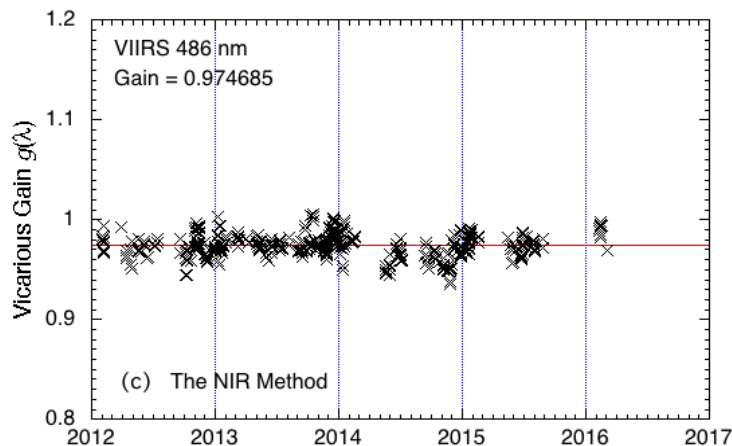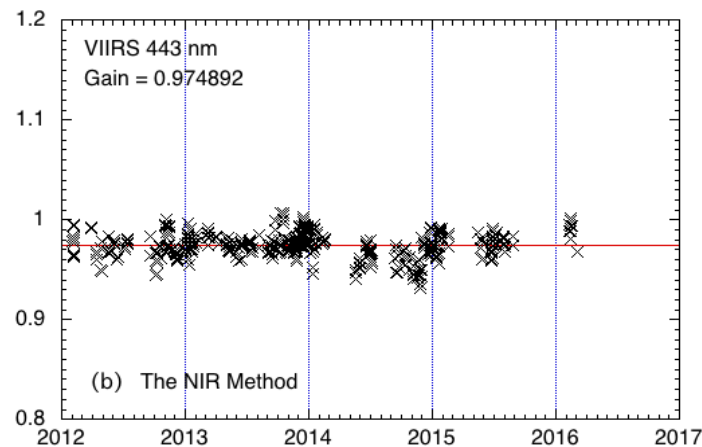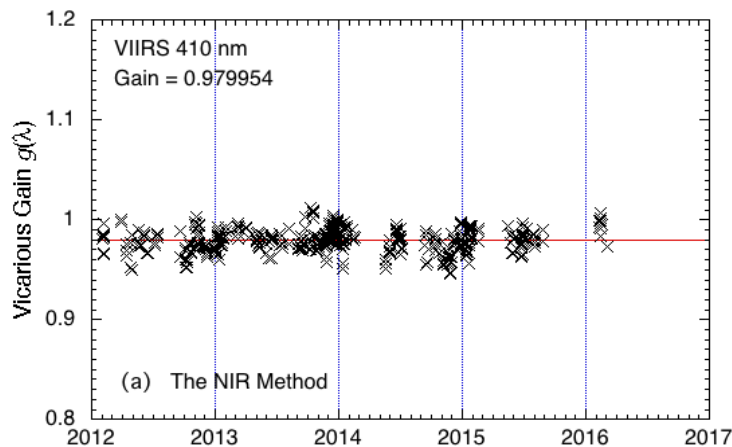
VIIRS vicarious gains derived using **MOBY** in situ data with the **NIR-based MSL12** ocean color data processing

High quality in situ measurements, e.g., MOBY in situ optics data, are crucial to derive reliable vicarious gains for satellite ocean color products

Wang, M., W. Shi, L. Jiang, and K. Voss (2016), "NIR- and SWIR-based on-orbit vicarious calibrations for satellite ocean color sensors", *Opt. Express*, **24**, 20437-20453, doi:10.1364/AO.55.006001.

VIIRS-SNPP

High quality MOBY daily in situ data are also important/useful for on-orbit sensor performance monitoring!

Satellite data were extracted using 5x5 pixels from L2 file. In Situ data: Q1 — MOBY Quality 1; Q2 — MOBY Quality 2.
Update 8/24/2018,   Last VIIRS data 7/31/2018,   Last MOBY data 7/8/2018

VIIRS-NOAA-20

High quality MOBY daily in situ data are also important/useful for on-orbit sensor performance monitoring!

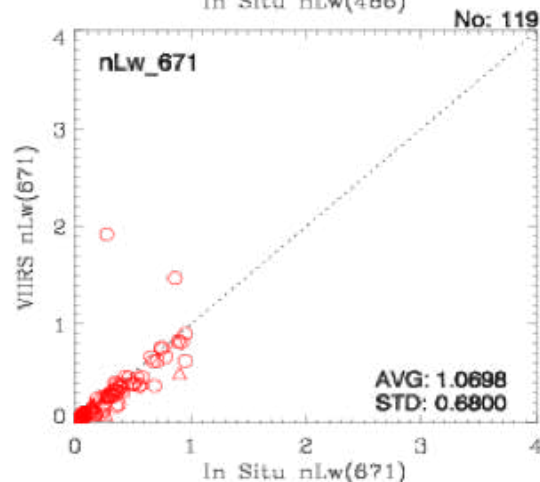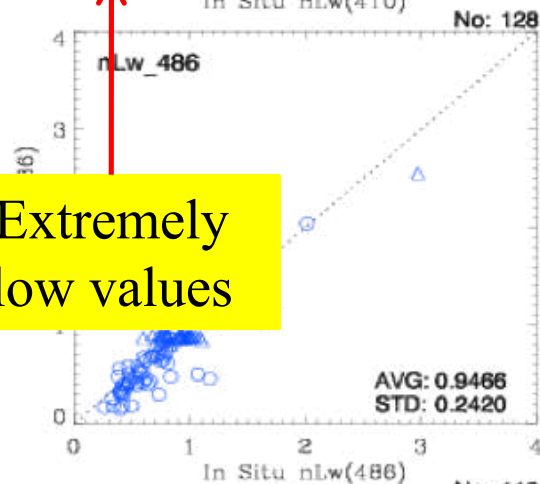Matchup of
MOBY In Situ
&
VIIRS-SNPP
(NIR-SWIR)

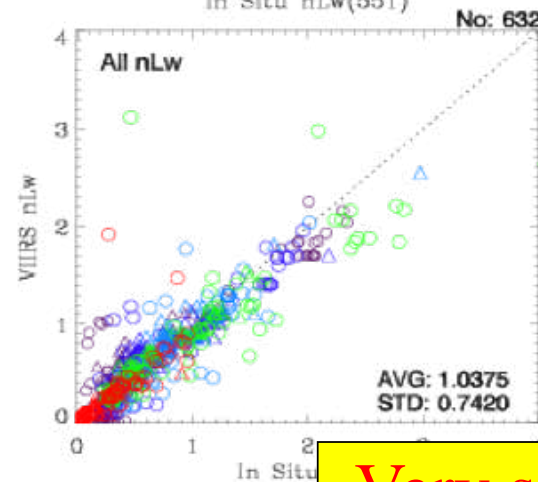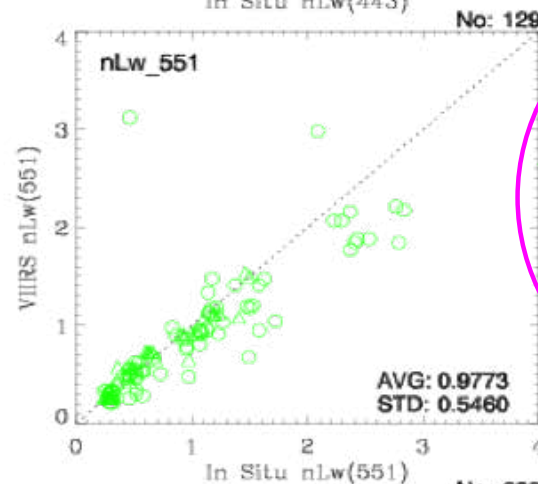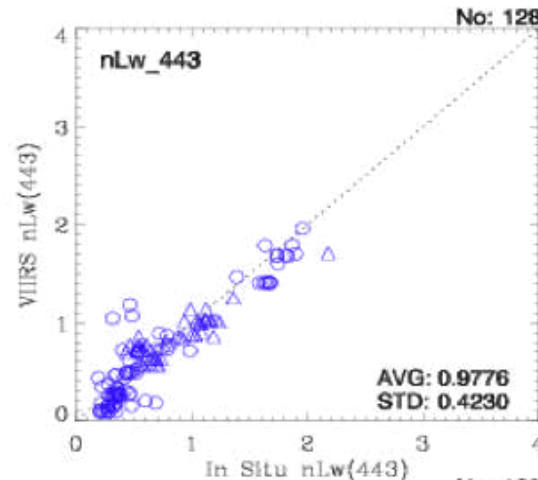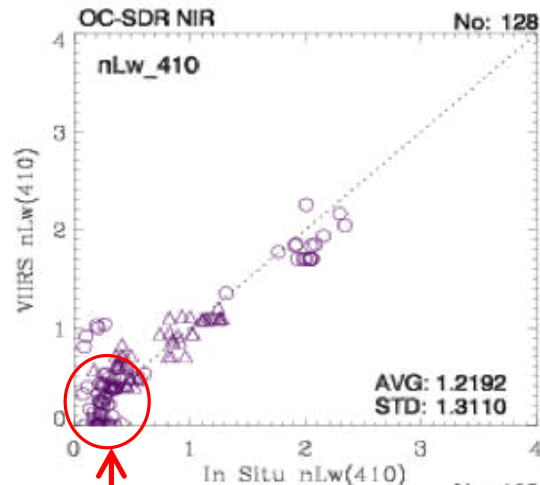**MOBY**
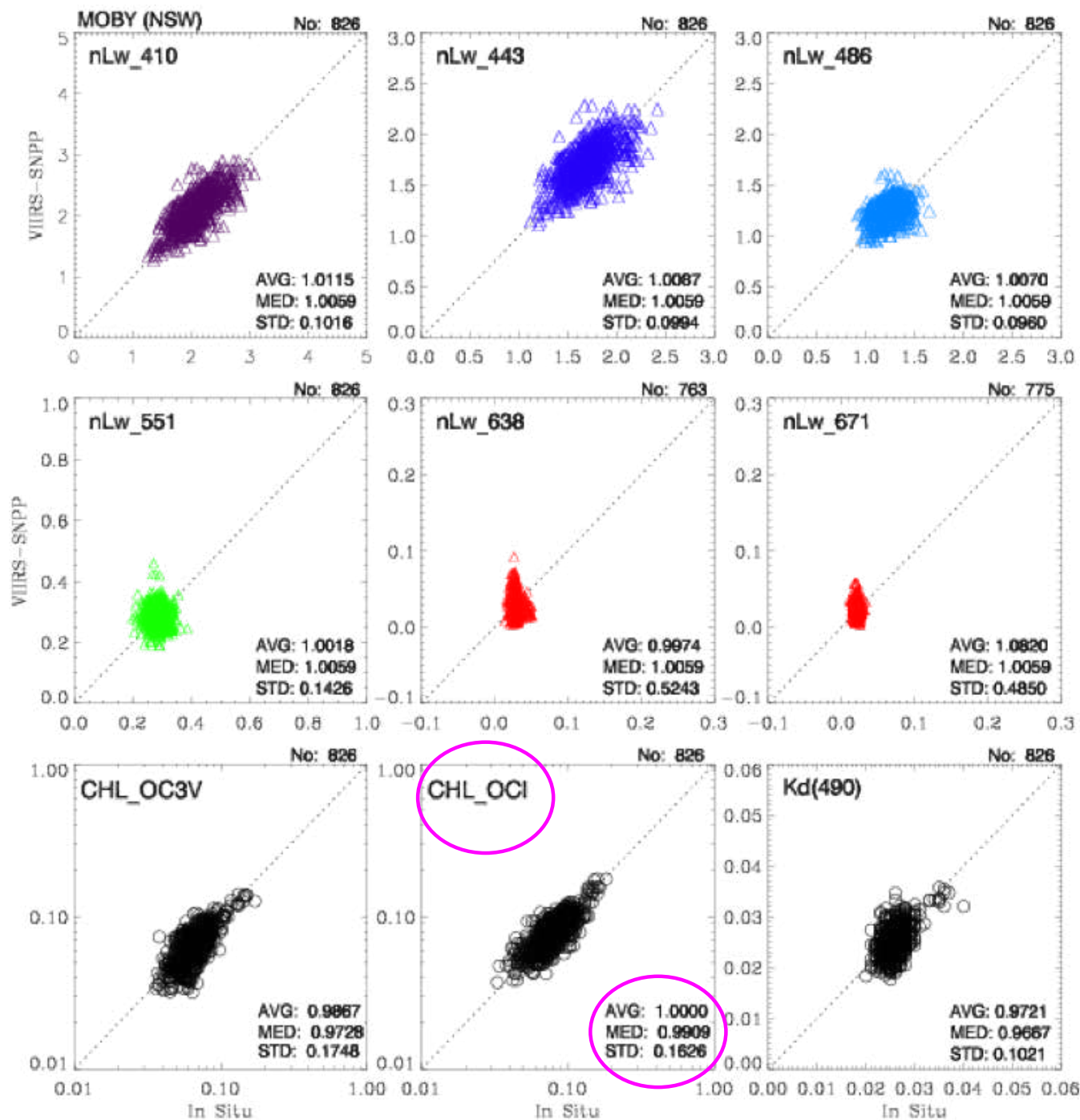
Validation Effort

VIIRS vs. In Situ Data

In Situ Data Sources:
R. Arnone (U. South Miss.)
C. Davis (Oregon State U.)
C. Hu (U. South Florida)
Z. Lee (U. Mass. Boston)
M. Ondrusek (NOAA/STAR)
G. Zibordi (JRC)

➢ Three dedicated Cal/Val cruises (2014-2016) and
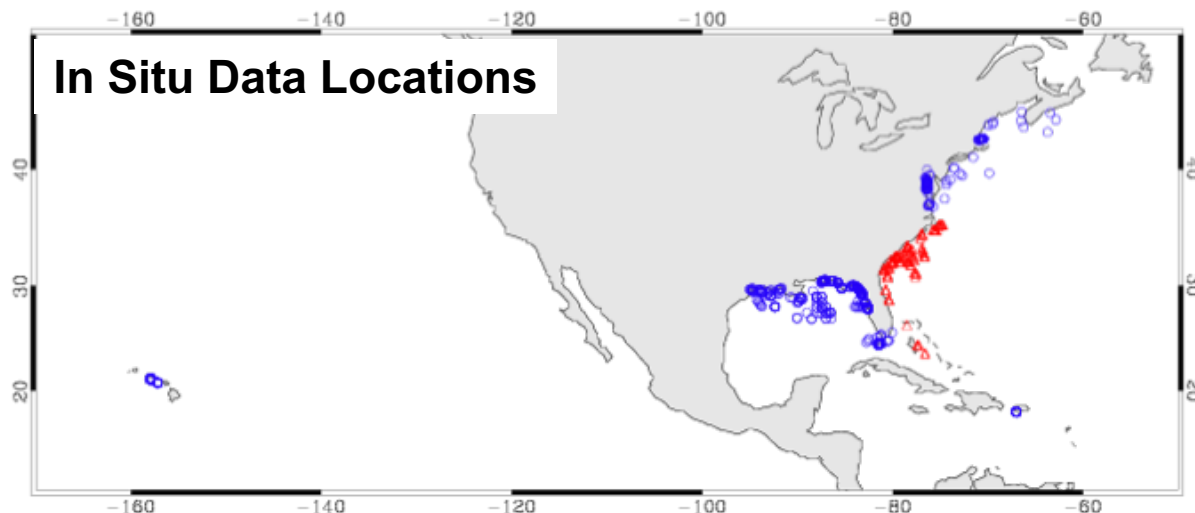➢ Various in situ measurement opportunities

Very significant amount of work!

Statistics of VIIRS vs. In Situ Data

VIIRS	OC-SDR NIR (Gain in 2017-03-27)							
Product	**RATIO (VIIRS/In Situ)**				**DIFFERENCE (VIIRS-In Situ)**			
	AVG	MED	STD	No	AVG	MED	STD	%Diff
$nL_w(410)$	1.2192	0.9658	1.311	128	0.0041	-0.0307	0.241	0.600
$nL_w(443)$	0.9776	0.9202	0.423	128	-0.0330	-0.0697	0.191	-4.310
$nL_w(486)$	0.9466	0.9298	0.242	128	-0.0471	-0.0520	0.192	-5.320
$nL_w(551)$	0.9773	0.9316	0.546	129	-0.0783	-0.0415	0.349	-8.830
$nL_w(671)$	1.0698	0.9768	0.680	119	-0.0102	0.0013	0.181	-4.120
All	1.0375	0.9383	0.742	632	-0.0333	-0.0290	0.241	-4.750

In Situ Data Locations

➤ **Red:** The three NOAA dedicated Cal/Val cruises
➤ **Blue:** Various in situ measurement opportunities
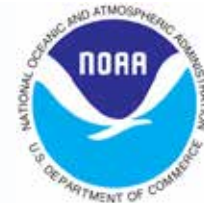
Conclusions

➤ VIIRS-SNPP and VIIRS-NOAA-20 global ocean color products have been routinely produced, providing necessary satellite data for various applications in open oceans, coastal and inland waters, as well as for further improving data quality.

➤ Our evaluation results (**using various in situ data)** show that VIIRS-SNPP can produce high quality ocean color data over global open oceans and reasonable data quality over coastal and inland waters.

➤ **FRM** data (i.e., MOBY in situ optics data) have been used for VIIRS on-orbit vicarious calibration, and routine sensor performance monitoring. Therefore, **FRM** data are required to be available to the community in **near-real-time**.

➤ We have successfully carried out four dedicated ocean color Cal/Val cruises with three cruise reports published. In addition, NOAA has been supporting four AERONET-OC sites for providing routine in situ data..

➤ We welcome collaborations for improving satellite ocean color products, e.g., Cal/Val activities using FRM data and other in situ data for satellite product validation.

VIIRS Images and Cal/Val:
https://www.star.nesdis.noaa.gov/sod/mecb/color/

VIIRS Ocean Color Data:
https://coastwatch.noaa.gov/

Thank You!