VIIRS Ocean Color Team Activities in 2017

Menghua Wang &
Ocean Color EDR Team

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

STAR JPSS 2016 Annual Science Team Meeting
NCWCP, College Park, Maryland, August 14-18, 2017

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

Acknowledgements: This work has been supported by JPSS/VIIRS funding. We thank MOBY team for in situ optics data, VIIRS Cal/Val PIs and their collaborators in support of VIIRS Cal/Val activities.

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.

VIIRS Spectral Bands for Ocean Color

VIIRS (Visible Infrared Imaging Radiometer Suite) on
Suomi National Polar-orbiting Partnership **(SNPP)**
VIIRS-**SNPP**, Oct. 28, **2011**, VIIRS-Joint Polar Satellite System (**JPSS**) **J1**, **2017**, VIIR-**J2**,
2021, and J3 & J4 (up to ~2038)

VIIRS†		MODIS		SeaWiFS
Ocean Bands (nm)	Other Bands (nm)	Ocean Bands (nm)	Other Bands (nm)	Ocean Band (nm)
410 (M1)	638 (I1)	412	645	412
443 (M2)	862 (I2)	443	859	443
486 (M3)	1600 (I3)	488	469	490
—		531	555	510
551 (M4)	*SWIR Bands*	551	*SWIR Bands*	555
671 (M5)	1238 (M8)	667	1240	670
745 (M6)	1601 (M10)	748	1640	765
862 (M7)	2257 (M11)	869	2130	865

†VIIRS-SNPP nominal center wavelength

Spatial resolution for VIIRS M-band: 750 m, I-band: 375 m

Menghua Wang, NOAA/NESDIS/STAR

Summary of VIIRS Ocean Color EDR Products

- **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** (9):
  - 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)

New added global products: ***nL_w*(638)** (I-band with 375 m), **QA Score**, and **Chl-a anomaly** and **Chl-a anomaly ratio**

- I
  - 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)
  - **QA Score** for data quality ($nL_w(\lambda)$ spectra) (*Wei et al.*, 2016)

We are open for adding new VIIRS global products

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

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---**measurement-based data processing system**.
  - 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**, ……,)
- **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.
- **O**cean **C**olor **D**ata **A**nalysis and **P**rocessing **S**ystem (**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.**

Two Data Streams for VIIRS Ocean Color EDR

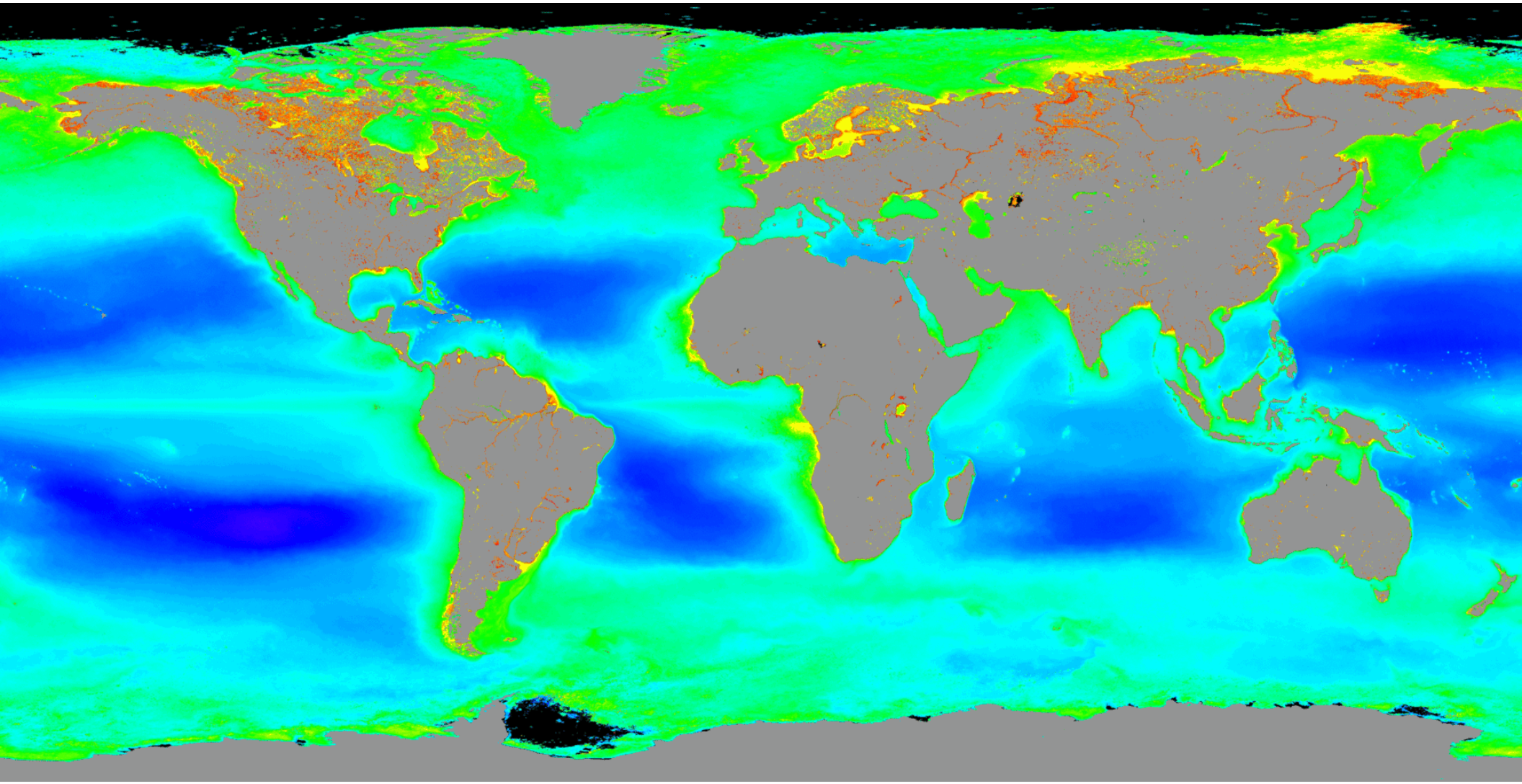
To meet requirements from **All** users (operational, research, modeling, etc.), we have been routinely producing VIIRS global ocean color products in **two data streams**: Near-Real-Time (NRT) and Delayed Science-Quality data.

Attribute	Near-Real Time (NRT)	Delayed Science-Quality
Latency:	Best effort, as soon as possible (~12-24h)	Best effort, on a 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
Spatial Coverage:	May be gaps due to various issues	Complete global coverage
Processed by:	CoastWatch, transferring to OSPO (operational) FY16	NOAA/STAR
Distributed by:	CoastWatch, OSPO	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

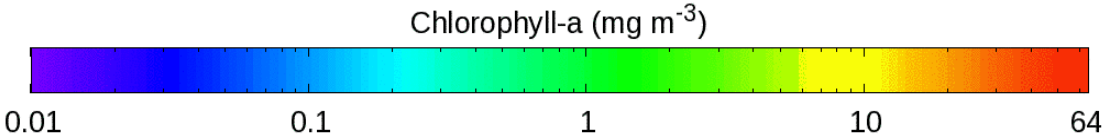
VIIRS Mission-long Ocean Color Data Reprocessing

- ✓ We have recently reprocessed VIIRS mission-long ocean color data products for the Science Quality data stream in **April 2017**. This is the **second data reprocessing** due to some significant improvements (algorithms and SDR). The first VIIRS mission-long OC data reprocessing was completed in May 2016. The science quality data stream has been going forward routinely.
- ✓ The Multi-Sensor Level-1 to Level-2 (**MSL12**) ocean color data processing system has been significantly improved (warrant for the second mission-long data reprocessing).
- ✓ For the Science Quality data stream, VIIRS mission-long SDR has been reprocessed using significantly improved on-orbit calibration (both **solar** and **lunar** approaches).
- ✓ VIIRS ocean color data are available through CoastWatch. In particular, the Science Quality data stream will also be distributed through **CoastWatch** and NCEI.
- ➢ The reprocessed VIIRS mission-long Science Quality ocean color data have been significantly improved, providing accurate and consistent ocean color data for science research and applications. It shows the importance of the lunar data for calibration, particularly in recent years (and forwarding).
- ➢ VIIRS chlorophyll-a (Chl-a), $K_d(490)$, $K_d(\mathrm{PAR})$, $nL_w(410)$, $nL_w(443)$, $nL_w(486)$, $nL_w(551)$, and $nL_w(671)$, as well as I-band $nL_w(638)$ data are routinely produced now using the **MSL12** ocean color data processing system.
- ➢ We show VIIRS global climatology ocean color product images, as well as some evaluation/validation results.

VIIRS Climatology Ocean Color Product Image (2012–2016)



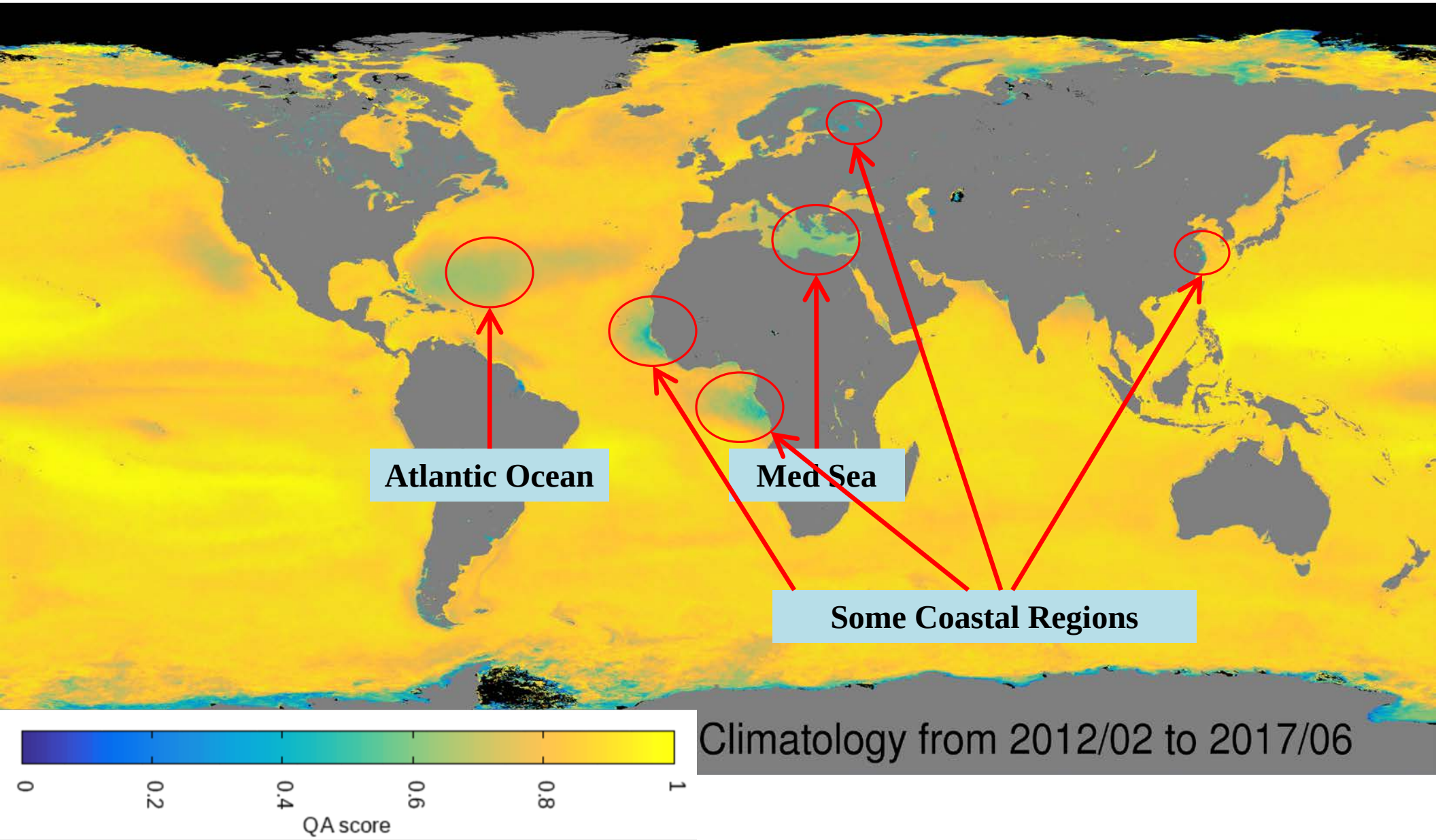
VIIRS SNPP
NOAA/NESDIS/STAR Ocean Color Team



climatology
2012 - 2016

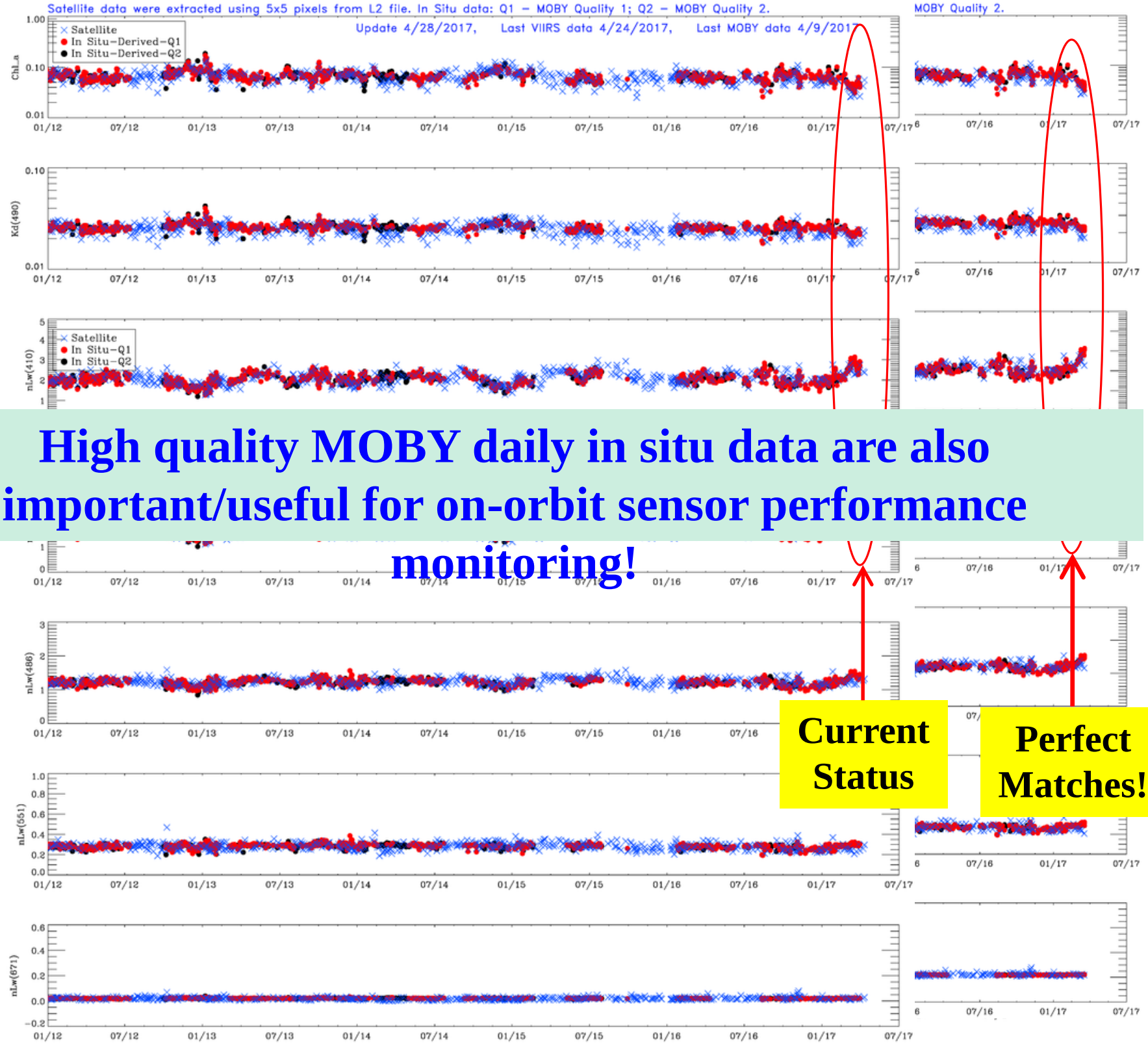
Menghua Wang, NOAA/NESDIS/STAR

VIIRS Climatology QA Score Image (2012–2017)



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



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

Menghua Wang, N(

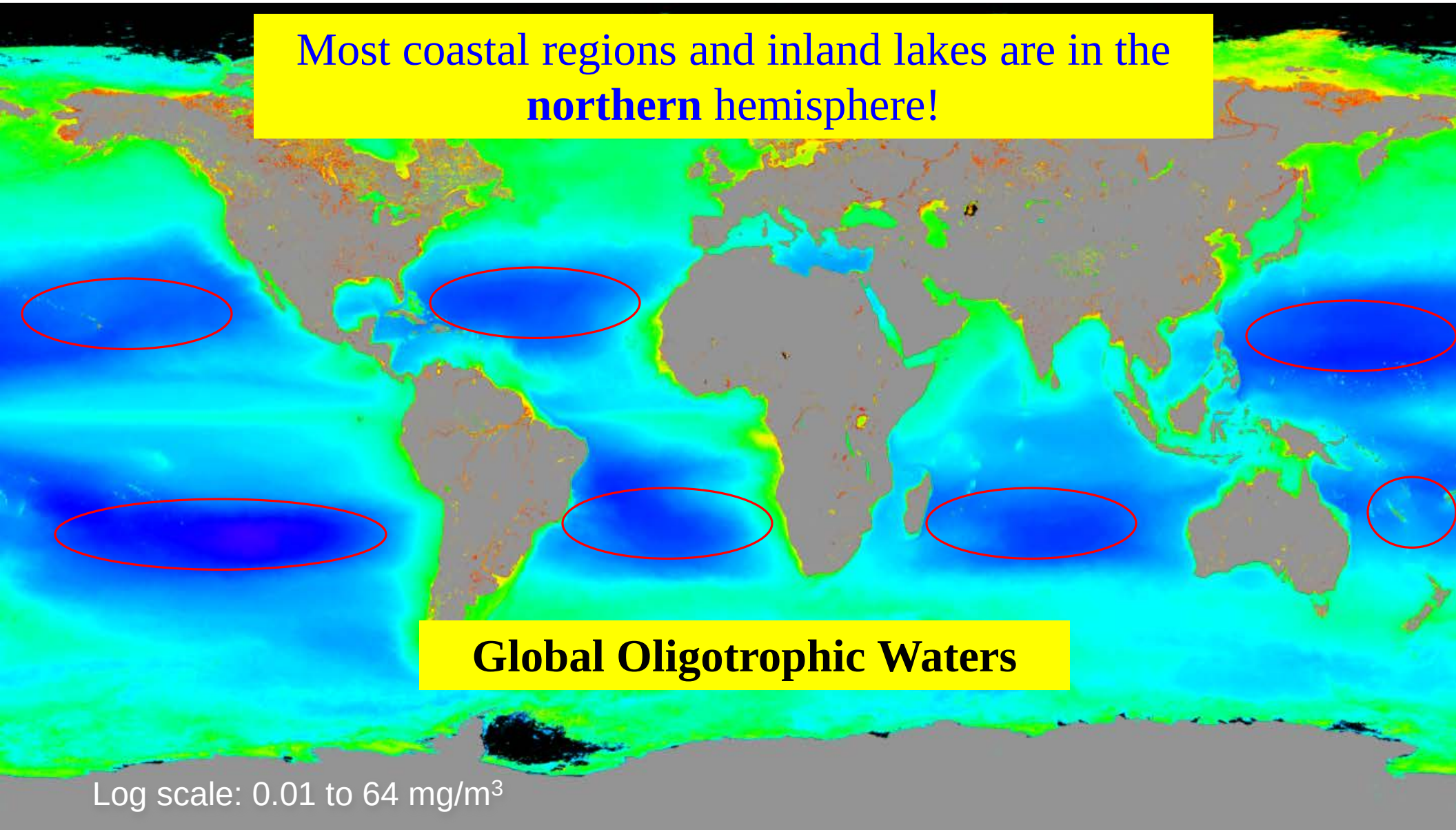
MOBY

Statistics of VIIRS versus In-Situ (MOBY)

VIIRS	OC-SDR NIR (Gain in 2017-03-26)				OC-SDR NIR (Gain in 2017-03-26)			
Product	**RATIO (SAT/ENV)**				**DIFFERENCE (SAT-ENV)**			
	AVG	**MED**	**STD**	**No**	**AVG**	**MED**	**STD**	**%Diff**
$nL_w(410)$	**1.0179**	1.0153	0.096	557	**0.0264**	0.0329	0.1899	**1.29**
$nL_w(443)$	**1.0159**	1.0119	0.092	557	**0.0196**	0.0181	0.1499	**1.18**
$nL_w(486)$	**1.0164**	1.0124	0.088	557	**0.0151**	0.0153	0.1048	**1.24**
$nL_w(551)$	**1.0276**	1.0098	0.135	557	**0.0062**	0.0029	0.0374	**2.17**
$nL_w(671)$	**1.1219**	1.0045	0.498	527	**0.0021**	0.0001	0.0099	**10.04**
$nL_w(638)$	**1.0656**	0.9366	0.545	555	**0.0010**	-0.0018	0.0155	**3.28**

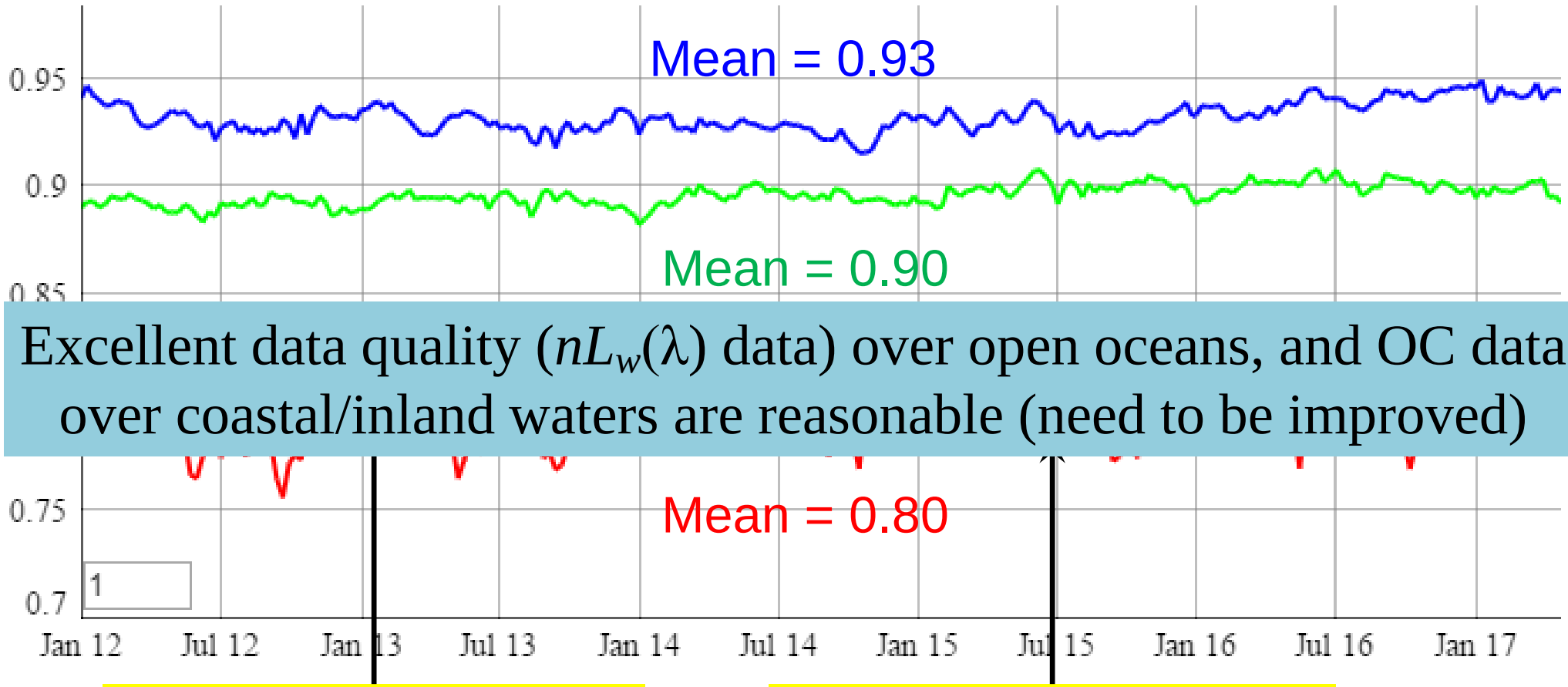
Menghua Wang, NOAA/NESDIS/STAR

VIIRS Climatology Chlorophyll-a Image (2012–2016)



Menghua Wang, NOAA/NESDIS/STAR

VIIRS Mission-long QA Score
(global 8-day mean value)



Excellent data quality ($nL_w(\lambda)$ data) over open oceans, and OC data over coastal/inland waters are reasonable (need to be improved)

Higher score in winter

Lower score in summer

Blue: Global Oligotrophic Waters

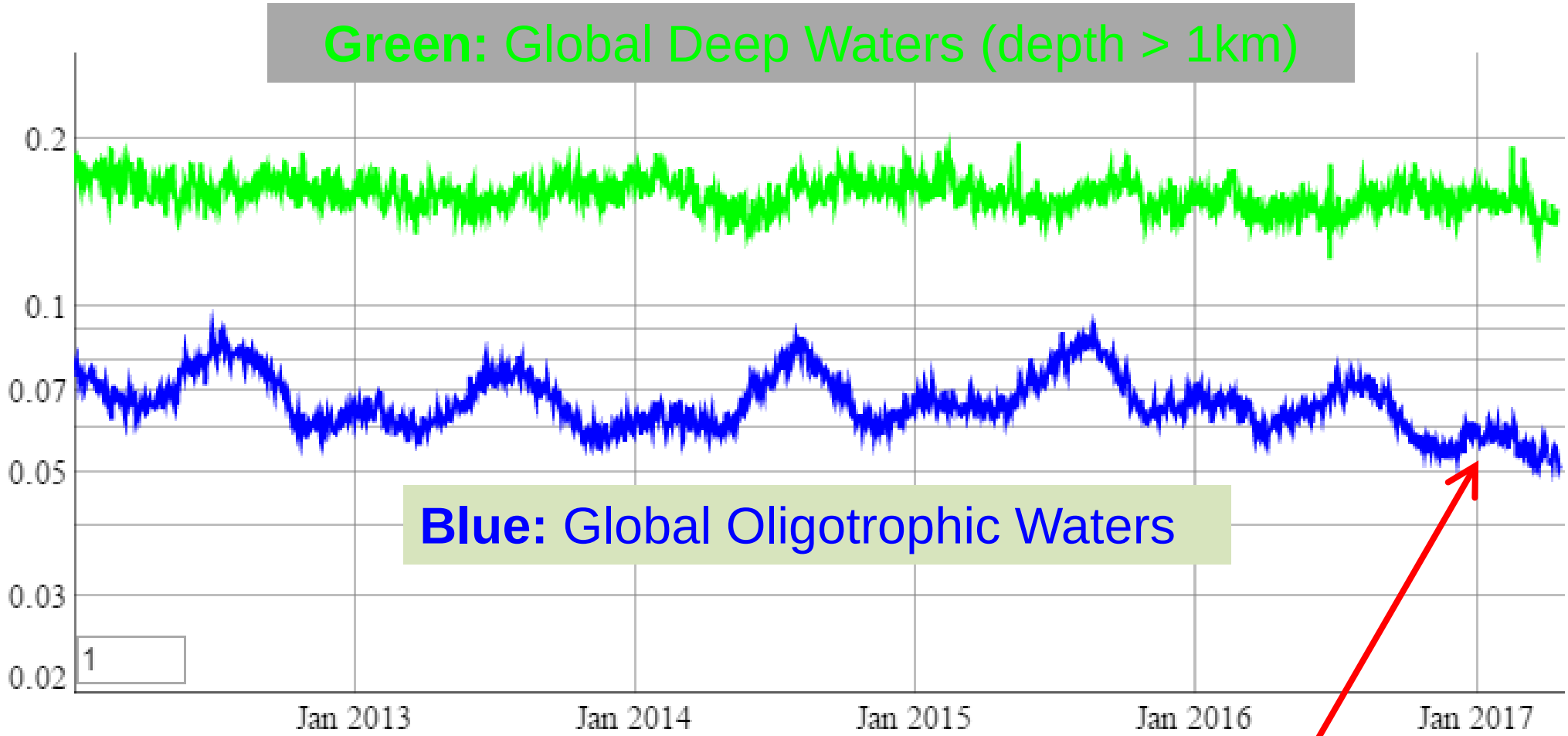
Green: Global Deep Waters (depth > 1km)

Red: Regions with depth ≤ 1km, e.g., coastal & inland waters

VIIRS science quality OC data are processed using the MSL12!

Menghua Wang, NOAA/NESDIS/STAR

VIIRS-derived Daily Chl-a

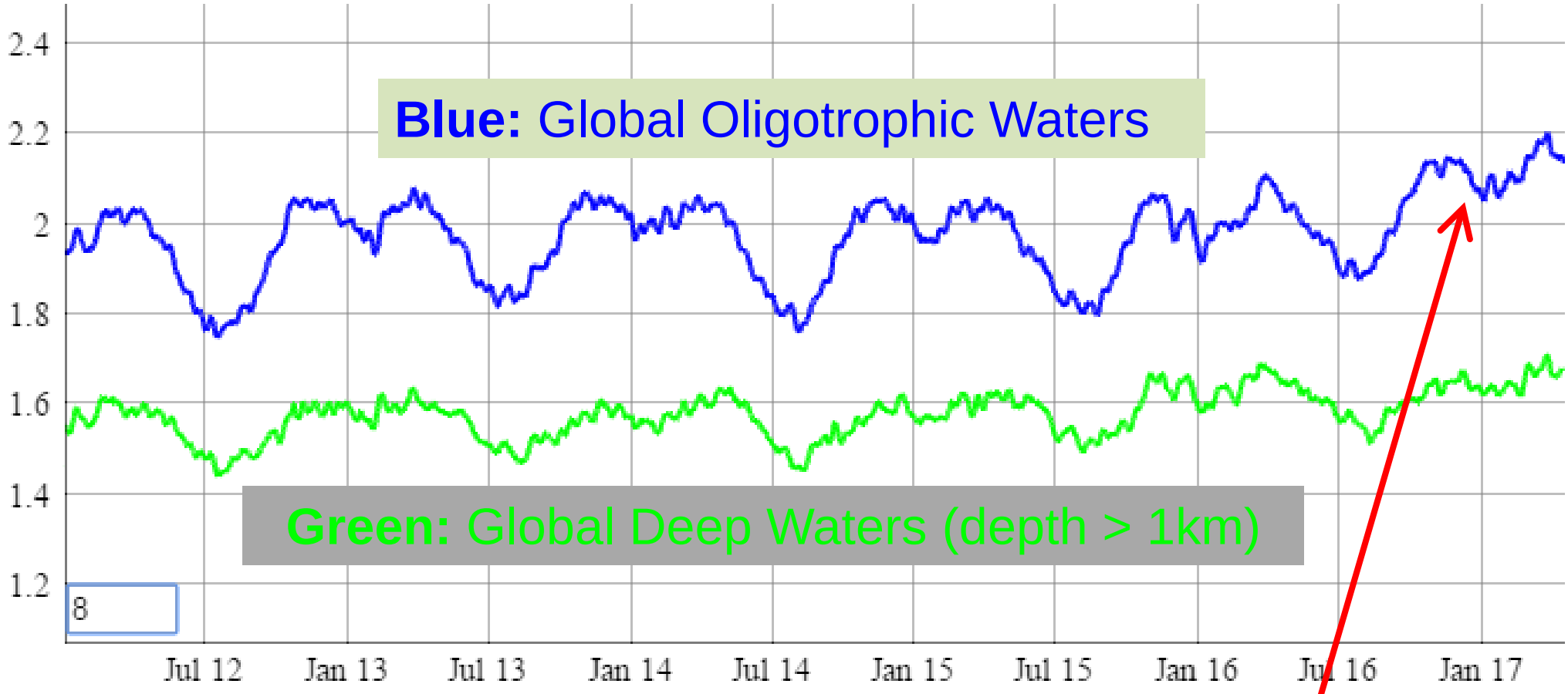


Slightly Chl-a drop over oligotrophic waters

VIIRS science quality OC data are processed using the MSL12!

Menghua Wang, NOAA/NESDIS/STAR

VIIRS-derived 8-day $nL_w(443)$

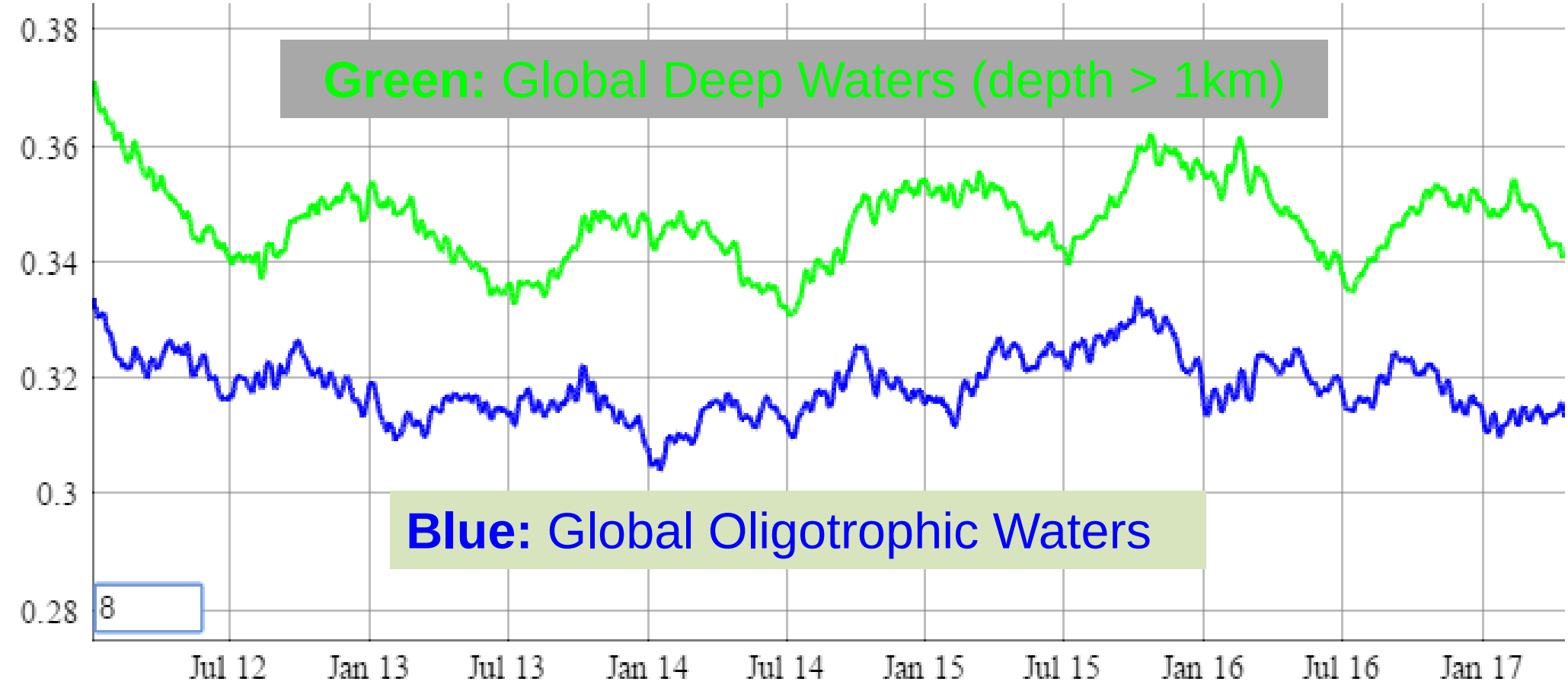


Water getting **Bluer** recently?

VIIRS science quality OC data are processed using the MSL12!

Menghua Wang, NOAA/NESDIS/STAR

VIIRS-derived 8-day $nL_w(551)$

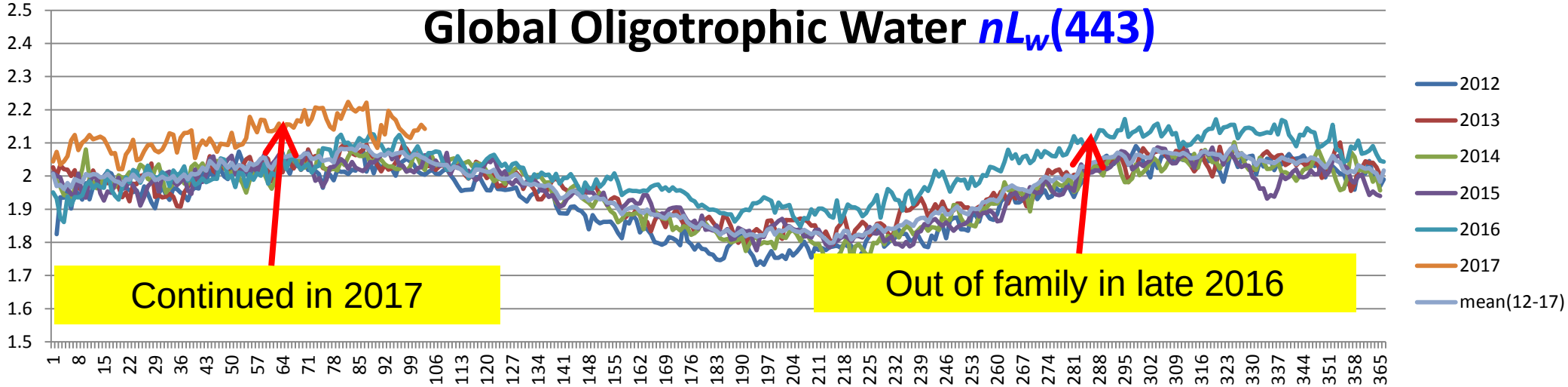


Quite stable in VIIRS-derived $nL_w(551)$!

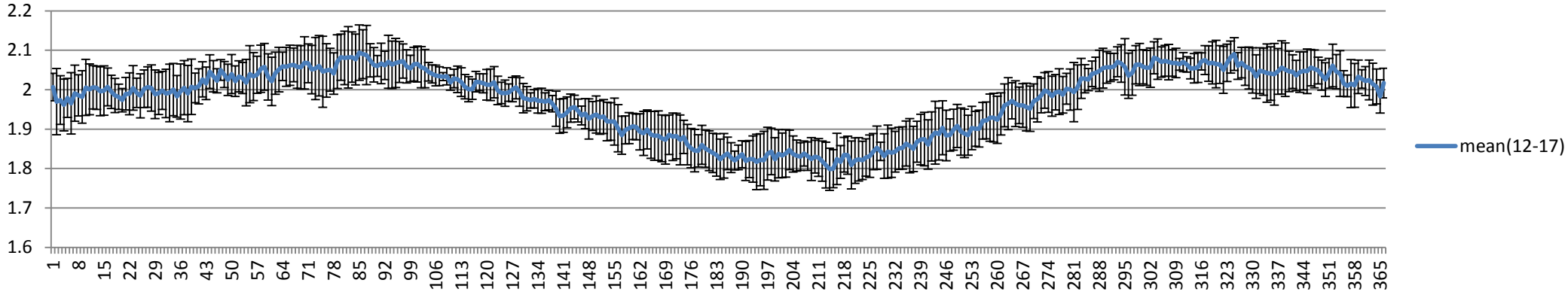
VIIRS science quality OC data are processed using the MSL12!

Menghua Wang, NOAA/NESDIS/STAR

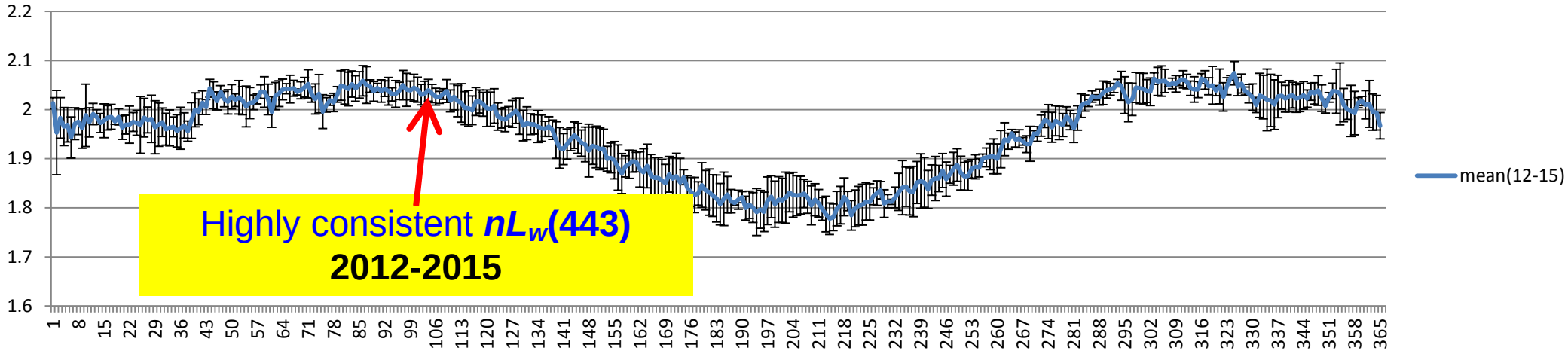
Global Oligotrophic Water $nL_w(443)$



Mean & STD (2012-2017)



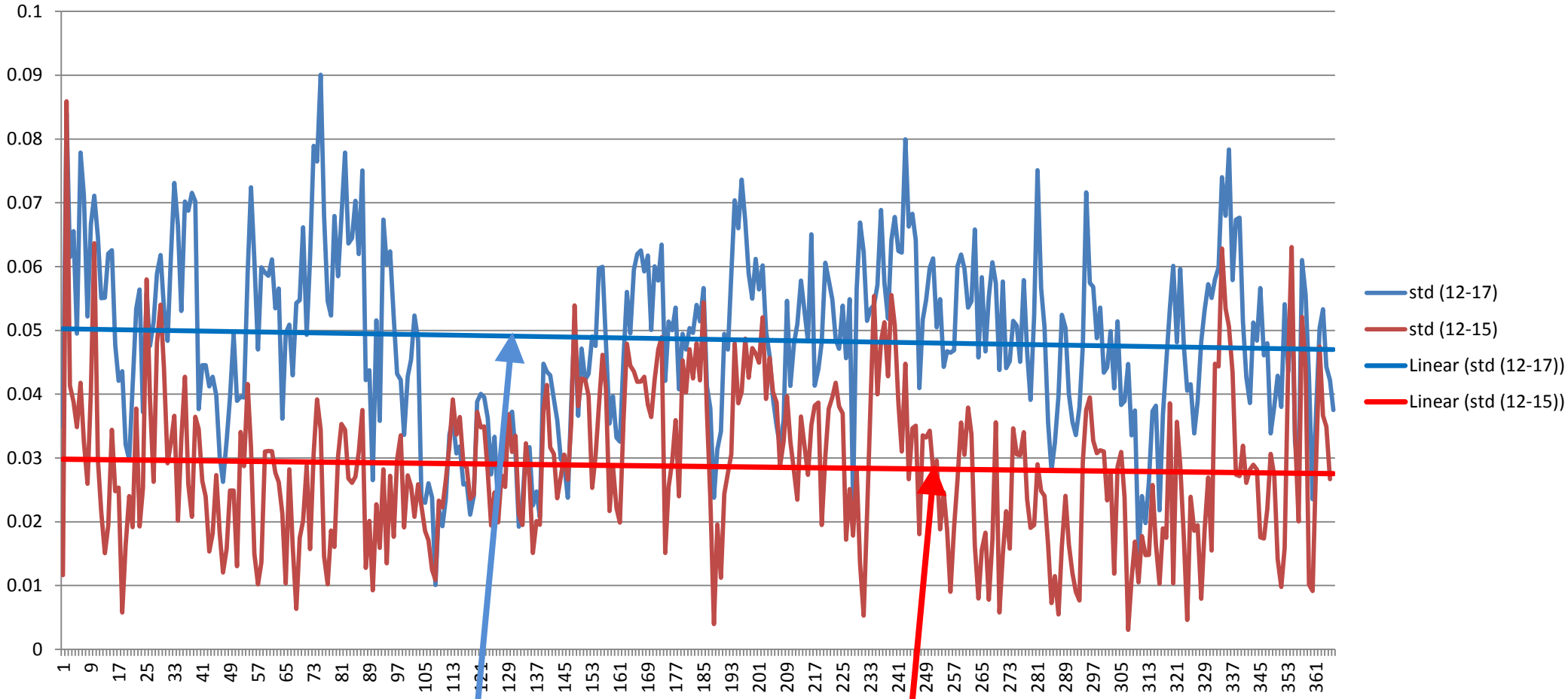
Mean & STD (2012-2015)



Menghua Wang, NOAA/NESDIS/STAR

Global Oligotrophic Water

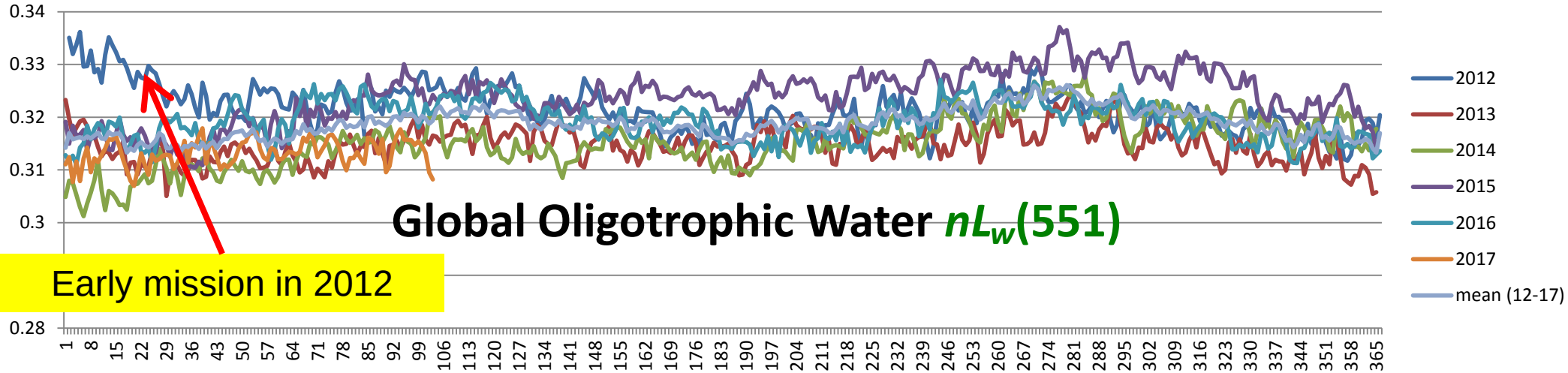
$nL_w(443)$ STD Values

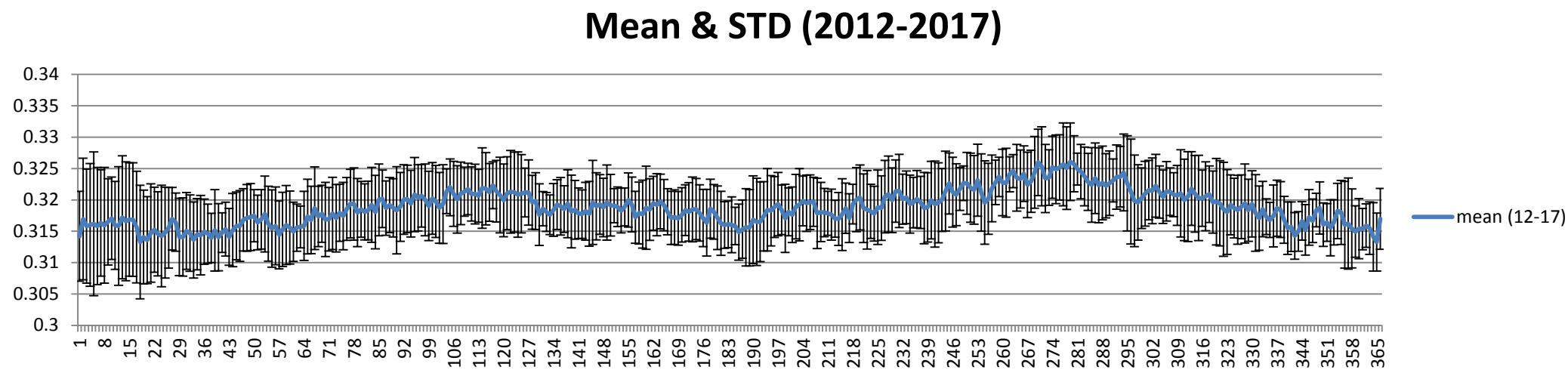


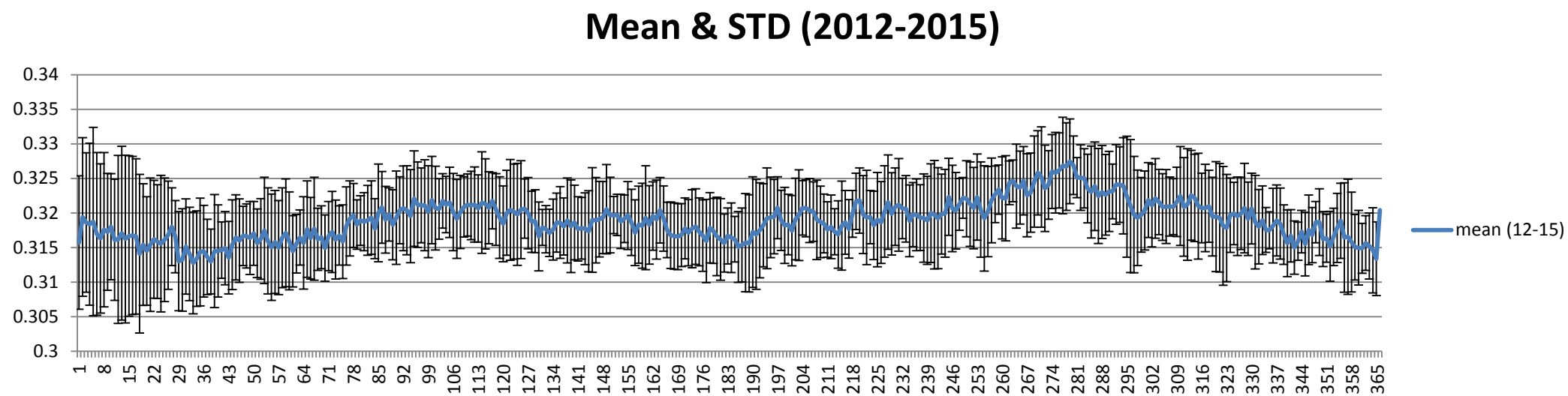
STD ~**0.05** for **2012-2017**

STD ~**0.03** for **2012-2015**

Menghua Wang, NOAA/NESDIS/STAR



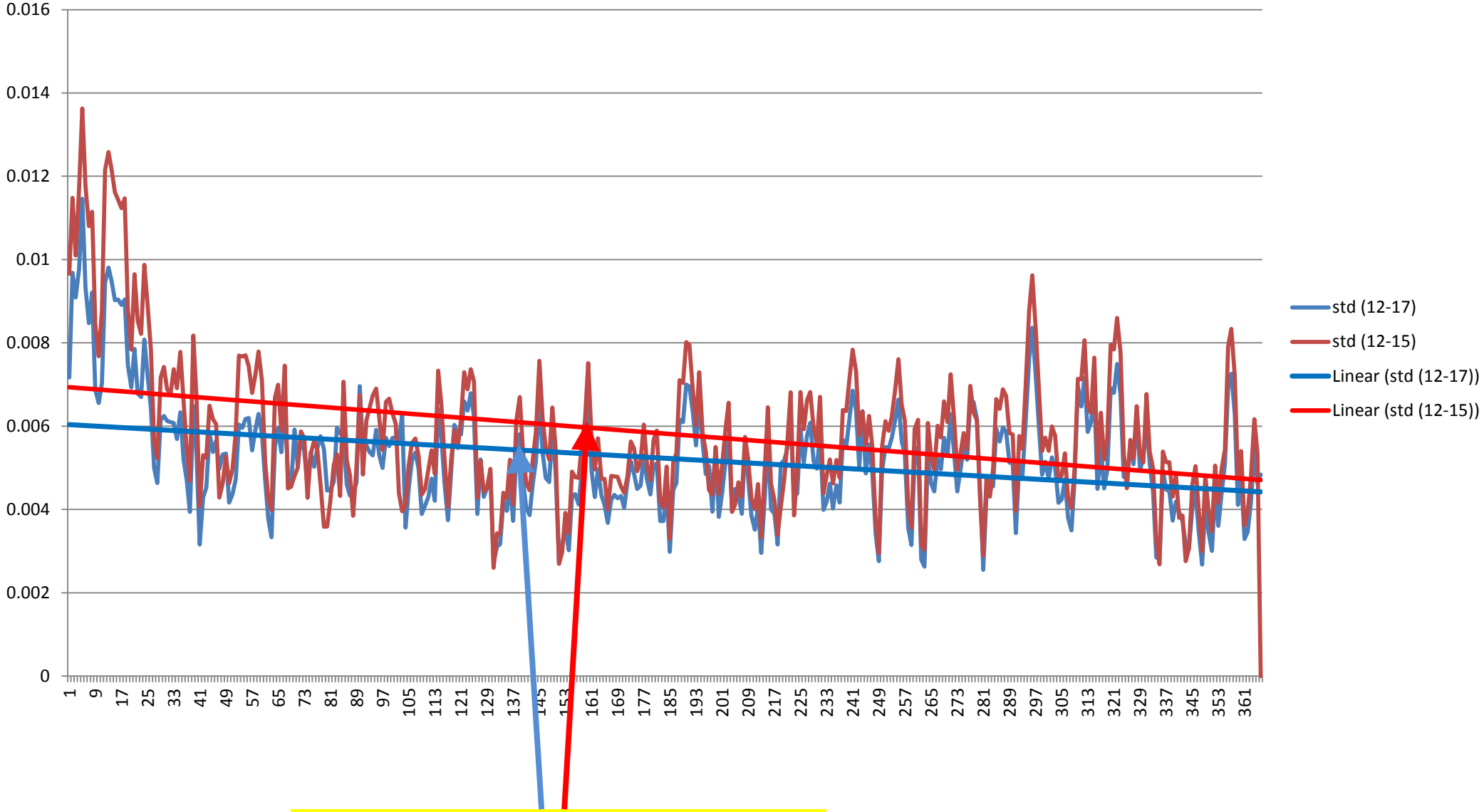




Menghua Wang, NOAA/NESDIS/STAR

Global Oligotrophic Water

$nL_w(551)$ STD Values



Similar STD ~**0.005-0.007**

Menghua Wang, NOAA/NESDIS/STAR

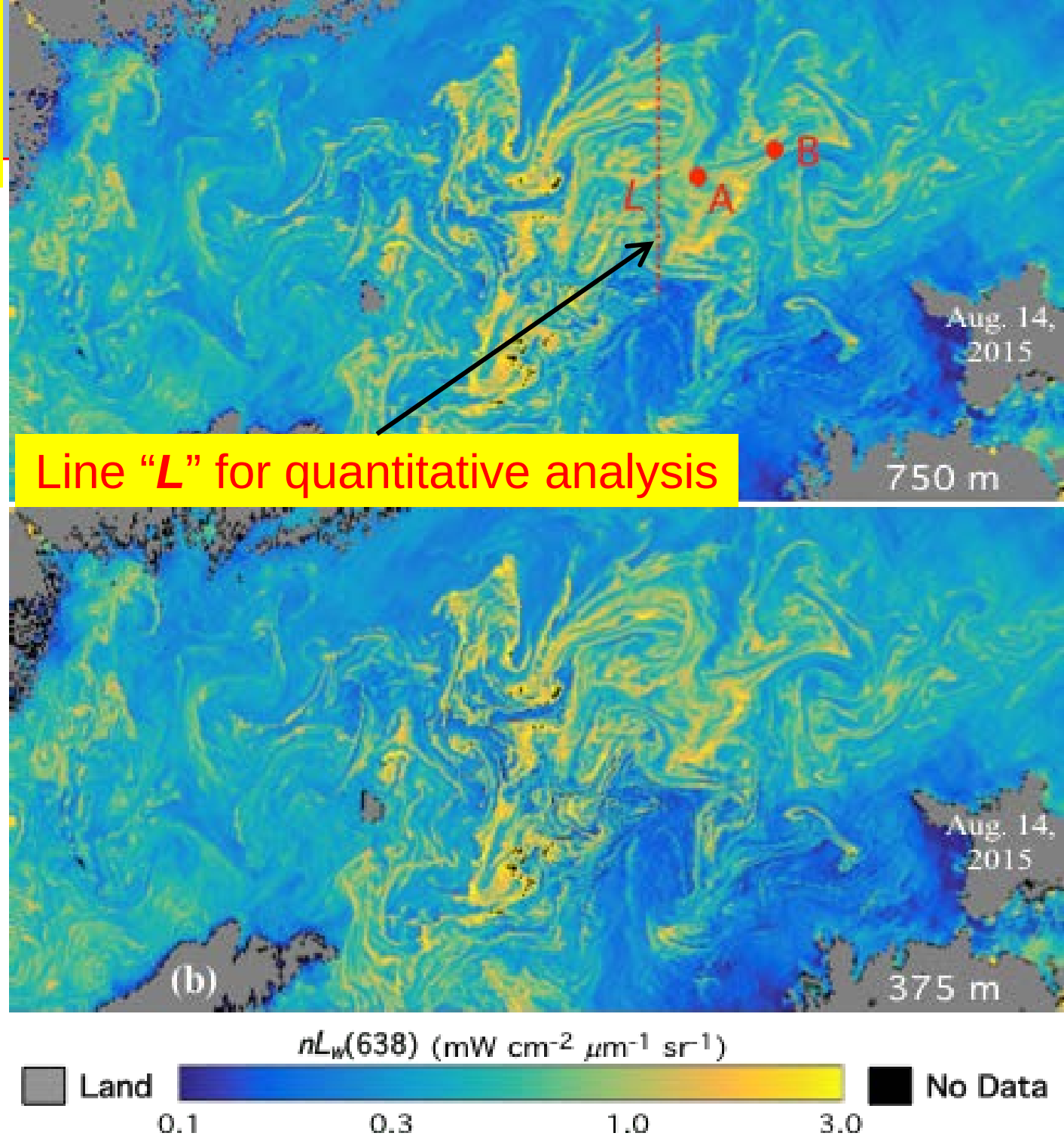
New VIIRS $nL_w(638)$ with Imaging Bands

(Resolution at 375 m)

Example:

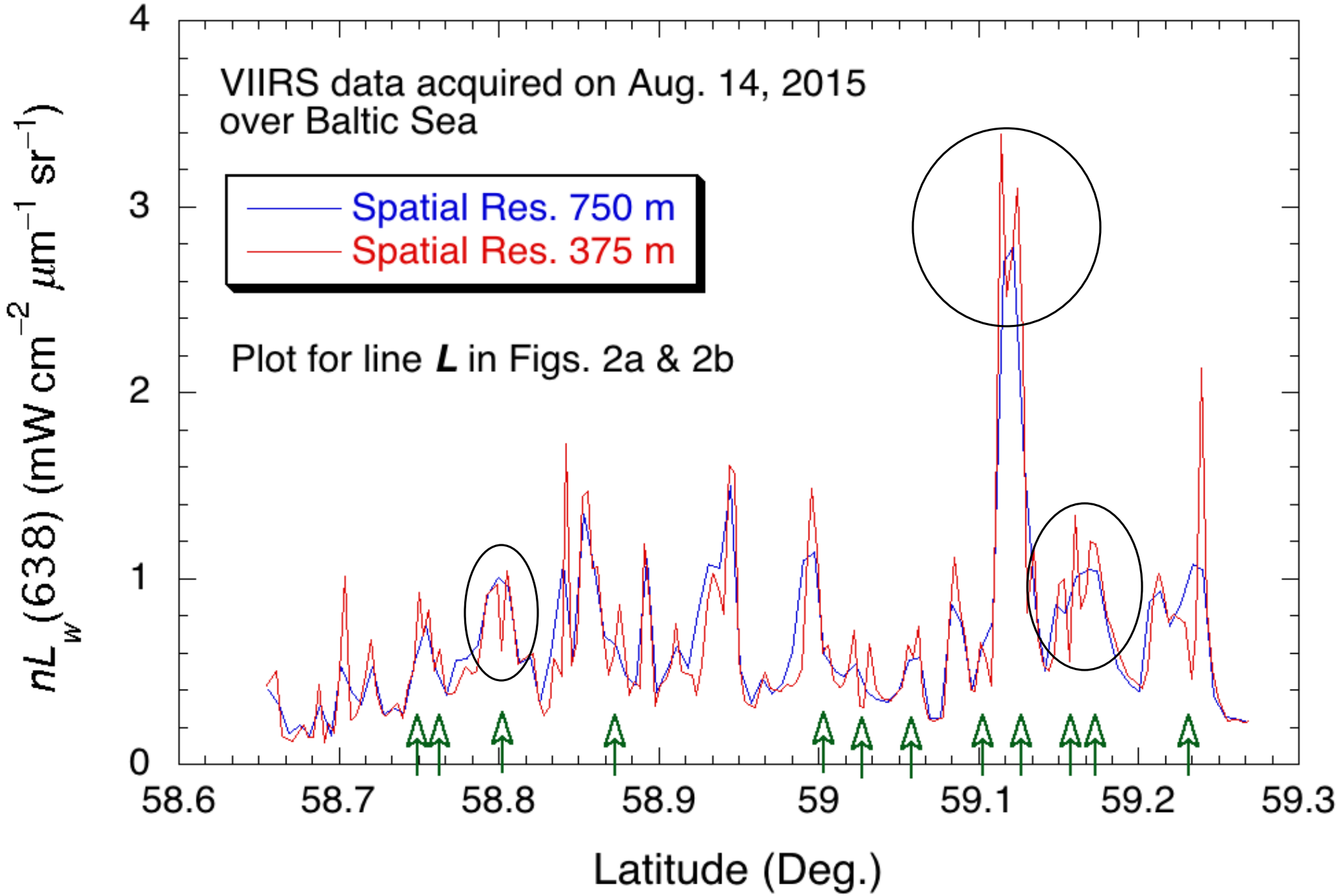
Algae Bloom in the Baltic Sea on August 14, 2015

One can see differences between two images for bloom size < ~500 m, showing high spatial resolution data providing more details for bloom spatial distribution/features

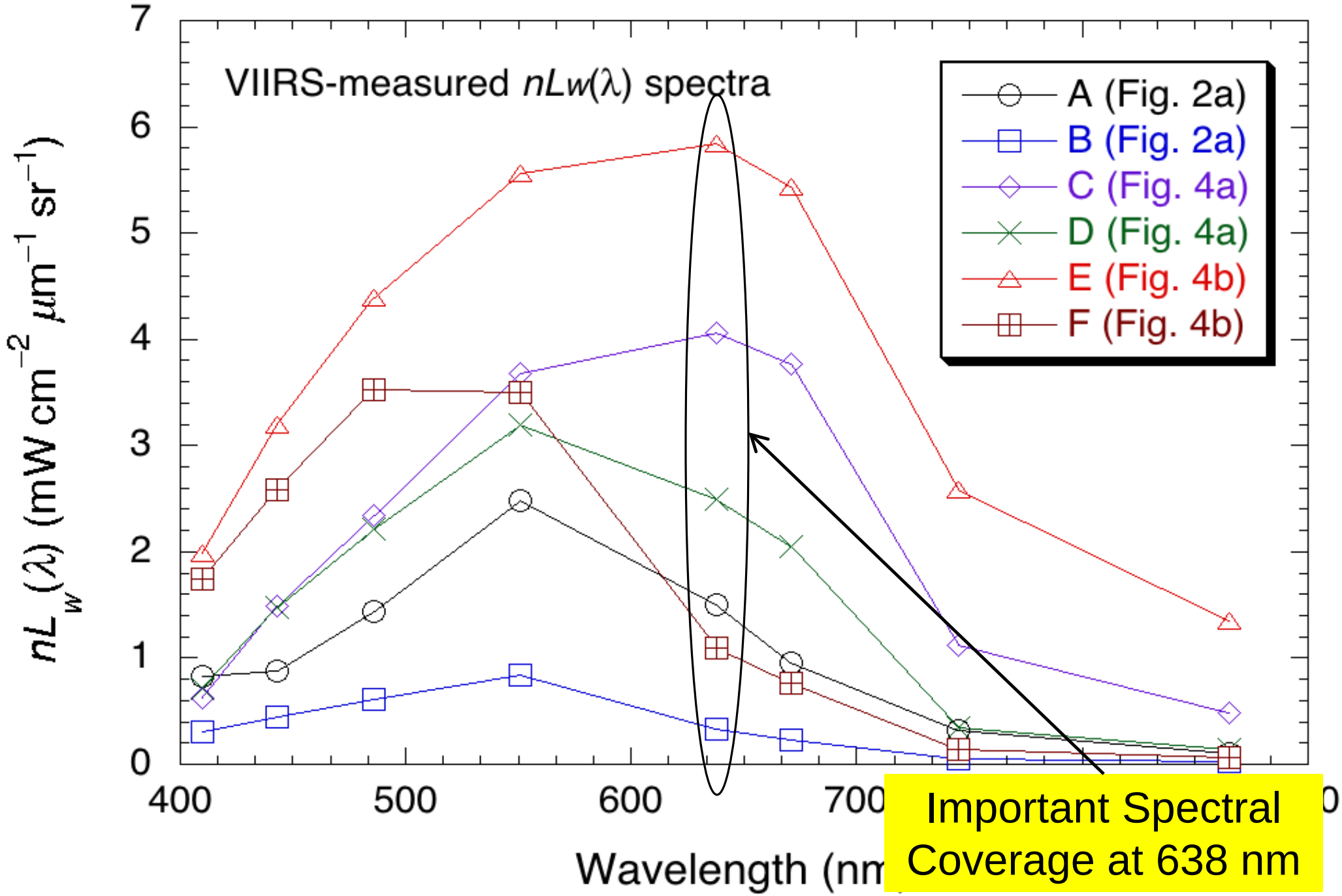


Wang, M. and L. Jiang (2017), "VIIRS-derived ocean color product using the imaging bands", *Remote Sen. Environ.* (Submitted).

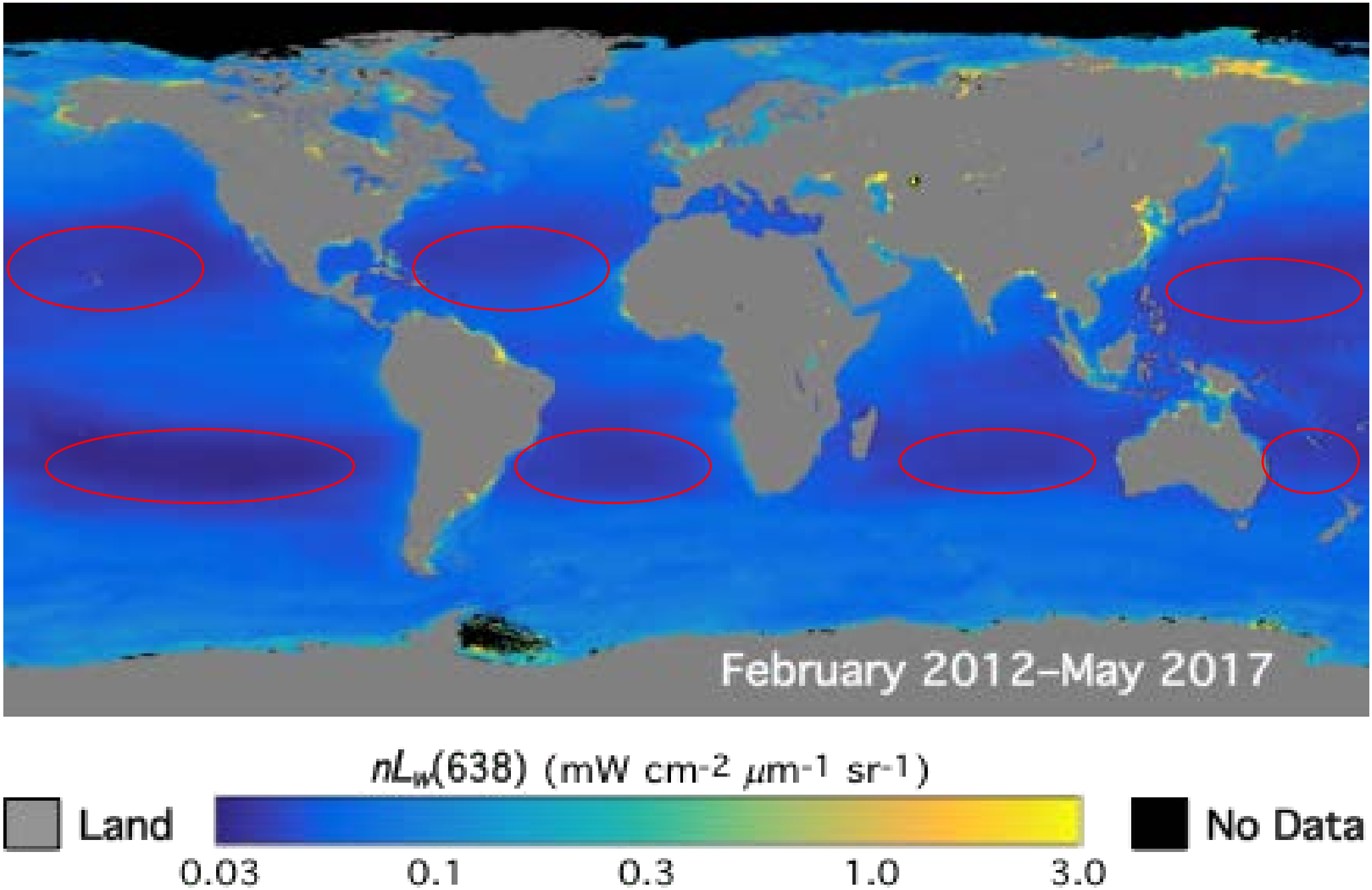
More Detailed Algae Bloom Information Provided by VIIRS High Spatial Resolution (375 m) $nL_w(638)$ Data



Increased spectral coverage with VIIRS new $nL_w(638)$ data, providing important spectral information

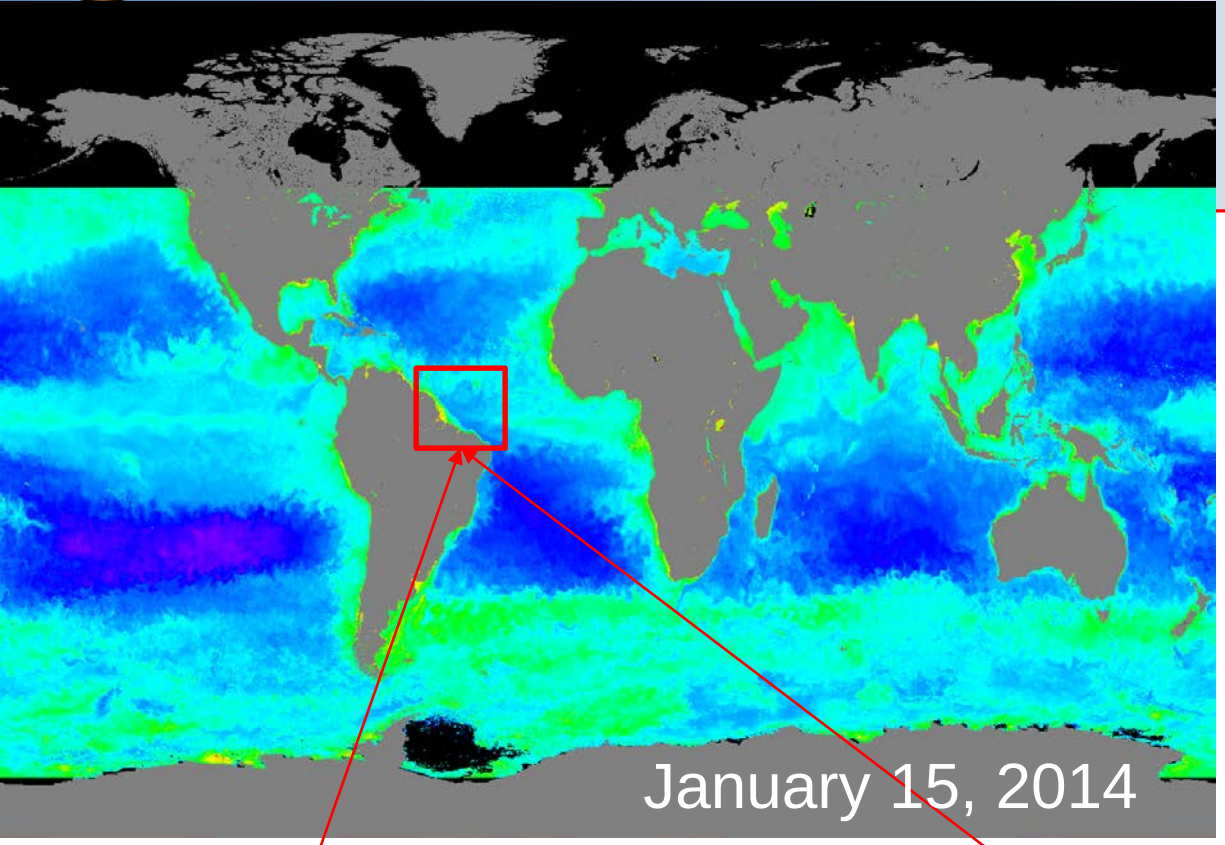


VIIRS-derived $nL_w(638)$ Climatology Image



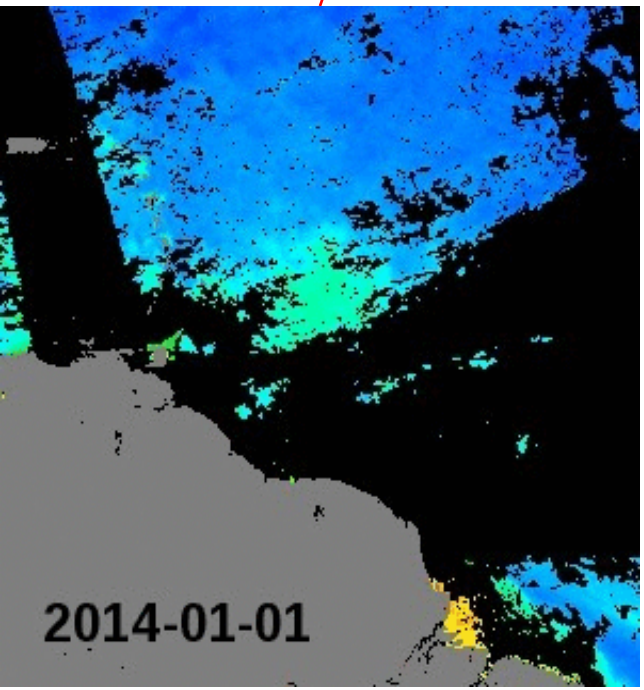
Menghua Wang, NOAA/NESDIS/STAR

Gap Filling Using the DINEOF Method

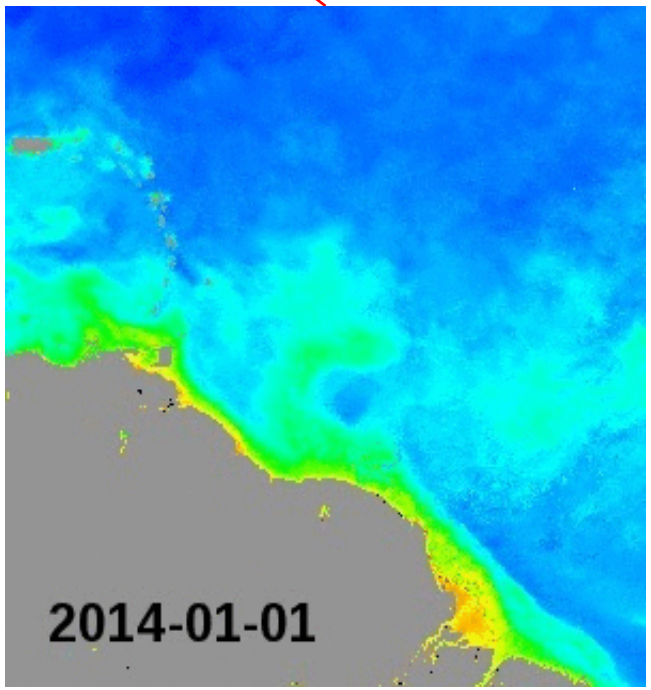


Examples of Reconstructed Chl-a Images (1)

Eddies near Amazon River
January 1-31, 2014



Original



Reconstructed

We can now see **eddy movement** in the reconstructed Chl-a images

Menghua Wang, NOAA/NESDIS/STAR

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

Washington, D.C.
September 2015

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Environmental Satellite, Data, and Information Service

Dedicated VIIRS Cal/Val Cruises

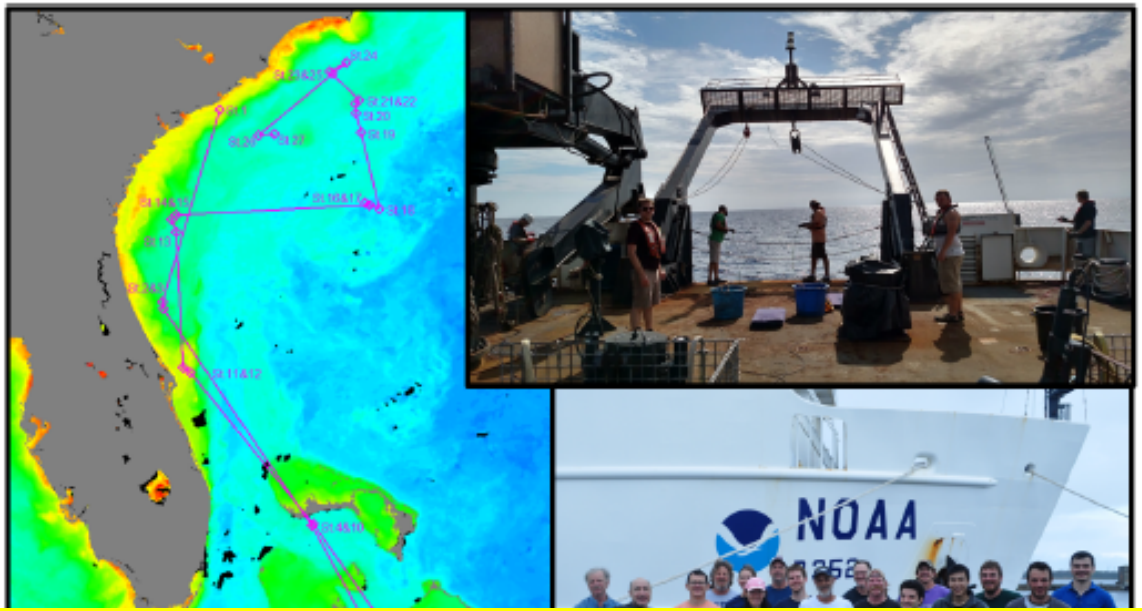
Ondrusek, M., E. Stengel, V. P. Lance, M. Wang, K. J. Voss, G. Zibordi, M. Talone, Z. P. Lee, J. Wei, J. Lin, C. Hu, D. English, C. Kovach, J. Cannizzaro, A. Gilerson, S. Ahmed, A. Ibrahim, A. El-Habashi, R. Foster, R. Arnone, R. Vandermeulen, S. Ladner, W. Goode, J. I. Goes, H. Gomes, A. Chekalyuk, 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

http://dx.doi.org/10.7289/V52B8W0Z

NOAA Technical Report NESDIS 148

doi:10.7289/V5/TR-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!

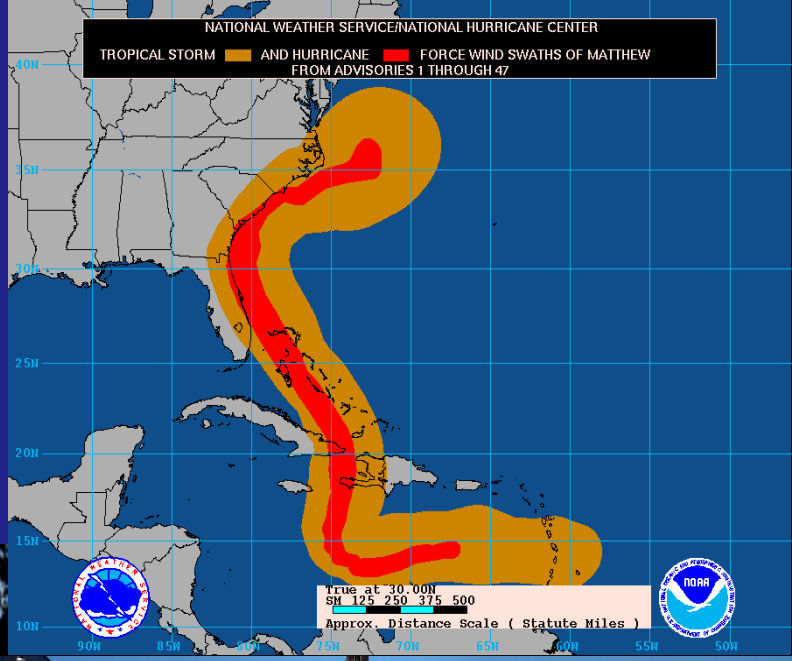
Ondrusek, M., V. P. Lance, E. Stengel, M. Wang, R. Arnone, S. Ladner, W. Goode, R. Vandermeulen, S. Freeman, J. E. Chaves, A. Mannino, A. Gilerson, S. Ahmed, C. Carrizo, A. El-Habashi, R. Foster, M. Ottaviani, J. I. Goes, H. Gomes, K. McKee, C. Hu, C. Kovach, D. English, J. Cannizzaro, B. C. Johnson, 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

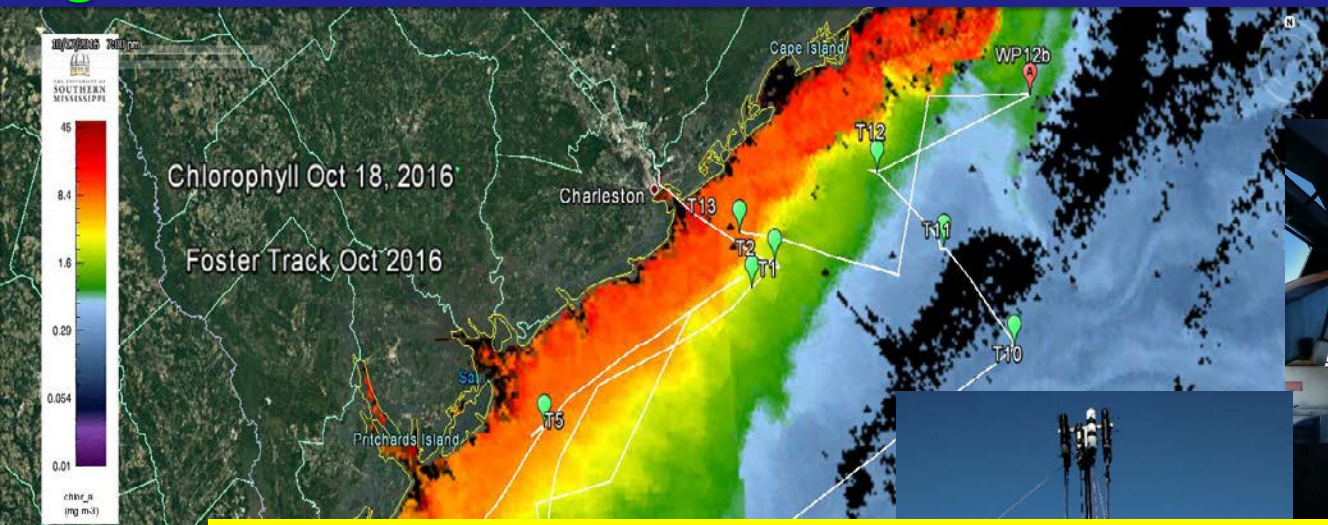
US DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Environmental Satellite, Data, and Information Service

Dedicated VIIRS Cal/Val Cruise III
NOAA Ship *Nancy Foster*
5-18 October 2016

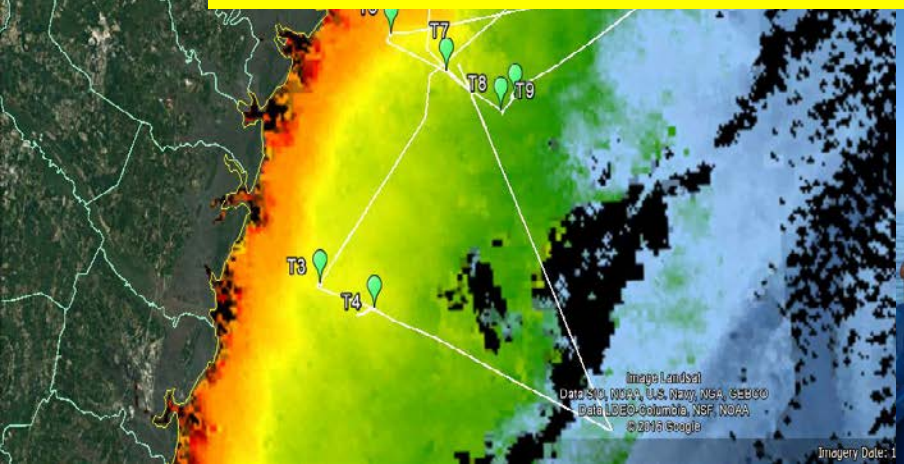
NOAA, NRL, NASA, USF, UMB, CUNY, IDEO, OSU

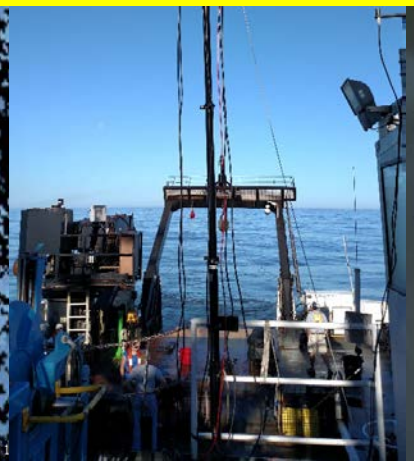
Measurements done just after Hurricane Matthew in the region **13-18 October 2016**.



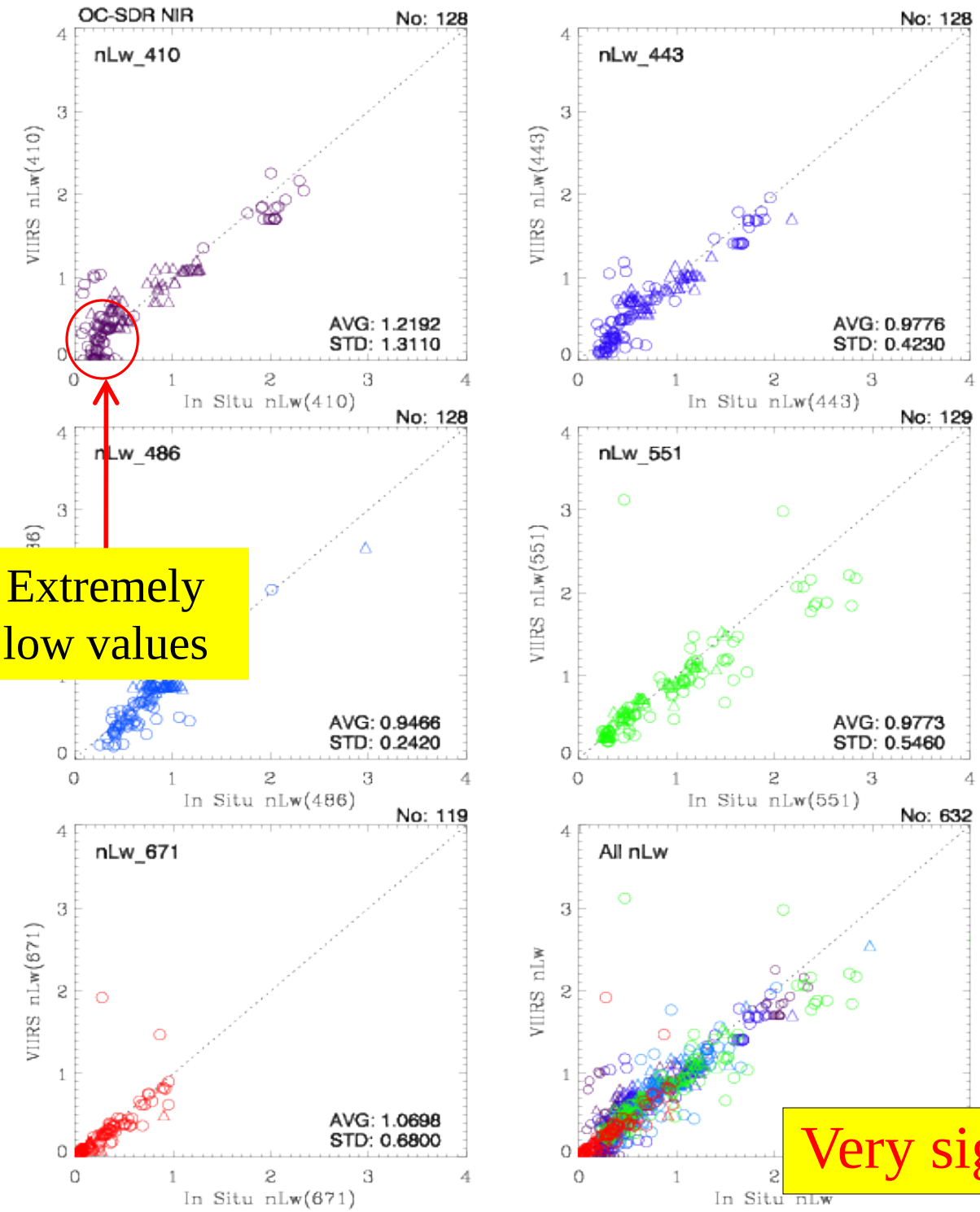


Report will be published soon (this year)!





Validation Effort



Extremely low values

VIIRS vs. In Situ Data

In Situ Data Sources:

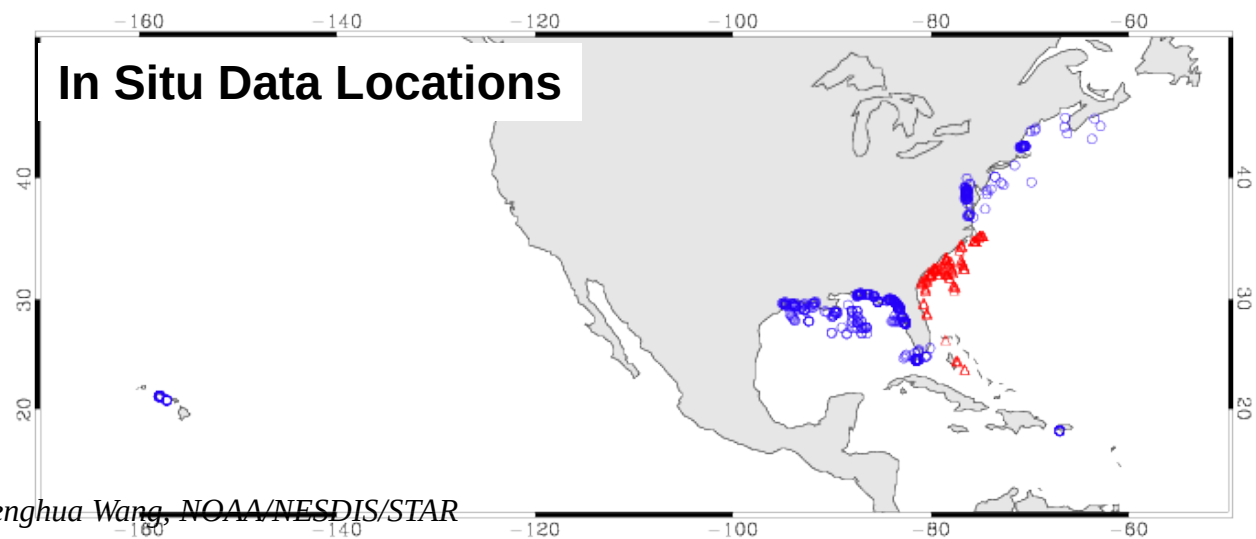
R. Arnone (U. South Miss.)
C. Davis (Oregon State U.)
C. Hu (U. South Florida)
Z. Lee (U. Mass. Boston)
M. Ondrusek (NOAA/STAR)
G. Zibordi (JRC)

- 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



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

Menghua Wang, NOAA/NESDIS/STAR

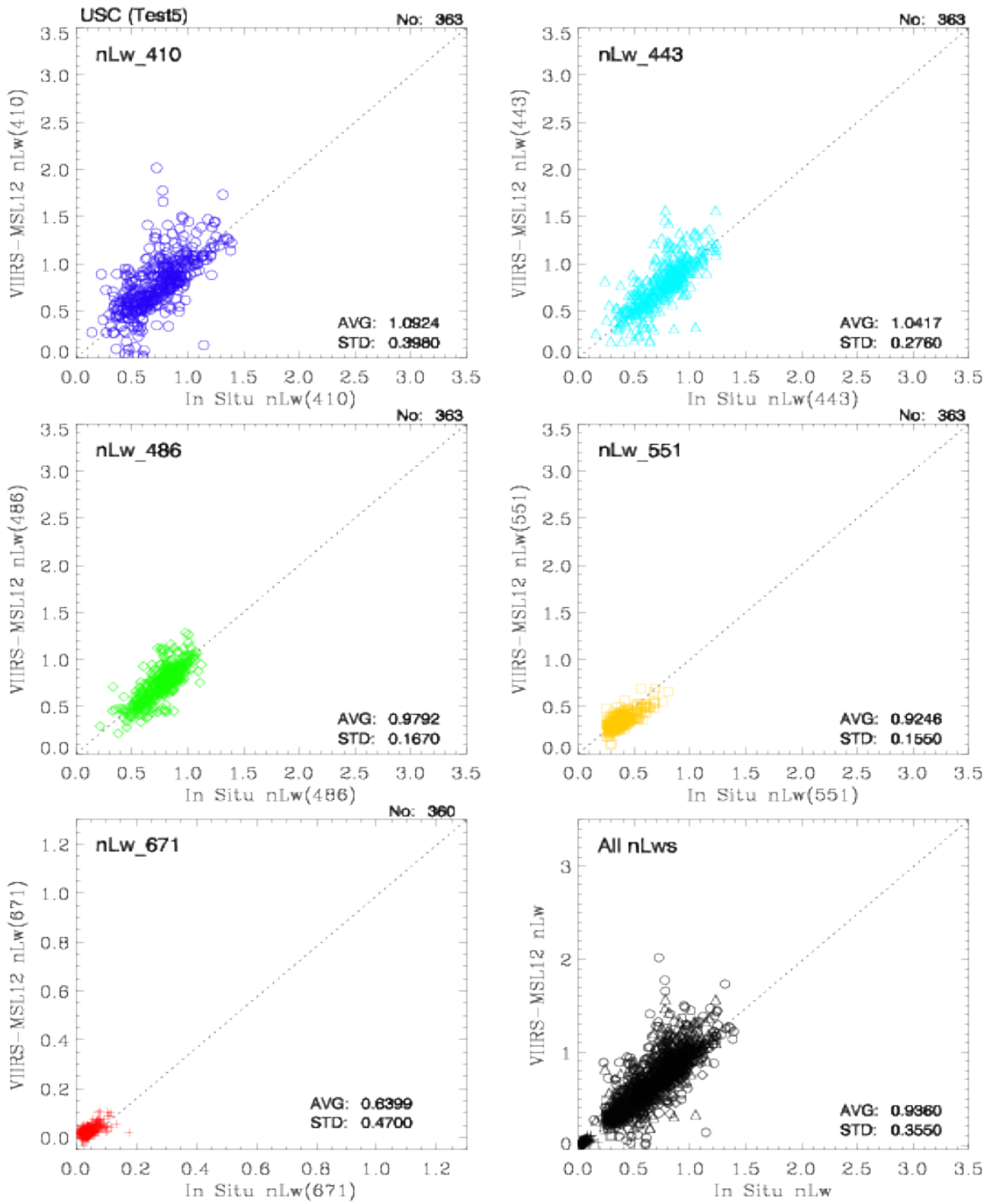
Matchup of

AERONET-OC In Situ

versus

VIIRS OC-SDR NIR

USC



Menghua Wang, NOAA/NESDIS/STAR

USC

Statistics of VIIRS OC (NIR) vs. In-Situ (AERONET-OC)

	OC-SDR The NIR Method							
	RATIO (SAT/ENV)				DIFFERENCE (SAT-ENV)			
	AVG	MED	STD	No	AVG	MED	STD	%Diff
$nL_w(410)$	**1.0924**	1.0213	0.398	363	**0.04474**	0.01420	0.2325	6.066
$nL_w(443)$	**1.0417**	0.9988	0.276	363	**0.02133**	-0.00100	0.1680	2.825
$nL_w(486)$	**0.9792**	0.9645	0.167	363	**-0.01838**	-0.02690	0.1145	-2.404
$nL_w(551)$	**0.9246**	0.9091	0.155	363	**-0.03356**	-0.03260	0.0598	-8.804
$nL_w(671)$	**0.6399**	0.5777	0.470	360	**-0.01737**	-0.01620	0.0185	-40.249
nL_w All	**0.9360**	0.9406	0.355	1812	**-0.00062**	-0.01760	0.1438	-0.115

Menghua Wang, NOAA/NESDIS/STAR

Conclusions

- VIIRS global ocean color products have been routinely produced using the **NIR-**, **SWIR-**, and **NIR-SWIR-**based atmospheric correction algorithms, 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 show that **VIIRS-SNPP is now capable of providing high quality global ocean color products in support of science research and operational applications**.
- We will prepare for the OC data processing for VIIRS-J1 in FY18, which will provide more complete global coverage with VIIRS-SNPP.

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

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

Thank You!