VIIRS Ocean Color Products

Menghua Wang &
Ocean Color EDR & Cal/Val Teams
Date: August 25, 2015

STAR JPSS 2015 Annual Science Team Meeting
College Park, MD, August 24-28, 2015

Ocean Color Teams contributed **21** posters (Thursday)

VIIRS Ocean Color EDR & Cal/Val Teams Members

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, V. Lance, **M. Ondrusek,** E. Stengel	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, algorithm improvements, software updates, data validations and analyses
Ocean Color	**Robert Arnone** Sherwin Ladner, Ryan Vandermeulen Adam Lawson, Paul Martinolich, Jen Bowers	U. Southern MS NRL QinetiQ Corp. SDSU	JPSS/NJO	Satellite data evaluation, in situ data Look Up Tables – SDR-EDR impacts, vicarious calibration Satellite matchup tool (SAVANT) – Golden Regions Cruise participation and support WAVE_CIS (AERONET-OC site) operation
	Carol Johnson	NIST	JPSS/NJO	Traceability, AERONET-OC Uncertainty
	Curt Davis, Nicholas Tufillaro	OSU	JPSS/NJO	Ocean color validation, Cruise data matchup West Coast
	Burt Jones, Matthew Ragan	USC	JPSS/NJO	Eureka (AERONET-OC Site)
	Sam Ahmed, Alex Gilerson	CUNY	JPSS/NJO	LISCO (AERONET-OC Site) Cruise data and matchup
	Chuanmin Hu	USF	JPSS/NJO	NOAA data continuity, cruise participation/support
	Ken Voss & MOBY team	RSMAS –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, cruise participation

Working with: NOAA **CoastWatch**, VIIRS **SDR team**, DPA/DPE, Raytheon, NOAA OC Working Group, NOAA Coral Reef Watch, NOAA various line-office reps, NASA OBPG, NOAA OCPOP, etc.

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

Summary of VIIRS Ocean Color EDR Products

- **Inputs**:
  - VIIRS M1-M7 and the **SWIR** M8, M10, and M11 bands SDR data
  - Terrain-corrected geo-location file
  - Ancillary meteorology and ozone data
- **Operational (Standard) Products** (8):
  - Normalized water-leaving radiance (nL_w's) at VIIRS visible bands M1-M5
  - Chlorophyll-a (Chl-a) concentration
  - Diffuse attenuation coefficient for the downwelling spectral irradiance at the wavelength of 490 nm, $K_d(490)$ (New)
  - Diffuse attenuation coefficient of the downwelling photosynthetically available radiation (PAR), $K_d(\mathrm{PAR})$ (New)
  - Level-2 quality flags
- **Experimental Products:**
  - 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)
  - Chlorophyll-a from ocean color index (OCI) method (Hu et al., 2012)
  - Others from users requests

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

Multi-Sensor Level-1 to Level-2 (MSL12) Ocean Color Data Processing

- Multi-Sensor Level-1 to Level-2 (MSL12)
  - ✓ **MSL12 is the official VIIRS ocean color data processing system.**
  - ✓ MSL12 was developed for the purpose of using a consistent and common data processing system to produce ocean color products from multiple satellite ocean color sensors (Wang, 1999; Wang and Franz, 2000; Wang et al., 2002), i.e., it is **measurement-based** ocean color data processing system.
  - ✓ It has been used for producing ocean color products from various satellite ocean color sensors, e.g., SeaWiFS, MOS, OCTS, POLDER, MODIS, GOCI, etc.
- MSL12 Ocean Color Data Processing
  - ✓ MSL12 is based on SeaDAS version 4.6.
  - ✓ Some significant improvements: (1) the SWIR-based data processing, (2) **Rayleigh** (new) and aerosol LUTs, (3) algorithms for detecting absorbing aerosols and turbid waters, (4) ice detection algorithm, (5) improved straylight/cloud shadow algorithm, & others.
  - ✓ In 2014, some new algorithms (BMW–new NIR reflectance correction, Destriping, K_d(PAR), etc.)
- MSL12 for VIIRS (and others) Ocean Color Data Processing
  - ✓ Routine ocean color data processing (daily, 8-day, monthly) since VIIRS launch.
  - ✓ Coastal turbid and inland waters from other approaches, e.g., the **SWIR approach**, results in the US east coastal, China's east coastal, Lake Taihu, Lake Okeechobee, Aral Sea, etc.
  - ✓ Capability for multi-sensor ocean color data processing, e.g., MODIS-Aqua, VIIRS, GOCI, and will also add J1, OLCI/Stentinel-3, and SGLI/GCOM-C data processing capability.

End-to-End Ocean Color Data Processing

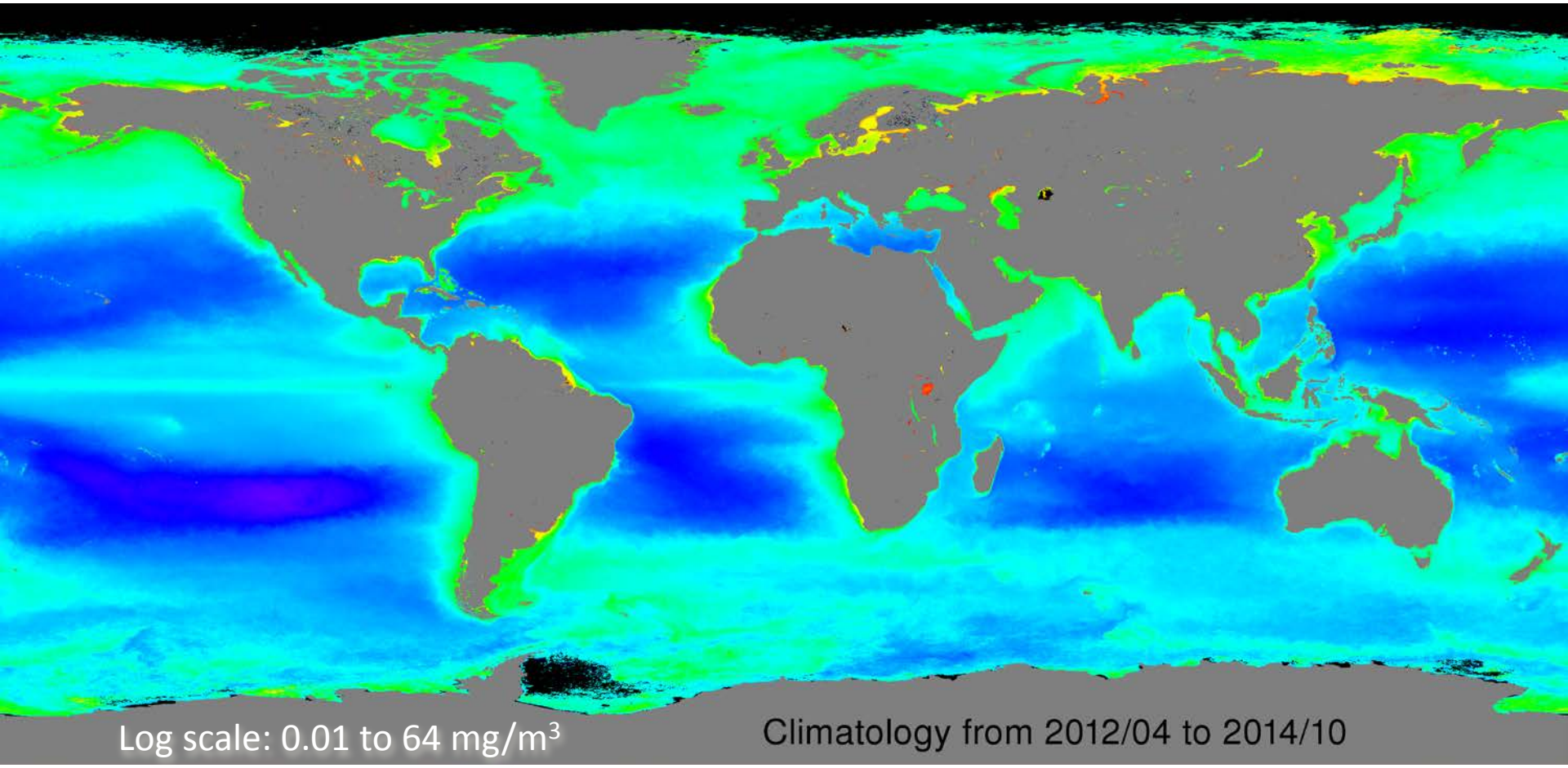
- NOAA Ocean Color Team has been developing/building the capability for the **End-to-End** satellite ocean color data processing including:
  - Level-0 (or Raw Data Records (RDR)) to Level-1B (or Sensor Data Records (SDR)).
  - Level-1B (SDR) to ocean color Level-2 (Environmental Data Records (EDR).
  - 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, **NOAA dedicated cruise**, etc.
- On-orbit instrument calibration (solar and **lunar**) for ocean color data processing (Cal effort is needed to meet ocean color requirement):
  - J. Sun and M. Wang, "Radiometric calibration of the VIIRS reflective solar bands with robust characterizations and hybrid calibration coefficients," *Appl. Opt.* (Submitted).
  - J. Sun and M. Wang, "On-orbit calibration of Visible Infrared Imaging Radiometer Suite reflective solar bands and its challengers using a solar diffuser," *Appl. Opt.*, **54**, 7210-7223, 2015.
  - J. Sun and M. Wang, "On-orbit characterization of the VIIRS solar diffuser and solar diffuser screen," *Appl. Opt.*, **54**, 236-252, 2015.
  - J. Sun and M. Wang, "Visible Infrared Imaging Radiometer Suite solar diffuser calibration and its challenges using solar diffuser stability monitor," *Appl. Opt.*, **53**, 8571-8584, 2014.
- RDR (Level-0) to SDR (Level-1B) data processing (needed for quick data reprocessing):
  - 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.
  - L. Tan, M. Wang, J. Sun, and L. Jiang, "VIIRS RDR to SDR Data Processing for Ocean Color EDR," *Proc. SPIE* 9261, *Ocean Remote Sensing and Monitoring from Space*, October 13-16, 2014.

Two Data Streams for VIIRS Ocean Color EDR

To meet requirements from **All** users (operational, research, modeling, etc.), we plan to produce VIIRS ocean color products in two data streams:

- **Near-Real-Time (NRT) Ocean Color Data Processing (**12-24 hours**):**
  - Quick turn around with ~12-24 hours latency (operational)
  - Using standard IDPS SDR data
  - Ancillary data using the Global Forecast System (GFS) model
  - Data may not be completed due to various issues (SDR missing, computer, etc.)
  - Data will be processed in NOAA CoastWatch and OSPO
- **Science Quality Ocean Color Data Processing (**One-two weeks delay**):**
  - About one-two weeks delay
  - Reprocessed mission-long ocean color data and continue-forward data stream
  - Using improved SDR (based on IDPS SDR data)
  - Science quality (assimilated) NCEP ancillary data
  - Complete global coverage
  - May expand to more experimental products & test with improved algorithms
  - Ocean color EDR will be reprocessed (mission-long) about every two-three years (or as needed, e.g., short-term data reprocessing, error fixing, etc.)
  - Data will be processed in NOAA/STAR and transferred to CoastWatch for distributions

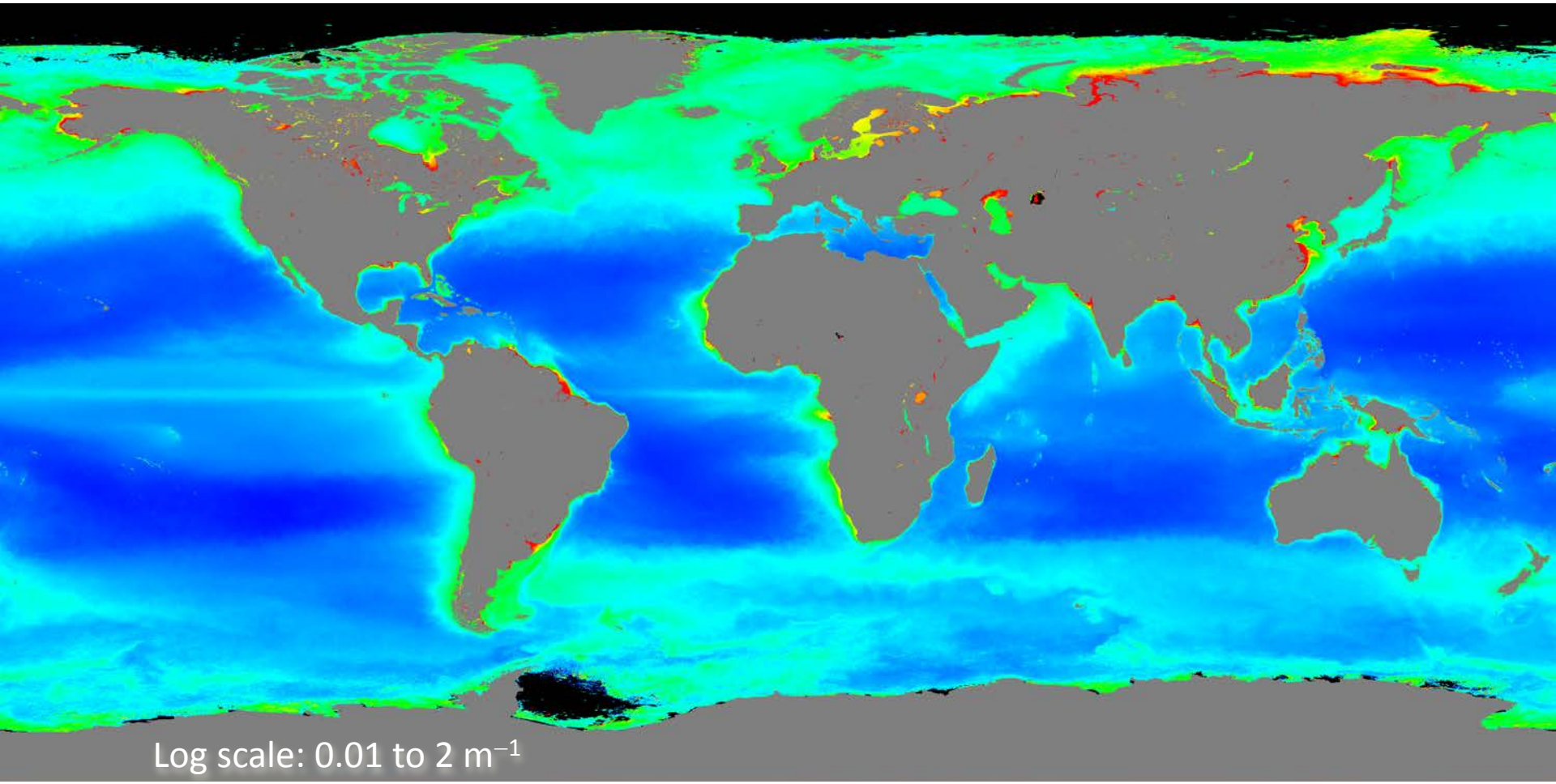
VIIRS Climatology Chlorophyll-a Image
(April 2012 to October 2014)



Generated using MSL12 for VIIRS ocean color data processing

Wang, M., X. Liu, L. Tan, L. Jiang, S. Son, W. Shi, K. Rausch, and K. Voss, "Impacts of VIIRS SDR performance on ocean color products," *J. Geophys. Res. Atmos.*, **118**, 10,347–10,360, 2013. http://dx.doi.org/10.1002/jgrd.50793

VIIRS Climatology K_d(490) Image
(March 2012 to February 2015)

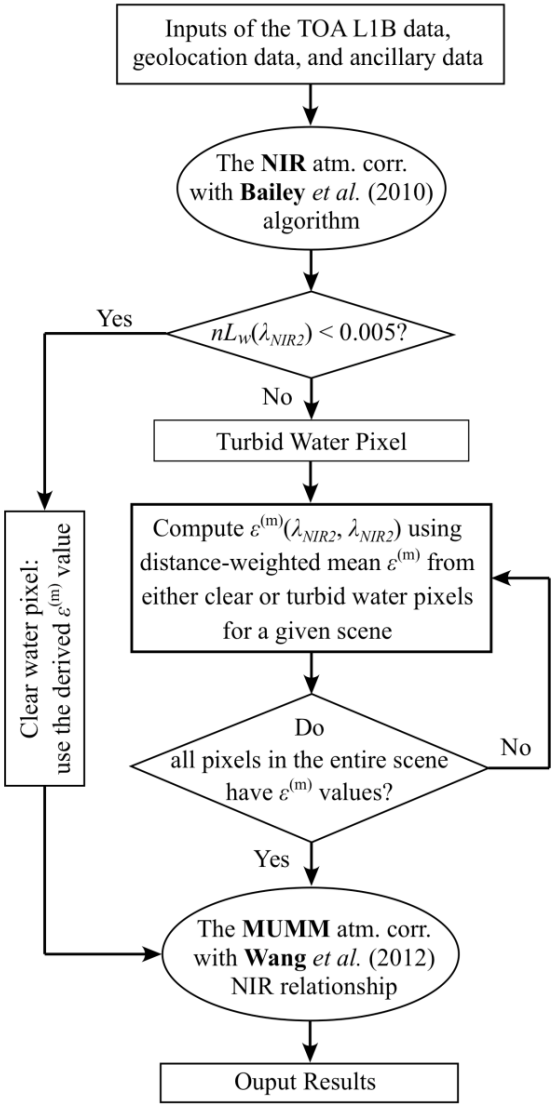


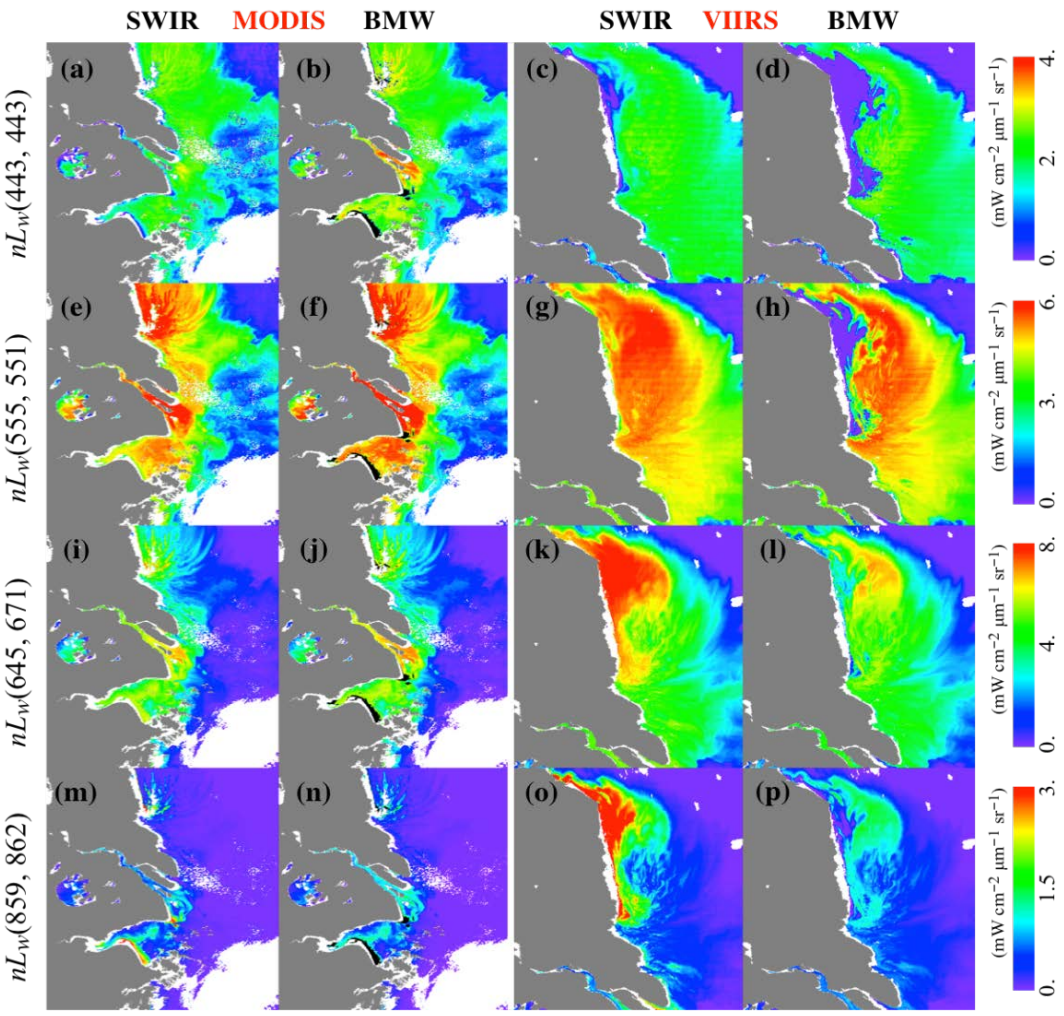
Generated using MSL12 for VIIRS ocean color data processing

Wang, M., S. Son, and L. W. Harding Jr., "Retrieval of diffuse attenuation coefficient in the Chesapeake Bay and turbid ocean regions for satellite ocean color applications," *J. Geophys. Res.*, **114**, C10011, 2009. http://dx.doi.org/10.1002/2009JC005286

Developed new NIR ocean reflectance correction algorithm: BMW (*Bailey* (2010), *MUMM* (2000), and *Wang* (2012))

The BMW Algorithm for Ocean Color Data Processing





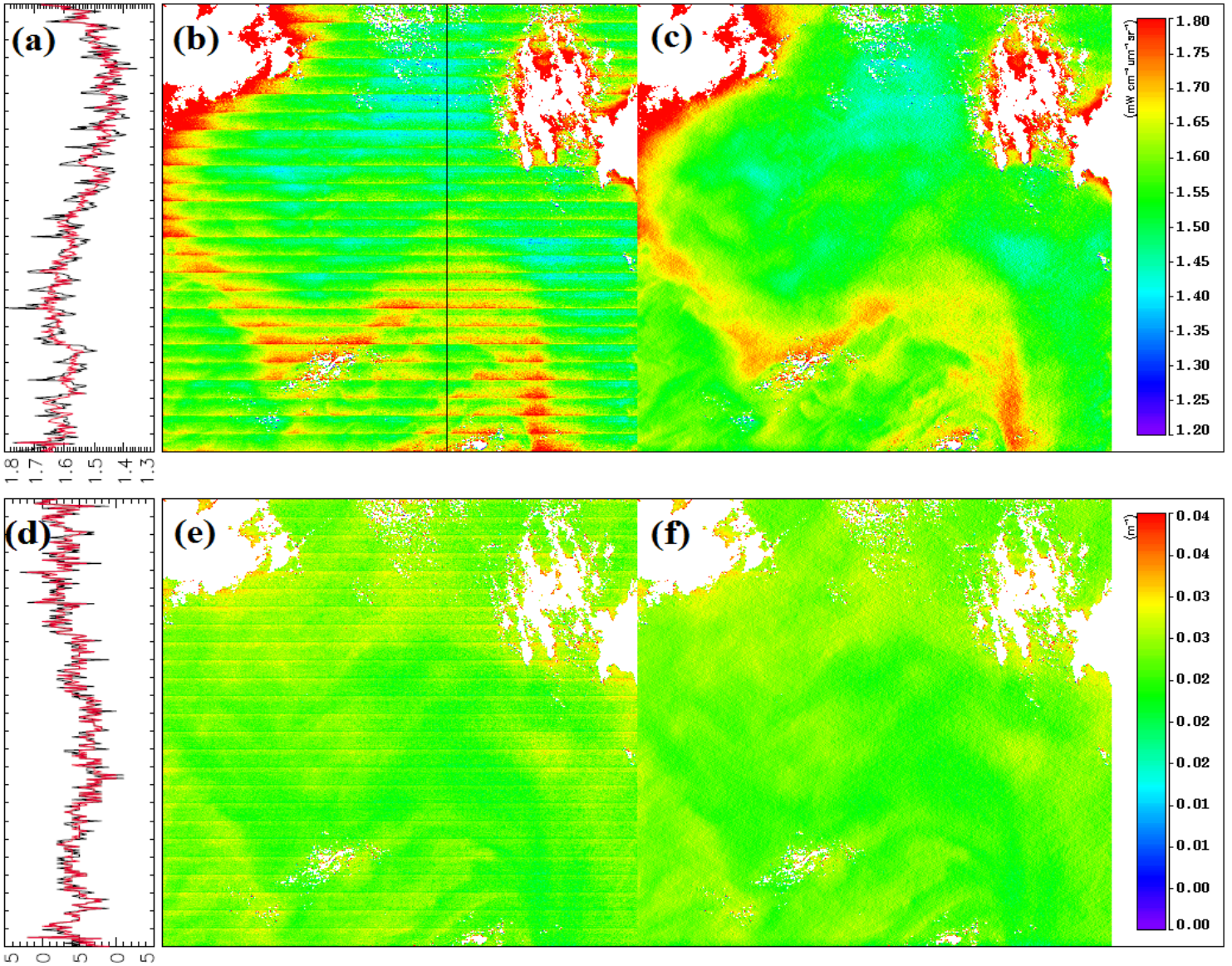
Comparisons of MODIS and VIIRS-derived $nL_w(\lambda)$ images at four selected bands.

Jiang, L. and M. Wang, "Improved near-infrared ocean reflectance correction algorithm for satellite ocean color data processing," *Opt. Express*, **22**, 21,657–21,678, 2014. http://dx.doi.org/10.1364/OE.22.021657

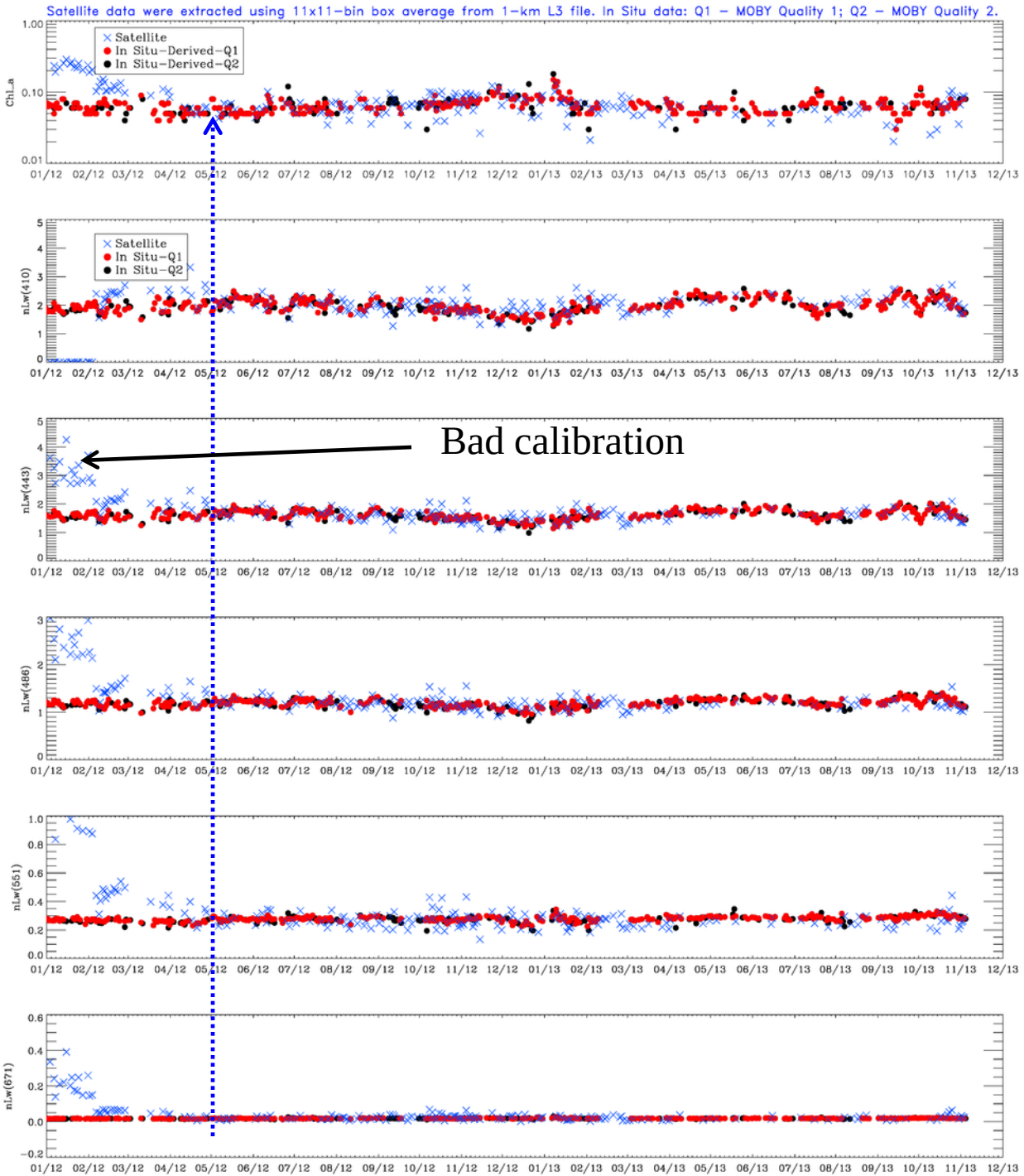
Destriping of VIIRS Ocean Color Products
(Examples)

$nL_w(412)$

$K_d(490)$



Mikelsons, K., M. Wang, L. Jiang, and M. Bouali, "Destriping algorithm for improved satellite-derived ocean color product imagery," *Opt. Express*, **22**, 28058-28070, 2014. http://dx.doi.org/10.1364/OE.22.028058



MOBY

Comparison of NOAA VIIRS ocean color products with **Marine Optical Buoy (MOBY)** in situ data.

Note:
Vicarious calibration gains applied since **May 2012**.

Vicarious gains were derived using **MOBY** in situ data.

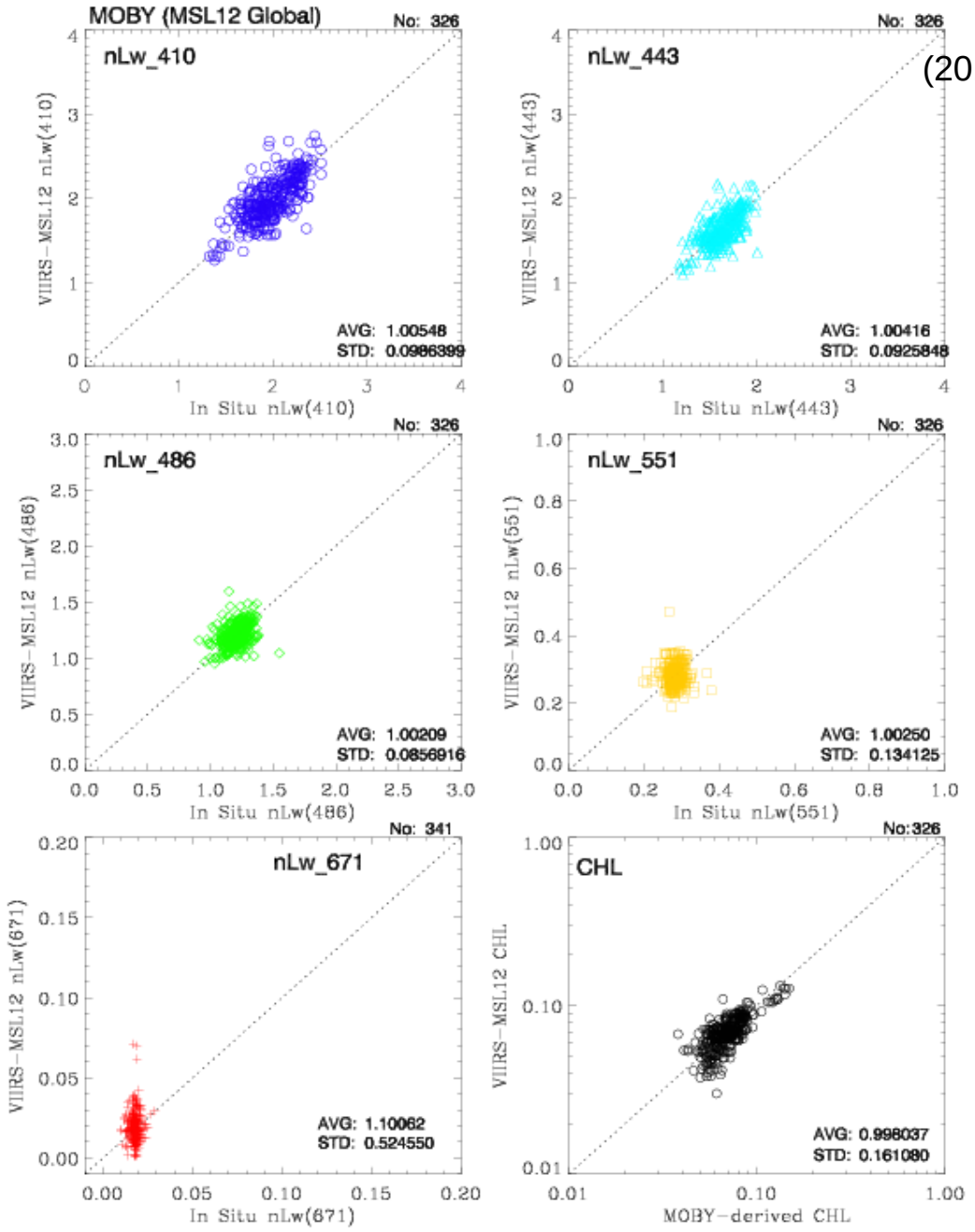
MOBY in situ optics data have been providing critical data set in support of VIIRS calibration and validation activities, including VIIRS Level-1B (SDR) data monitoring for sensor on-orbit calibration.

MOBY Matchup
with
VIIRS OC-SDR/EDR Processing (BMW-nc4)

Use OC-SDR with New MSL12

MOBY

(2012-01-01 ~ **2014-05-31**)
Q1+Q2, ±3hr



Menghua Wang, NOAA/NES

MOBY

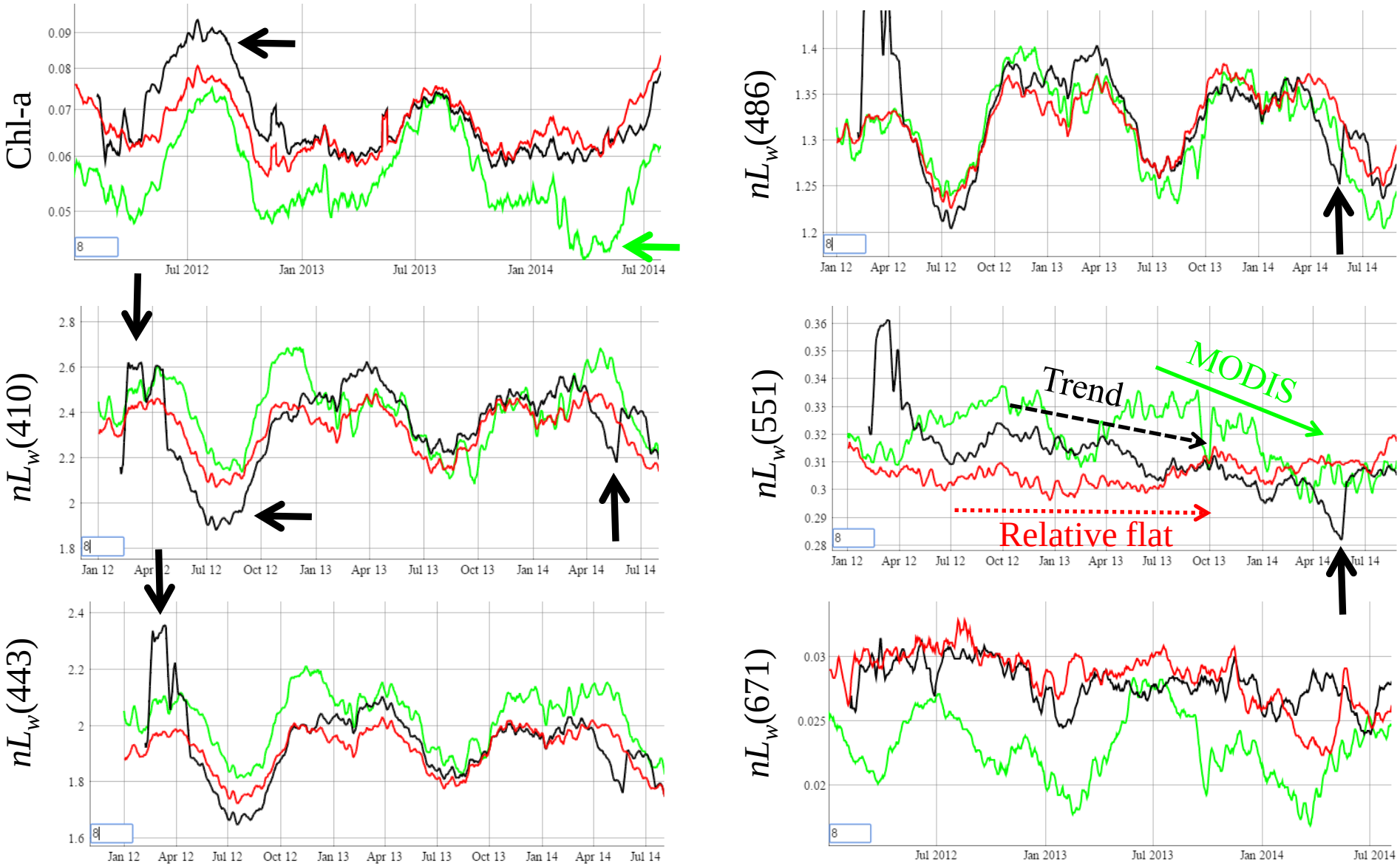
Statistics of VIIRS MSL12 vs. In-Situ (MOBY)

	Current Data Processing (2012-01-01 ~ **2014-05-31**)				New EDR Processing (BMW-hdf) (2012-01-01 ~ **2014-05-31**)				OC-SDR/EDR Processing (BMW-netCDF4) (2012-01-01 ~ **2014-05-31**)			
	AVG	**MED**	**STD**	**No**	**AVG**	**MED**	**STD**	**No**	**AVG**	**MED**	**STD**	**No**
nL_w**(410)**	**1.0426**	1.0329	0.126	304	**1.0110**	1.0065	0.099	287	**1.0055**	1.0002	0.099	326
nL_w**(443)**	**1.0679**	0.9904	0.294	329	**1.0436**	1.0107	0.210	299	**1.0042**	1.0009	0.093	326
nL_w**(486)**	**1.0642**	0.9743	0.329	329	**1.0472**	1.0071	0.225	299	**1.0021**	0.9992	0.086	326
nL_w**(551)**	**1.2029**	0.9225	0.897	329	**1.1376**	1.0077	0.600	299	**1.0025**	0.9947	0.134	326
nL_w**(671)**	**1.9579**	1.1263	2.796	340	**1.5479**	1.1000	2.599	315	**1.1006**	1.0588	0.525	341
Chl-a	**1.1372**	0.9488	0.781	329	**1.1293**	1.0333	0.501	299	**0.9980**	0.9852	0.161	326
K_d**(490)**	**1.0867**	0.9846	0.435	329	**1.0698**	1.0214	0.281	299	**0.9769**	0.9769	0.101	506

Global Oligotrophic Water OC Product Time Series

OC-SDR: Generated by the OC Team with OC calibration approach
IDPS-SDR: From operational IDPS-generated SDR

Reprocessed both mission-long SDR data using the **same new MSL12**



Red: VIIRS **OC-SDR** Black: VIIRS **IDPS-SDR** Green: **MODIS**-Aqua (NASA)

Dedicated VIIRS Cal/Val Cruise

NOAA Ship *Nancy Foster*

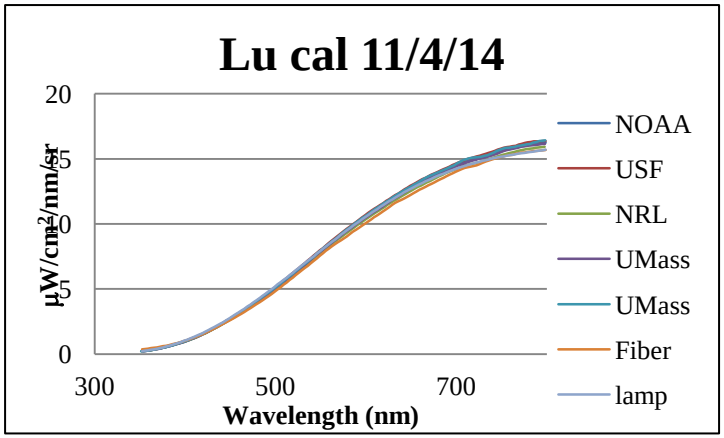
11-21 November 2014

International, Interagency, and Academic Collaborations:

4 US Agencies, EU-JRC, 6 Universities

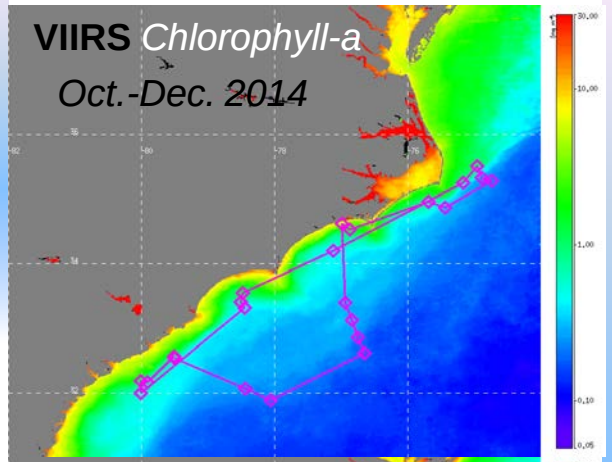
Validation Measurements

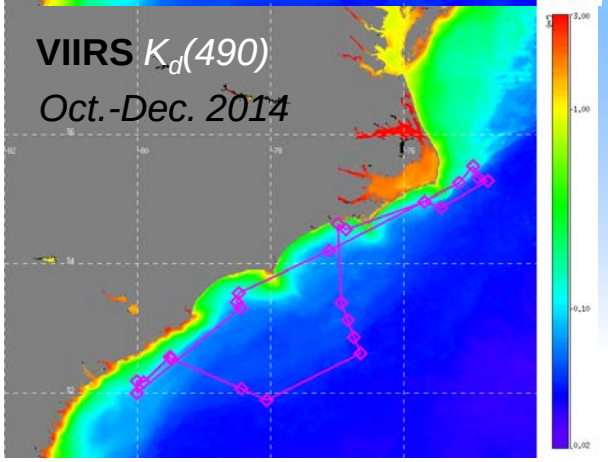
Water-leaving radiance; Chlorophyll-a; Absorption and backscattering coefficients; Bi-directional radiance distribution; Phytoplankton physiology; Carbon; Total suspended matter; Aerosol optical depth, etc.



Pre-cruise inter-calibration results for 5 radiance sensors

Cruise Track





Validation Results

- **Occupied 23 stations over 10 days**
- **Simultaneous measurements at each station for:**
  - ✓**4 profiling radiometers**
  - ✓**2 floating radiometers**
  - ✓**6 above-water radiometers**
- **Conducted pre- and post-cruise inter-calibrations**

11 potential station matchups with VIIRS

The cruise report is completed!

Conclusions/Path Forward (1)

- With improved SDR (calibration) and EDR (data processing algorithms), **VIIRS ocean color products are now comparable to or better than those from MODIS-Aqua.**
- We have completed mission-long OC data reprocessing using IDPS-SDR with new MSL12.
- We have started VIIRS mission-long science quality ocean color data **reprocessing** (including **SDR** and **EDR**), and will finish that in **late 2015**, & the data stream will go forward. **Two data streams will be produced: near-real-time and science quality ocean color data.**
- Calibration from both solar and lunar is necessary. We need lunar model data!

- VIIRS ocean color products have been improved after the implementation of some important updates, new algorithms, and with vicarious calibrations.
- In general, VIIRS **normalize water-leaving radiance** spectra show reasonable agreements with in situ measurements at MOBY, AERONET-OC sites, and various other ocean regions.
- The new NIR ocean reflectance correction algorithm (BMW) improves ocean color data over coastal and inland waters. The destriping algorithm significantly improves VIIRS-derived ocean color imageries.
- New K_d**(PAR)** product has been developed and routinely produced to meet users requirements.
- NOAA dedicated Cal/Val cruise in Nov. 2014, and plan to have it in late 2015. The report for the 2014 Cal/Val cruise has been completed.
- There will be many applications using VIIRS ocean color products.
- We have developed VIIRS instrument calibration capability, and with new calibration LUTs, VIIRS ocean color products are significantly improved.
- Our evaluation results show that VIIRS-SNPP is capable of providing high-quality global ocean color products in support of science research and operational applications.
- We have been actively working with other current and future ocean color sensors, e.g., MODIS-Aqua, Korean GOCI, EUMETSAT for Sentinel-3 (launch late 2015), JAXA GCOM-C (launch early 2017), and **VIIRS on J1** (launch 2017).

Conclusions/Path Forward (2)

- Complete VIIRS mission-long ocean color data reprocessing (science quality, i.e., improved SDR, algorithms, and science quality ancillary data).
- VIIRS reprocessed data stream will go forward (about one-two weeks delay). VIIRS science quality data will be distributed through CoastWatch and other means (e.g., NODC effort).
- Cal/Val team will finish the 2014 VIIRS dedicated cruise report and in situ data analyses (e.g., improve in situ data quality).
- More in situ data are needed for validation and improvement of VIIRS ocean color products.
- In situ data quality (instrument calibration, measurement protocols, data processing methodology, etc.)
- Dedicated VIIRS ocean color Cal/Val cruise in December 2015, and establishing annual Cal/Val cruises.
- Continue work on sensor on-orbit calibration (solar and lunar), algorithms improvements, etc.
- We have been working on J1 instrument. Need more efforts for J1 VIIRS pre-launch data analyses as J1 close to launch (access to J1 sensor data).
- Algorithms improvements for both open oceans and coastal/inland waters. In particular, significant efforts are needed for coastal/inland waters.

Details: Ocean color breakout session and the Team 21 posters on Thursday!