# VIIRS Ocean Color Team Activities

**Menghua Wang** &

NOAA Ocean Color 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 8-12, 2016*

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

Website for VIIRS ocean color data:
http://coastwatch.noaa.gov/cwn/cw_products_ocLOM.html

**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 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, M. Chu, V. Lance, **M. Ondrusek,** E. Stengel | NOAA/NESDIS/ STAR | JPSS/NJO | Leads – Ocean Color EDR Team & Cal/Val Team<br>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**<br>Sherwin Ladner, Ryan Vandermeulen<br>Adam Lawson, Paul Martinolich,<br>Jen Bowers | U. Southern MS<br>NRL<br>QinetiQ Corp.<br>SDSU | JPSS/NJO | Look Up Tables – SDR-EDR impacts, vicarious calibration<br>Satellite matchup tool (SAVANT) – Golden Regions<br>Cruise participation and support<br>WAVE_CIS (AERONET-OC site) operation |
| | **Carol Johnson** | NIST | JPSS/NJO | Traceability, AERONET 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 Site) |
| | **Alex Gilerson**, **Sam Ahmed** | CUNY | JPSS/NJO | LISCO (AERONET site)<br>Cruise data and matchup |
| | **Chuanmin Hu** | USF | JPSS/NJO | NOAA data continuity |
| | **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<br>Ocean color optics matchup |

Working with: NOAA **CoastWatch**, VIIRS **SDR team**, DPA/DPE (R. Williamson, Neal Baker), Raytheon, NOAA OC Working Group, NOAA various line-office reps, NOAA NCEI, NOAA OCPOP, NASA, 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**

# Nominal Center Wavelength for VIIRS

## SNPP & JPSS-1

| VIIRS Nominal Center Wavelength (nm) | | |
|---|---|---|
| **Band** | **SNPP** | **JPSS-1** |
| M1 | 410 | 411 |
| M2 | 443 | 445 |
| M3 | 486 | 489 |
| M4 | 551 | 556 |
| M5 | 671 | 667 |
| M6 | 745 | 746 |
| M7 | 862 | 868 |
| I1 | 642 | 638 |
| I2 | 862 | 867 |

# 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, $K_d(490)$
  - Diffuse attenuation coefficient of the downwelling photosynthetically available radiation (PAR), $K_d(\mathrm{PAR})$
  - 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*)
  - Chl-a from ocean color index (OCI) method (*Hu et al.*, 2012; *Wang and Son*, 2016)
  - 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 System

## ➢ NOAA-MSL12 Ocean Color Data Processing

- ✓ NOAA-MSL12 is based on SeaDAS version 4.6.
- ✓ Some significant improvements: (1) the SWIR-based ocean color data processing for coastal and inland waters, (2) improved Rayleigh and aerosol LUTs, (3) algorithms for detecting absorbing aerosols and turbid waters, (4) ice detection algorithm, (5) improved straylight and cloud shadow algorithm, (5) improved NIR water reflectance correction algorithm, (6) new destriping algorithm, and others.

## ➢ MSL12 for VIIRS Ocean Color Data Processing

- ✓ Routine ocean color data processing (daily, 8-day, monthly) since VIIRS launch.
- ✓ Routine global VIIRS ocean color data productions for the two data streams: Near-Real-Time (NRT) and Science Quality ocean color data processing.
- ✓ 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.

# MSL12 Ocean Color Algorithms, Improvements, and Updates

- **Algorithms used in the ocean color EDR data processing:**
  - Atmospheric corrections:
    - Gordon & Wang (1994) (and Wang et al. (2005)) for open ocean using the NIR bands
    - Wang (2007) and Wang and Shi (2007) using the SWIR bands
    - The NIR reflectance correction algorithm using **BMW** (Jiang and Wang, 2014) for costal/inland waters
  - Operational chlorophyll-a: OC3V algorithm
  - $K_d$(490) algorithm: Wang et al. (2009) algorithm
  - $K_d$(PAR) algorithm: Son and Wang (2015)
  - Destriping algorithm: Mikelsons et al. (2014)
  - Stray light/Cloud shadowing effects: Jiang and Wang (2013)
- **Updates**
  - Polarization correction algorithm (errors are corrected)
- **Experimental Products**
  - IOPs: Quasi-Analytical Algorithm (QAA) (Lee et al., 2002)
  - PAR: Frouin et al. (2003)
  - Chlorophyll-a data from the OCI method: Hu et al. (2012) and implemented in VIIRS using Wang and Son (2016)

# 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 cruises** (2014, 2015, 2016, ….,)

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

- 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.
- 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, "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, "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:**

- Developed the NIR- and SWIR-based vicarious calibration approach with a unified gain set for OC data processing.
- M. Wang, W. Shi, L. Jiang, and K. Voss, "The NIR- and SWIR-based on-orbit vicarious calibrations for satellite ocean color sensors," *Opt. Express* (Submitted).

➢ **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.

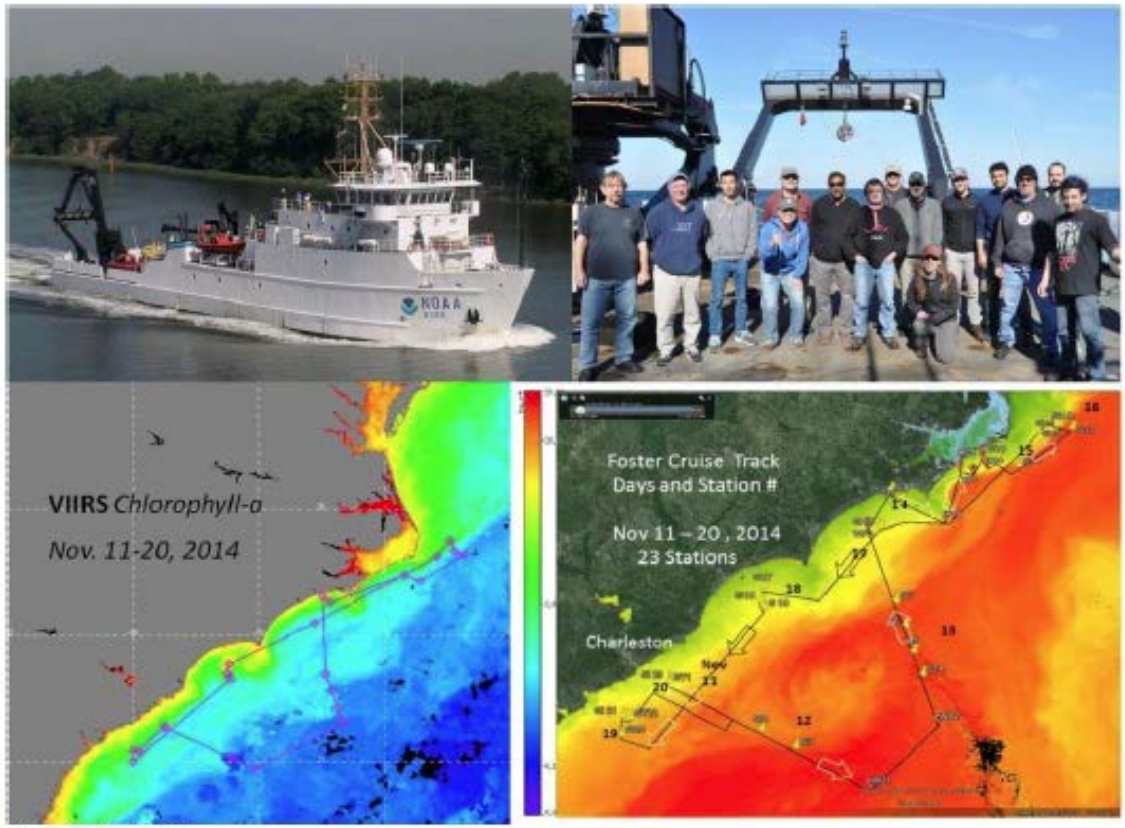
- **O**cean **C**olor **D**ata **A**nalysis and **P**rocessing **S**ystem (**OCDAPS**)—IDL-based VIIRS ocean color data visualization and processing package
  - Wang, X., X. Liu, L. Jiang, M. Wang, and J. Sun, "VIIRS ocean color data visualization and processing with IDL-based NOAA-SeaDAS", *Proc. SPIE 9261*, 8 Nov. 2014.

# 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

# Dedicated VIIRS Cal/Val Cruises

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

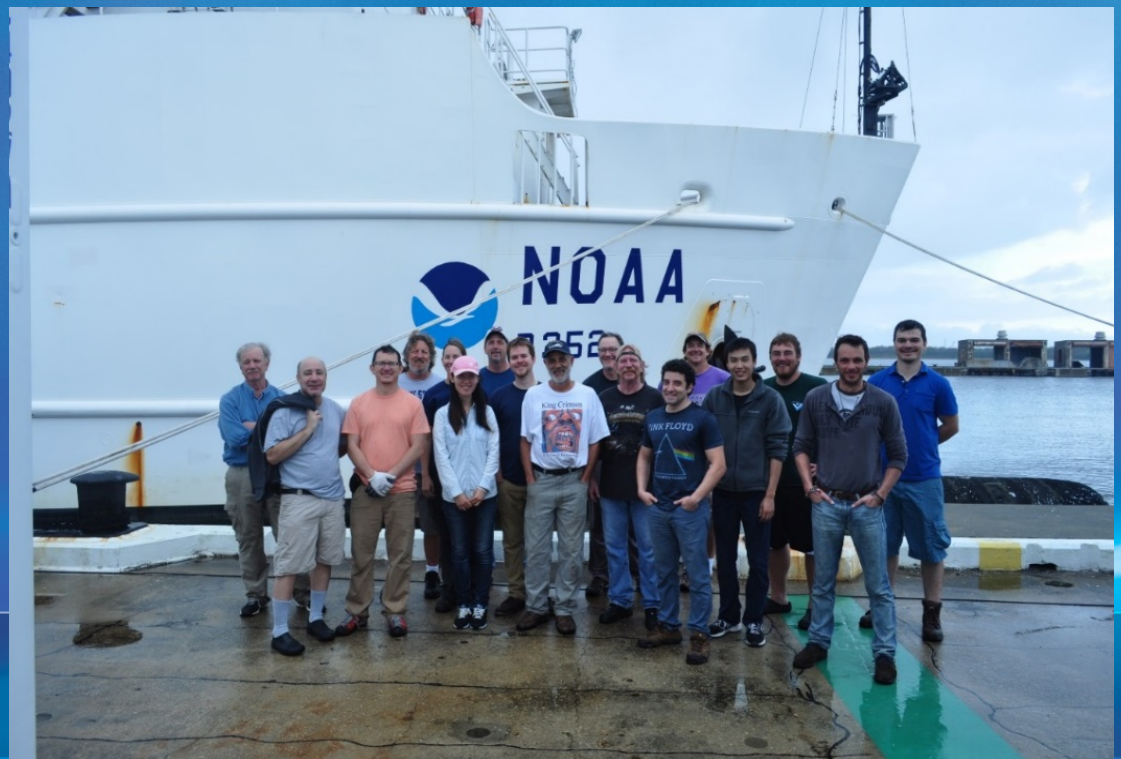
U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Environmental Satellite, Data, and Information Service

# Dedicated VIIRS Cal/Val Cruise
# NOAA Ship Nancy Foster
## 2-14 December 2015




### *Validation Measurements*

- **Water-Leaving Radiance** - HyperPro, MicroPro, C-OPS, GER, SBA, TRIOS, HyperSAS, ASD
- **Aerosol Optical Depth** - Microtops
- **Chlorophyll** - HPLC, Fluorometric, (in situ and extracted)
- **Absorption** - ACS, AC9, Spectrophotometric
- **Backscatter** - BB9, BB7, BB3, ECO Puck
- **Bi-directional radiance distribution** - NURADS
- **Phytoplankton Physiology -** FRRF, FIRe, Alf-a
- **Carbon** - POC and DOC water analysis; plus CDOM
- **Total Suspended Matter** - Gravimetric




### *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**)

**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
- Oregon State University

# Two Data Streams for VIIRS Ocean Color EDR

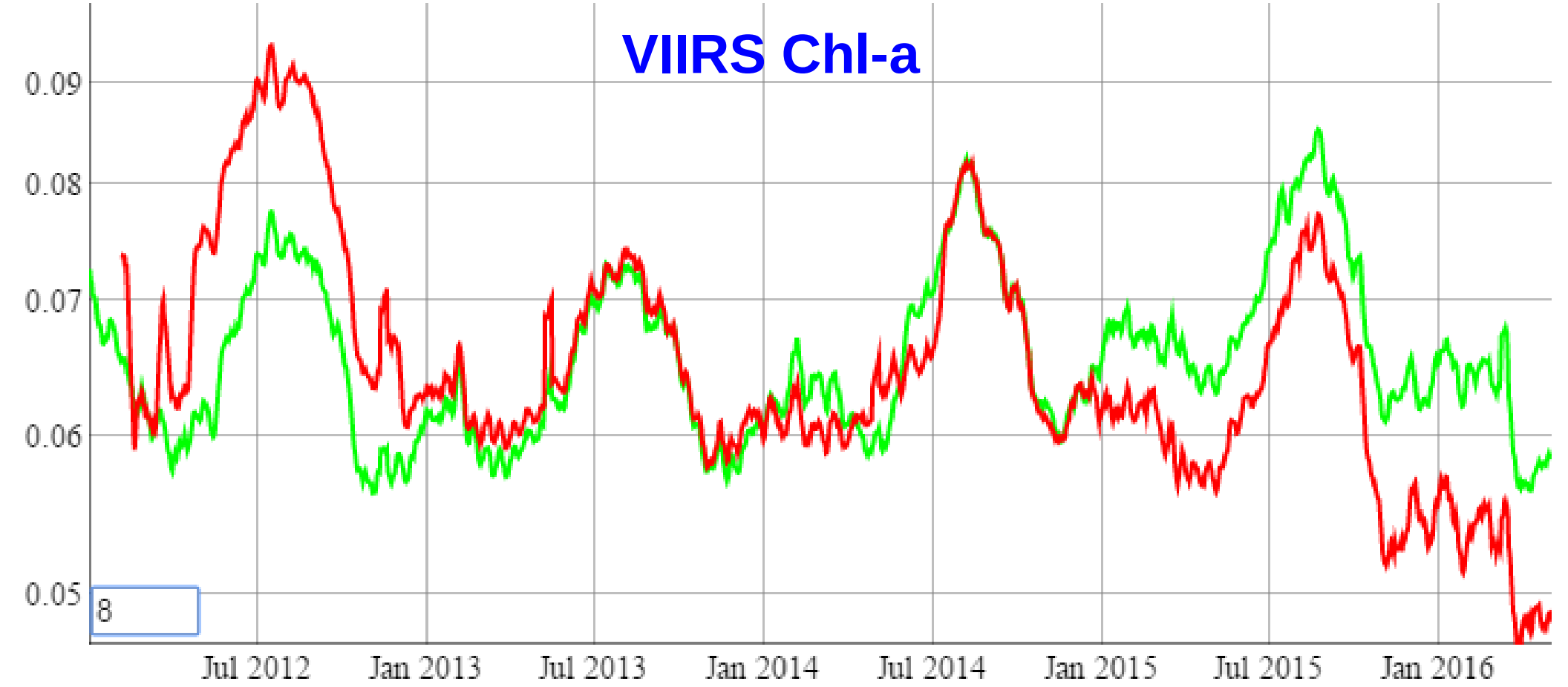
To meet requirements from **All** users (operational, research, modeling, etc.), we proposed and have been routinely producing VIIRS global ocean color products in **two data streams**:

- **Near-Real-Time (NRT) Ocean Color Data Processing (12-24 hours):**
  - Quick turn around with ~12-24 hours latency (operational)
  - Using standard IDPS operational 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 SDR)
  - 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 Mission-long Ocean Color Data Reprocessing

- ✓ We have successfully reprocessed VIIRS mission-long ocean color data products for the Near-Real-Time data stream in summer 2015 and the Science Quality data stream just recently (May 2016). Both data streams have been going forward routinely.
- ✓ For the Science Quality data stream, VIIRS mission-long SDR has been reprocessed using significantly improved on-orbit calibration (both solar and lunar approaches).
- ✓ Both VIIRS ocean color data are available through CoastWatch. In particular, the ocean color Science Quality data stream is now distributed through **CoastWatch** (will also be distributed in NCEI) at: **http://coastwatch.noaa.gov/cwn/cw_products_ocLOM.html**.
- ➢ 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)**.
- ➢ In particular, significant improved VIIRS ocean color data over global **high altitude lakes**, which is a very significant progress for remote sensing of inland water quality.
- ➢ VIIRS chlorophyll-a, $K_d(490)$, $nL_w(443)$ and $nL_w(551)$ data from global oligotrophic waters for two data streams: Near-real-time data stream with IDPS SDR and the recently reprocessed Science Quality data stream with the new OC-SDR. The same **MSL12** ocean color data processing system has been used for both data streams. We also show some global images and quantitative comparisons with MOBY in situ data.

# Global Oligotrophic Waters

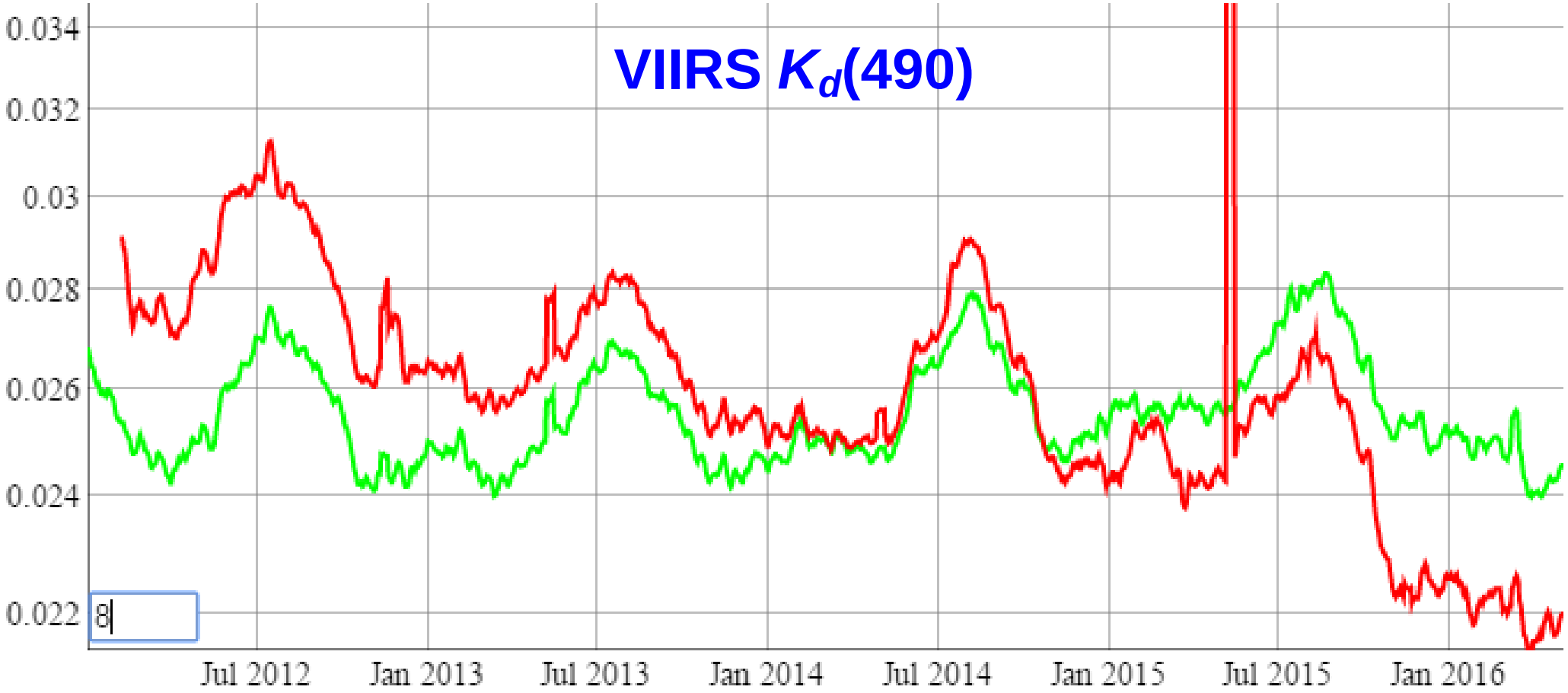



Red: VIIRS **IDPS-SDR**
**Near-real-time data**

Green: VIIRS **OC-SDR**
**Science quality data**

Both data are reprocessed using the same MSL12!

# Global Oligotrophic Waters




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# Global Oligotrophic Waters

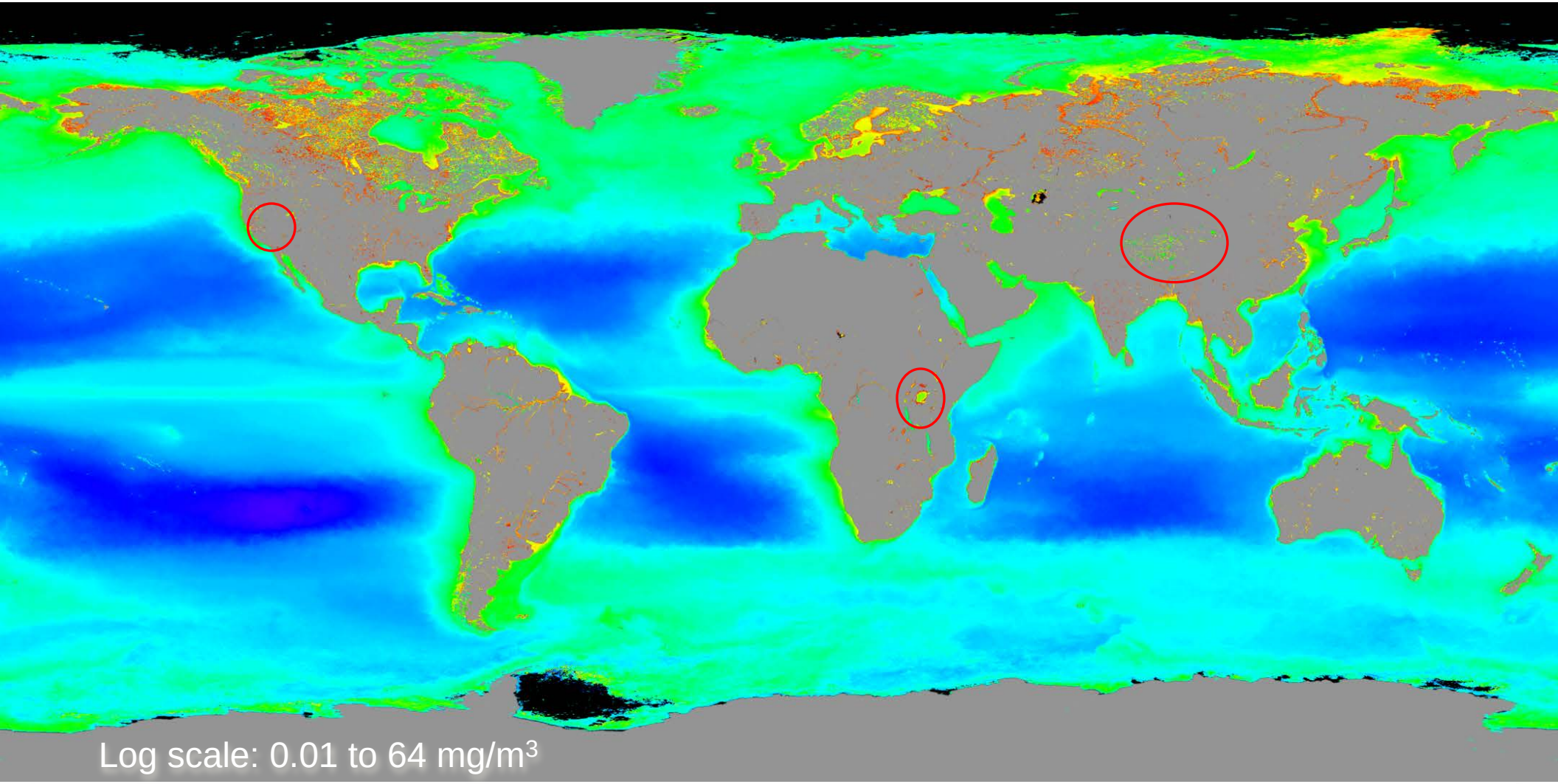



Red: VIIRS **IDPS-SDR**
**Near-real-time data**

Green: VIIRS **OC-SDR**
**Science quality data**

Both data are reprocessed using the same MSL12!

# VIIRS Climatology Chlorophyll-a Image
## (February 2012 to January 2016)

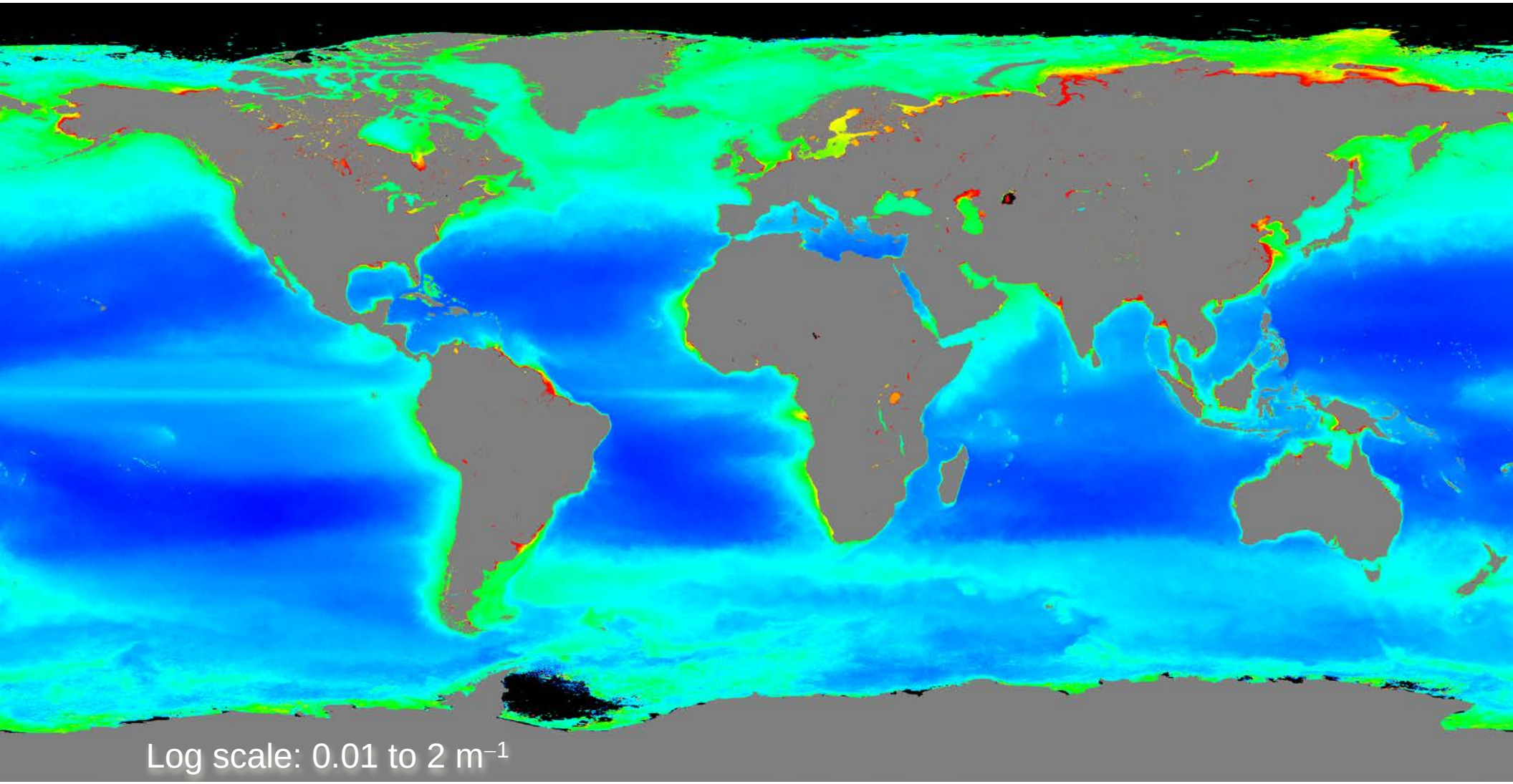



**Generated using MSL12 for VIIRS mission-long ocean color data reprocessing**

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 (OLD)

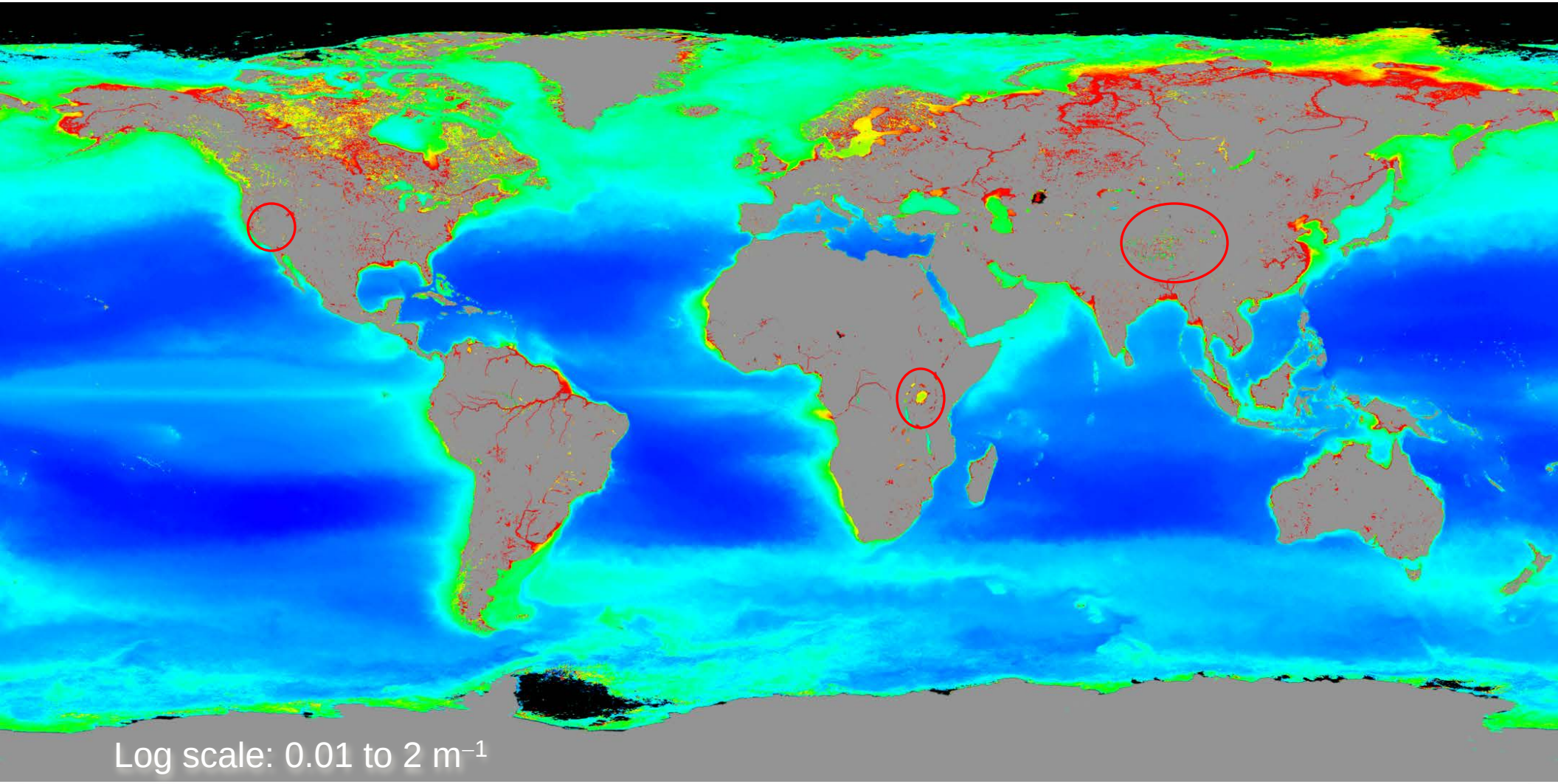
## (March 2012 to February 2015)




## 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

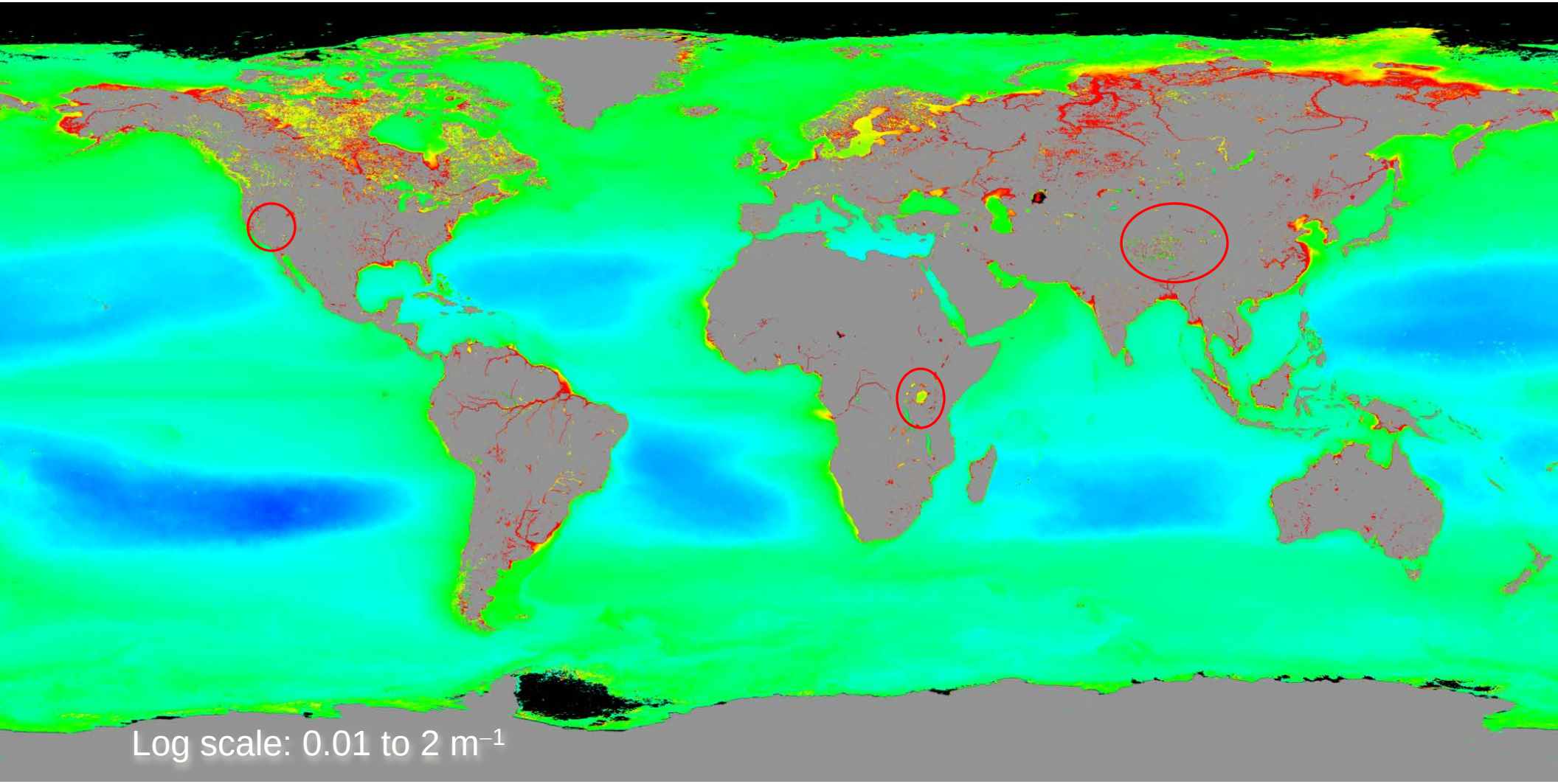
# VIIRS Climatology $K_d(490)$ Image
## (February 2012 to January 2016)




**Generated using MSL12 for VIIRS mission-long ocean color data reprocessing**

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

# VIIRS Climatology $K_d$(PAR) Image
## (February 2012 to January 2016)




**Generated using MSL12 for VIIRS mission-long ocean color data reprocessing**

Son, S. and M. Wang, "Diffuse attenuation coefficient of the photosynthetically available radiation Kd(PAR) for global open ocean and coastal waters," *Remote Sens. Environ.*, **159**, 250–258, 2015. http://dx.doi.org/10.1016/j.rse.2014.12.011

Matchup of

**VIIRS-MSL12**

&

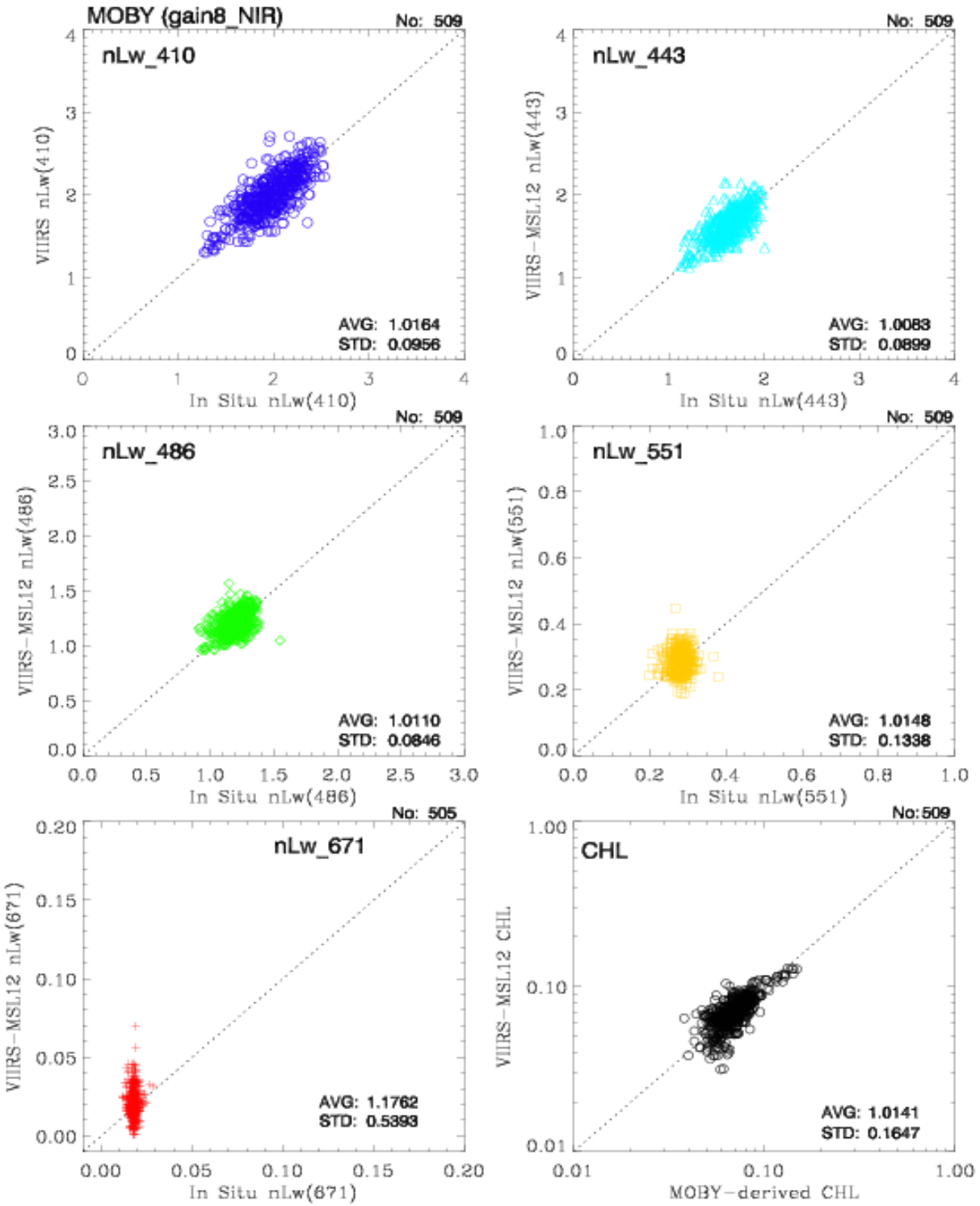
**MOBY In Situ**

(2016-05-05)

**Science Quality Data**

**MOBY**

**Marine Optical Buoy (MOBY)** --- In situ hyperspectral radiometric data measured at water off the island of Lanai in Hawaii.



# Statistics of VIIRS Data vs. In Situ (MOBY)

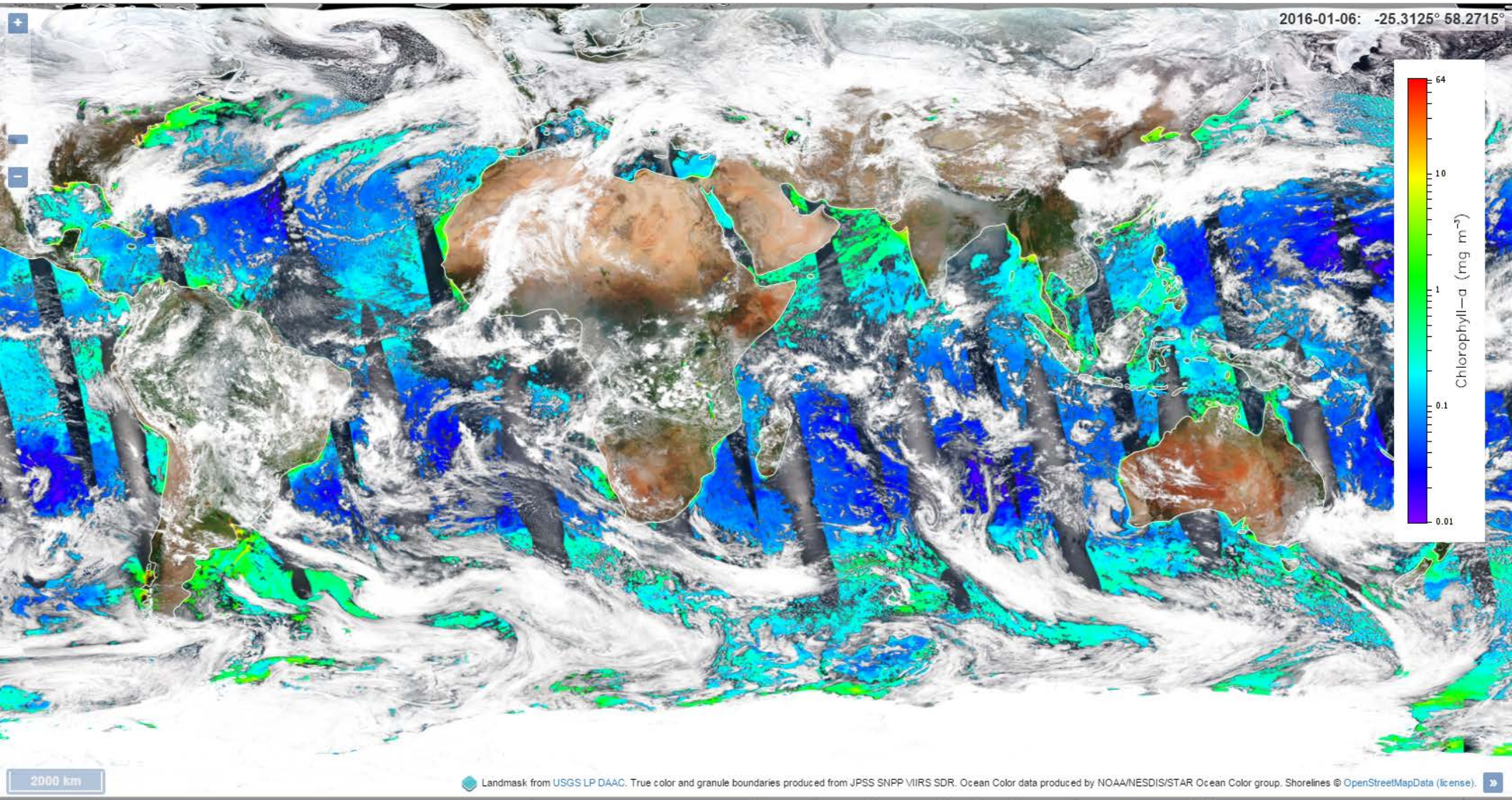
(2012-01-01 to 2016-04-27)

| | IDPS-SDR MSL12 (ver. 1.10) (Near-Real-Time Data) | | | | OC-SDR MSL12 (ver. 1.10) (Science Quality Data) | | | |
|---|---|---|---|---|---|---|---|---|
| | **AVG** | **MED** | **STD** | **No** | **AVG** | **MED** | **STD** | **No** |
| $nL_w(410)$ | **1.0083** | 1.0065 | 0.0961 | 463 | **1.0164** | 1.0157 | 0.0956 | 509 |
| $nL_w(443)$ | **1.0191** | 1.0005 | 0.1733 | 475 | **1.0083** | 1.0062 | 0.0899 | 509 |
| $nL_w(486)$ | **1.0258** | 0.9991 | 0.1861 | 475 | **1.0110** | 1.0103 | 0.0846 | 509 |
| $nL_w(551)$ | **1.0604** | 0.9809 | 0.4910 | 475 | **1.0148** | 1.0004 | 0.1338 | 509 |
| $nL_w(671)$ | **1.3366** | 1.0059 | 2.1345 | 487 | **1.1762** | 1.1053 | 0.5393 | 505 |
| *Chl-a* | **1.0508** | 0.9764 | 0.4254 | 468 | **1.0141** | 1.0041 | 0.1647 | 509 |
| $K_d(490)$ | **1.0135** | 0.9826 | 0.2437 | 471 | **0.9842** | 0.9760 | 0.1007 | 505 |

**MOBY**

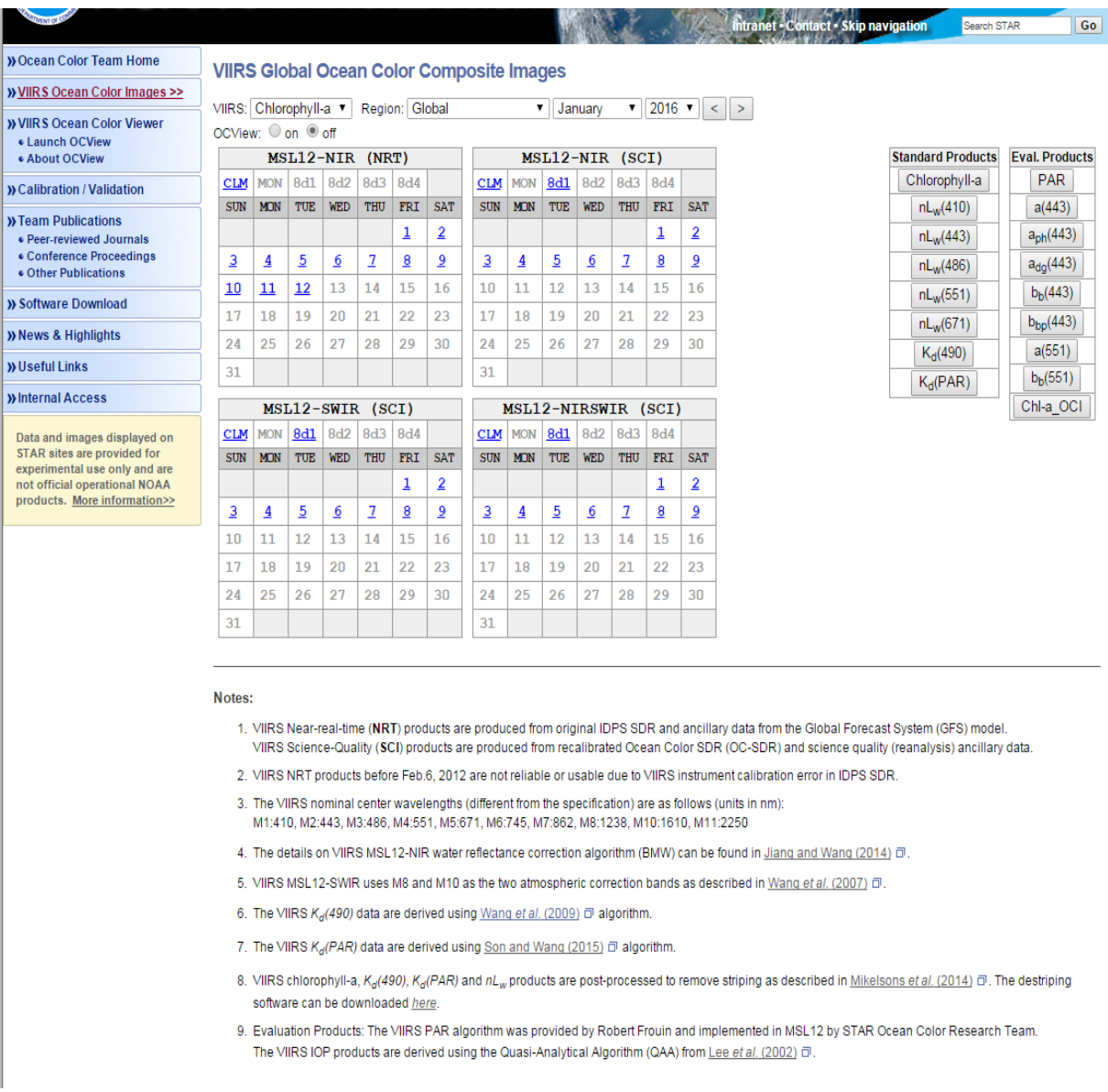
NIR Gain 8 = [0.979954, 0.974892, 0.974685, 0.965832, 0.979042, 0.982065, 1.00000, 1.01812, 0.994676, 1.20252]

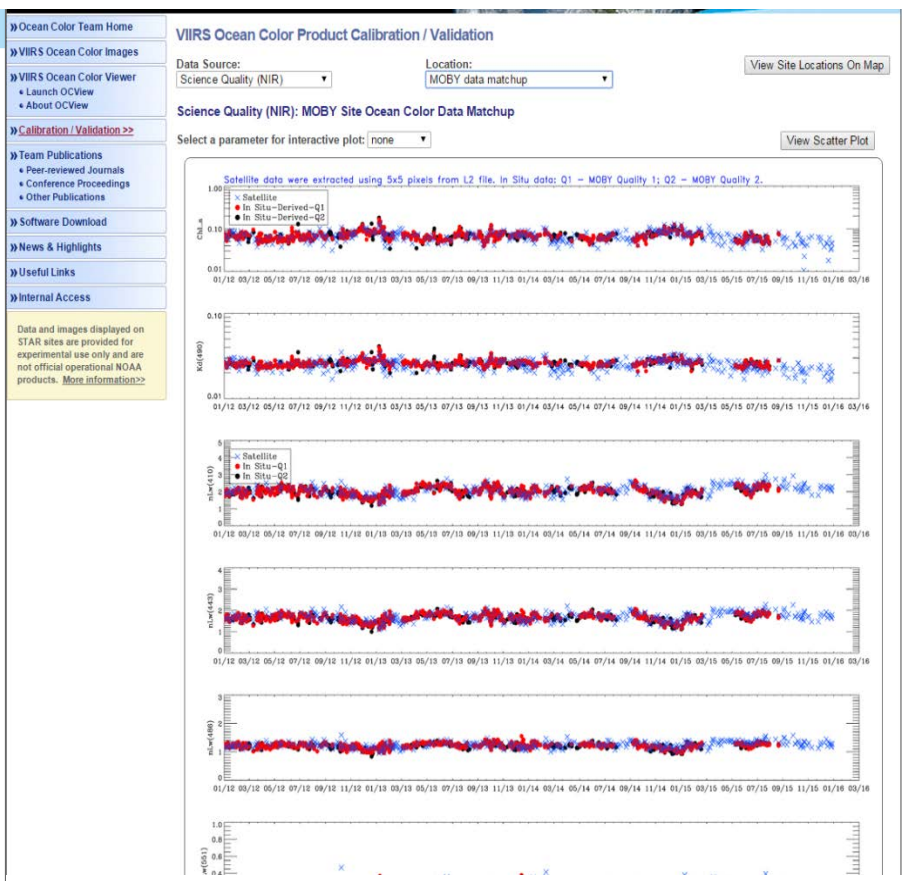
# OCView: Seamless Global Coverage




Website: http://www.star.nesdis.noaa.gov/sod/mecb/color/

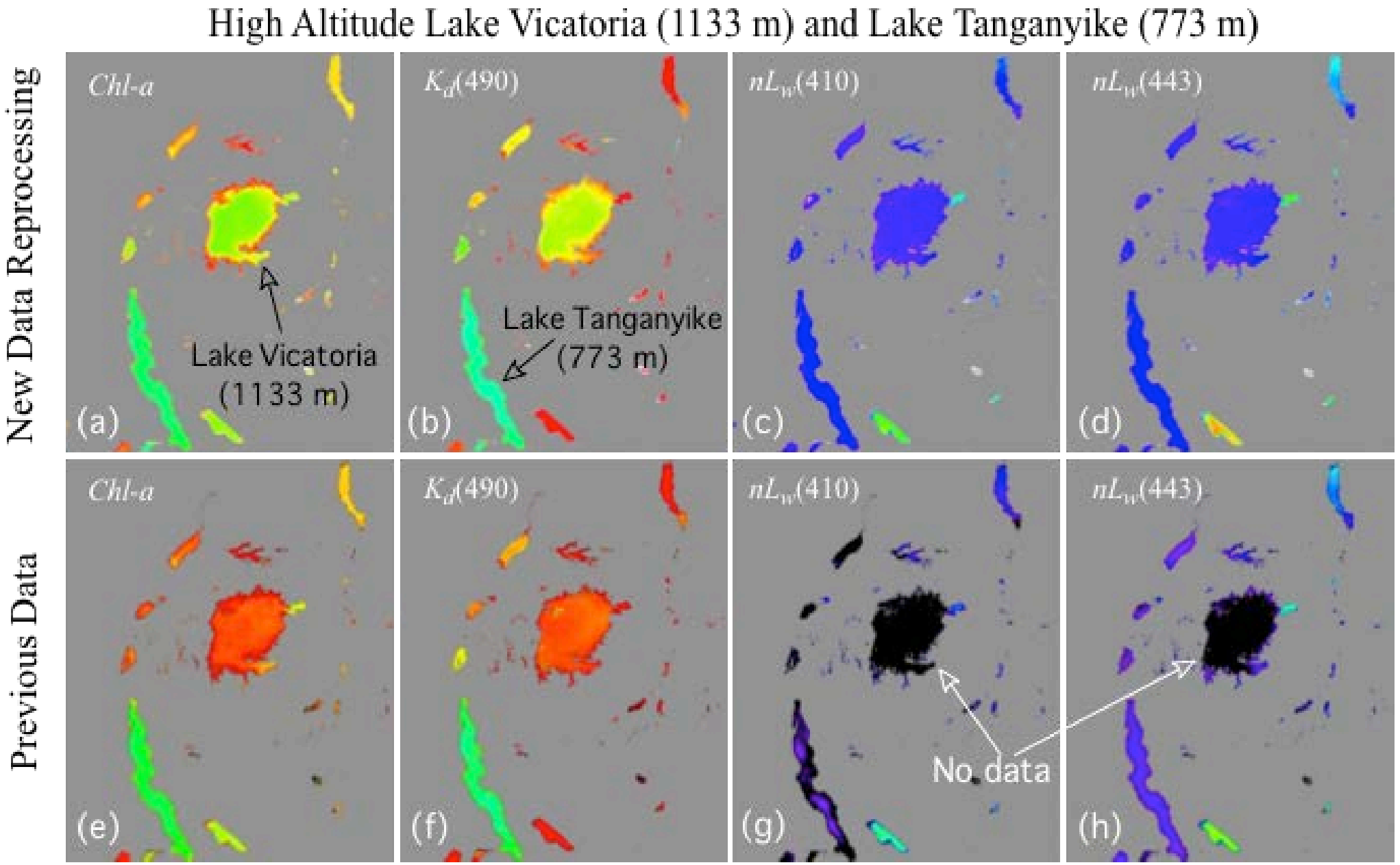
# Composite Images & Cal/Val




Routinely producing VIIRS global ocean color products (**daily**, **8-day**, **monthly**, **climatology**) using the **MSL12** with the **NIR**, **SWIR**, and **NIR-SWIR** atmospheric correction algorithms.

# Significantly Improved Water Property Data Over High Altitude Lakes (1)

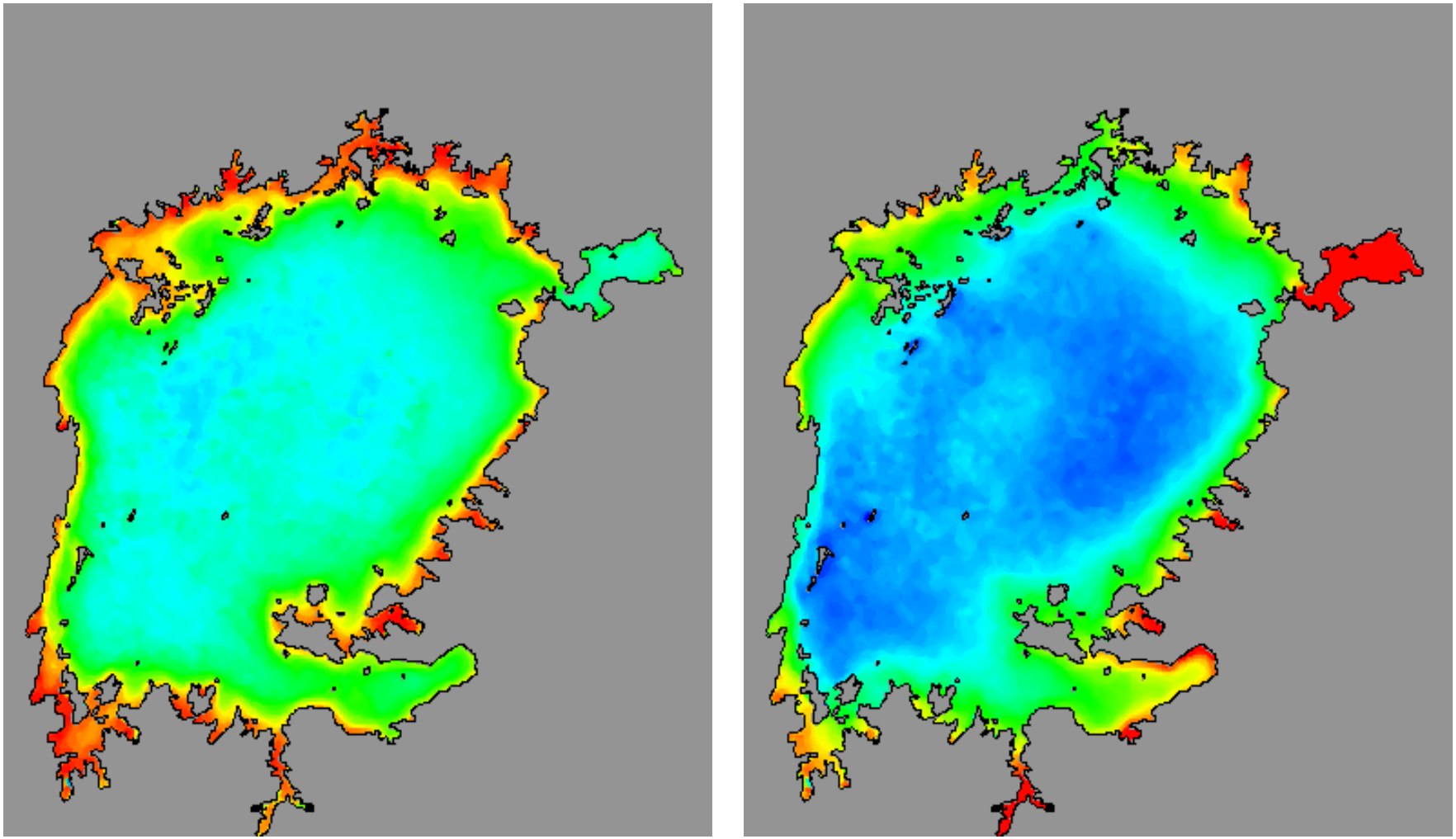



VIIRS mission-long ocean color data have been successfully reprocessed using improved MSL12. VIIRS ocean color data over open oceans and coastal/inland waters have been significantly improved, in particular, over high altitude lakes. This is a significant progress for remote sensing of inland water quality.

**Lake Victoria**---Fresh water (South Africa, Area: 68,800 km$^2$, Ave. depth: 40 m)

# **VIIRS Climatology Images** (Jan. 2012–May 2016)

**VIIRS *Chl-a*** | **VIIRS $K_d$(490)**



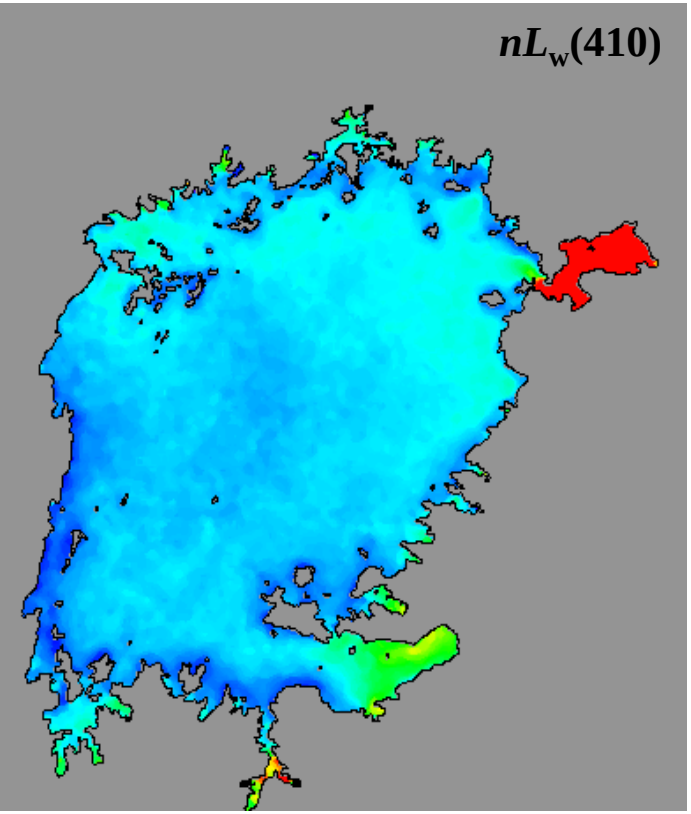
Color scales: Chl-a (1~64.0 mg $m^{-3}$) & $K_d$(490) (0.3~2.0 $m^{-1}$) in log-scale

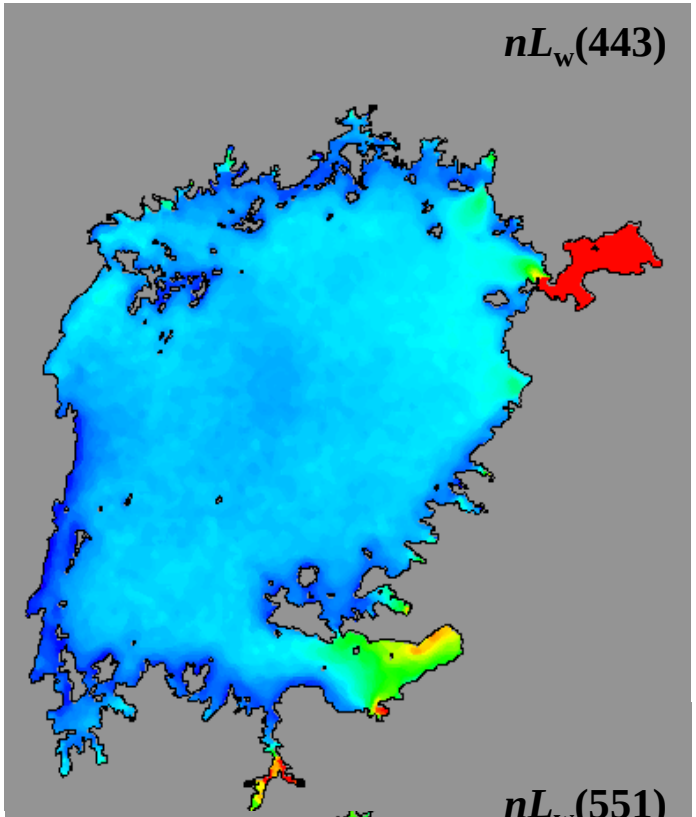
5 × 5 Median Filter

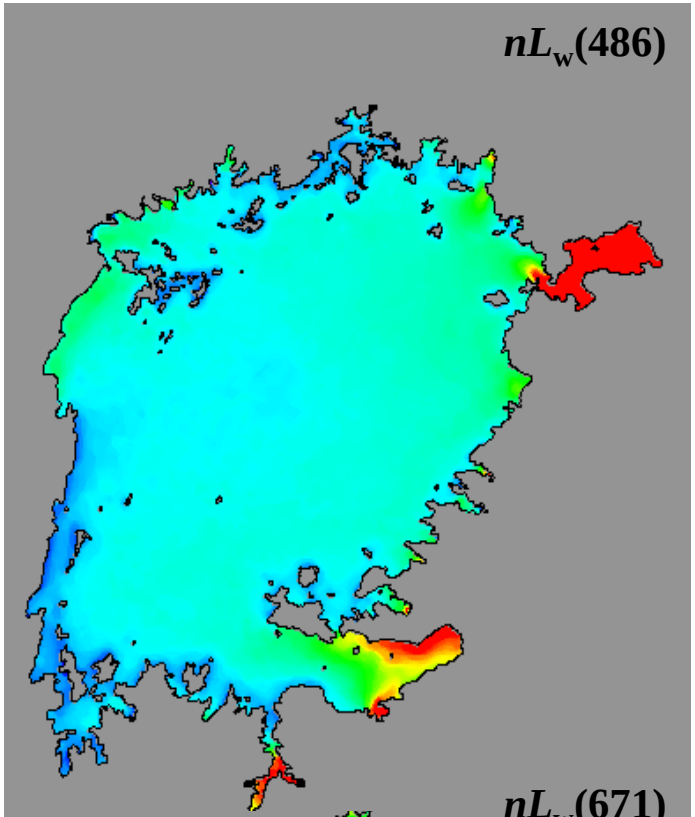
**Lake Victoria**

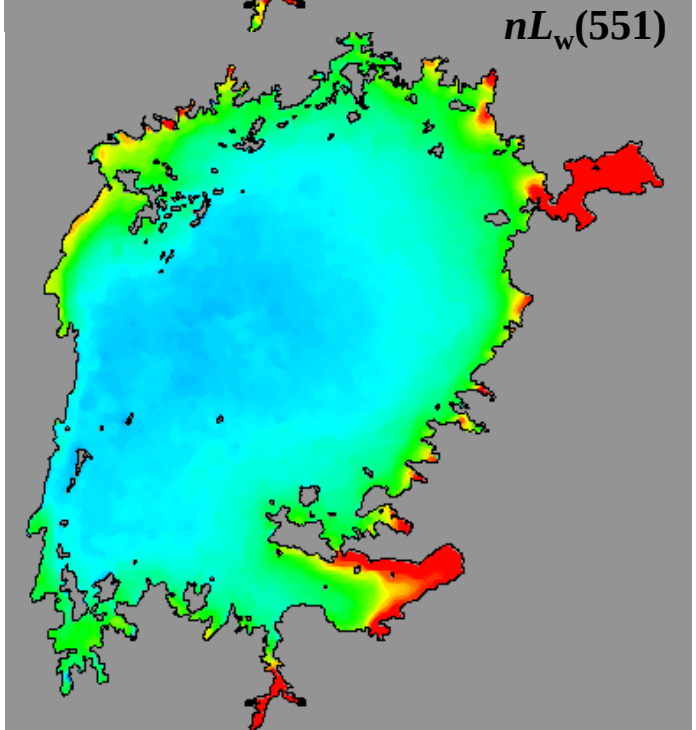
# VIIRS Climatology Images (Jan. 2012–May 2016)

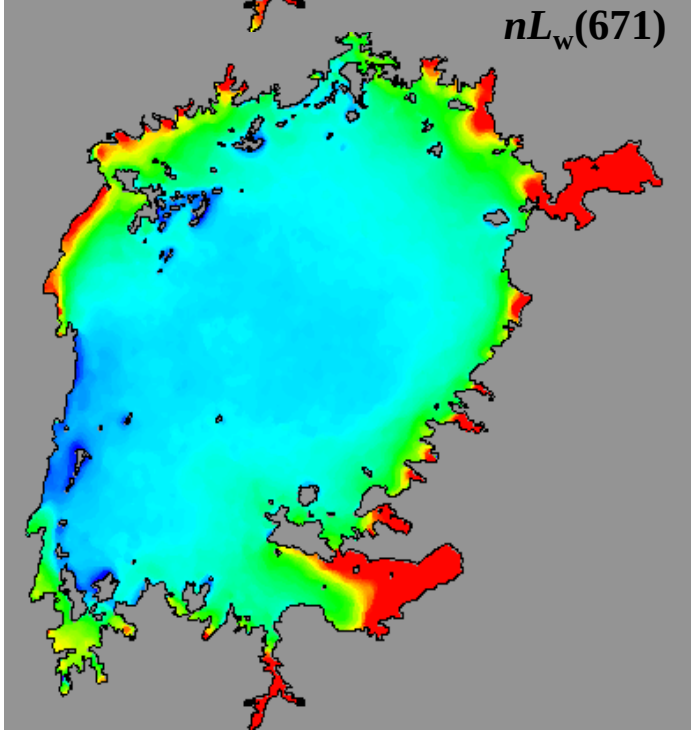
Lake Victoria






Color scales (linear-scale):

$nL_w(410)$: 0 ~ 1.0

$nL_w(443)$: 0 ~ 1.2

$nL_w(486)$: 0 ~ 1.5

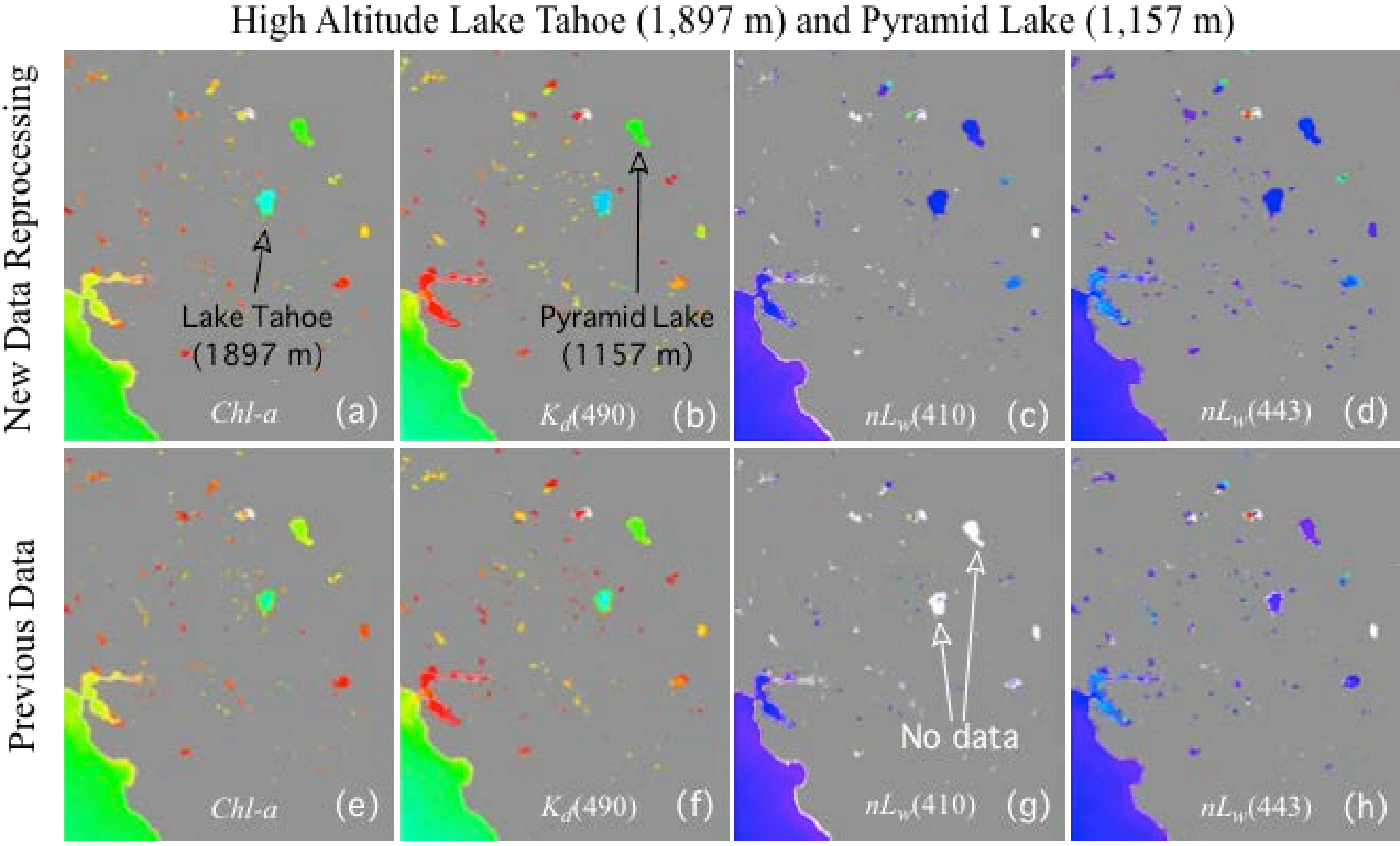
$nL_w(551)$: 0 ~ 2.0

$nL_w(671)$: 0 ~ 0.5

Unit: mW $cm^{-2}$ ⌈ $m^{-1}$ $sr^{-1}$

5 × 5 Median Filter

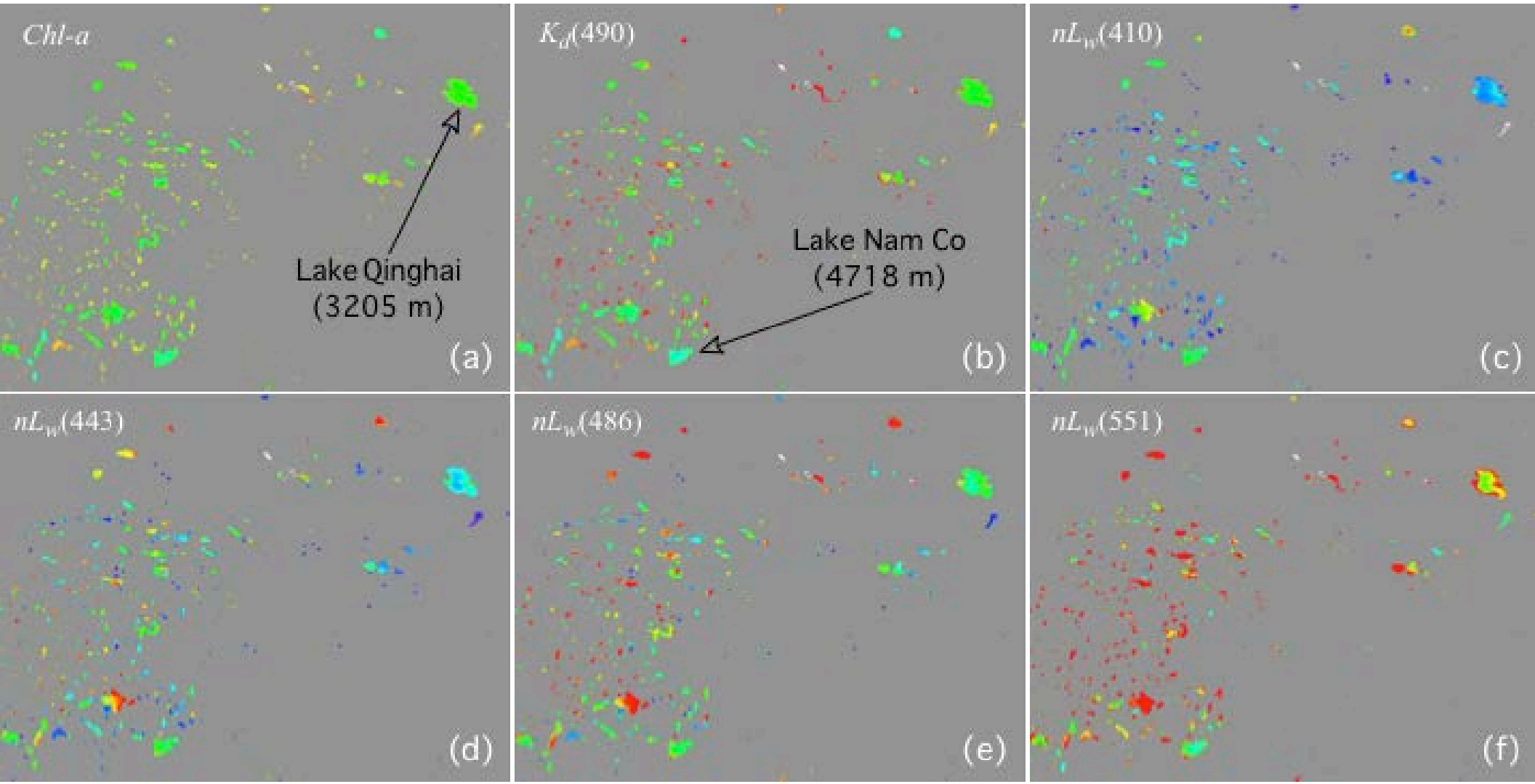
# Significantly Improved Water Property Data Over High Altitude Lakes (2)




**Lake Tahoe**---Fresh water (California/Nevada, Area: 490 km$^2$, Ave. depth: 300 m)
**Pyramid Lake**---1/6 salinity (Nevada, Area: 490 km$^2$, Max. depth: 109 m)

# Significantly Improved Water Property Data Over High Altitude Lakes (3)

High Altitude Lake Qinghai (3,205 m) and Lake Nam Co (4,718 m)




**Lake Qinghai**---Saline lake (Qinghai, China, Area: 4489 km$^2$, Ave. depth: 21 m)
**Lake Nam Co**---Saline lake (Tibetan, China, Area: 1920 km$^2$, Ave. depth: 33 m)

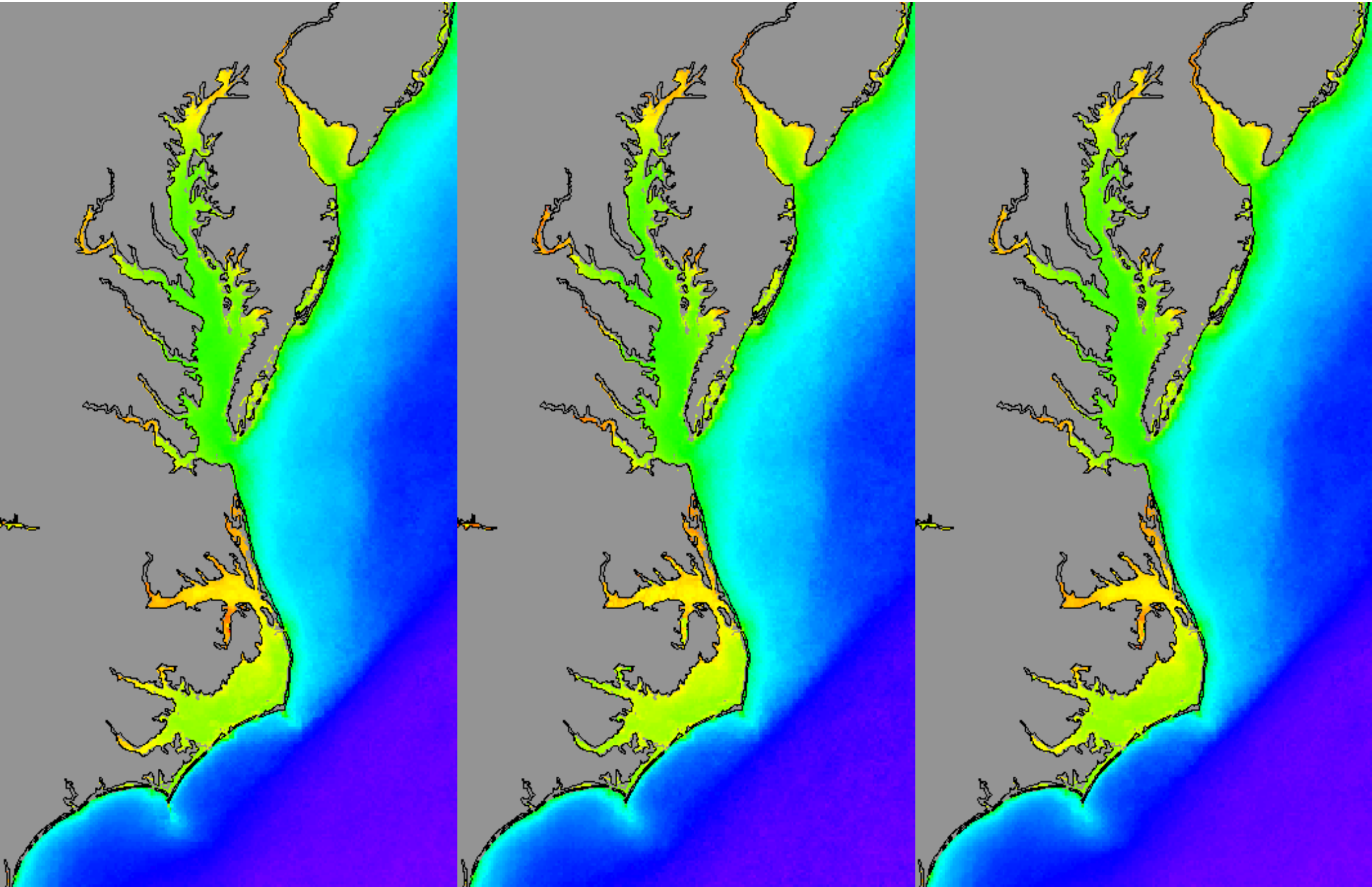

Wang, M., "Rayleigh radiance computations for satellite remote sensing: Accounting for the effect of sensor spectral response function," *Opt. Express*, **24**, 12414–12429, 2016. http://dx.doi.org/10.1364/OE.24.012414.

# VIIRS (OC-SDR) Climatology Images (2012–2015)

$K_d(490)$ (0.03−8.0 $m^{-1}$ in log scale)

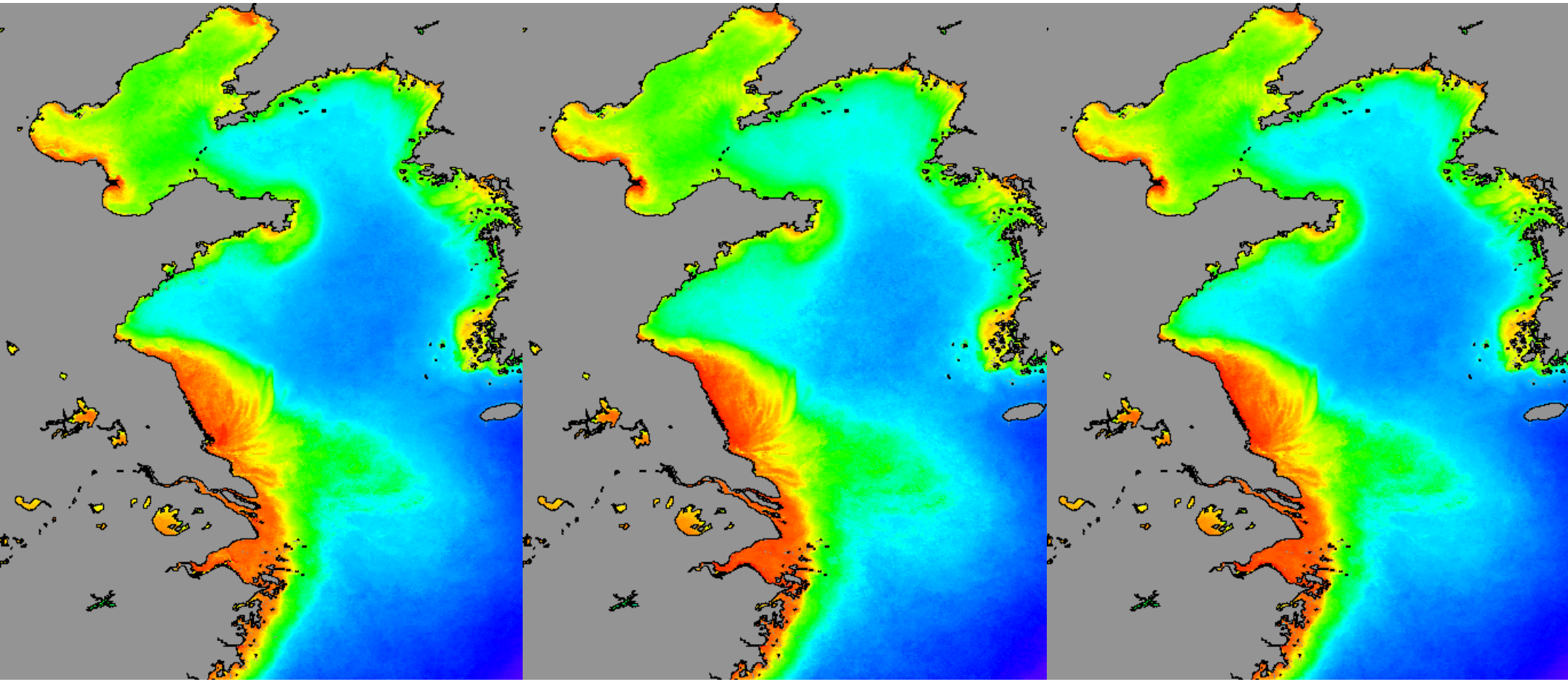
**US East Coast**

**NIR** | **SWIR** | **NIR-SWIR**



# VIIRS (OC-SDR) Climatology Images (2012–2015)

NIR | SWIR | NIR-SWIR

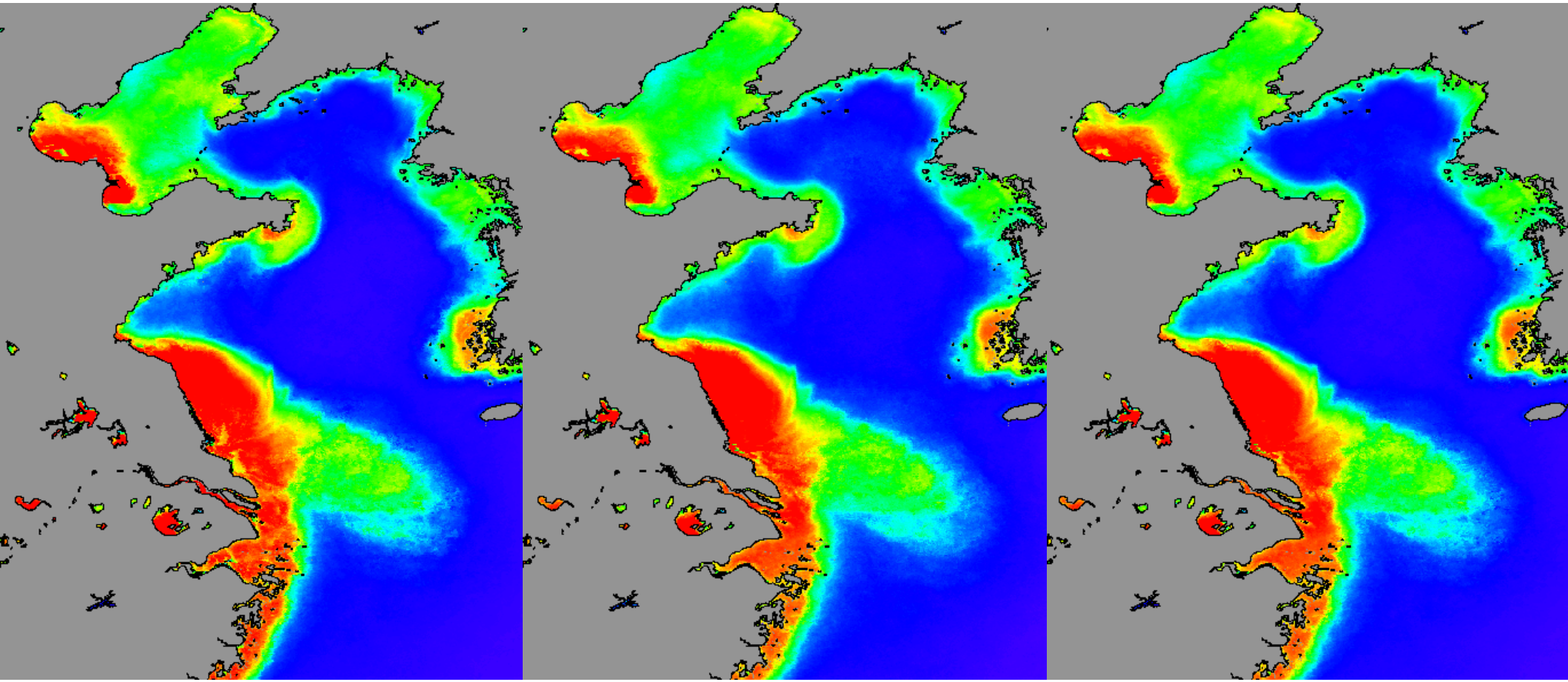


$K_d(490)$ (0.03~8.0 $m^{-1}$ in log scale)

**China East Coast**

# VIIRS (OC-SDR) Climatology Images (2012–2015)

NIR | SWIR | NIR-SWIR



$nL_w(551)$ (0.0~5.0 mW/cm$^2$ μm sr in linear scale)

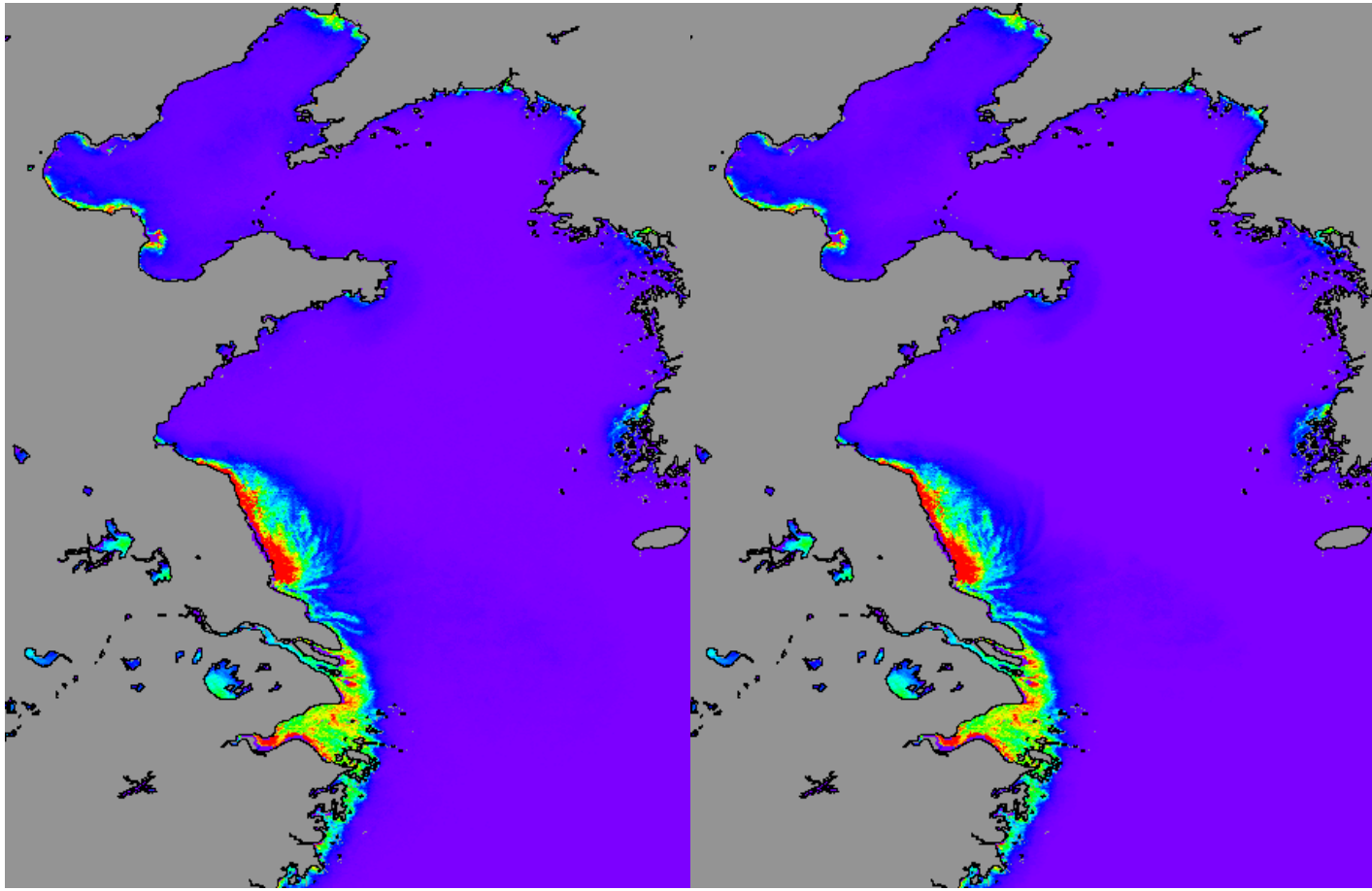
**China East Coast**

# VIIRS (OC-SDR) Climatology Images (2012–2015)

The **NIR** normalized water-leaving radiance contribution in highly turbid coastal regions.

**China East Coast**

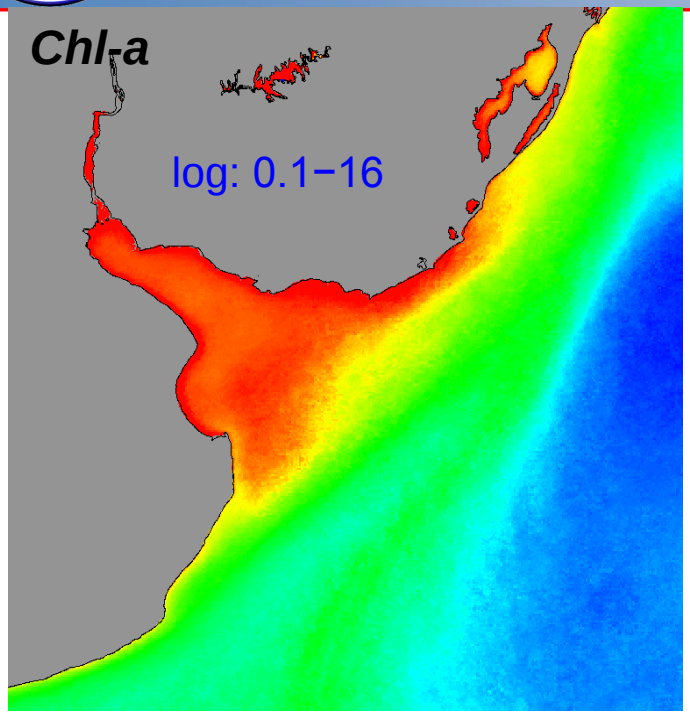
**SWIR** **NIR-SWIR**

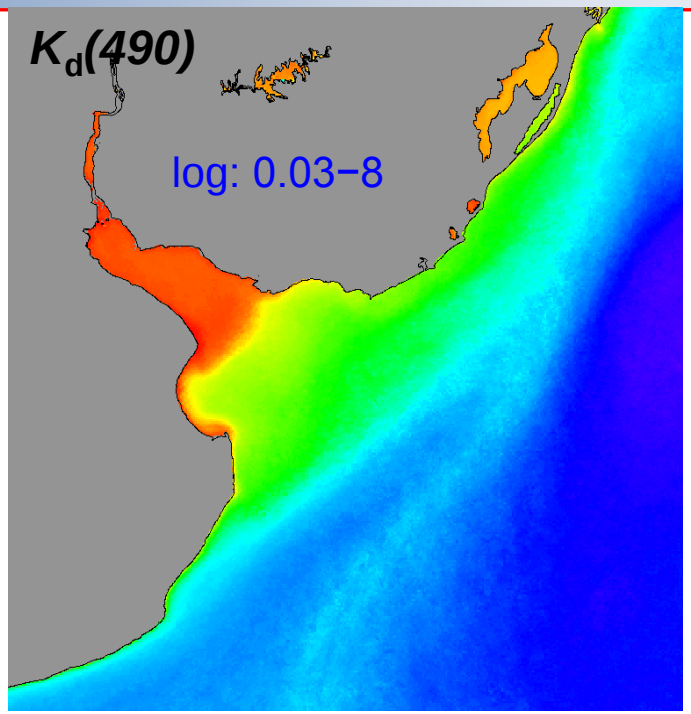


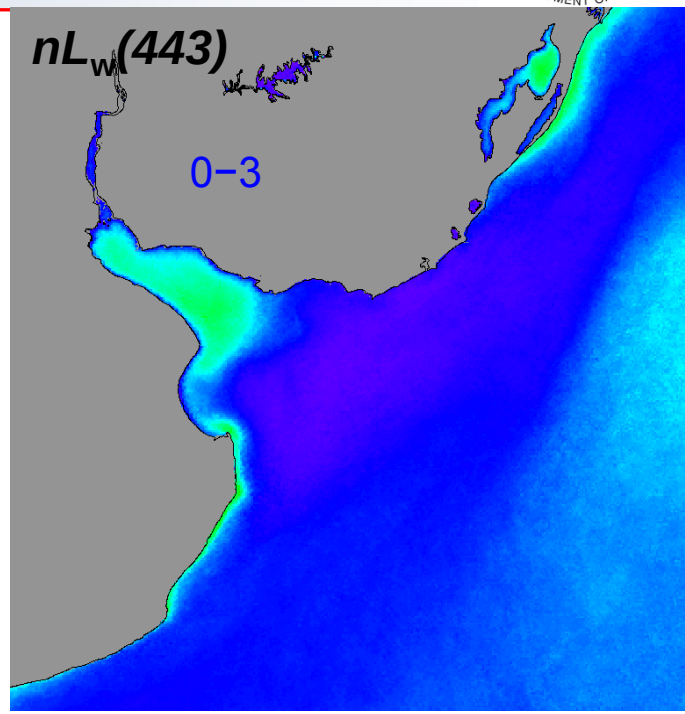
***nL*$_w$(862)** (0.0~**2**.0 mW/cm$^2$ μm sr in linear scale)

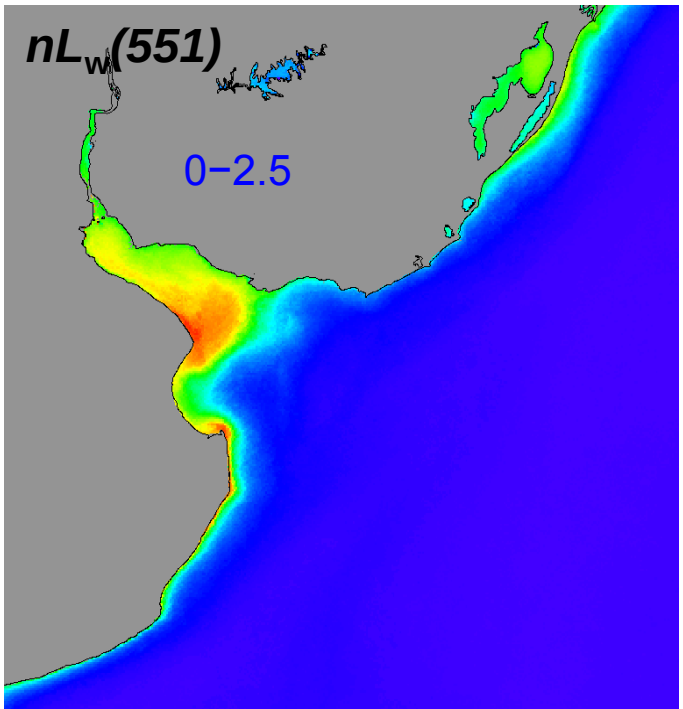
# VIIRS Climatology (2012-2015) using the NIR-SWIR Approach

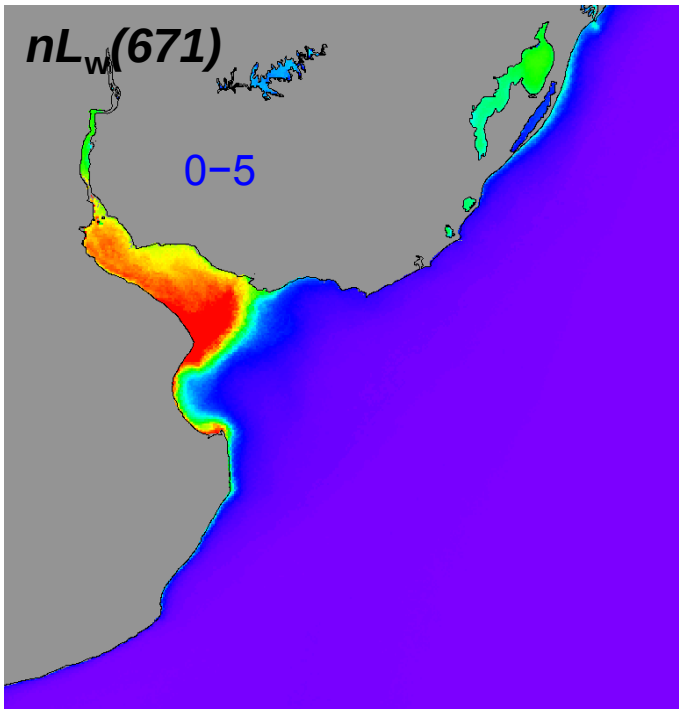
## La Plata

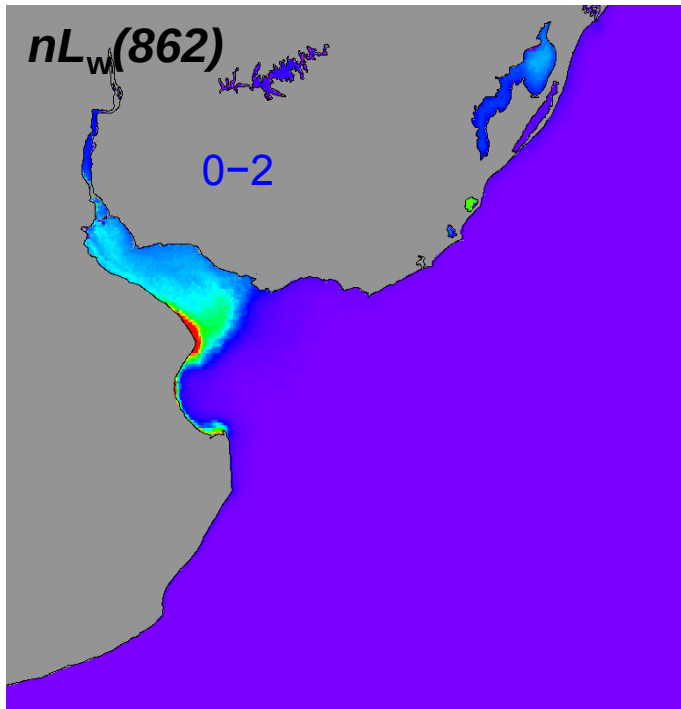


# Conclusions

- We have completed VIIRS mission-long science quality ocean color data **reprocessing** (including **SDR** and **EDR**), and the data stream is now going forward. **Two data streams have been routinely produced: near-real-time and science quality ocean color data.**
- We have developed VIIRS instrument calibration capability, and with new calibration LUTs, VIIRS ocean color products are significantly improved.
- VIIRS ocean color products have been significantly improved (**over global high altitude lakes**) after the implementation of some important updates, new algorithms, and with vicarious calibrations using MOBY data.
- 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.
- VIIRS global ocean color products have been routinely produced using the **NIR**, **SWIR**, and **NIR-SWIR** atmospheric correction algorithms, providing necessary satellite data for various applications in 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**.
- Have been/will be working on **VIIRS-JPSS-1**, **OLCI-Sentinel-3**, **GOCI**, **SGLI-GCOM-C**.

**VIIRS Images and Cal/Val:**
**http://www.star.nesdis.noaa.gov/sod/mecb/color/**
**VIIRS Ocean Color Data:**
**http://coastwatch.noaa.gov/cwn/cw_products_ocLOM.html**

# VIIRS SDR Calibration for Improvement of Ocean Color Products

Junqiang Sun[1,2] and Menghua Wang[1]

[1]NOAA/NESDIS Center for Satellite Applications and Research
E/RA3, 5830 University Research Ct., College Park, MD 20740, USA
[2]Global Science and Technology, 7855 Walker Drive, Maryland, USA

8/10/2016 9:00-9:15 AM

***Star JPSS 2016 Annual Science Team Meeting***

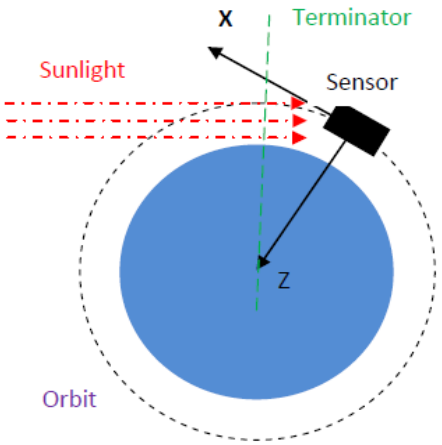
***8-12 August 2016, College Park, Maryland***

# Key Points

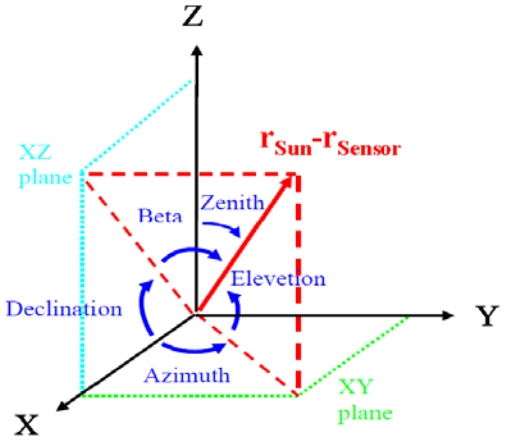
- **Ocean color products are highly sensitive to details in processing algorithms and SDR calibration.**
- VIIRS RSB uncertainty specification is 2%; For ocean color EDR products, the ocean bands (M1-M7) are required to be calibrated with an uncertainty of ~0.1-0.3%.
- We recently discovered the "*Solar diffuser (SD) degradation nonuniformity*", which result in long-term bias in calibration, especially for short wavelength bands
- A hybrid approach properly combining the SD and lunar calibration coefficients restores the accuracy of the calibration coefficients from the non-uniformity issue and other various effects:
  - Lunar calibration provides long-term baseline
  - SD calibration provides smoothness and frequency
- **Every component must itself be accurately characterized!**
  - SDSM calibration/SD calibration; Lunar calibration; Hybrid approach
- Challenges and potential issues

# Solar Illumination and Sweet Spot

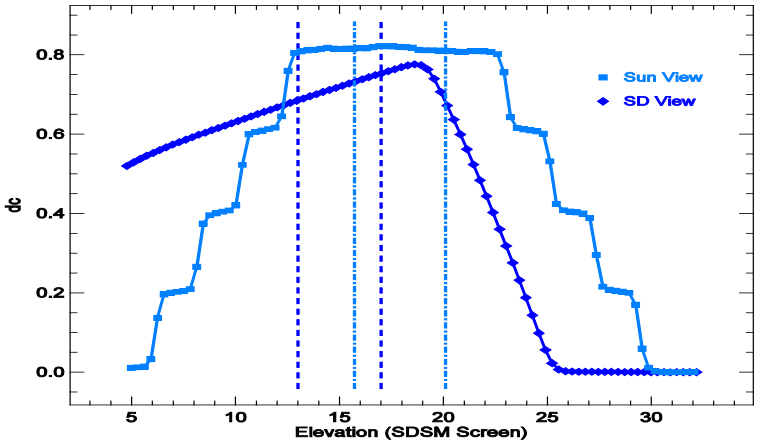
## Illumination of SD and SDSM Aperture



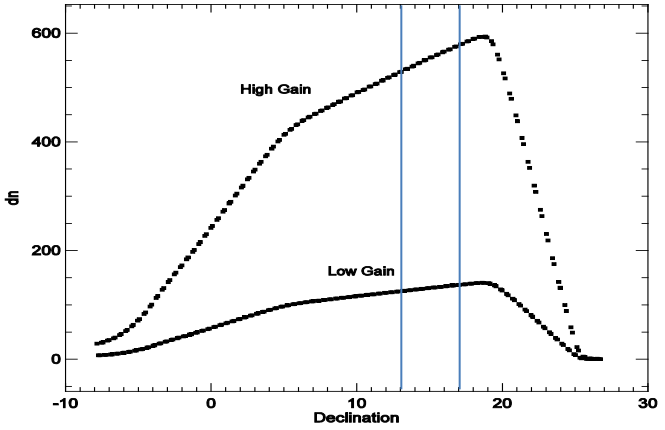

## Solar angles




## SDSM response

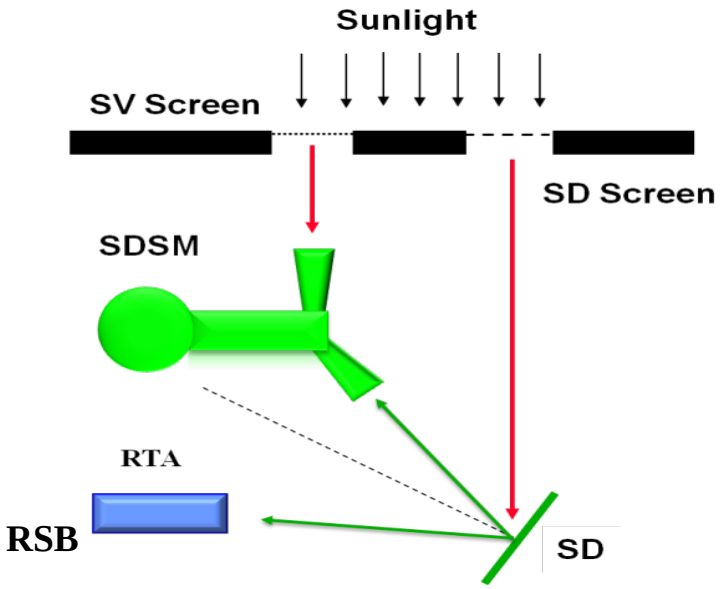



## Band M1 Detector 1 response




**Good selections stabilizes results, reduce noise – Different from ATBD**

# Prelaunch BRFs of the SD and the VFs of SD and SDSM Screens




- SD and SDSM sun view screens:
  - Prevent RSB and SDSM saturation
  - Vignetting functions (VFs)
  - VFs measured prelaunch and validated by yaw measurements
- SD bidirectional reflectance factors (BRFs)
  - BRFs measured prelaunch and validated by yaw measurements
  - SD on-orbit degradation is tracked by the SDSM measurements at 8 wavelength from 412 nm to 935 nm

***The author carefully made yaw planning in 2012 with NASA colleagues for on-orbit validation of BRDF and VF.***

**We have carefully re-derived BRFs and VFs from the yaw measurements (removes seasonal variation artifacts and noises)**

*J. Sun and X. Xiong, "Solar and lunar observation planning for Earth-observing sensor", Proc. SPIE, **8176**, 817610, (2011).*

*J. Sun and M. Wang, "On-orbit characterization of the VIIRS solar diffuser and solar diffuser screen," Appl. Opt., 54, 236 -252(2015).*

# SDSM Calibration Algorithm

- SDSM is a ratio radiometer, which views SD, Sun, and an internal dark scene successively in three-scan cycles.
- SD BRF for SDSM view direction

$$BRF_{SD,SDSM}(\lambda) = \rho_{SD,SDSM}(\lambda) H(\lambda)$$

  - $\rho_{SD,SDSM}(\lambda)$: Prelaunch BRF for SDSM view direction
  - $H(\lambda)$ is solar diffuser degradation since launch

- SD degradation, H factors, for SDSM view direction at the wavelength of the SDSM detector D

$$H(\lambda_D) = \left\langle \frac{dc_{SD,D}}{\rho_{SD,SDSM}(\lambda_D)\tau_{SDS}\cos(\theta_{SD})} \right\rangle_{Scan} \Bigg/ \left\langle \frac{dc_{SV,D}}{\tau_{SVS}} \right\rangle_{Scan}$$

- ***Improvements***
  - *Carefully re-derived the VFs and BRFs from yaw measurements*
  - ***Ratio of the averages (different from ATBD!)***
  - *Sweet spots selection*

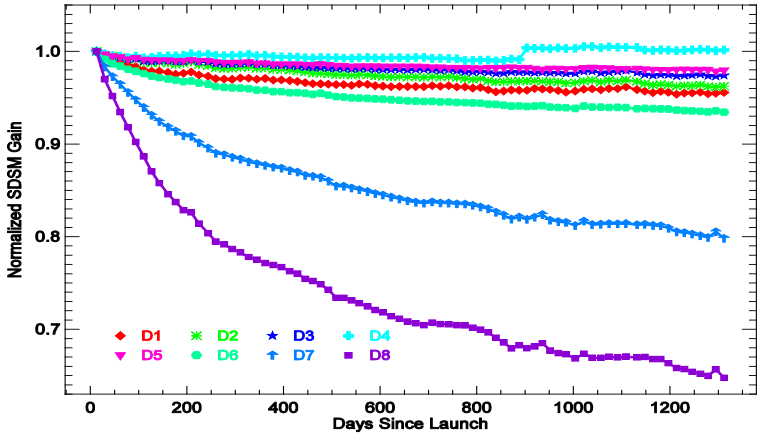


*SDSM operations: Every orbit first few months, then once per day for about two years, and once per two days since May, 2014.*

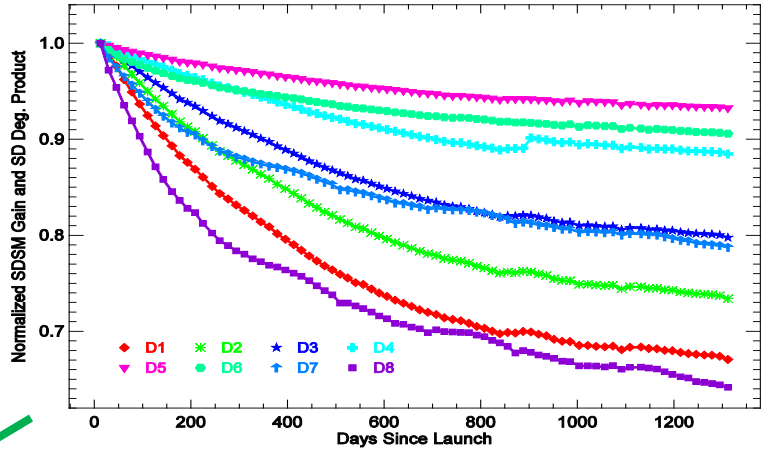
*J. Sun and M. Wang, "Visible infrared image radiometer suite solar diffuser calibration and its challenges using solar diffuser stability monitor," Appl. Opt., 53, 8571-8584 (2014).*

# SDSM Calibration Results

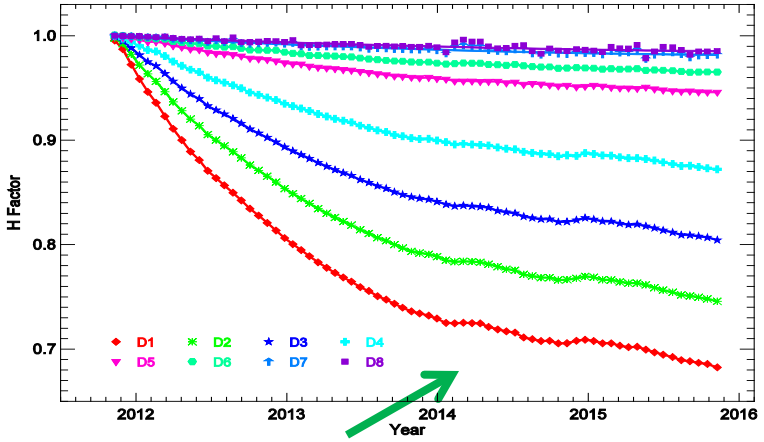
Sun view response trending



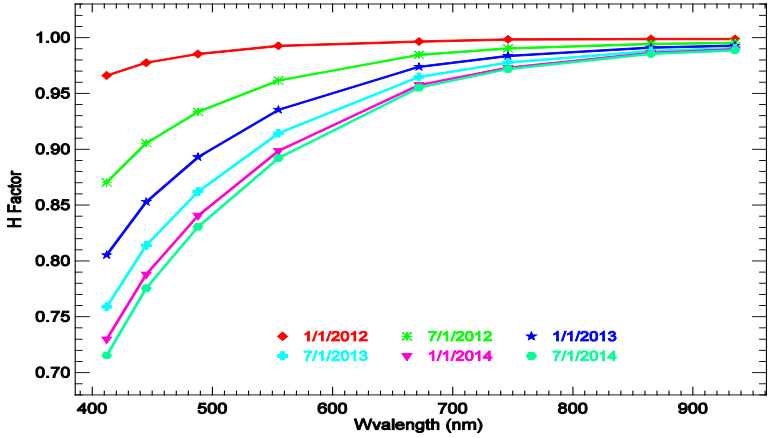

SD view response trending




SD degradation




SD degradation




***Unexpected but real degradation (Nov., 2014)***

***SDSM can accurately track the SD degradation for SDSM direction***

# SD Calibration Algorithm

- SD is made of Spectralon®, near Lambertian property
- Solar radinace reflected by the SD

$$L_{SD}(\lambda) = I_{Sun}(\lambda) \cdot \tau_{SDS} \cdot \cos(\theta_{SD}) \cdot \rho_{SD,RTA}(\lambda) \cdot h(\lambda) / d_{VS}^2$$

  - $\rho_{RSD,RTA}(\lambda)$: Prelaunch BRF for RTA view direction
  - $h(\lambda)$: SD degradation for SDSM view direction is used as the SD degradation for the RTA direction

- RSB calibration coefficients, F factors

$$F(B,D,M,G,t) = \frac{RVS_{B,SD} \cdot \int RSR_B(\lambda,t) \cdot L_{SD}(\lambda) \cdot d\lambda}{\sum_i c_i(B,D,M,G) \cdot dn^i \cdot \int RSR_B(\lambda,t) \cdot d\lambda}$$

  - *B*, *D*, *M*, *G*: Band, Detector, HAM side, and gain status

*J. Sun and M. Wang, "On-orbit calibration of Visible Infrared Imaging Radiometer Suite reflective solar bands and its challenges using a solar," Appl. Opt., 54, 7210-7223 (2015).*

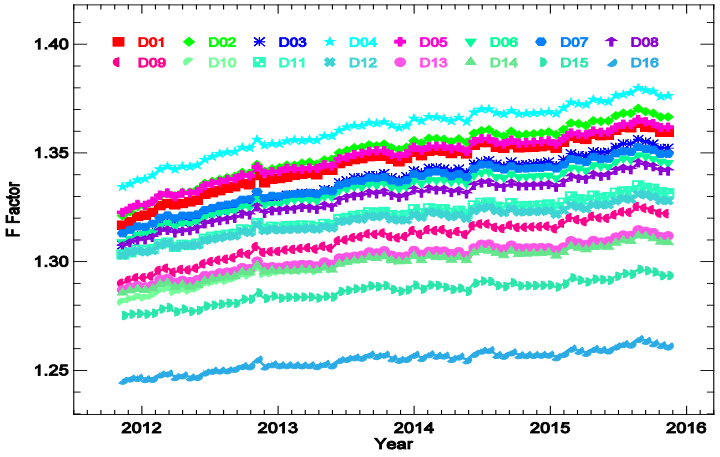


*SD Calibration: Every orbit*

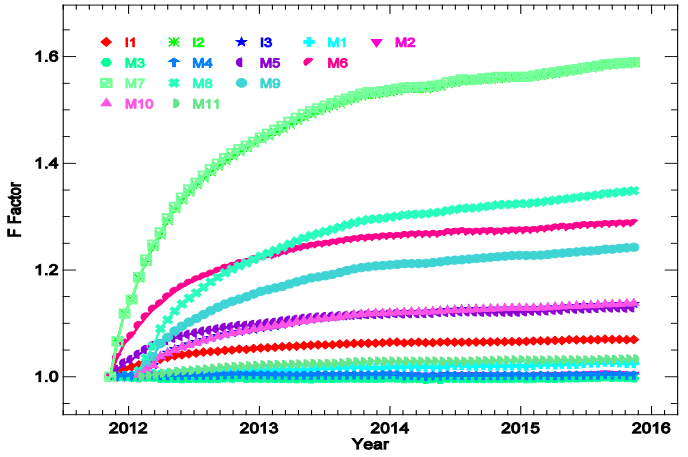
- ***Improvements***
  - *Carefully re-derived the VFs and BRFs from yaw measurements*
  - ***Improved H-factors***
  - *Sweet spot selection*
  - ***Time-dependent RSR***

# SD Calibration Results

Band M1 HAM 1 HG F-factors

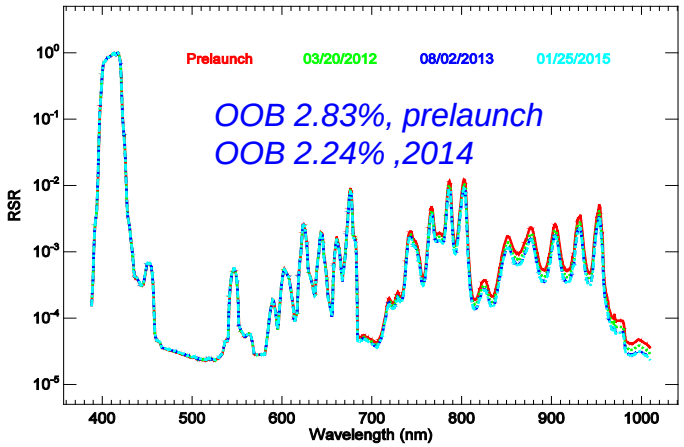



Band Averaged HAM1 HG F-factors

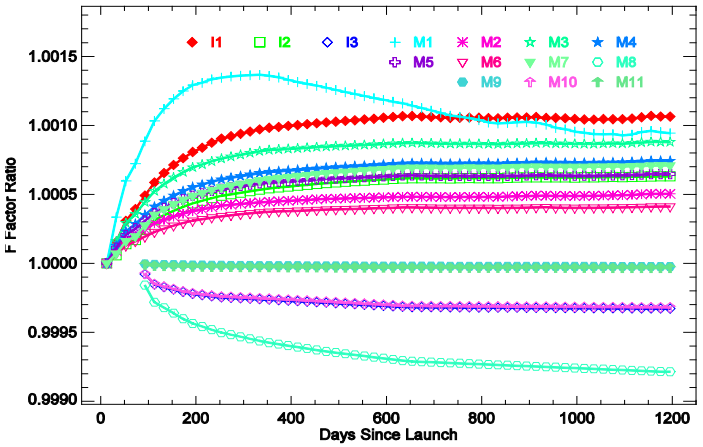



*HG = High Gain*
*LG = Low Gain*

Time-dependent RSR




Impact of RSR on F-factors




***SD can accurately track the RSB gain change as long as SD degradation for the RTA view can be approximated as that for the SDSM view.***

# Lunar Calibration Algorithm

- Moon is very stable in its reflectance
- RSB calibration coefficients , F factors, from lunar observations



$$F(B,M) = \frac{g(B)N_{t,M}}{\sum_{D,S,N} L_{pl}(B,D,S,N)\delta(M,M_N)},$$

– *g(B)*: View geometric effect correction (ROLO lunar model and extra correction to remove seasonal oscillations)

SNPP VIIRS is scheduled to view the Moon approximately monthly (about nine months every year)

- *Advantages*
  - *Lunar surface reflectance has no observable degradation*
  - *Can be used for inter-comparison*

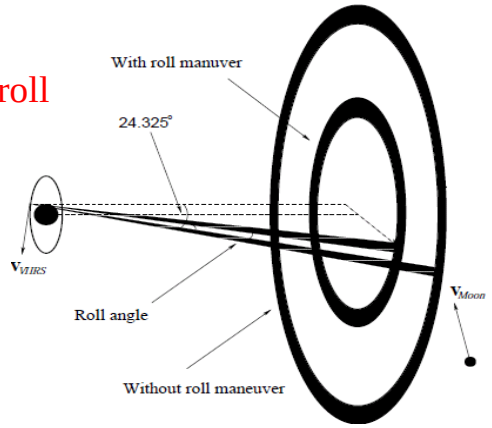
*J. Sun, X. Xiong, and J. Butler, "NPP VIIRS on-orbit calibration and characterization using the moon", Proc. SPIE, 8510,85101I, (2012).*

*X. Xiong, J. Sun, J. Fulbright, Z. Wang, and J. Butler, "Lunar Calibration and Performance for S-NPP VIIRS reflective Solar Bands", IEEE Trans. Geosci. Remote Sens.*, **54**, 1052-1061, (2016).

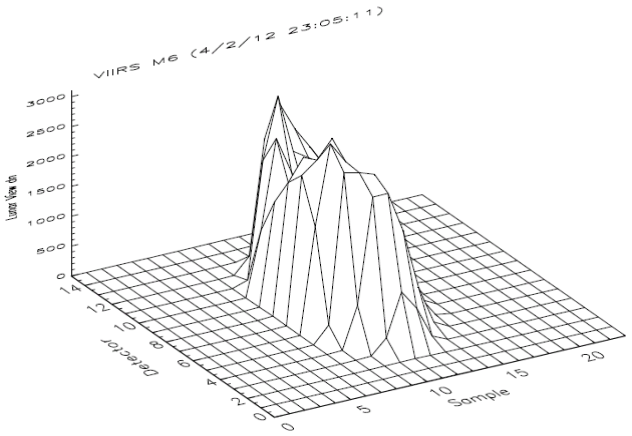
# Lunar Planning and Calibration Results

Roll maneuver

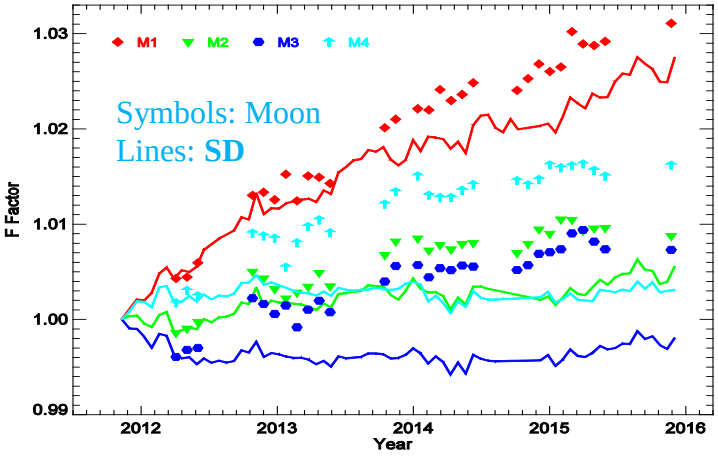
Required roll maneuver




Lunar image (M6 in April, 2012)




Lunar and SD F Factors




- View geometry dependence
- ***Planning is important starting point – made lunar planning tool and planned lunar observations in early mission***
- However, the phase angle range change from [-56º, -55º] to [-50.5º, 51.5º]
- Size of the moon
- Oversampling effect
- Scans seeing full lunar image

*J. Sun and X. Xiong, "Solar and lunar observation planning for Earth-observing sensor", Proc. SPIE, **8176**, 817610, (2011).*

# Hybrid Approach

- SD Calibration
  - SD degrades non-uniformly, resulting long-term drifts
  - Results are stable and smooth
  - Observation in every orbit
- Lunar Calibration
  - No degradation issue
  - Infrequent and no observation in three months every year
- Hybrid Approach

$$\mathcal{F}(B,D,M,G) = R(B,t)\cdot F(B,D,M,G)$$

$$R(B,t) = \left\langle f(B,M,t)\right\rangle_{M} / \left\langle F(B,D,M,0,t)\right\rangle_{D,t-15<t_i<t+15,M}$$

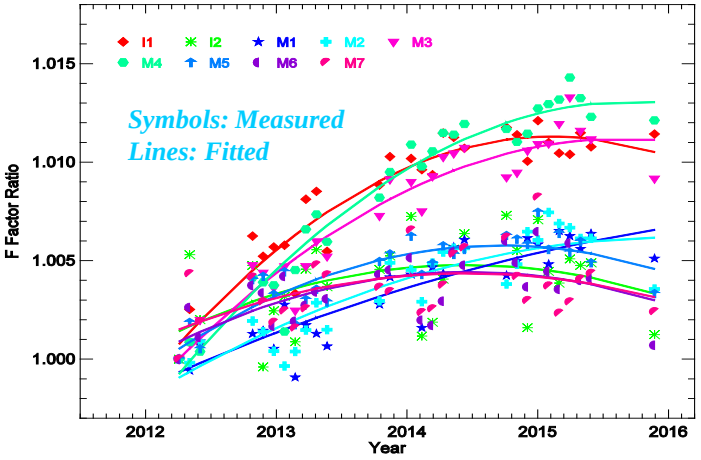
***F-Factors Ratios are fitted to quadratic polynomials of time***

  - **Lunar calibration provides long-term baseline**
  - **SD calibration provides smoothness and frequency**

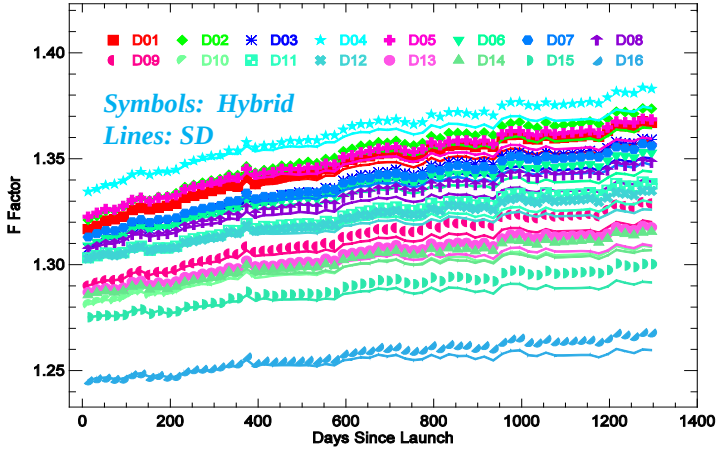
*J. Sun and M. Wang, "Radiometric Calibration of the VIIRS Reflective Solar Bands with Robust Characterizations and Hybrid Calibration Coefficients," Appl. Opt.*, **54**, 9331-9342, 2015.
*J. Sun and M. Wang, "VIIRS reflective solar bands calibration progress and its impact on ocean color products," Remote Sensing, 8, 194, (2016).*

# Hybrid Calibration Coefficients

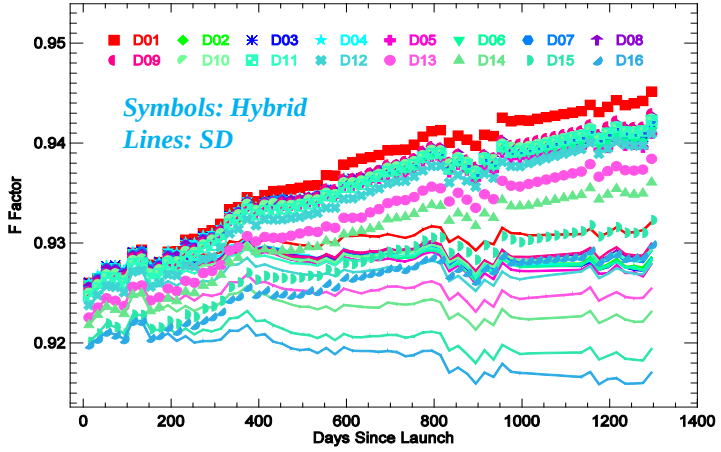
## Calibration coefficients Ratios



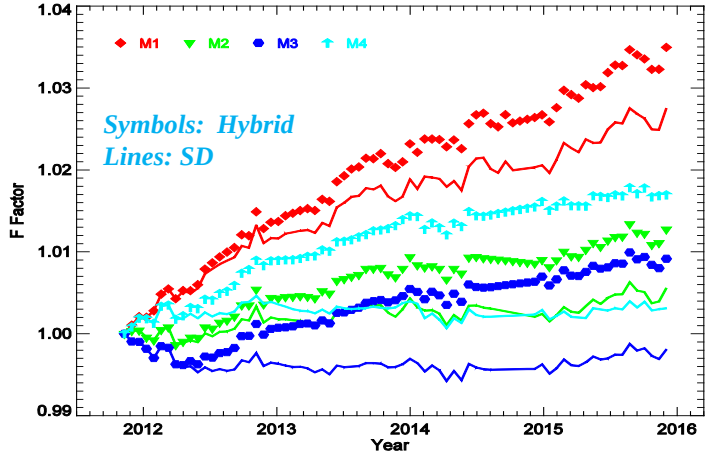

## Calibration Coefficients (M1)



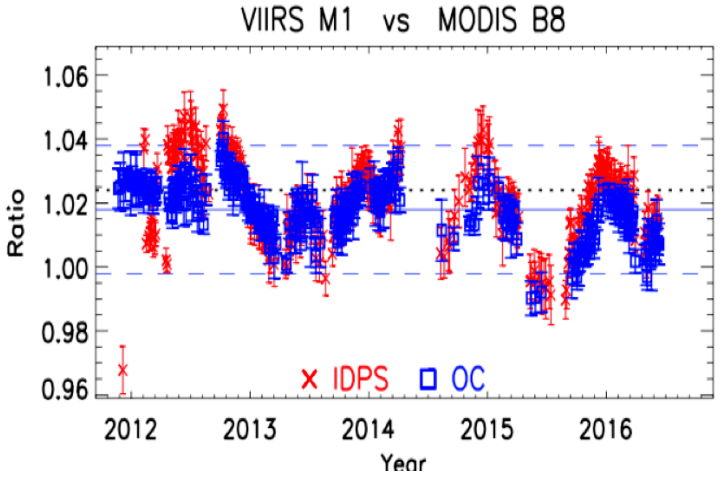

## Calibration Coefficients (M4)

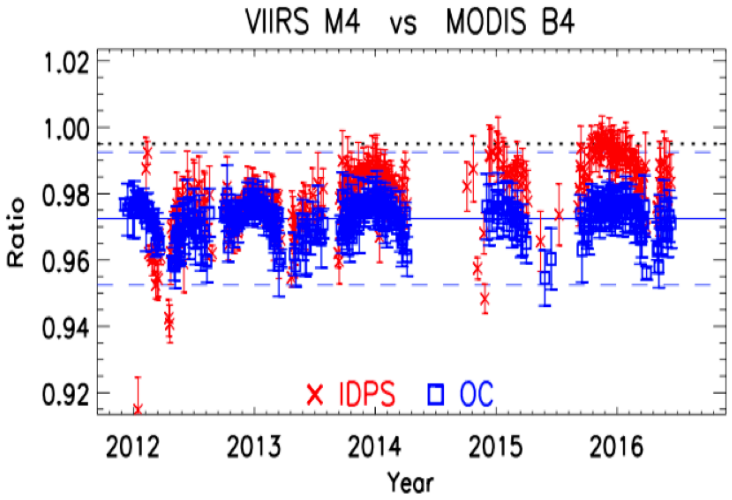



## Calibration Coefficients

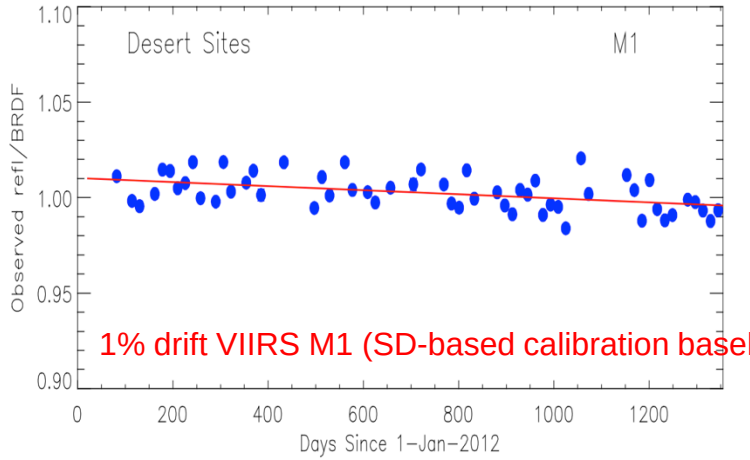


# Improvements in SDR




*Poster: "Radiometric Comparison of the RSBs of the SNPP VIIRS and Aqua MODIS through SNO analysis" by M. Chu, J. Sun and M. Wang.*

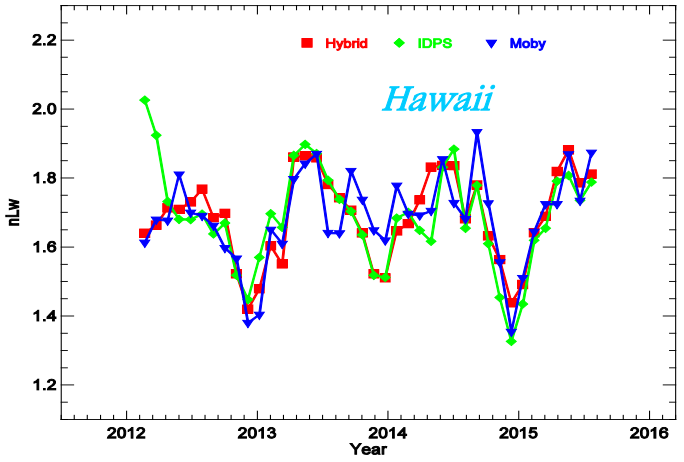


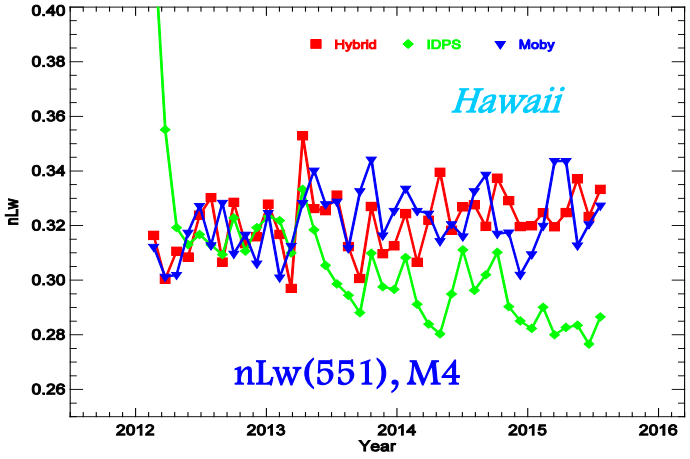

*A. Wu et al., "Assessment of SNPP VIIRS VIS/NIR Radiometric Calibration Stability Using Aqua MODIS and Invariant Surface Targets", IEEE TGRS, 54, 2918-2924, 2016.*

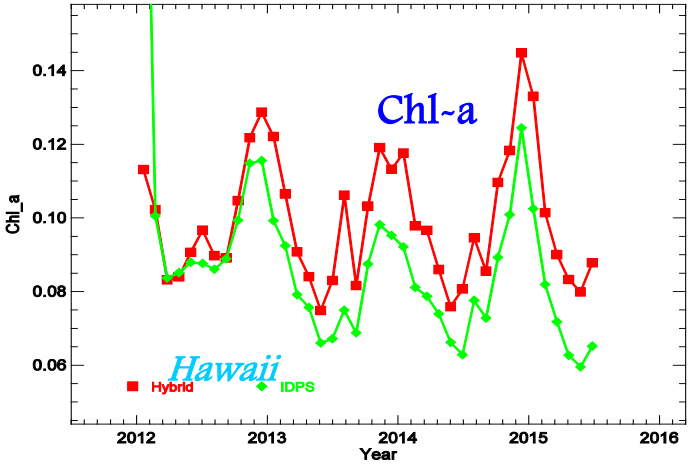
- **Hybrid-method corrected M4 is clearly better**
- **Uncorrected M1 desert trending shows 1% drift (NASA reprocessed VIIRS SDR with SD-based calibration baseline)**
- **Hybrid-method corrected M1 SDR removes the 1% drift**
- **Aqua MODIS Band 8 has long-term drift**

# Improvements in Ocean Color Products

- VIIRS data were reprocessed using **MSL12** with SDR generated with updated hybrid calibration coefficients.
- NOAA ocean color products produced with the hybrid calibration coefficients have met validated maturity in March 2015.
- **Hybrid results agree with MOBY in situ!**



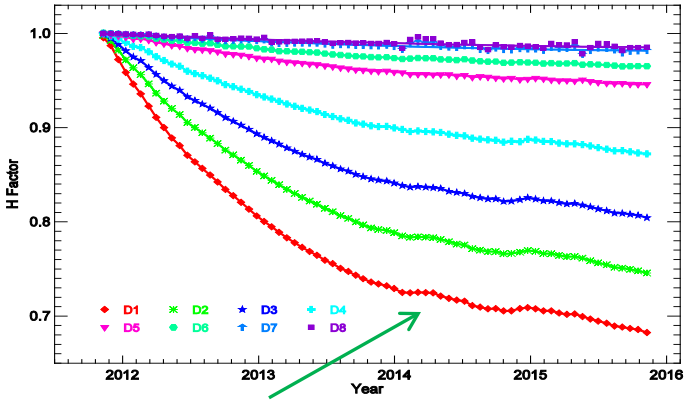




*Green: VIIRS IDPS; **Red: VIIRS Hybrid; Blue: Moby in Situ***


- *J. Sun and M. Wang, "VIIRS Reflective Solar Bands On-Orbit Calibration and Performance: A Three-Year Update," Proc. SPIE, 9264, 92640L (2014).*
- *M. Wang, et al, "Evaluation of VIIRS ocean color products," Proc. SPIE 9261, 92610E (2014).*

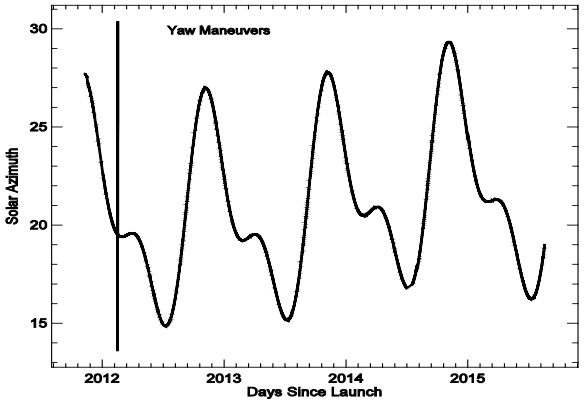
# Some Other Challenges

- SD degrades abnormally




***Unexpected but real degradation (Nov., 2014)***

- S-NPP orbit drift

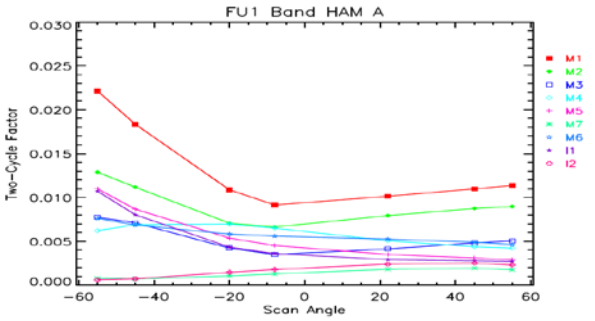



*Azimuth angle in instrument coordinate system*

- RVS may change on-orbit
  - Aqua and Terra MODIS RVS have changed more than 20% and 40%, respectively, at small AOI.

- *J. Sun, X. Xiong, A. Angal, H. Chen, A. Wu, and X. Geng, "Time dependent response versus scan angle for MODIS reflective solar bands," IEEE Trans. Geosci. Remote Sens., 52, 3159-3174 (2014).*
- *J. Sun and X. Xiong, "MODIS polarization sensitivity analysis", IEEE Trans. Geosci. Remote Sens., 45, 2875-2885 (2007).*

- Polarization sensitivity may change on-orbit




  - Terra MODIS polarization sensitivity changed dramatically on-orbit

# Summary

- RSB calibration is demanding, and especially so for the very stringent ocean color product requirements. Every component must be rigorously examined.
- Robust characterizations of essential calibration components have been completed, achieving accurate reprocessed ocean color EDR and becoming routine for forwarding science quality products
- "*Solar diffuser degradation nonuniformity effect*" will be a key issue for all instruments such as VIIRS J1, VIIRS J2, etc., that use SD/SDSM for reflective solar bands calibration - hybrid-method mitigation will be vital.
- There will be more challenging and non-trivial problems when the instrument begins to age.

# Backup

# VIIRS RSB Specification

Table 1. Specification for SNPP VIIRS RSBs and SDSM detectors.

| VIIRS Band | CW* (nm) | Band Gain | Detectors | Resolution* | SDSD Detector | CW* (nm) |
|---|---|---|---|---|---|---|
| M1 | 410 | DG | 16 | 742m x 776m | D1 | 412 |
| M2 | 443 | DG | 16 | 742m x 776m | D2 | 450 |
| M3 | 486 | DG | 16 | 742m x 776m | D3 | 488 |
| M4 | 551 | DG | 16 | 742m x 776m | D4 | 555 |
| I1 | 640 | SG | 32 | 371m x 387m | NA | NA |
| M5 | 671 | DG | 16 | 742m x 776m | D5 | 672 |
| M6 | 745 | SG | 16 | 742m x 776m | D6 | 746 |
| M7 | 862 | DG | 16 | 742m x 776m | D7 | 865 |
| I2 | 862 | SG | 32 | 371m x 387m | D7 | 865 |
| NA | NA | N | 16 | | D8 | 935 |
| M8 | 1238 | SG | 16 | 742m x 776m | NA | NA |
| M9 | 1378 | SG | 16 | 742m x 776m | NA | NA |
| M10 | 1610 | SG | 16 | 742m x 776m | NA | NA |
| I3 | 1610 | SG | 32 | 371m x 387m | NA | NA |
| M11 | 2250 | SG | 16 | 742m x 776m | NA | NA |

*CW: Center Wavelength; DG: Dual Gain; SG: Singla Gain; Resolution: Track x Scan at Nadir after aggregation

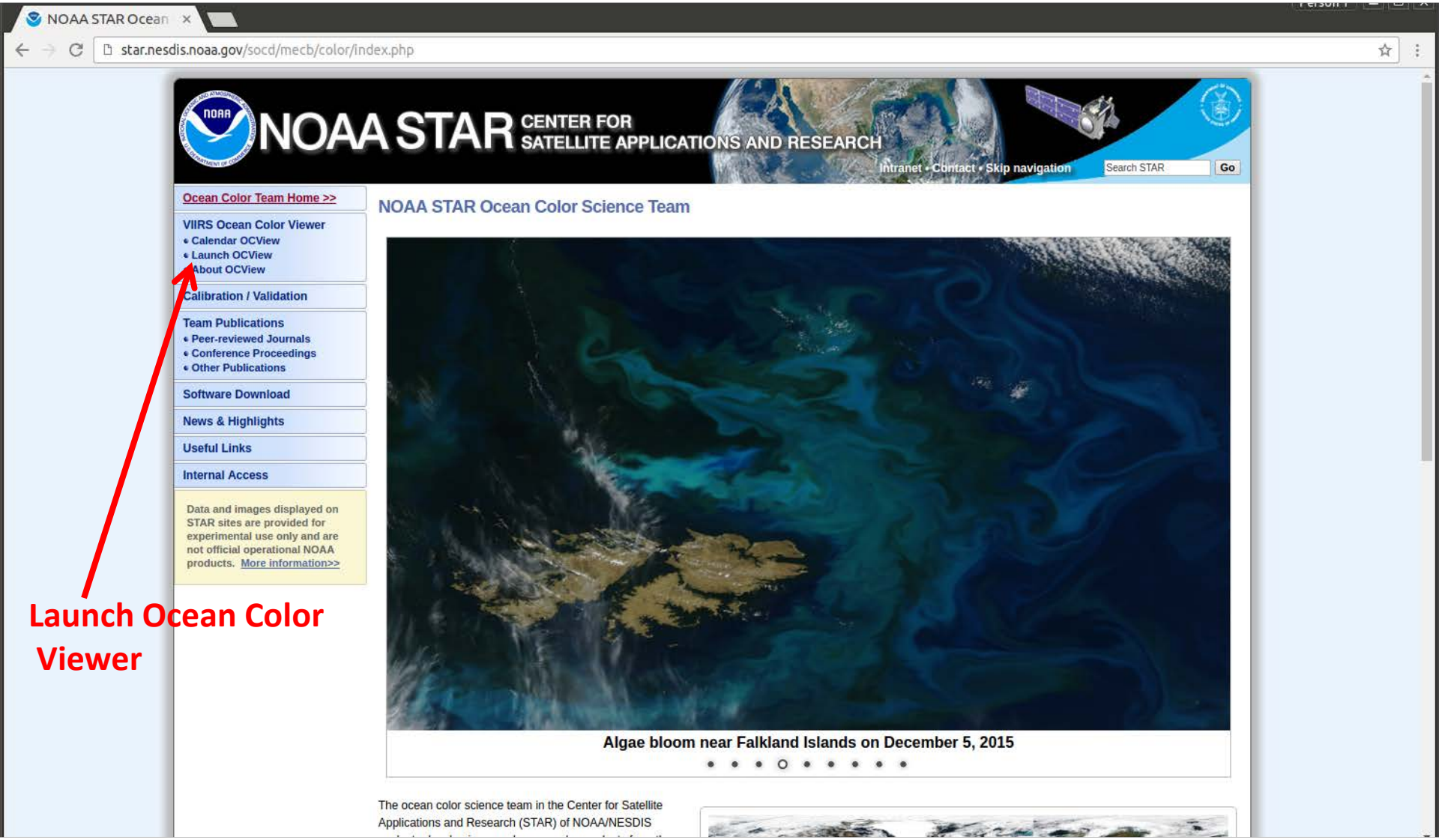
# OCView – Online display and monitoring of ocean color product imagery

Karlis Mikelsons
NOAA Ocean Color Science Team

STAR JPSS
2016 Annual Science Team Meeting
August 10, 2016

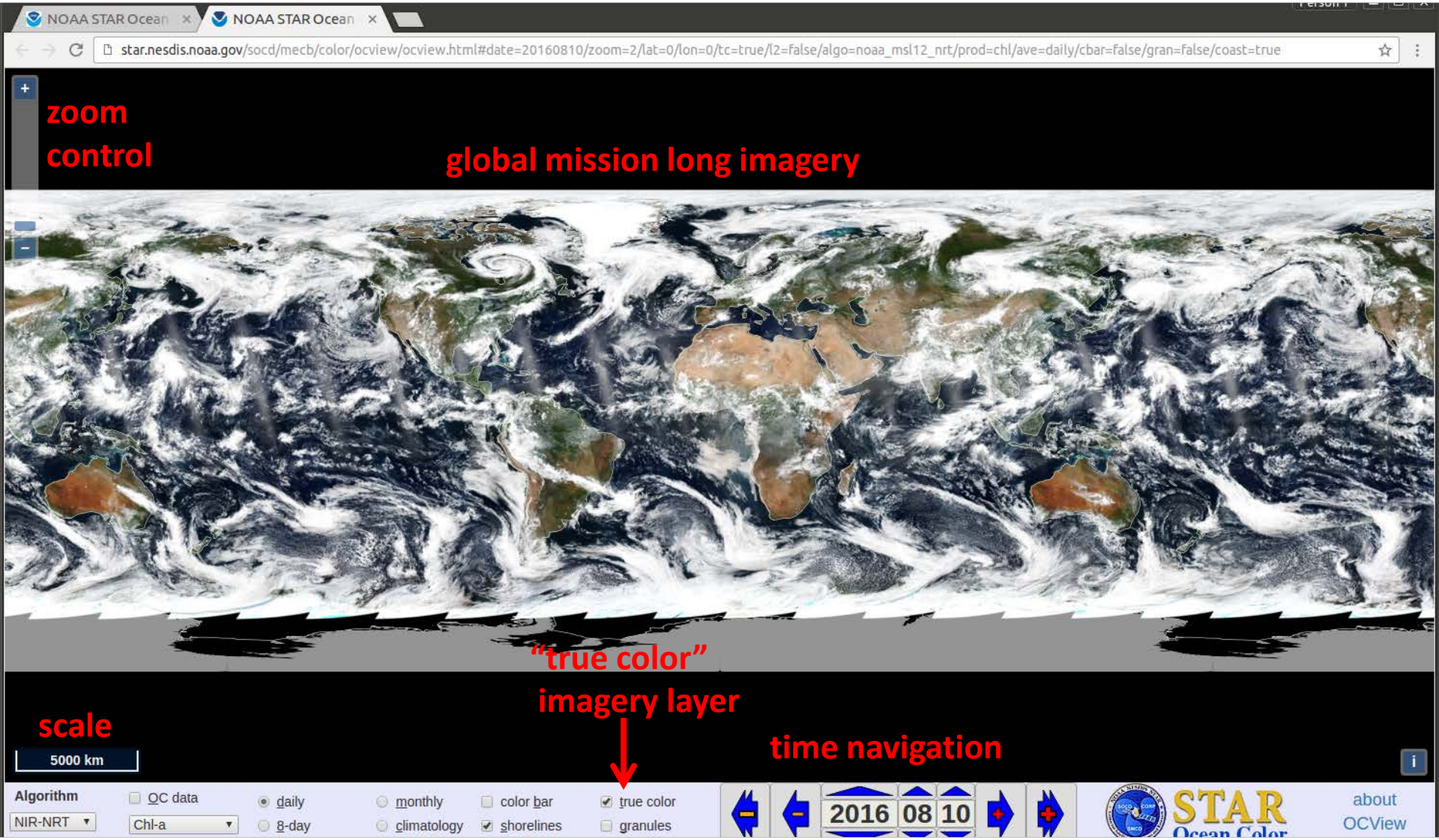
# NOAA Ocean Color Science Team web page

star.nesdis.noaa.gov/socd/mecb/color/index.html



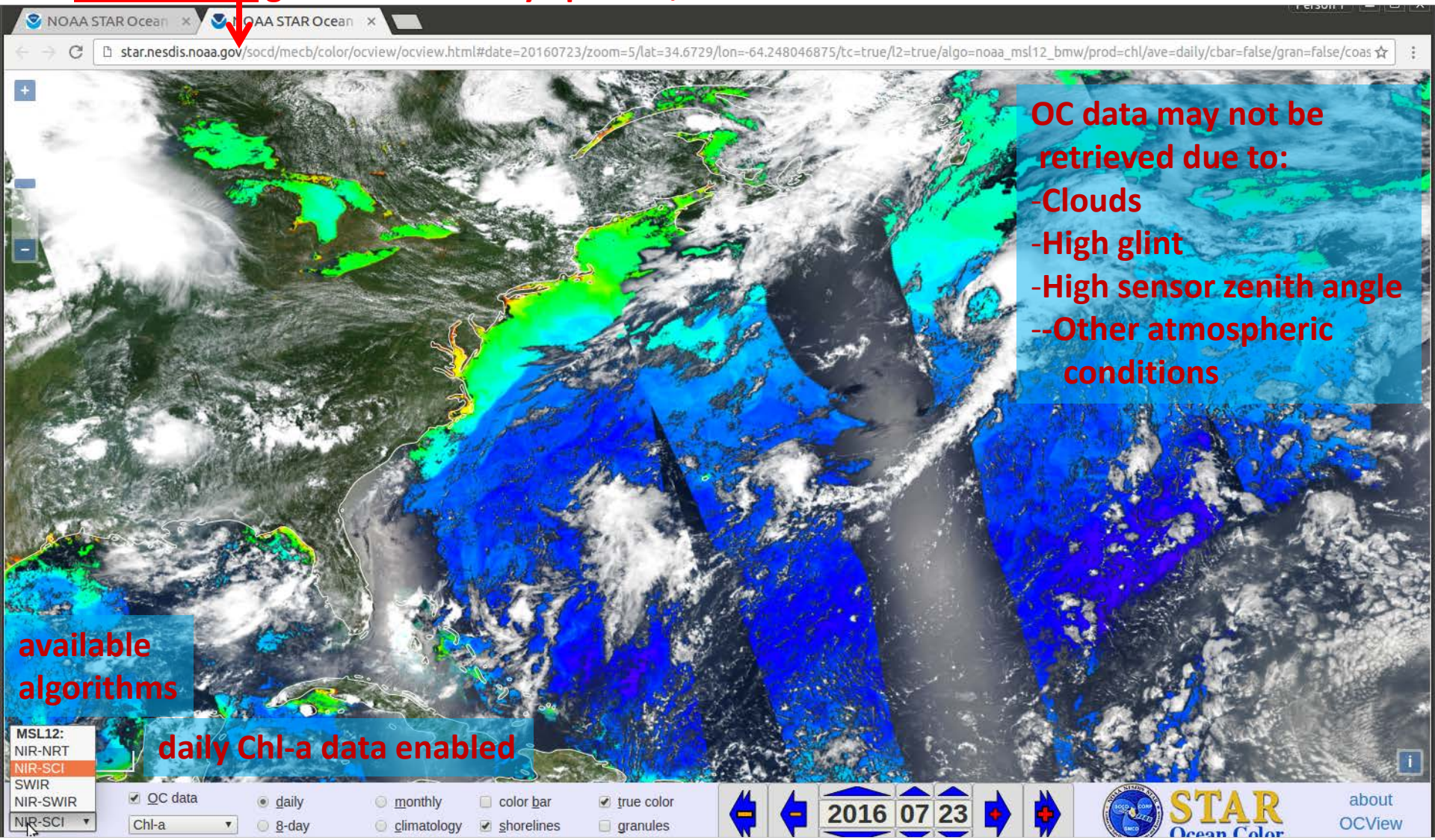

**Launch Ocean Color Viewer**

# OCView – Ocean Color Viewer

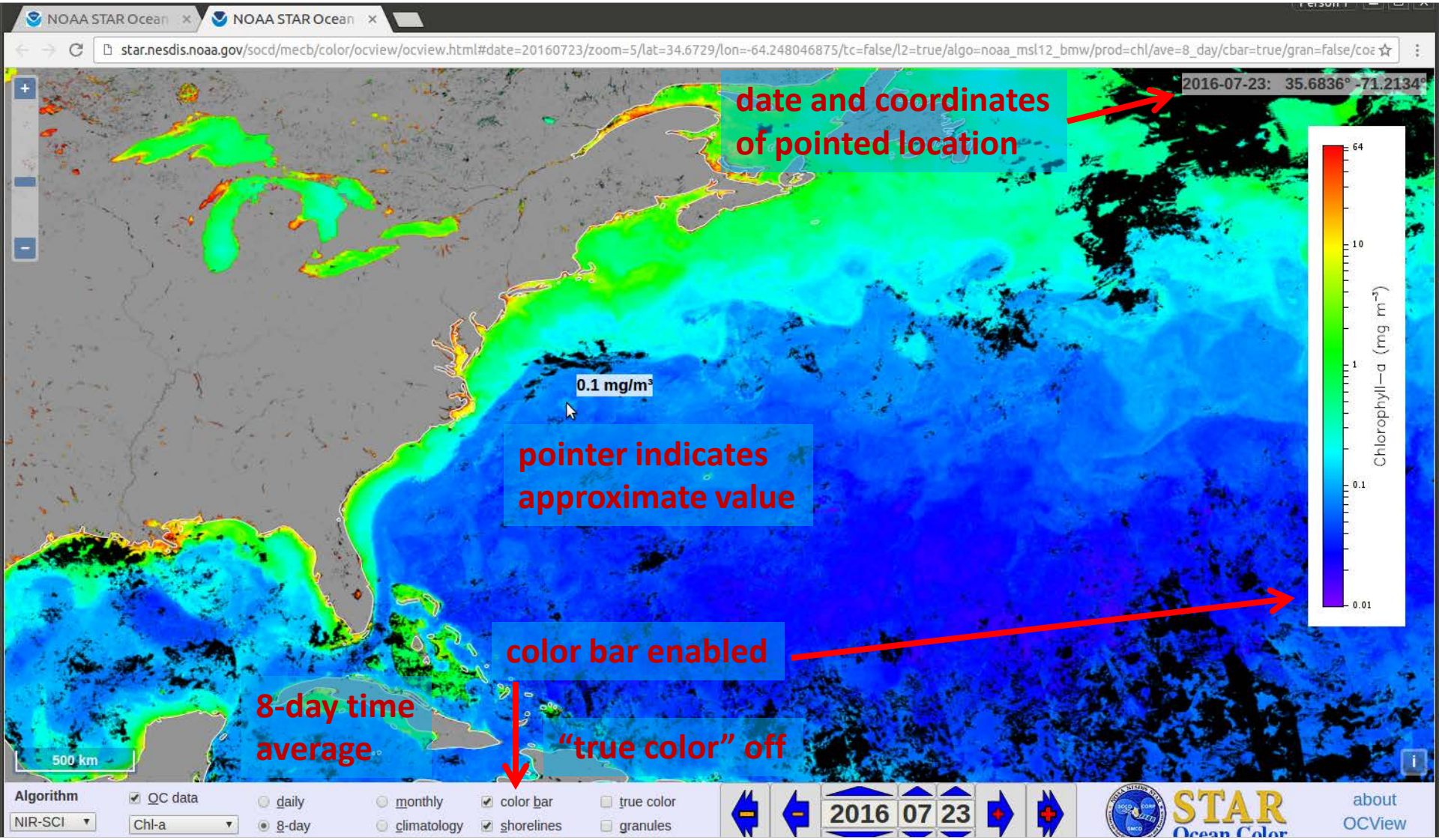


# OCView – regional view

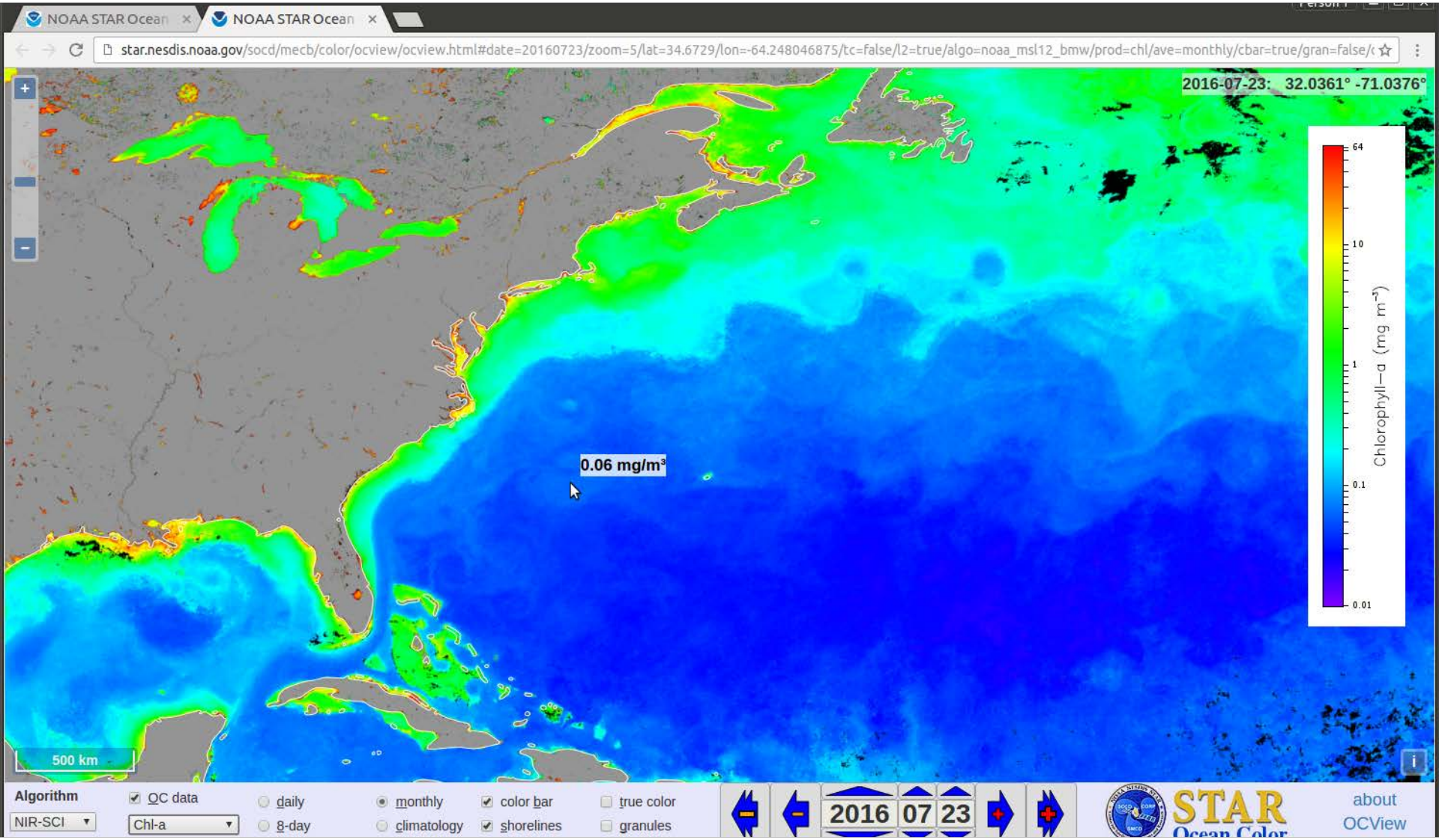
**browser link gets automatically updated, and can be used to share or restore the view**



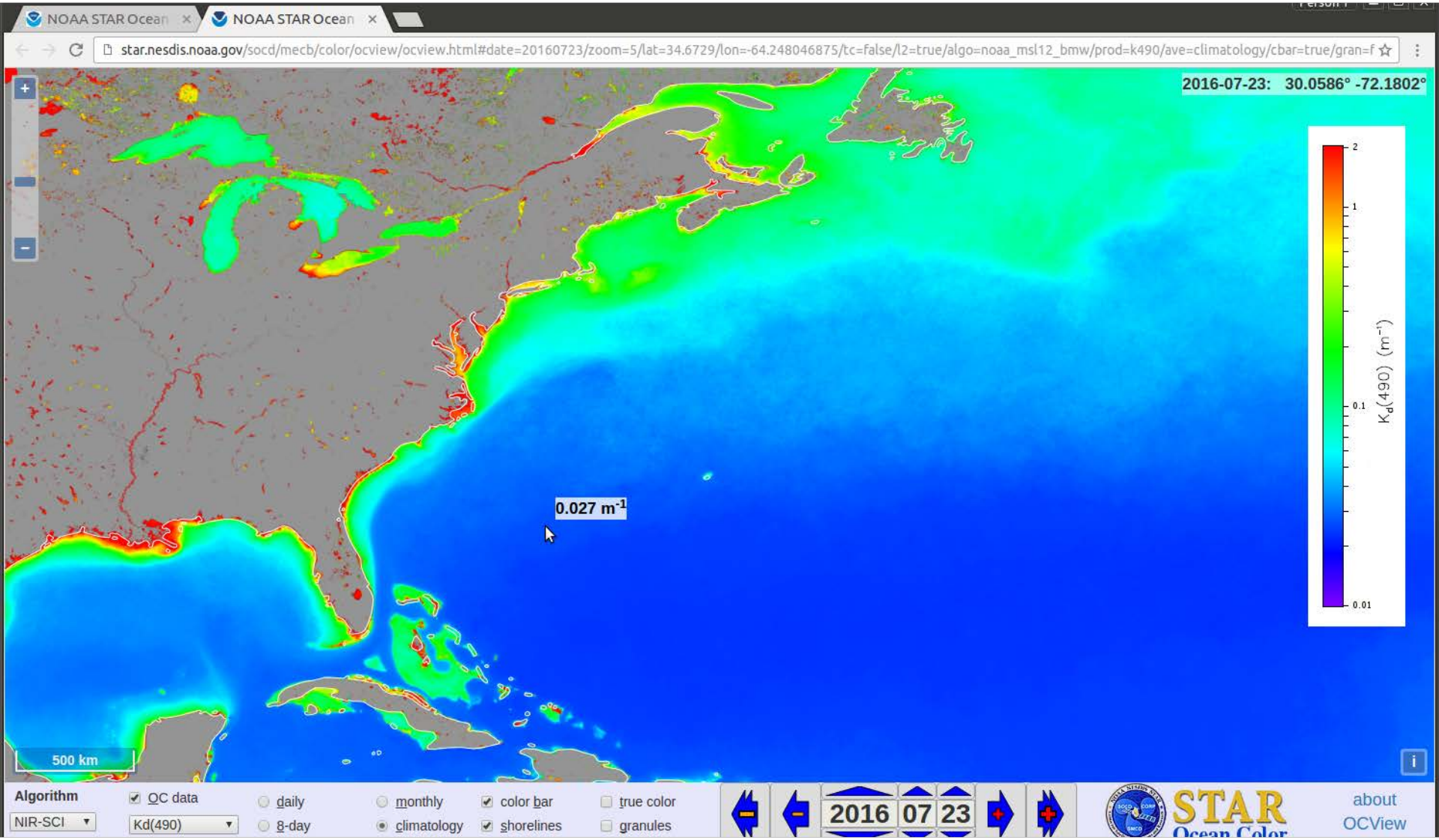
# Chl-a 8 day time average



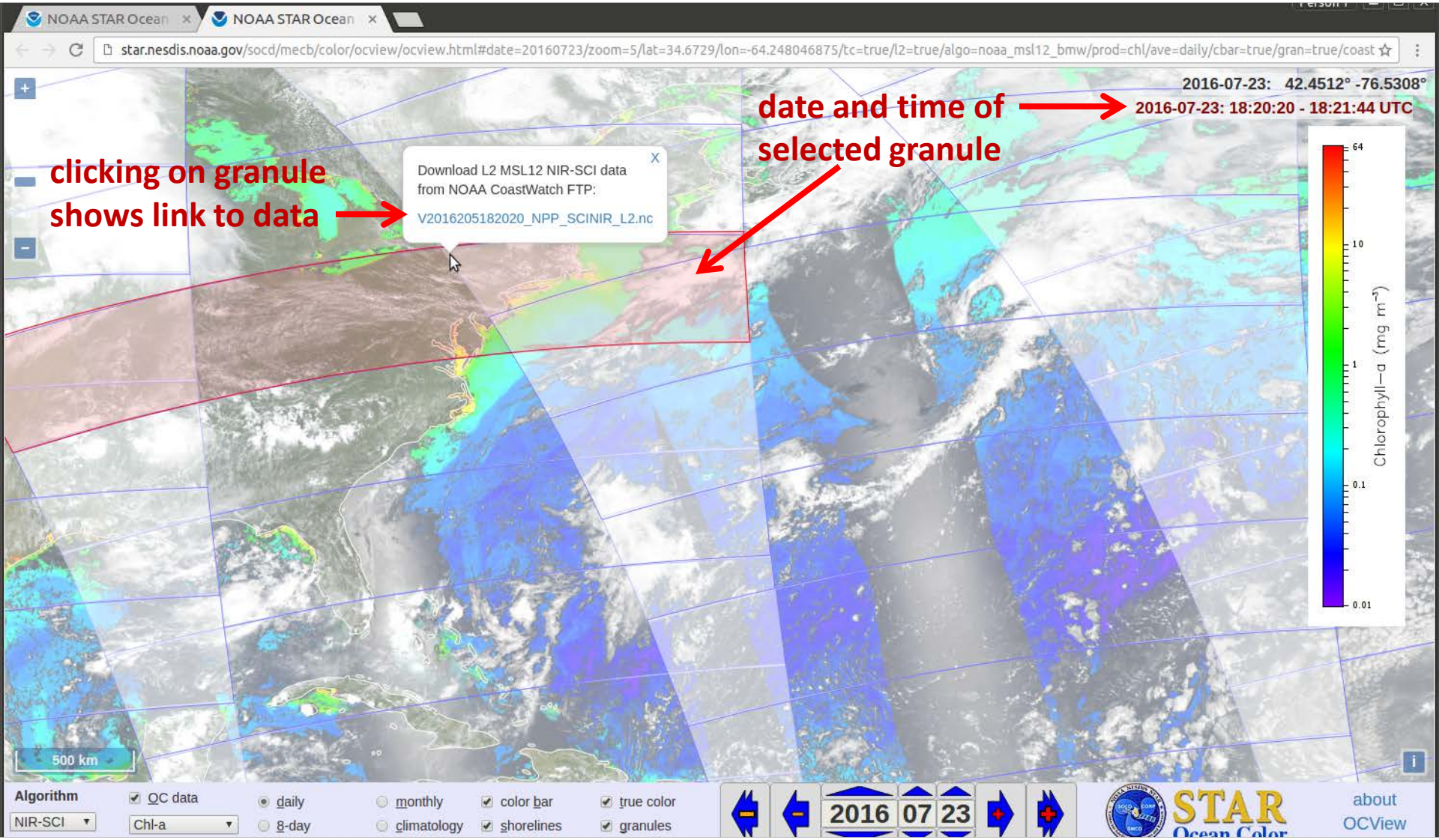
# Chl-a monthly time average



# $K_d(490)$ climatology



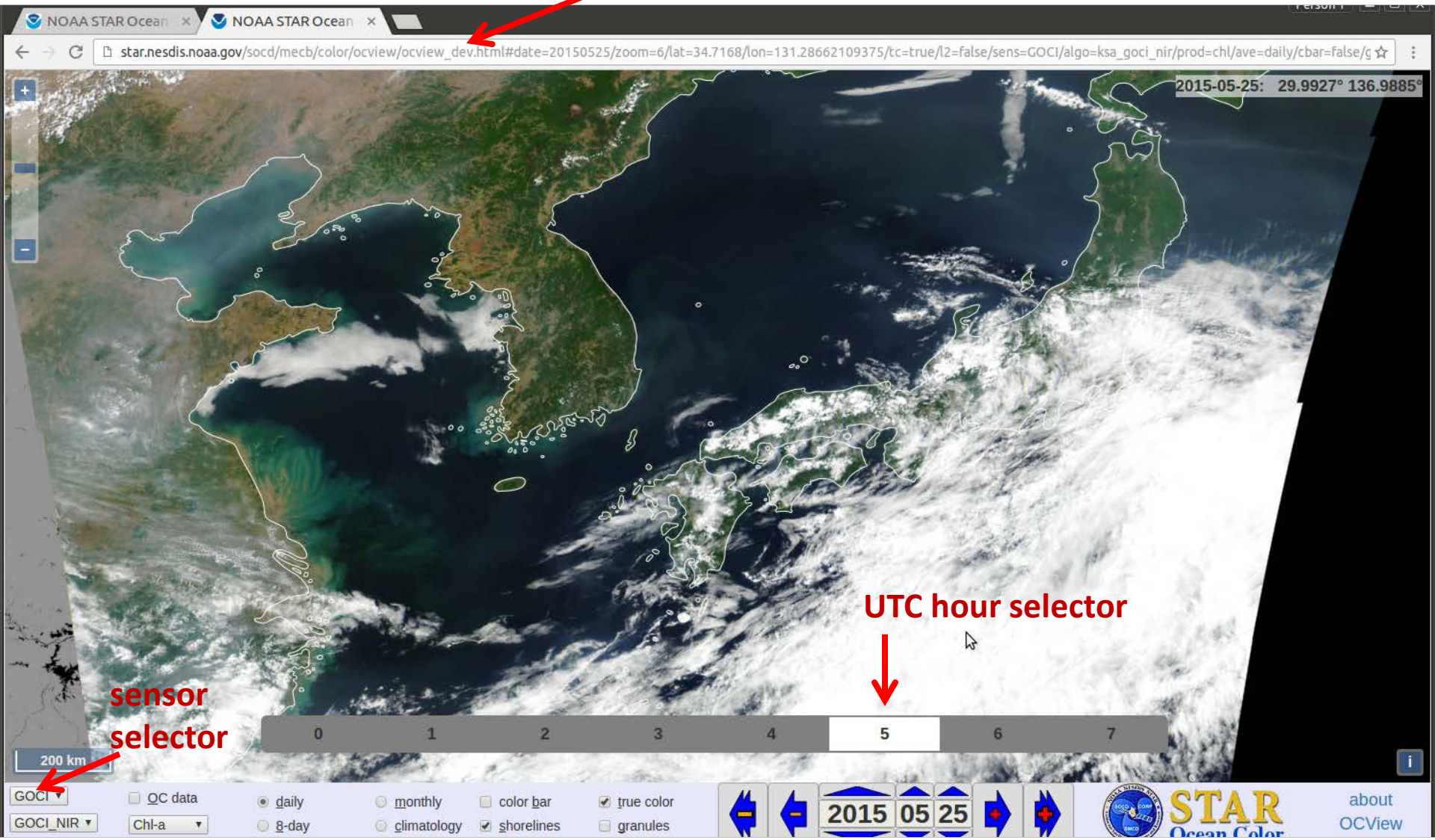
# Granule display, selection, and download




granule overlay enabled

# GOCI true color

## (development site)



# NIR and SWIR-Based On-Orbit Vicarious Calibrations for VIIRS Ocean Color Data Processing

Wei Shi and Menghua Wang

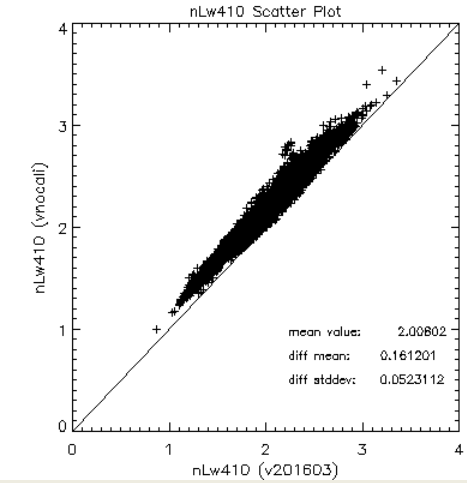
NOAA/NESDIS
Center for Satellite Applications and Research
5830 University Research Ct.
College Park, MD 20740, USA

2016 STAR JPSS Science Meeting
August 10, 2016

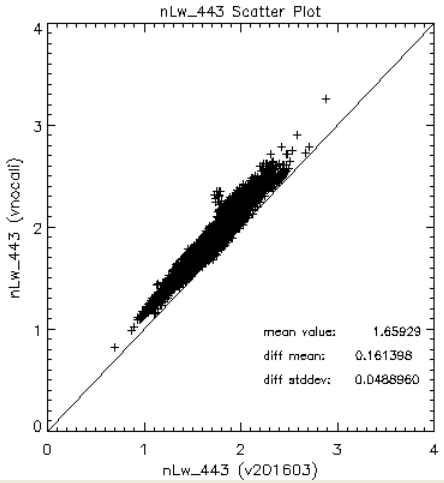
# Comparison of VIIRS Ocean Color Products

(w/o vicarious calibration vs. Ref. V201603)

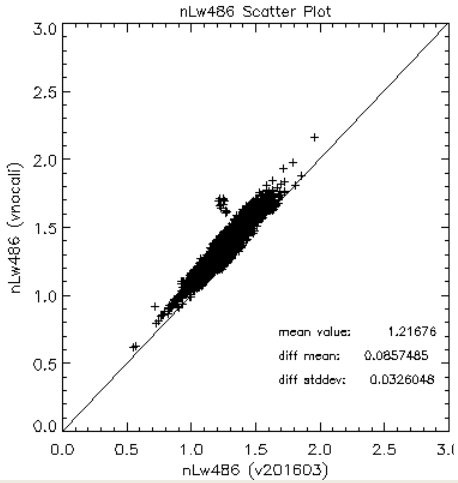
$nL_w(410)$



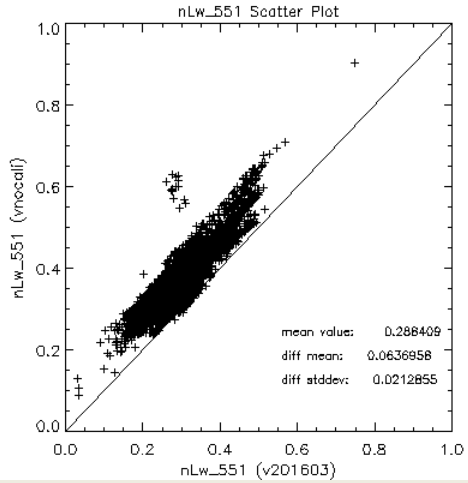

$nL_w(443)$



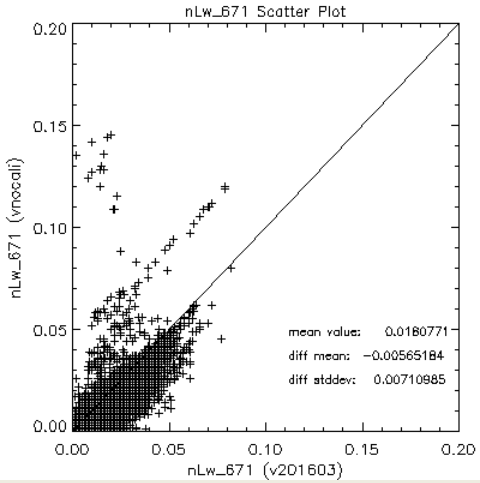

$nL_w(486)$



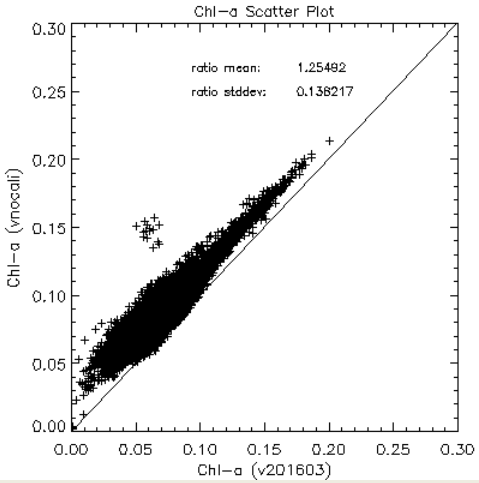

$nL_w(551)$



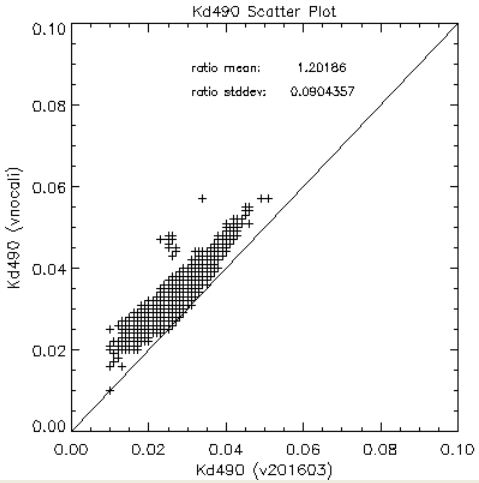

$nL_w(671)$



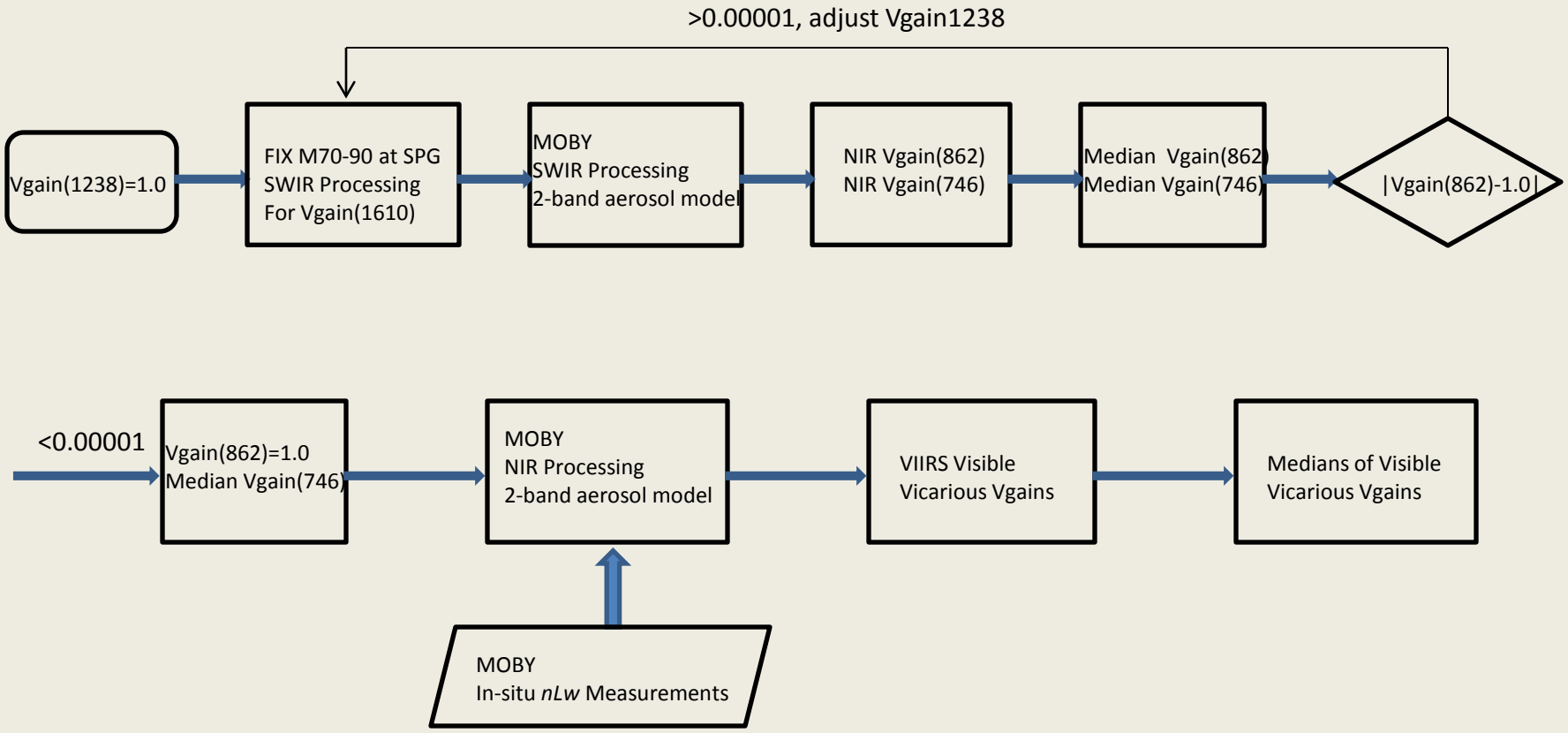

*Chl-a*



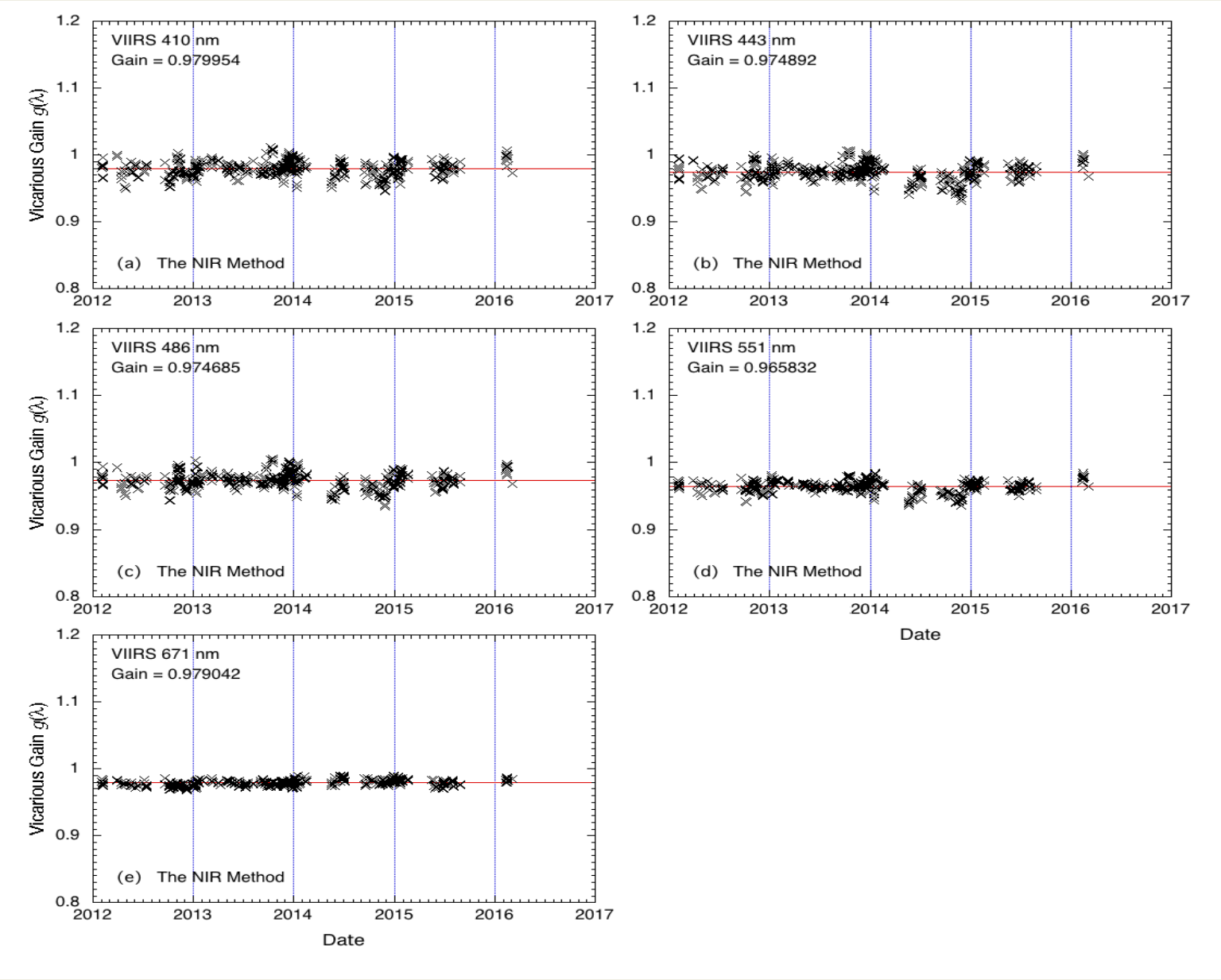

$K_d(490)$



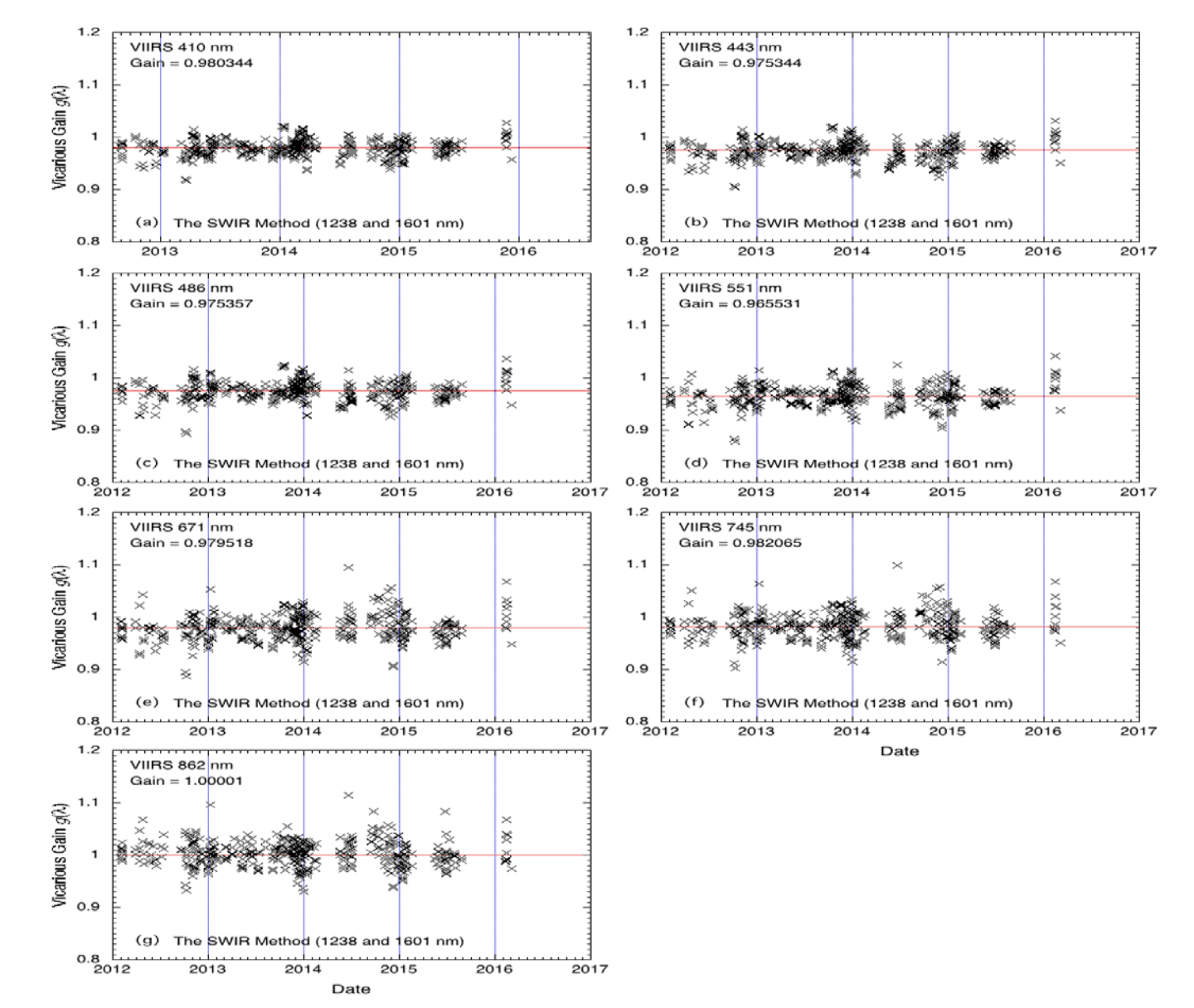
# Vicarious Calibration Flow Chart



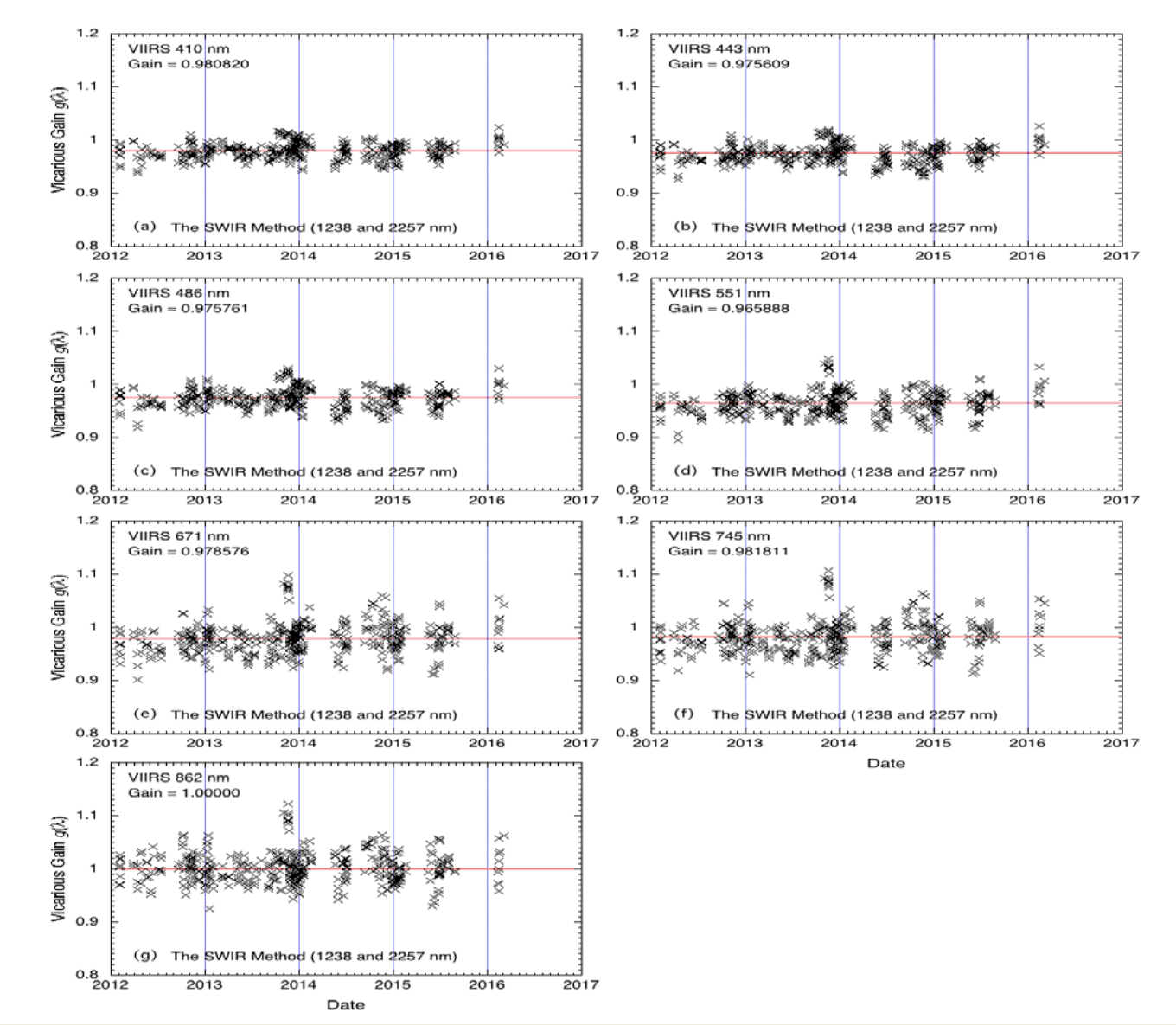
# The NIR-Derived (M6, M7) Vicarious Calibration Gains $g^{(NIR)}(\lambda)$



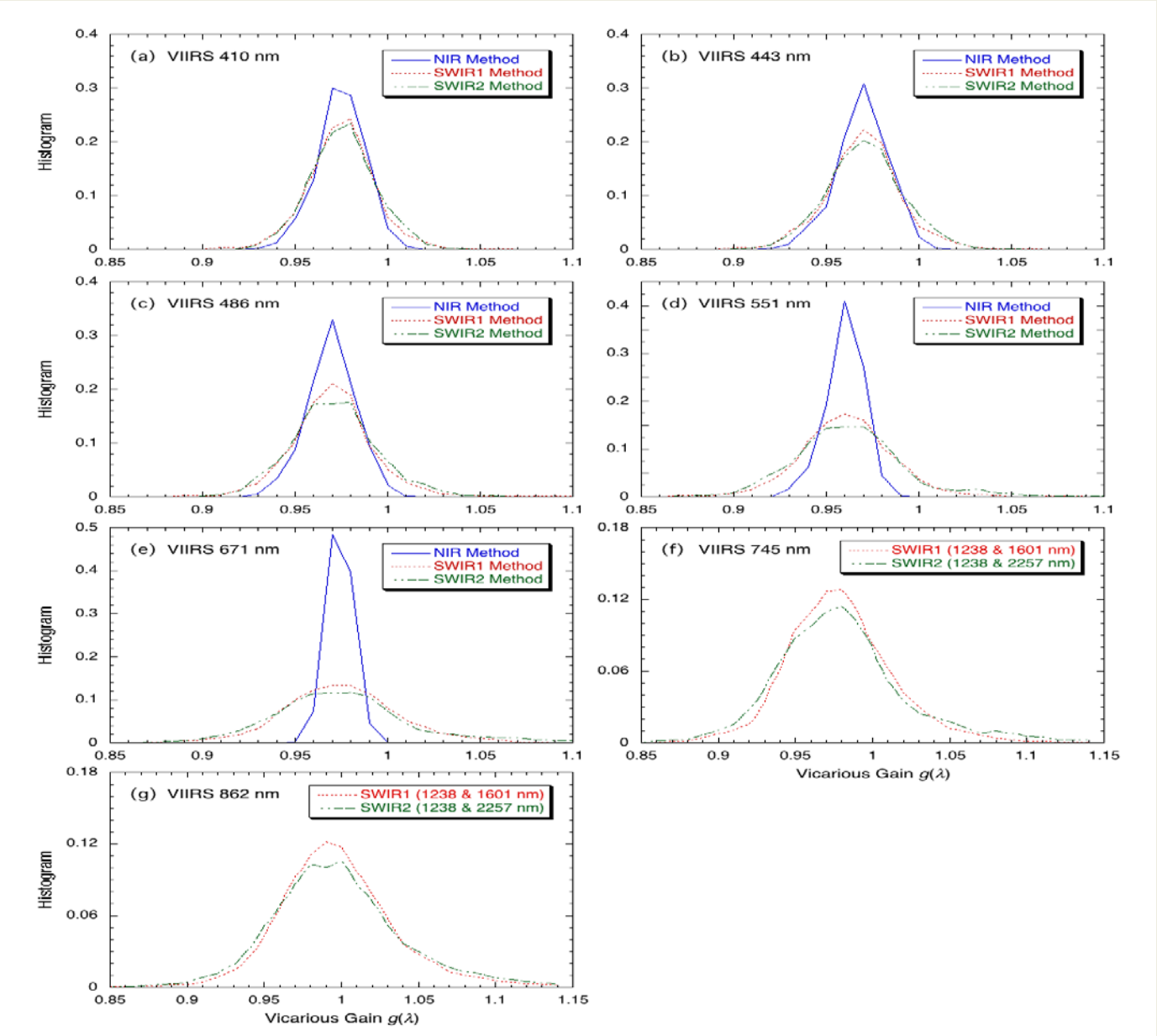
# The SWIR1-Derived (M8, M10) Vicarious Calibration Gains $g^{(SWIR1)}(\lambda)$



# The SWIR2-derived (M8, M11) Vicarious Calibration Gains $g^{(SWIR2)}(\lambda)$



# Histograms of the NIR-, SWIR1-, and SWIR2- Derived Vicarious Gains



# VIIRS-SNPP NIR- and SWIR-based Vicarious Gains (May 2016)

| **VIIRS** Spectral Band (nm) | **VIIRS SWIR- and NIR-Based Vicarious Calibration Gains** | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | NIR-derived $g^{(NIR}(\lambda)$ and STD | | SWIR1-derived $g^{(SWIR1)}(\lambda)$ | | SWIR2-derived $g^{(SWIR2)}(\lambda)$ | | Diff1 (%) (SWIR1 vs. NIR) | Diff2 (%) (SWIR2 vs. NIR) |
| 410 (M1) | 0.979954 | 0.0129 | 0.980344 | 0.0190 | 0.980820 | 0.0181 | 0.040 | 0.088 |
| 443 (M2) | 0.974892 | 0.0142 | 0.975344 | 0.0219 | 0.975609 | 0.0212 | 0.046 | 0.074 |
| 486 (M3) | 0.974685 | 0.0131 | 0.975357 | 0.0246 | 0.975761 | 0.0240 | 0.069 | 0.110 |
| 551 (M4) | 0.965832 | 0.0100 | 0.965531 | 0.0299 | 0.965888 | 0.0314 | -0.031 | 0.006 |
| 671 (M5) | 0.979042 | 0.0064 | 0.979518 | 0.0356 | 0.978576 | 0.0445 | 0.049 | -0.048 |
| 745 (M6) | 0.982065 | — | 0.982065 | 0.0379 | 0.981811 | 0.0476 | 0.000 | -0.026 |
| 862 (M7) | 1.00000 | — | 1.00001 | 0.0423 | 1.00000 | 0.0490 | 0.001 | 0.000 |
| 1238 (M8) | — | — | 1.01812 | — | 1.01812 | — | — | — |
| 1601 (M10) | — | — | 0.994676 | — | — | — | — | — |
| 2257 (M11) | — | — | — | — | 1.20252 | — | — | — |

Gain differences from the NIR- and SWIR-based approaches are within ~0.05%!

# Unified NIR- and SWIR-based Vicarious Gains (May 2016)

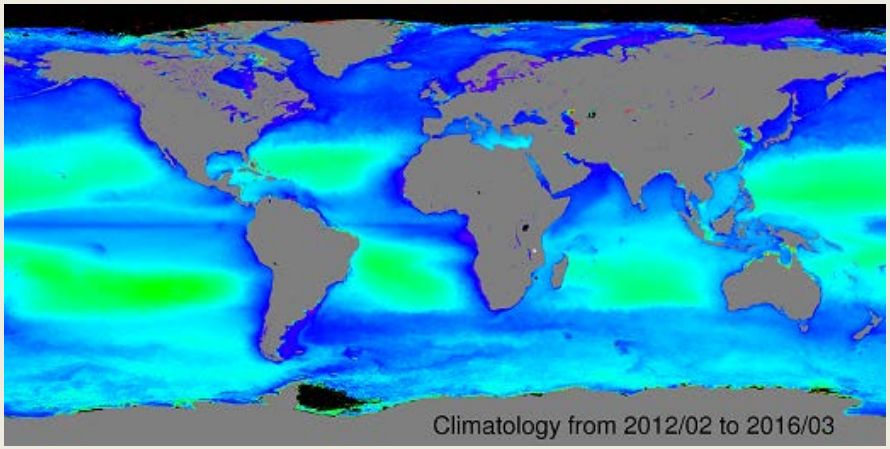
| VIIRS Spectral Band (nm) | VIIRS Unified Vicarious Gains for the MSL12 |
|---|---|
| 410 (M1) | 0.979954 |
| 443 (M2) | 0.974892 |
| 486 (M3) | 0.974685 |
| 551 (M4) | 0.965832 |
| 671 (M5) | 0.979042 |
| 745 (M6) | 0.982065 |
| 862 (M7) | 1.00000 |
| 1238 (M8) | 1.01812 |
| 1601 (M10) | 0.994676 |
| 2257 (M11) | 1.20252 |

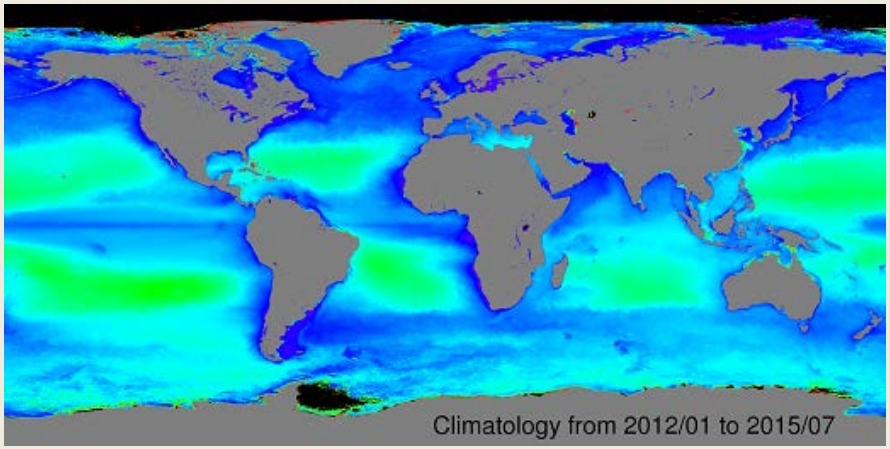
# Comparison of Climatology of VIIRS NIR- and SWIR-based Ocean Color Products

VIIRS NIR Ocean Color Product

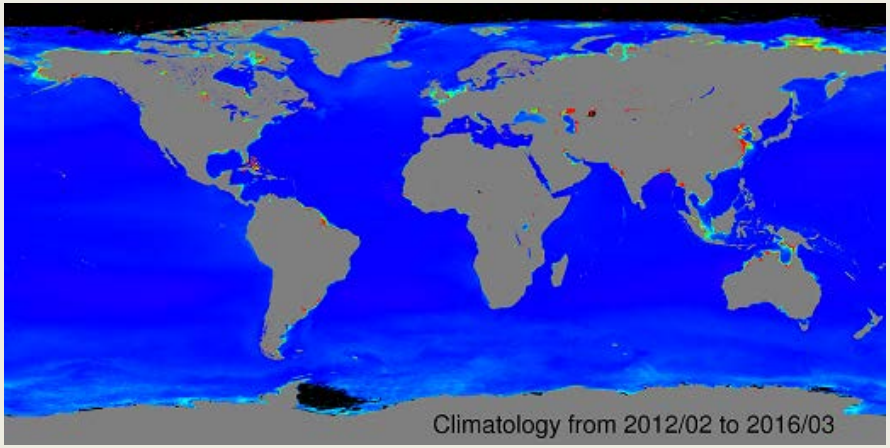
VIIRS SWIR Ocean Color Product

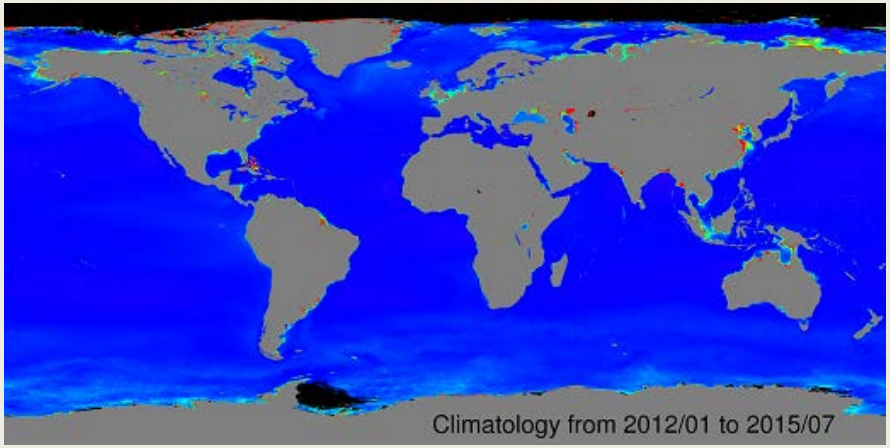
$nL_w(443)$




$nL_w(551)$



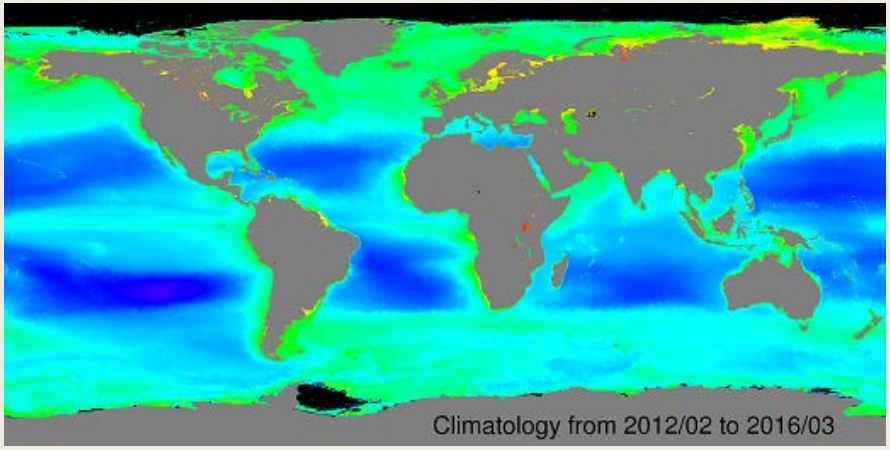



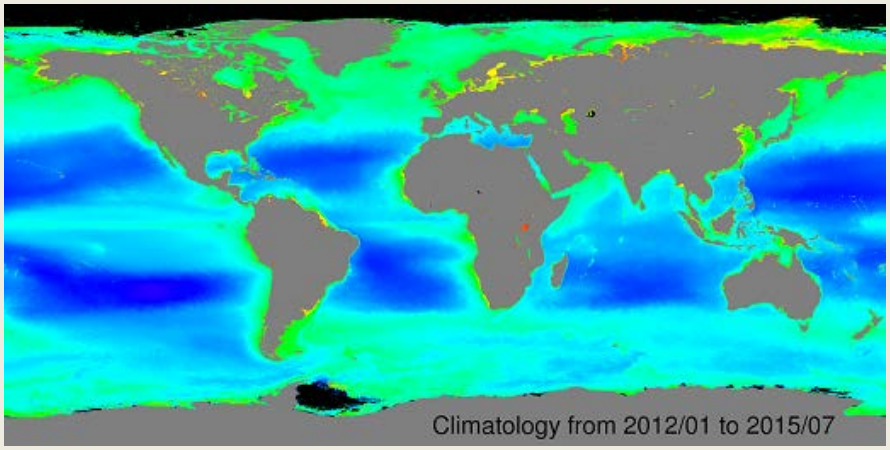
# Comparison of Climatology of VIIRS NIR- and SWIR-based Ocean Color Products

VIIRS NIR Ocean Color Products

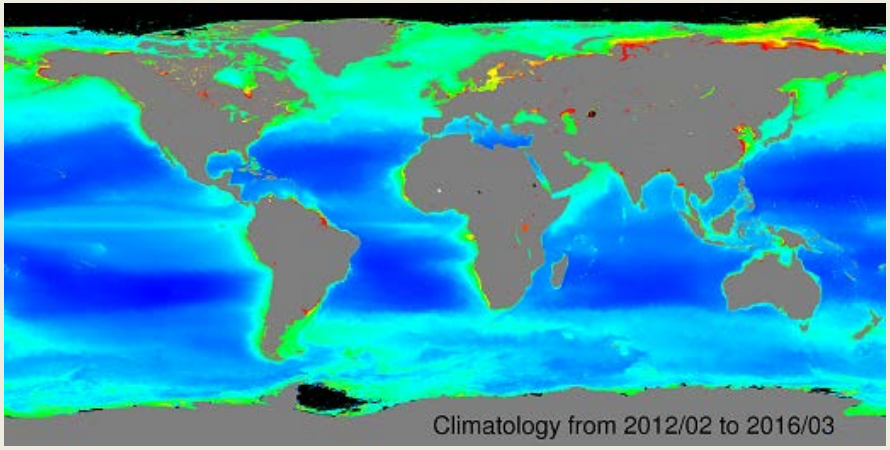
VIIRS SWIR Ocean Color Product

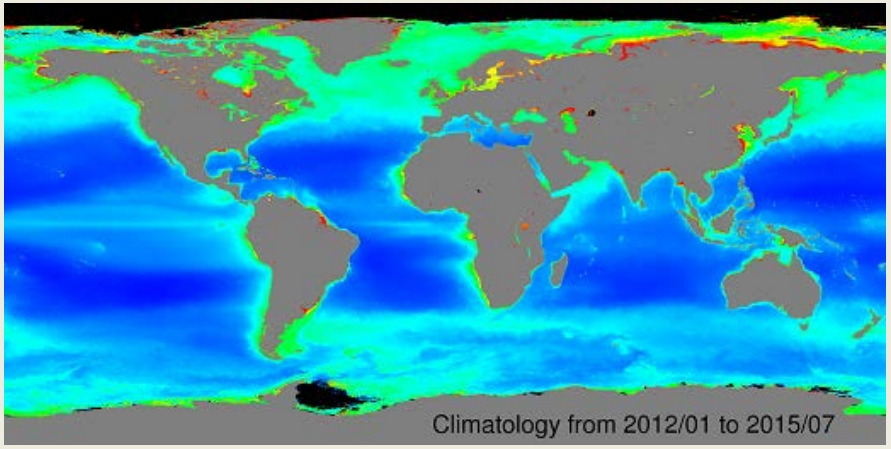
***Chl-a***



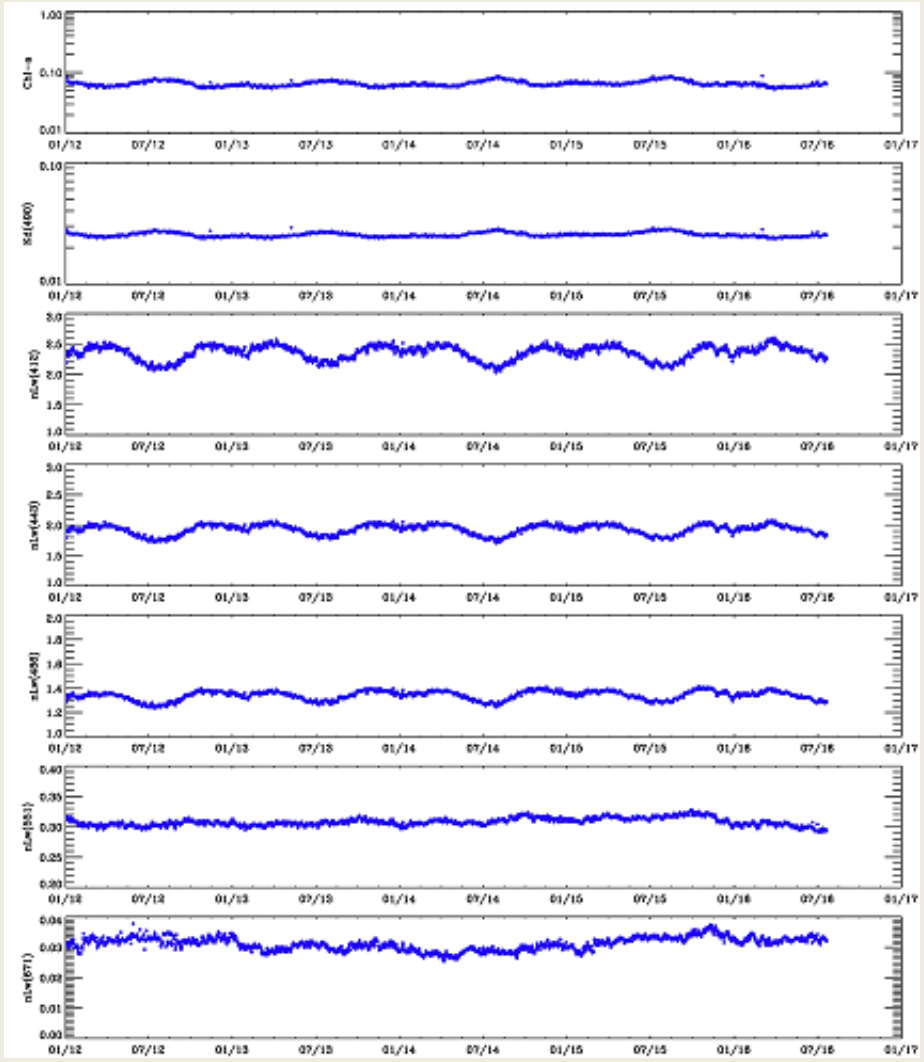

***$K_d$(490)***



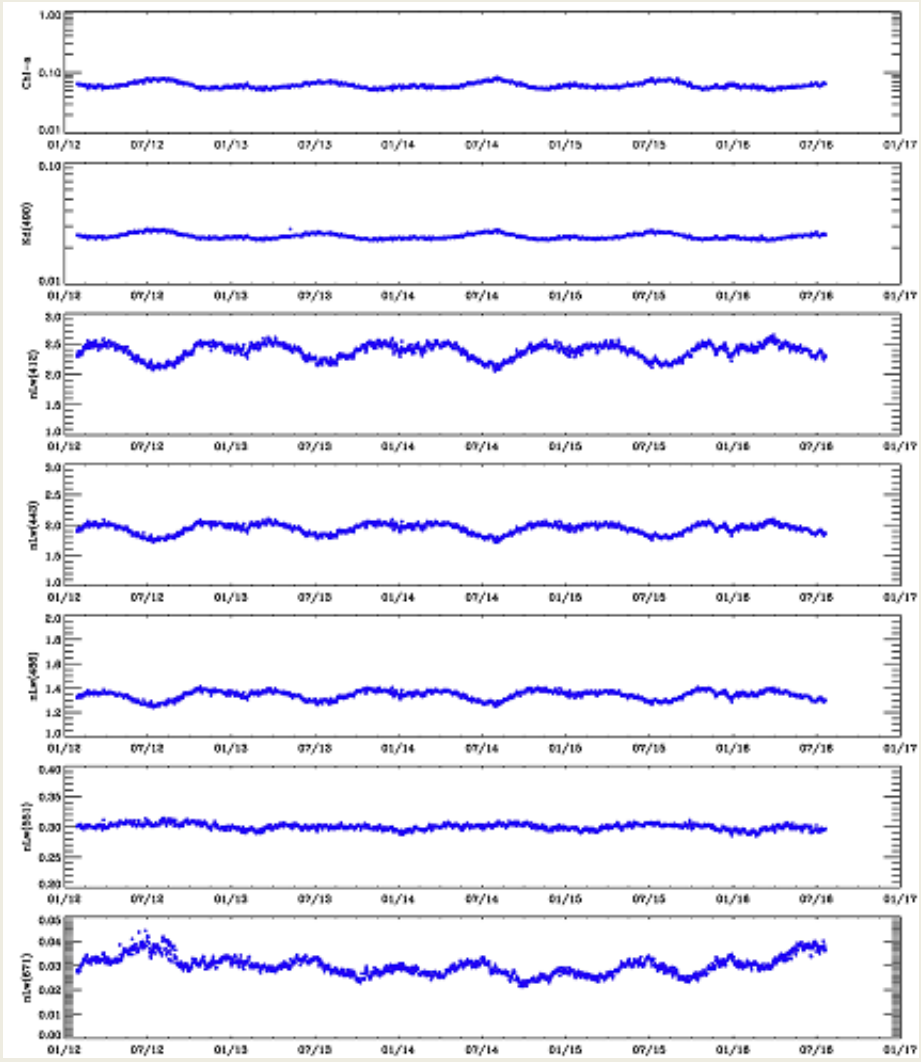



# Comparison of VIIRS NIR- and SWIR-based Ocean Color Products in Global Oligotrophic Water

VIIRS NIR Ocean Color Products

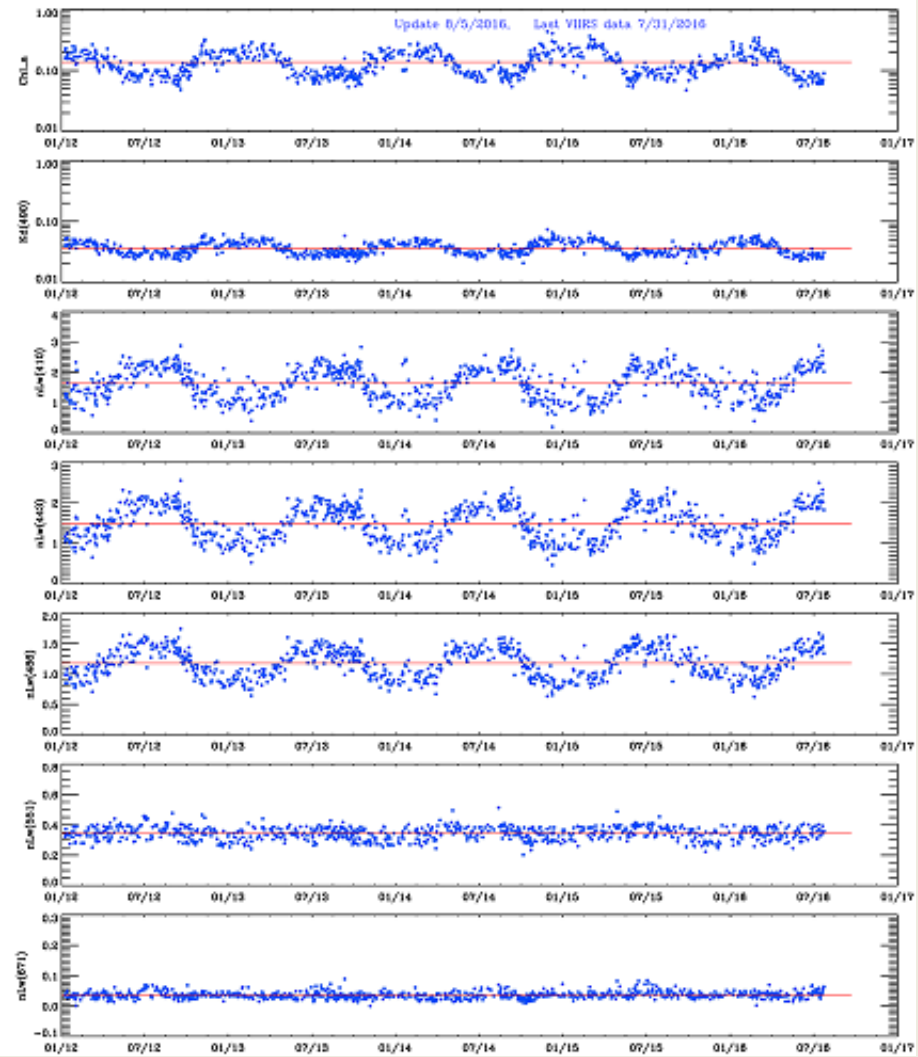


VIIRS SWIR1 Ocean Color Products

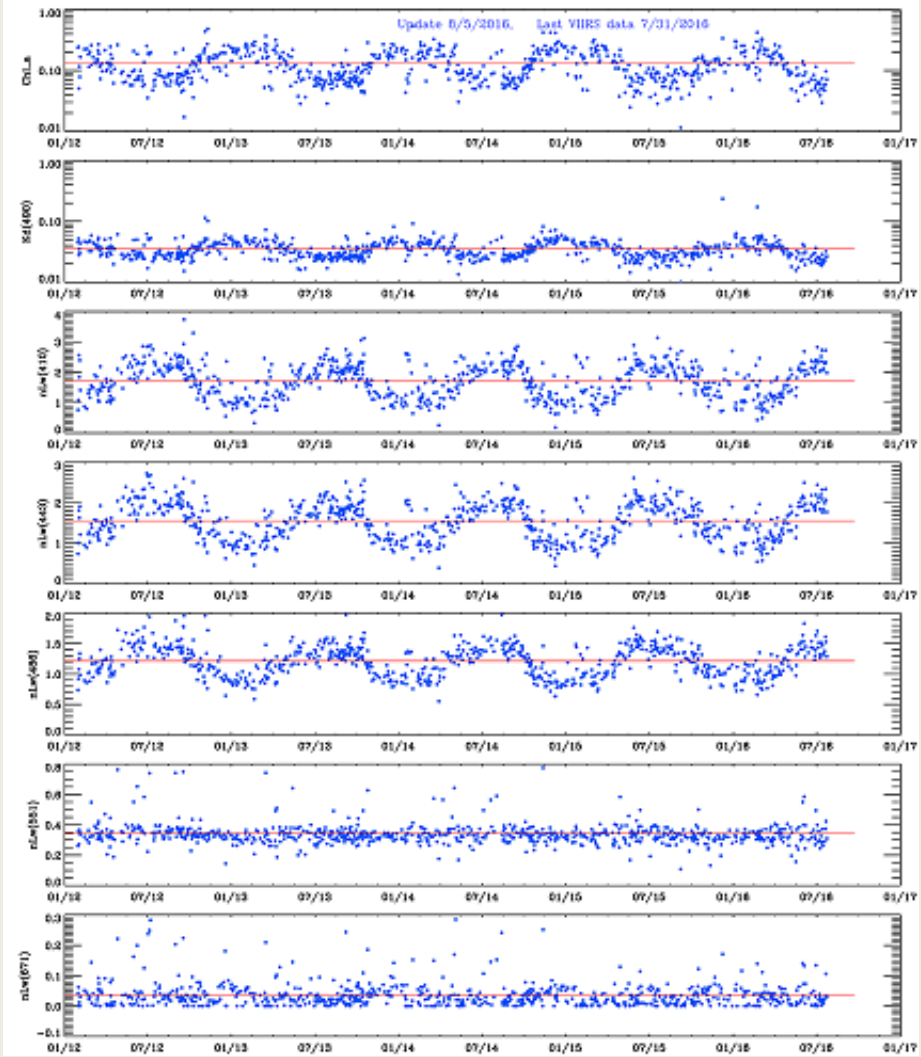


# Comparison of VIIRS NIR- and SWIR-based Ocean Color Products in the US East Coast

VIIRS NIR Ocean Color Product




VIIRS SWIR Ocean Color Product



# Summary

- Vicarious calibrations with high accurate in situ observations (e.g., MOBY) are indispensible for satellite ocean color data processing.
- We developed a strategy to vicariously calibrate VIIRS-SNPP observations for both the NIR- and SWIR-based ocean color data processing, including the NIR-SWIR combined approach.
- Vicarious calibration gains for VIIRS spectral bands are derived using the in-situ normalized water-leaving radiance $nL_w(\lambda)$ spectra from the MOBY in the waters off Hawaii.
- The NIR-based vicarious calibration gains are consistent with those from the two SWIR-based approaches, with discrepancies mostly within ~0.05% from three data processing methods.
- A unified vicarious gain set for VIIRS bands M1–M8 and M10–M11, has been implemented in the VIIRS ocean color data processing for routine ocean color production.
- Using the unified vicarious gain set, VIIRS mission-long ocean color data have been successfully reprocessed using the NIR, SWIR, and NIR-SWIR approaches in May 2016. The science quality data streams have been going forward since then.

# VIIRS-derived Chlorophyll-a using the Ocean Color Index method

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[2]CIRA/Colorado State Univ., Fort Collins, CO, USA

STAR JPSS 2016 Annual Science Meeting, College Park, MD, USA
August 10, 2016

**Acknowledgements:** This work was supported by **JPSS** and NOAA Ocean Remote Sensing (**ORS**) funding.

# INTRODUCTION

- For satellite ocean color remote sensing, phytoplankton chlorophyll-a (Chl-a) concentrations are generally measured using empirical regressions of spectral ratios of normalized water-leaving reflectances (or remote sensing reflectances).
- Widely used Chl-a algorithm for the ocean color satellite sensors such as SeaWiFS, MODIS, & VIIRS is based on the ocean chlorophyll-type (OCx) (*O'Reilly et al.*, 1998) (e.g., OC3V for VIIRS).
- The band ratio-based Chl-a algorithm can have considerable noise errors for oligotrophic waters (Hu et al., 2012). A new Chl-a algorithm based on the color index (CI) has been developed (Hu et al., 2012).
- The CI-based Chl-a algorithm can improve VIIRS Chl-a data over oligotrophic waters with much reduced data noise from instrument calibration and the imperfect atmospheric correction.
- However, the CI-based Chl-a algorithm is only applicable for low Chl-a concentration (< ~0.3 mg $m^{-3}$). A merging method between CI-based and OCx Chl-a algorithms has been proposed based on Chl-a concentration.
- All coefficient related to the CI-based Chl-a algorithm need to be re-derived for VIIRS spectral bands.
- It is noticed that there are obvious discontinuities for VIIRS Chl-a data in the Chl-a transition between the two algorithms.

# OBJECTIVES

- To Evaluate Performance of the original OCI-derived Chl-a products from VIIRS measurements with comparison of the VIIRS OC3V-derived Chl-a products for the global ocean.

- To Improve the CI-based Chl-a algorithm for VIIRS spectral bands and to be overall consistent with the OC3V-derived Chl-a data.

- To develop a new merging method for the two Chl-a algorithms between CI-based and OC3V algorithms.

- To Implement the newly improved OCI-based Chl-a algorithm to the VIIRS ocean color products.

# MOBY In Situ Measurements

- In situ hyperspectral radiometeric measurements at the MOBY site moored off the island of Lanai in Hawaii (*Clark et al.*, 1997) were used.
- VIIRS spectral-band-weighted MOBY in situ normalized water-leaving radiance, $nL_w(\lambda)$, data at 410, 443, 486, 551, and 671 nm are obtained from the NOAA CoastWatch website (http://coastwatch.noaa.gov/moby/).
- MOBY-derived Chl-a data using the CI-based and OC3V-based Chl-a algorithms were compared with VIIRS-derived Chl-a data to evaluate performance of the CI-based Chl-a algorithm.

# Satellite Ocean Color Data

- NOAA Multi-Sensor Level-1 to Level-2 (MSL12) ocean color data processing system has been used for processing satellite ocean color data from Level-1B to Level-2.
- **Science Quality VIIRS ocean color product data** were generated using NOAA-MSL12. VIIRS ocean color Environmental Data Records (EDR) (or Level-2) were processed from the improved Sensor Data Records (SDR) (or Level-1B) (*Sun & Wang*, 2015).
- The VIIRS EDR data were derived using the NIR-SWIR combined atmospheric correction algorithm.
- VIIRS ocean color Level-3 data products for the global ocean were processed from the VIIRS-derived Level-2 products with a spatial resolution of 9 km.
- Matchups of VIIRS and in situ Chl-a data were developed using pixels with a $5 \times 5$ box centered at the location of in situ measurements following the procedure of *Wang et al.* (2009).

# OCx Based Chl-a Algorithm

- **OC3V** Chl-a algorithm for **VIIRS**

$$\text{Chl-a} = 10^{\wedge}[a_0 + a_1 \cdot \boldsymbol{R} + a_2 \cdot \boldsymbol{R}^2 + a_3 \cdot \boldsymbol{R}^3 + a_4 \cdot \boldsymbol{R}^4]$$

where $\boldsymbol{R} = Log_{10}\{ \text{Max}[R_{rs}(443), R_{rs}(486)] / R_{rs}(551) \}$

$a = [0.2228, -2.4683, 1.5867, -0.4275, -0.7768]$

# Color Index based Chl-a Algorithm

- Color Index based Chl-a algorithm (*Hu et al.*, 2012):

$$CI = R_{rs}(555) - [R_{rs}(443)+(B_2-B_1)/(B_3-B_1)(R_{rs}(670)-R_{rs}(443)]$$

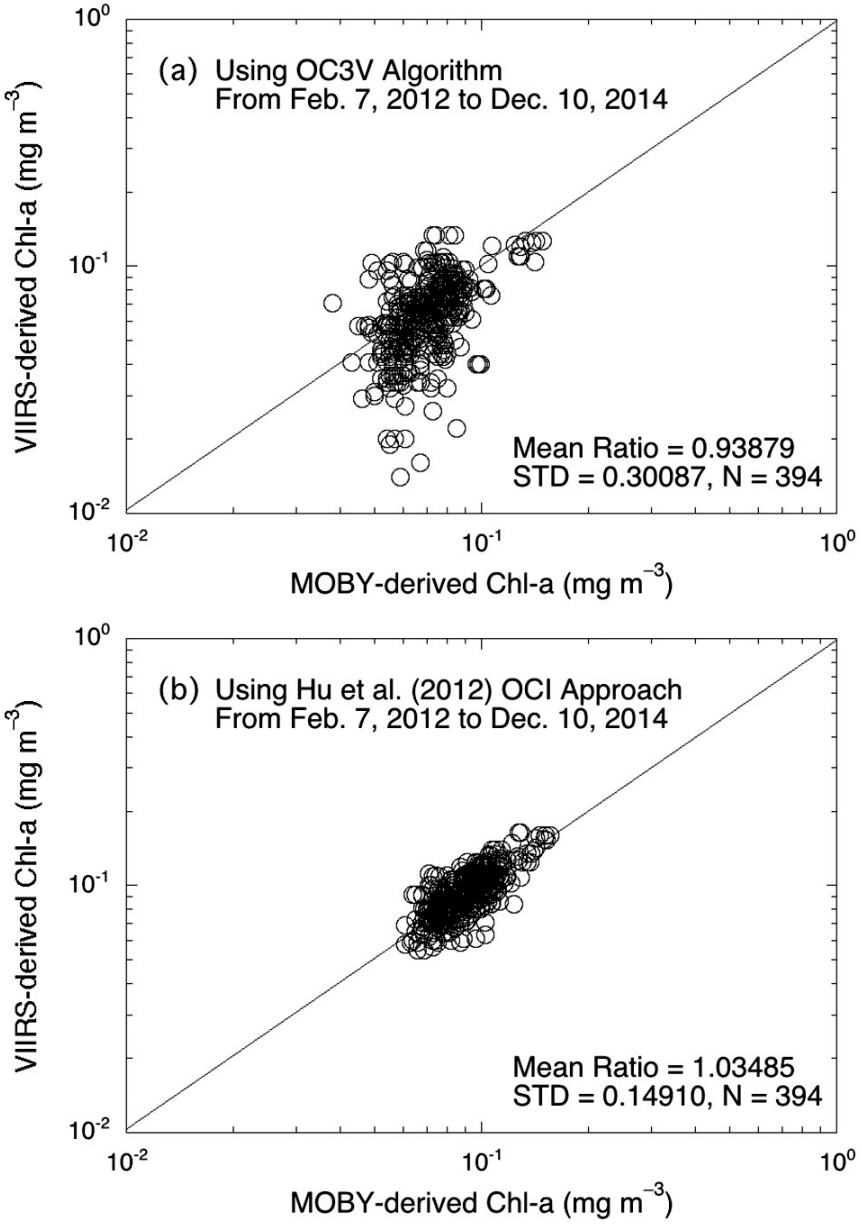
where $B_1=443$, $B_2=555$, $B_3=670$

$$Chl_{CI} = 10^{[191.6590 \cdot CI - 0.4909]} \qquad (CI \leq -0.0005\ sr^{-1})$$

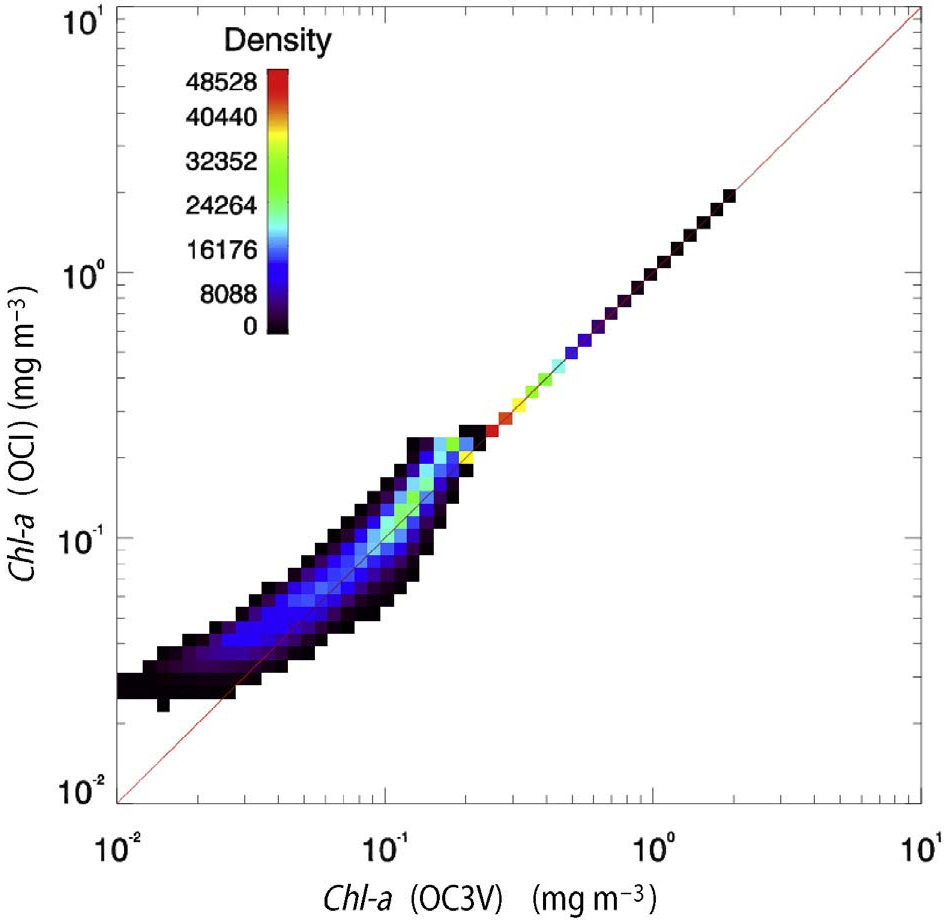
$$Chl_{OCI} = \begin{cases} Chl_{CI} & (CHL_{CI} \leq 0.25\ mg\ m^{-3}) \\ Chl_{OC4} & (CHL_{CI} > 0.30\ mg\ m^{-3}) \\ \alpha \times Chl_{OC4} + \beta \times Chl_{CI} & (0.25\ mg\ m^{-3} < CHL_{CI} \leq 0.30\ mg\ m^{-3}) \end{cases}$$

where $\alpha=(Chl_{CI}-0.25)/(0.3-0.25)$ and $\beta=(0.3- Chl_{CI})/(0.3-0.25)$

# VIIR-derived Chl-a data compared with those derived from the in situ MOBY data



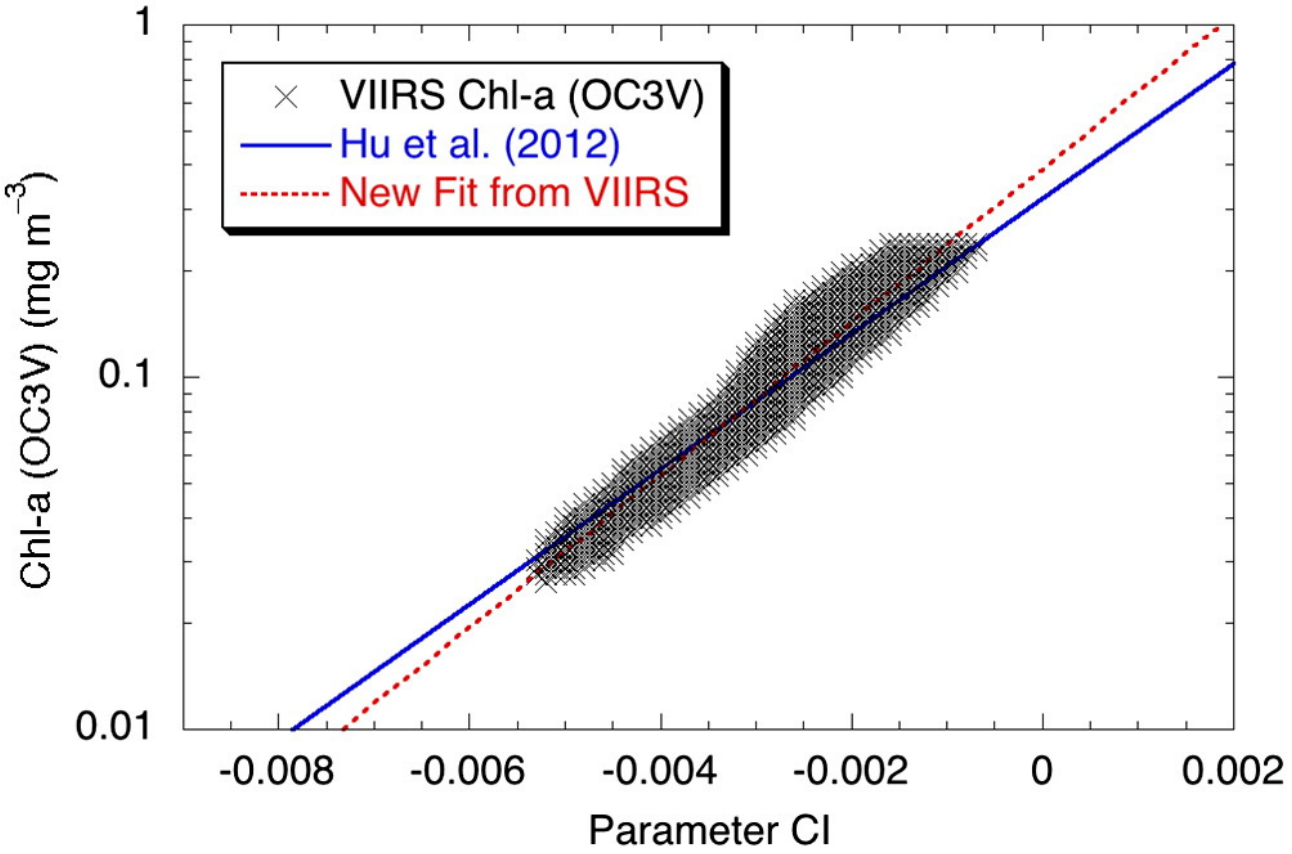
# Density Scatter plot for VIIRS-derived Chl-a using OC3V and OCI Chl-a algorithms




-. Global (binned) VIIRS Level-3 daily data on March 29, 2015

-. Only pixels with water depths > 1 km are used

Scatter plot for VIIRS-derived Chl-a with OC3V vs CI values




-. All the data in the plot were extracted from the density plot that requires density > 5000 pixels.

# New OCI Chl-a Algorithm

- **New OCI Chl-a algorithm for VIIRS ocean color data:**

$$CI = R_{rs}(551) - [R_{rs}(443)+(B_2-B_1)/(B_3-B_1)(R_{rs}(671)-R_{rs}(443)]$$

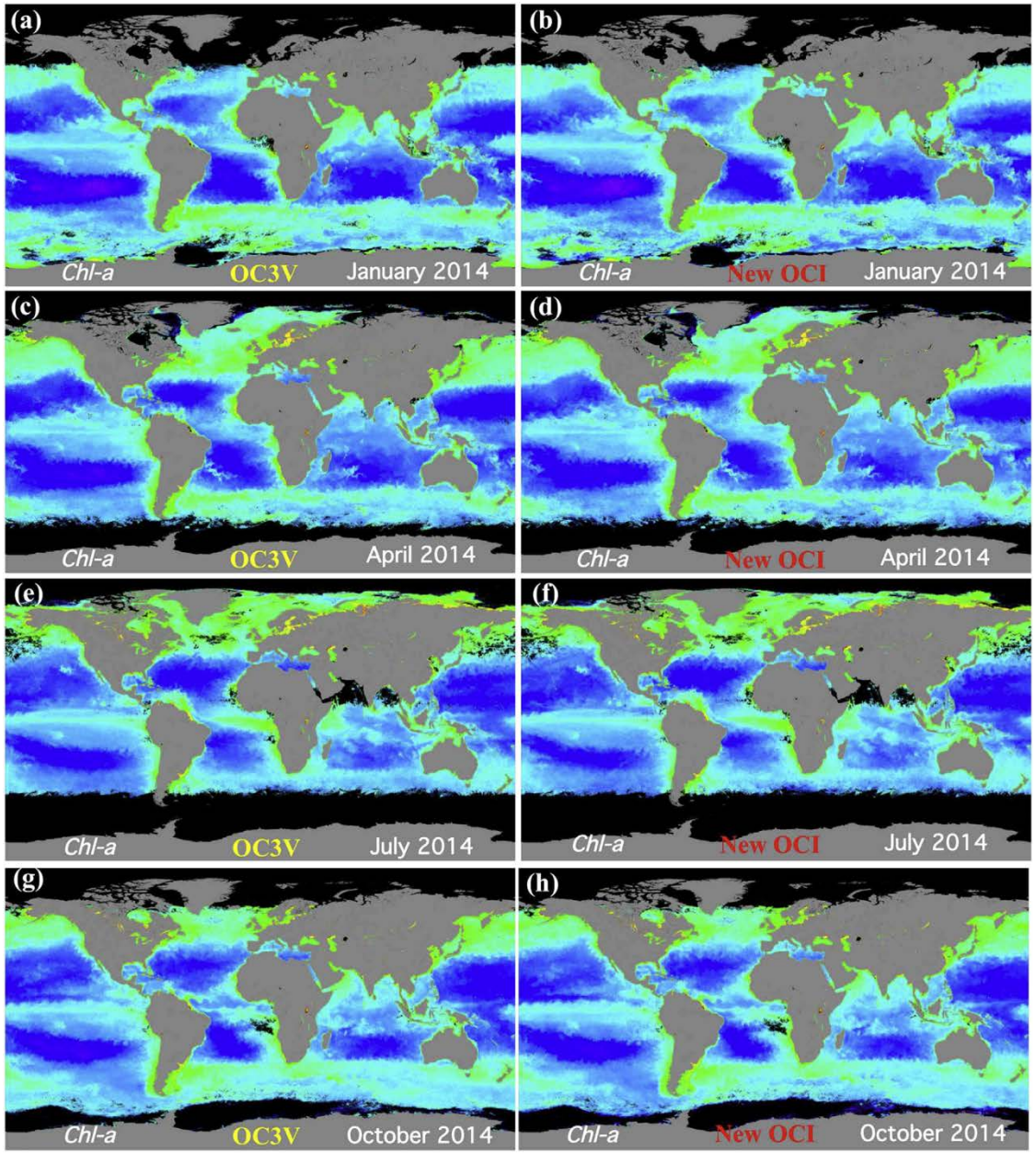
where $B_1=443$, $B_2=551$, $B_3=671$

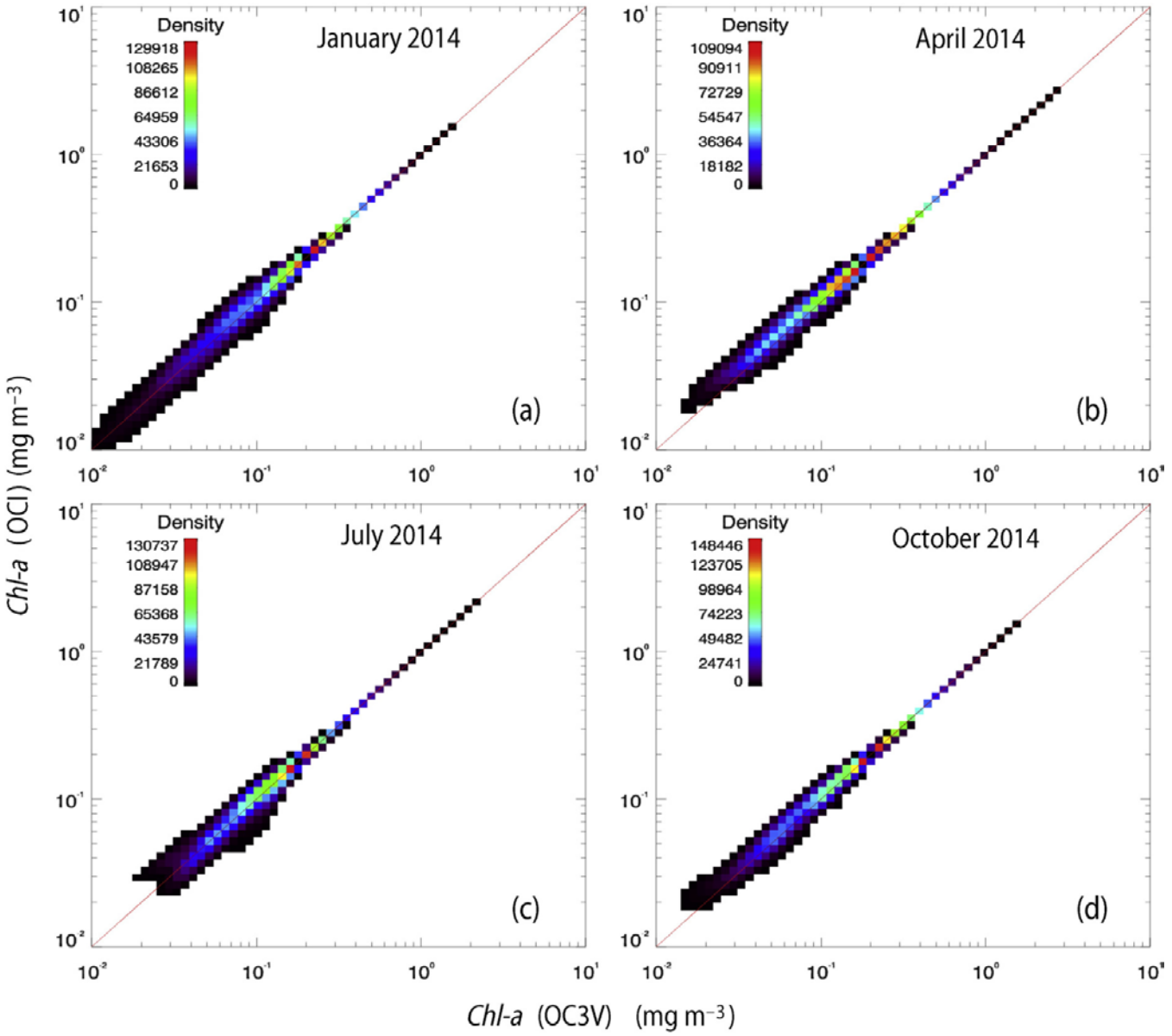
$$Chl_{CI} = 10\text{^}[216.76 \cdot CI - 0.4093]$$

$$Chl_{OCI} = \begin{cases} Chl_{OC3V} & (R \le 2.0) \\ Chl_{OC3V} & (R > 4.0) \\ w \times Chl_{CI} + (1-w) \times Chl_{OC3V} & (2.0 < R \le 4.0) \end{cases}$$

where $R=R_{rs}(443)/R_{rs}(551)$ & $w=(R-2.0)/(4.0-2.0)$

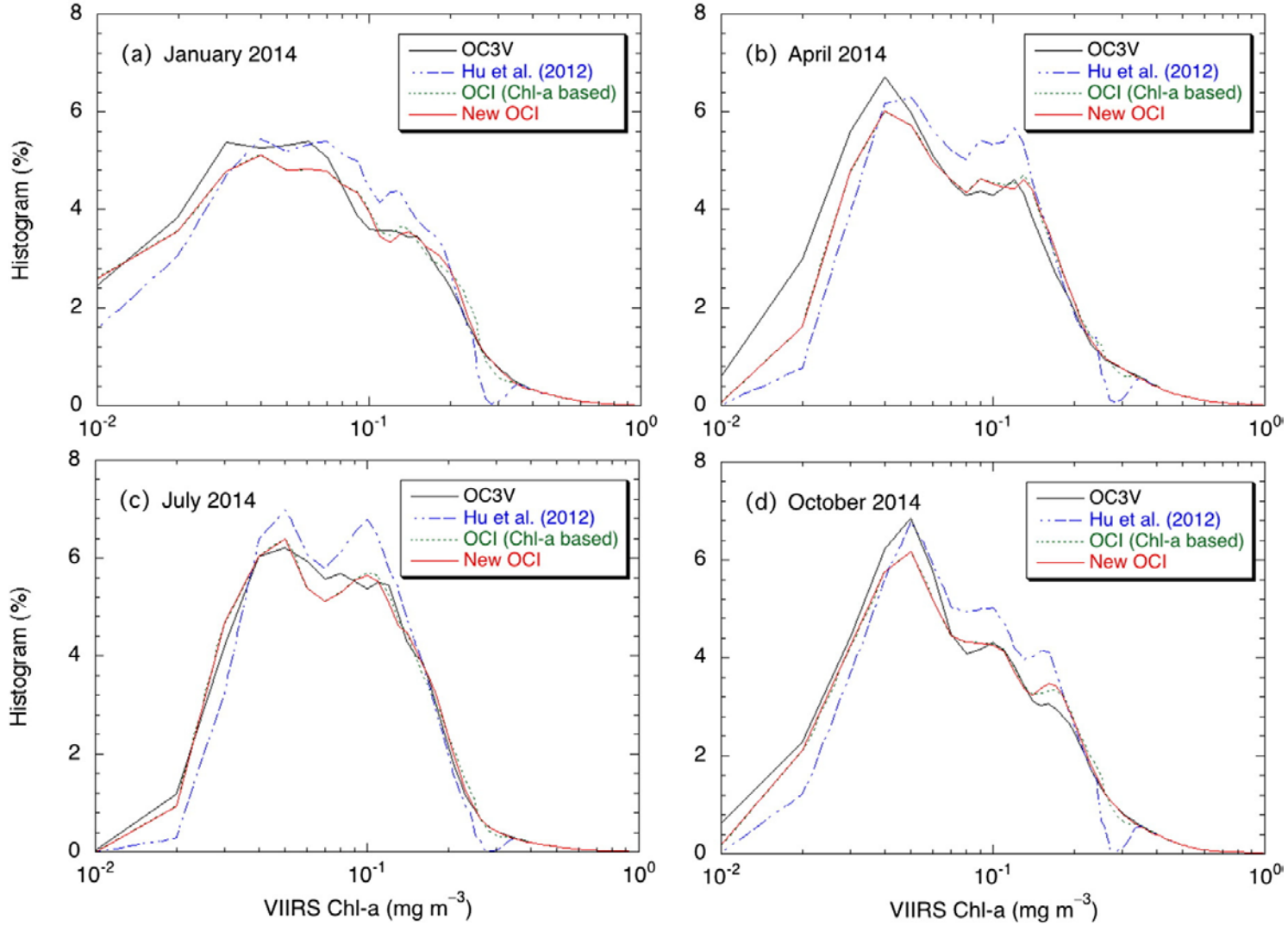
# VIIRS-derived global Chl-a monthly composite images



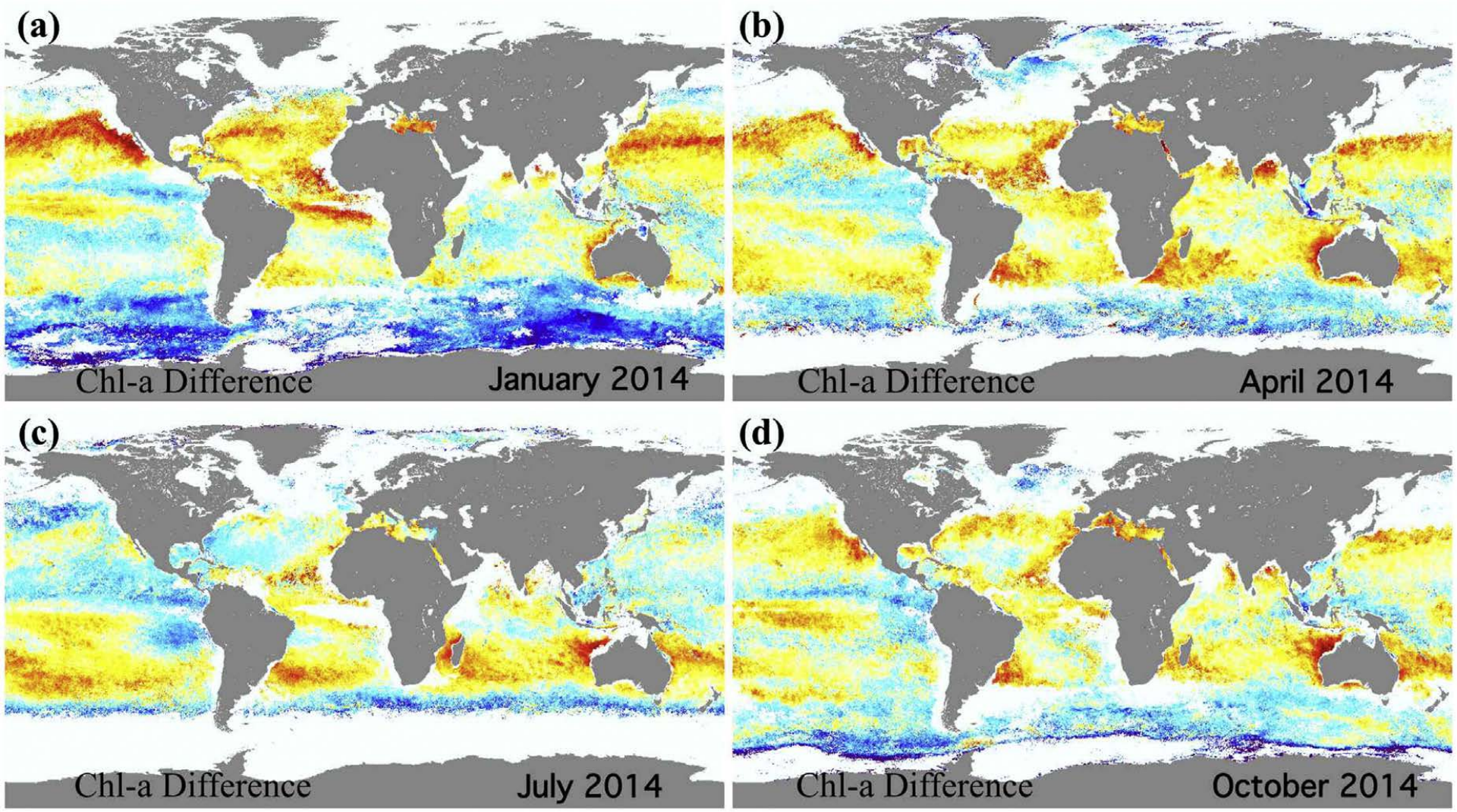



Density scatter plots of global VIIRS Level-3 monthly composite Chl-a images

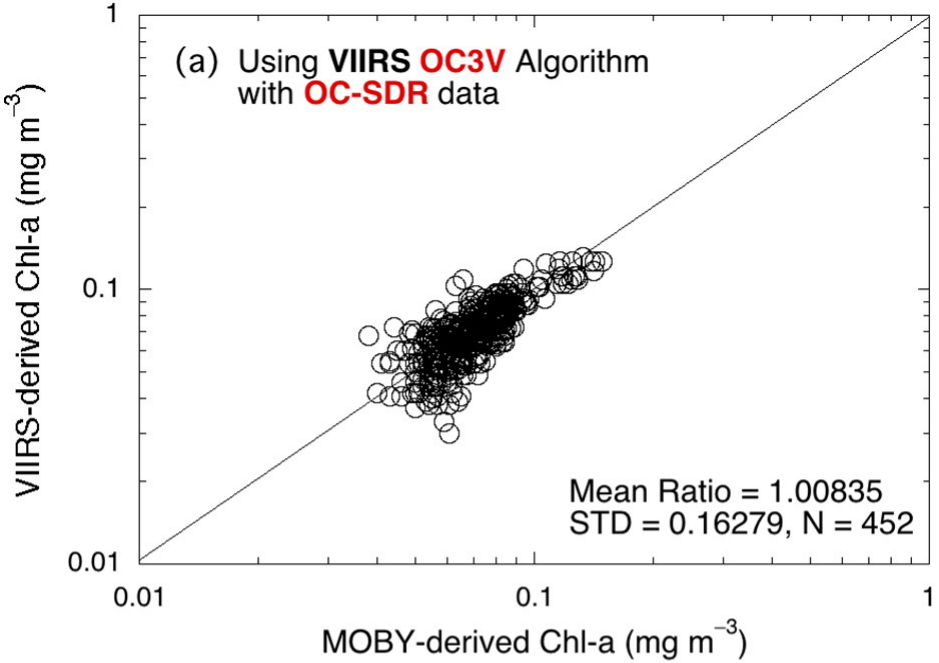
# Histogram plots of VIIRS global Level-3 monthly composite Chl-a data

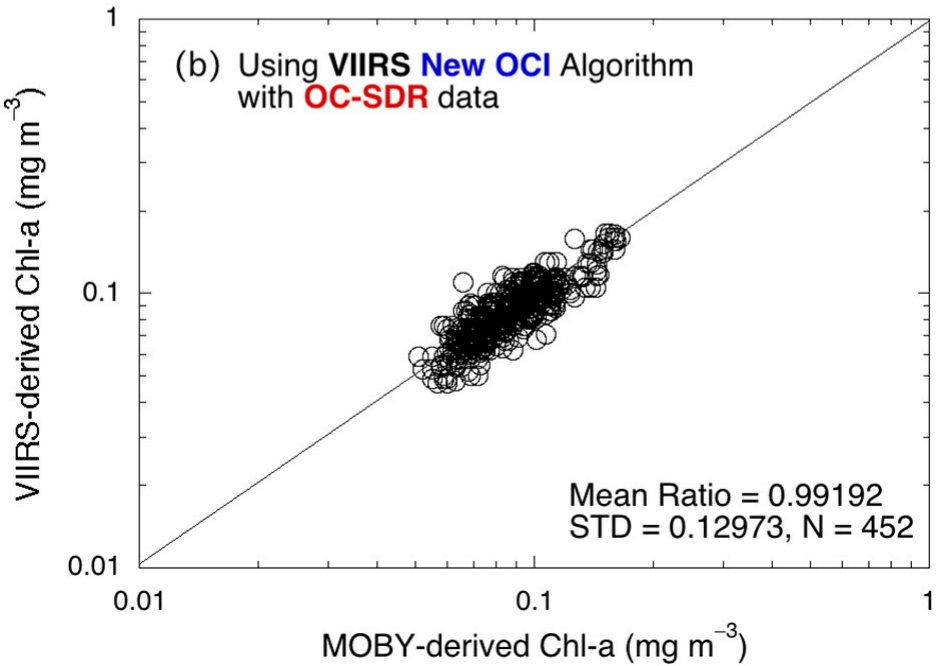


# Global images of Chl-a difference between new OCI and OC3V Chl-a data



# VIIR-derived Chl-a data compared with those derived from the in situ MOBY data



# Conclusions

- An implementation approach using the ocean color index (OCI)-based chlorophyll-a (Chl-a) algorithm for the VIIRS has been developed.
- The CI-based Chl-a algorithm can improve VIIRS Chl-a data over oligotrophic waters with much reduced data noise from instrument calibration and the imperfect atmospheric correction.
- We developed CI-based algorithm specifically for VIIRS and further improved the two Chl-a algorithm merging method using the blue-green reflectance ratio values.
- New OCI Chl-a algorithm for VIIRS can produce consistent Chl-a data compared with those from the OC3V algorithm.
- In particular, the data transition between CI-based and OC3V-based Chl-a algorithms is quite smooth and there are no obvious discontinuities in VIIRS-derived Chl-a data.
- New OCI-based Chl-a algorithm has been implemented in the MSL12 for routine production of VIIRS global Chl-a data.
- A paper has just been published:

Wang, M. and S. Son, "VIIRS-derived chlorophyll-a using the ocean color index method," *Remote Sens. Environ.*, **182**, 141–149, 2016.

# Thank you!

# NOAA Okeanos Ocean Color System Development Update in Support to SNPP-VIIRS Products Processing

**Dr. Banghua Yan**

**NOAA Ocean Color Operational Product Area Lead**

**NOAA/NESDIS/OSPO/SPSD/Satellite Products Branch**

# OUTLINE

- Current Okeanos Ocean Color Operational Production System (OPS)
- New Okeanos Ocean Color System Development for VIIRS OC Products
- SNPP-VIIRS MSL12 OC Products Processing Update from New Okeanos

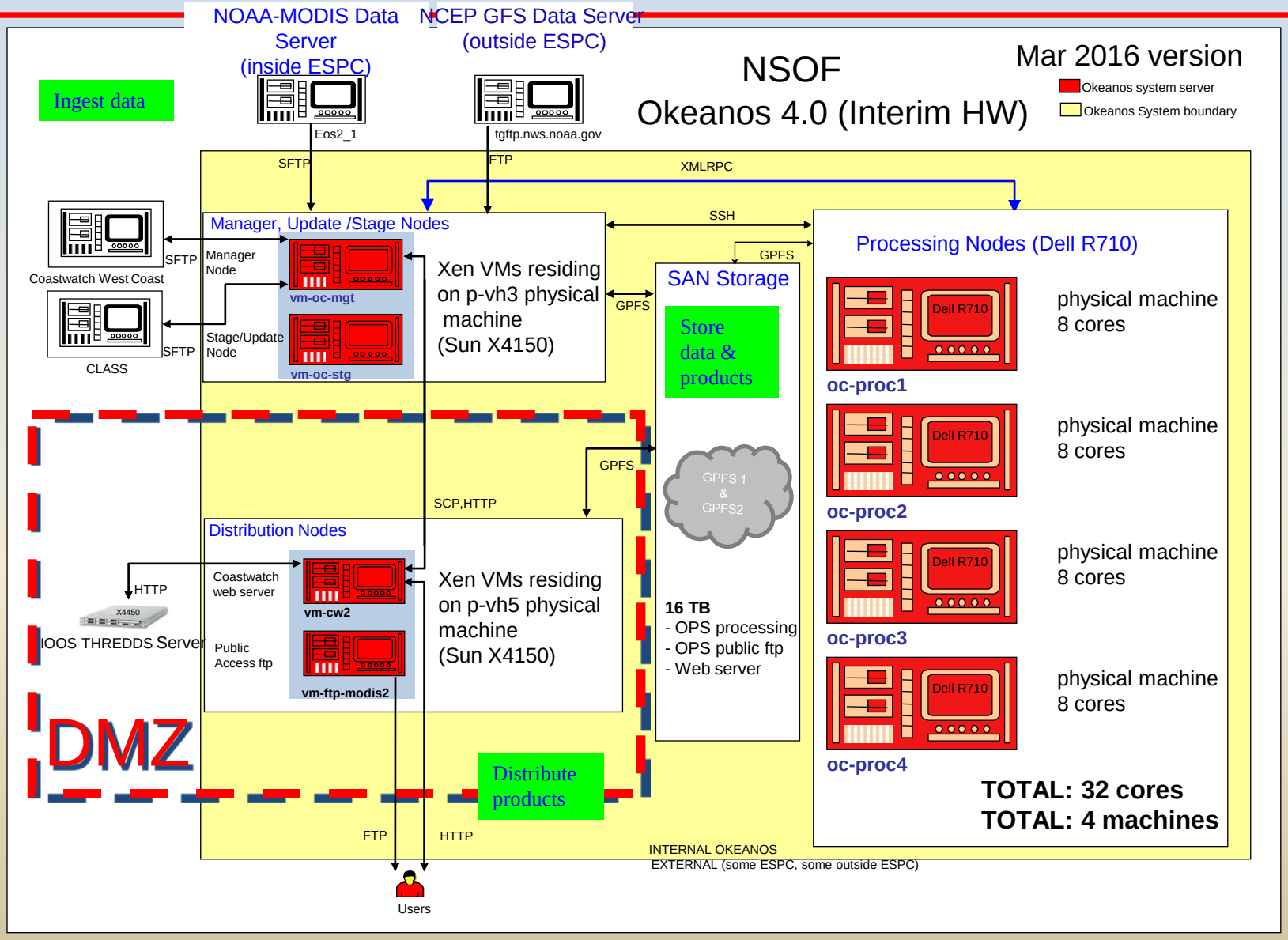
# OSPO Ocean Color Products Team

- Lead: Banghua Yan and Antonio Irving
- Members:
  - **Okeanos System Design and Maintenance**: Ian Simpson (primary), Dan Jacob, and Edmond Rodriguez
  - **Okeanos System Building and Configuration**: Okechukwu Nwosu (primary), Ian Simpson, Dewayne Countiss, Michael O Johnson, and Ed Ladd
  - **Okeanos QA Monitoring Tool Development**: Fengying Sun (primary), Dan Jacob, XiaoChuan Huang, and Shen Zhao

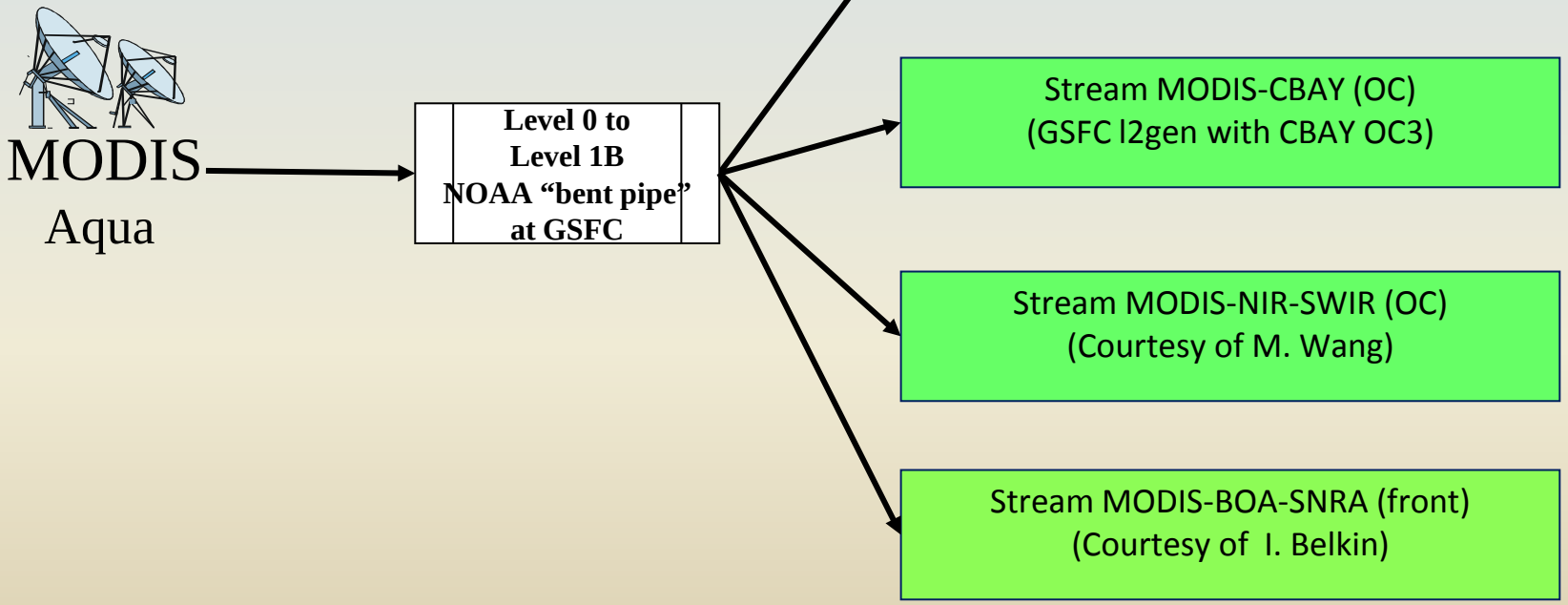
# Okeanos Ocean Color System Concept

- The Okeanos system is a flexible, expandable linux-based system capable of processing multiple satellite streams of ocean color products.
- CoastWatch Automatic Processing Software (CWAPS) (developed by STAR CoastWatch team)
  - File Ingest module
  - CWAPS module
  - Process Manager and Control Module
  - Disk Space Control Module
  - Merge Module
  - Publication Module I (ftp distribution)
  - Publication Module II

# Current Okeanos OPS: IT Architecture



# MODIS/Aqua Ocean Color Product Processing Streams



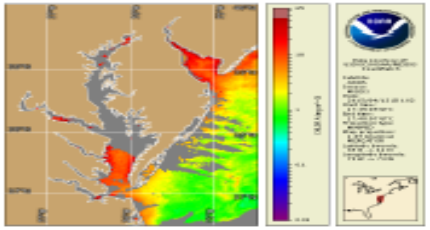

(Courtesy of Phillip Keegstra)

# Operational Ocean Color Products from MODIS/Aqua

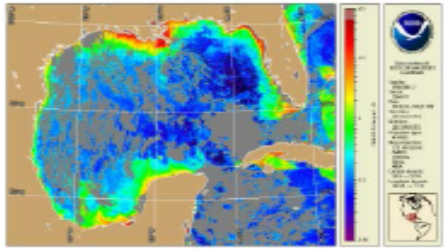
## ❑ NOAA Okeanos Ocean Color Operational Products

- ➢ **Satellites**: Moderate Resolution Imaging Spectroradiometer (MODIS)
- ➢ **Instruments**: AQUA (Primary) and TERRA (Backup)
- ➢ **Product Specifications**
  - **Products**: daily merged chlorophyll concentration (Chl-a) and remote sensing reflectance (Rrs667) ; bi-monthly (monthly) mean Chl-a and Rrs667; daily anomaly of Chl-a and Rrs667; daily Chl-a fronts and $K_d490$
  - **Format:** GeoTiff, PNG, NetCDF4
  - **Coverage**: Northeast (NE), Southeast (SE), Gulf of Mexico (GOM), Caribbean (CB), West Coast (WC), Alaska (AK), East Tropical Pacific (EP), Great Lakes (GL), Hawaii (HI), Equatorial Atlantic (EA), North Atlantic (NA) and Pacific Basin (PB), Chesapeake Bay (CY)
  - **Format**: HDF 4.1, GeoTiff, PNG, netCDF
  - **Horizontal Resolution**: 1 km
  - **Timeliness**: 12 hours
  - **Algorithms**: NASA NIR (SCW), NOAA NIR-SWIR (WCW), and Chlorophyll Frontal Algorithms (BOA)
- ➢ **Data Access:** ftp://cw-okeanos.noaa.gov/pub/modis/

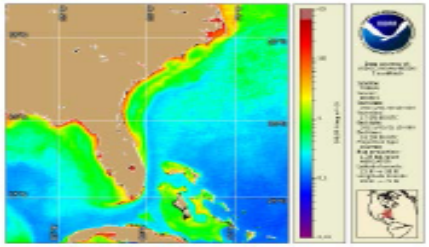
Examples of products are shown in **Figures** 2(a) -(f).



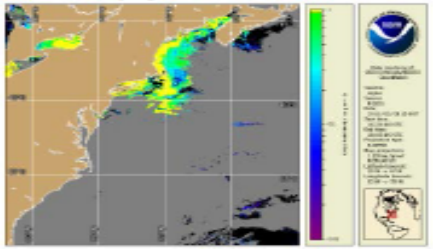
2(c) Chesapeake Bay Daily Chlorophyll Concentration



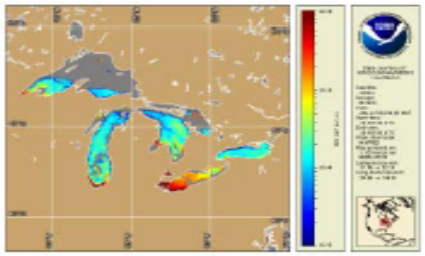
2(a) Daily Chlorophyll Concentration



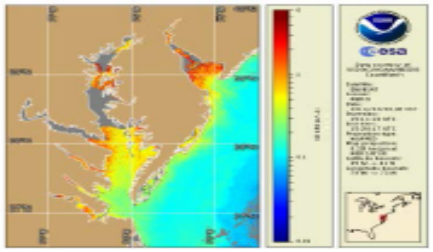
2(b) Bimonthly-mean Chlorophyll Concentration



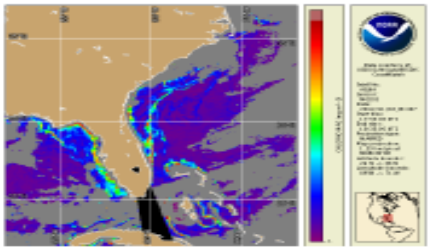
2(d) New algal growth (Positive Chlorophyll Concentration Anomaly)



2(e) Suspended Sediment Proxy (Remote Sensing Reflectance at 667 nm)



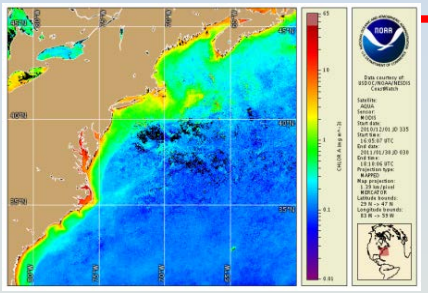
2(f) Water Turbidity(Diffuse Attenuation Coefficient at 490 nm)



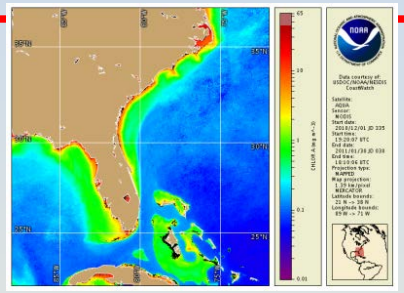
2(g) Chlorophyll Front (Magnitude)

# MODIS/Aqua OC Product Coverage

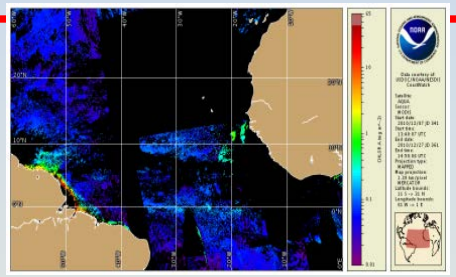
**Northeast**



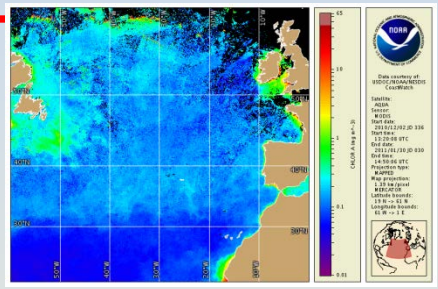
**Southeast**



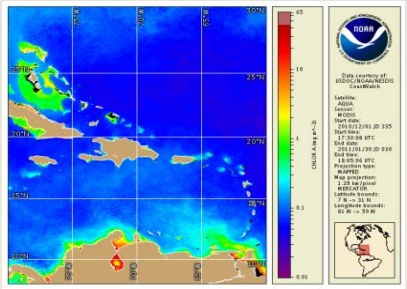
**Equatorial Atlantic**



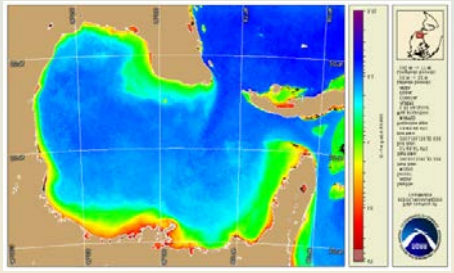
**North Atlantic**



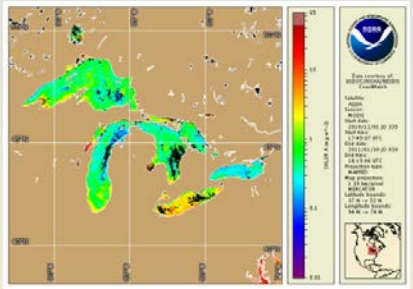
**Caribbean**



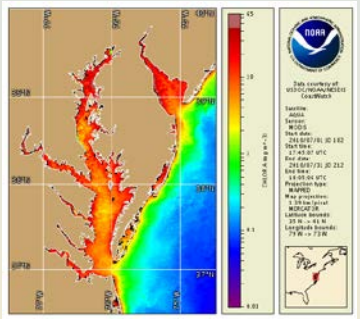
**Gulf of Mexico**



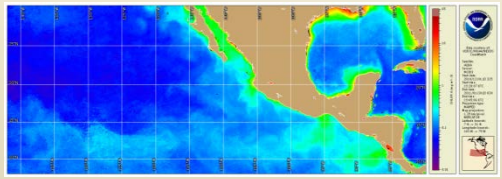
**Great Lakes**



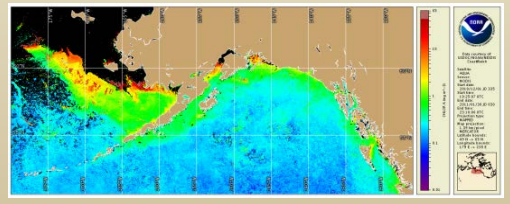
**Chesapeake Bay**



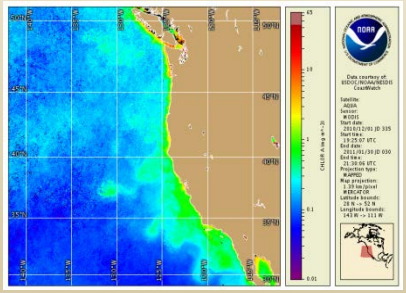
**Eastern Tropical Pacific**



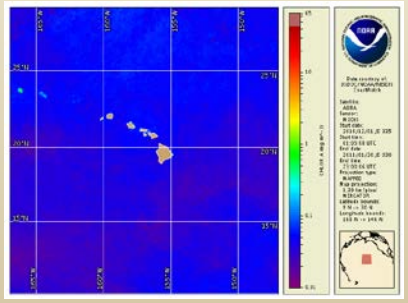
**Alaska**



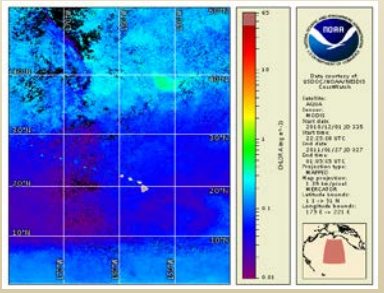
**West Coast**



**Hawaii**

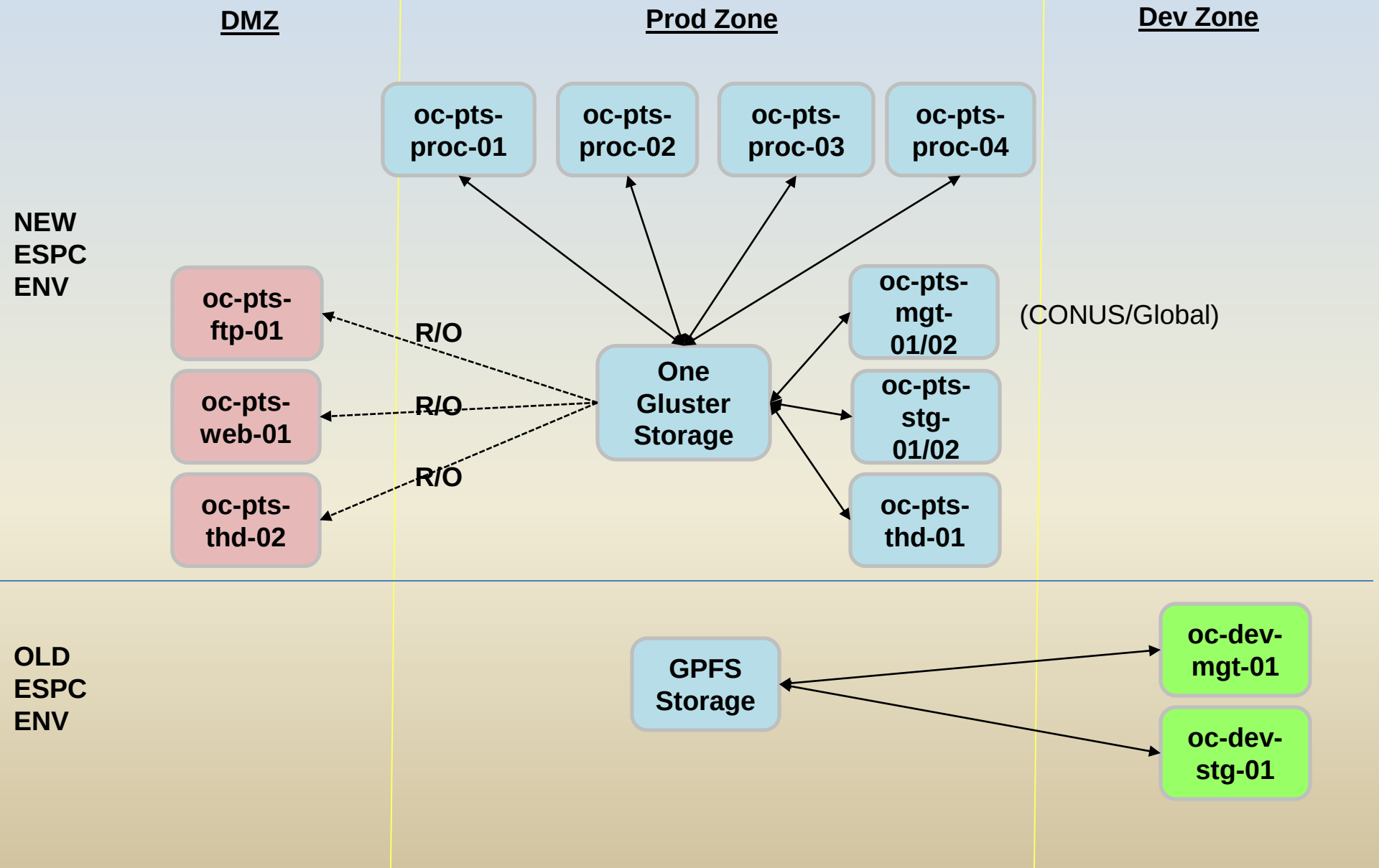


**Pacific Basin**

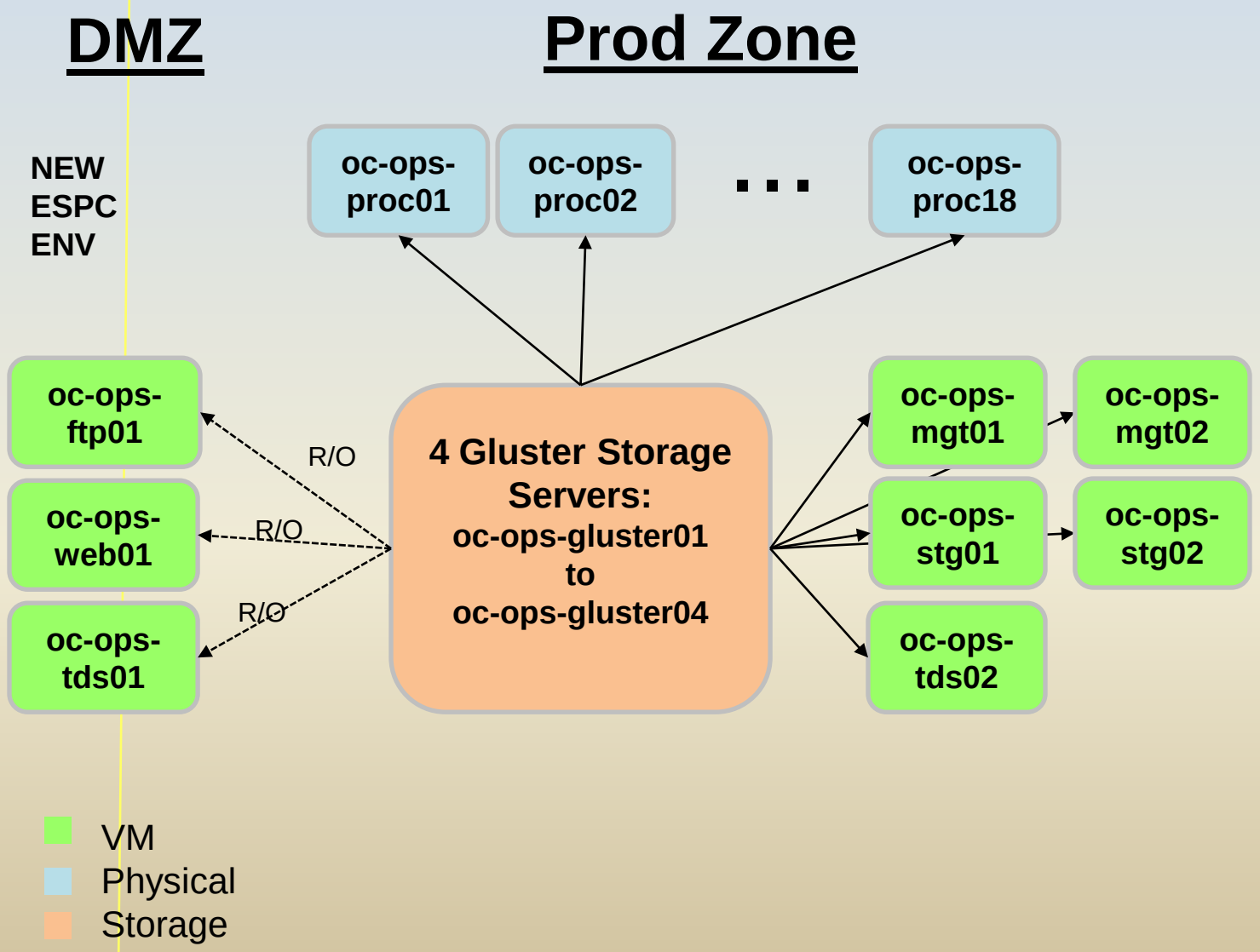


# Development of New Okeanos Parallel Test System (PTS) and Operational Production System (OPS) in Support to SNPP-VIIRS Ocean Color Products Processing

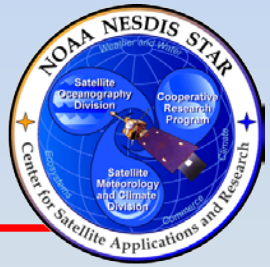
# New Okeanos PTS in Support to SNPP-VIIRS OC Products Processing: IT Architecture



# New Okeanos OPS in Support to SNPP-VIIRS OC Products Processing: IT Architecture



# New OKEANOS Systems Integrated into the ESPC Environment




## ESPC Physical Operating Environment

**10 CHOPS Processing HW Systems**

- For distributed batch tasks
- Jobs allocated via Tidal & Condor scheduler

N **Okeanos Processor Node HW Systems**

- New PTS: N= 4 processors
- New OPS: N= 18 processors

1 2 . . . 10 + 1 2 . . . N

## ESPC VMware Operating Environment

**5 Vmware HW Systems:**

- Non-Okeanos applications
- Okeanos applications: 8 VMs
  - 2 Manager VM
  - 2 Update/Stage VM
  - 1 ftp server VM
  - 1 web server VM
  - 2 Thredds VMs

1 2 . . . 5

## ESPC Switched Network

1 2 . . . 4 + 1 2 . . . 4

**4 CHOPS + 4 Okeanos**

- NG OPS adds 4 nodes to CHOPS storage pool
- Not separate storage: allocated quota from the pool
- Increases overall CHOPS data storage throughput

## ESPC Shared Data Storage

**Benefits of New Okeanos**

- Low Cost : system development, maintenance, integration, due to more than eight years' legacy resources in Okeanos
- Fast integration and migration: early availability of NOAA ocean color NUPS
- Easy adaptation to a different satellite stream (e.g., J1/J2 VIIRS, and Sentinel-3)
- Reliable Product Assurance Monitoring Tool

# SNPP VIIRS Operational Ocean Color Products Category Briefing

- Global
  - Chlorophyll (granule, daily merge per sector, 7-day rolling merge per sector, and global 4km)
  - $K_d490$ (granule, daily merge per sector, 7-day rolling merge per sector and global 4km)
  - Kd PAR (L2 Granule, daily merge per sector, 7-day rolling merge per sector and global 4km)
  - TOA True Color (L2 granule)
- CONUS (8 CONUS regions, 750 m resolution)
  - Chlorophyll (granule, daily merge per CW region, and bimonthly mean per CW region)
  - Remote Sensing Reflectance (672 nm) (granule and daily merge per CW region)
  - TOA True Color (daily merge per CW region)
  - Chlorophyll anomaly (granule and daily merge per CW region)
  - Chlorophyll frontal products (granule and daily merge per CW region)

# Upcoming Operational S-NPP Ocean Color NOAA Unique Products: CONUS Products

| | | | | | Product Type and Number | | |
|---|---|---|---|---|---|---|---|
| **Date** | **Product Delivery Tracking Name** | **Environmental Observational Parameters** | **Satellites** | **Sensors** | **N #** | **T #** | **Comments** |
| FY16 | Ocean Color S-NPP NUPS | **True Color** | **S-NPP** | **VIIRS** | **1** | **31** | **Formats: CWHDF, PNG, NetCDF4, GeoTiff<br>Coverage areas: 8 CW Regions (CONUS)<br>Resolutions: 750 m<br>Distribution: Okeanos ftp/Thredds/CW Website** |
| FY16 | Ocean Color S-NPP NUPS | **Chlorophyl-a including Harmful Algal Bloom Products (Daily Merge, Daily Anomaly, 61-Day Merge)** | **S-NPP** | **VIIRS** | **3** | **93 (3x8x4, excluding New)** | **Formats: CWHDF, PNG, NetCDF4, GeoTiff<br>Coverage areas: 8 CW Regions (CONUS)<br>Resolutions: 750 m<br>Distribution: Okeanos ftp/Thredds/CW Website** |
| FY16 | Ocean Color S-NPP NUPS | **Chlorophyll Frontal** | **S-NPP** | **VIIRS** | **1** | **19** | **Formats: CWHDF, PNG, NetCDF4, GeoTiff<br>Coverage areas: 5 Sectors<br>( covering 9 CW regions)<br>Resolutions: 750 m<br>Distribution: Okeanos ftp/Thredds/CW Website** |
| FY16 | Ocean Color S-NPP NUPS | **K490 (7-day Merge)** | **S-NPP** | **VIIRS** | **1** | **31** | **Formats: CWHDF, PNG, NetCDF4, GeoTiff<br>Coverage areas: 8 CW Regions (CONUS)<br>Resolutions: 750 m<br>Distribution: Okeanos ftp/Thredds/CW Website** |
| FY16 | Ocean Color S-NPP NUPS | **Kpar (7-day Merge)** | **S-NPP** | **VIIRS** | **1** | **31** | **Formats: CWHDF, PNG, NetCDF4, GeoTiff<br>Coverage areas: 8 CW Regions (CONUS)<br>Resolutions: 750 m<br>Distribution: Okeanos ftp/Thredds/CW Website** |
| FY16 | Ocean Color S-NPP NUPS | **Rrs672 nm (Daily Merge , Anomaly and 61-Day Merge)** | **S-NPP** | **VIIRS** | **3** | **93 (3x8x4, excluding New)** | **Formats: CWHDF, PNG, NetCDF4, GeoTiff<br>Coverage areas: 8 CW Regions (CONUS)<br>Resolutions: 750 m<br>Distribution: Okeanos ftp/Thredds/CW Website** |

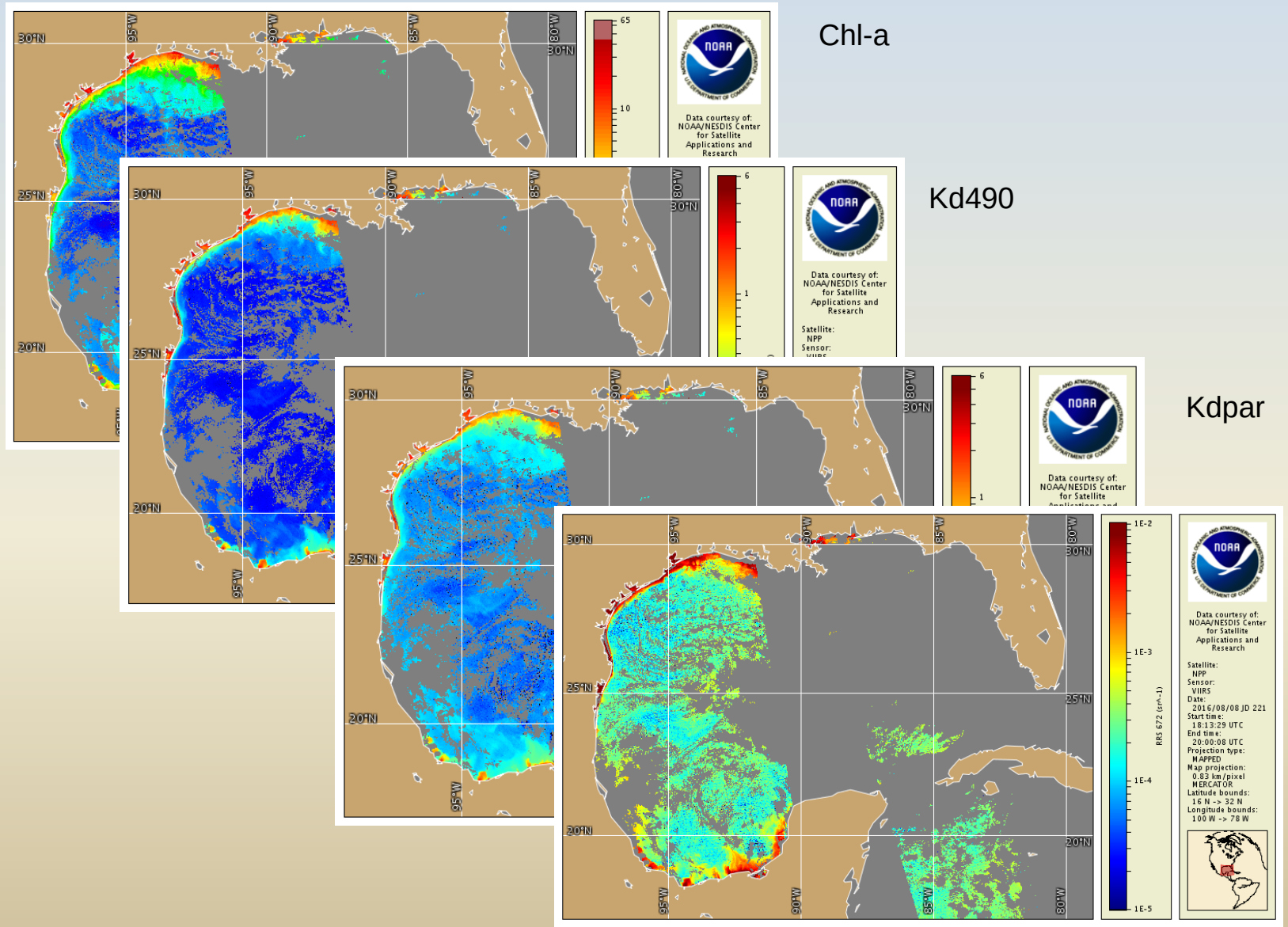
# Upcoming Operational S-NPP Ocean Color NOAA Unique Products: Global Products

| | | | | | Product Type and Number | | |
|---|---|---|---|---|---|---|---|
| Date | Product Delivery Tracking Name | Environmental Observational Parameters | Satellites | Sensors | N # | T # | Comments |
| FY16 | Ocean Color S-NPP NUPS | Chlorophyl-a (7-Day Merge, True Month) | S-NPP | VIIRS | 2 | 198 | Formats: CWHDF, PNG, NetCDF4, GeoTiff<br>Coverage areas 1 global and 24 sectors<br>Resolutions: 4km (global) and 750 m (sector)<br>Distribution: Okeanos ftp/Thredds/CW Website |
| FY16 | Ocean Color S-NPP NUPS | K490 (Daily Merge) | S-NPP | VIIRS | 1 | 99 | Formats: CWHDF, PNG, NetCDF4, GeoTiff<br>Coverage areas 1 global and 24 sectors<br>Resolutions: 4km (global) and 750 m (sector)<br>Distribution: Okeanos ftp/Thredds/CW Website |
| FY16 | Ocean Color S-NPP NUPS | Kpar (Daily Merge) | S-NPP | VIIRS | 1 | 99 | Formats: CWHDF, PNG, NetCDF4, GeoTiff<br>Coverage areas 1 global and 24 sectors<br>Resolutions: 4km (global) and 750 m (sector)<br>Distribution: Okeanos ftp/Thredds/CW Website |
| FY16 | Ocean Color S-NPP NUPS | nLwns (412, 445, 488, 555, and 672 nm; 7-day Merge) | S-NPP | VIIRS | 5 | 495 (25x5x4) | Formats: CWHDF, PNG, NetCDF4, GeoTiff<br>Coverage areas 1 global and 24 sectors<br>Resolutions: 4km (global) and 750 m (sector)<br>Distribution: Okeanos ftp/Thredds/CW Website |

# Where Are We Now?

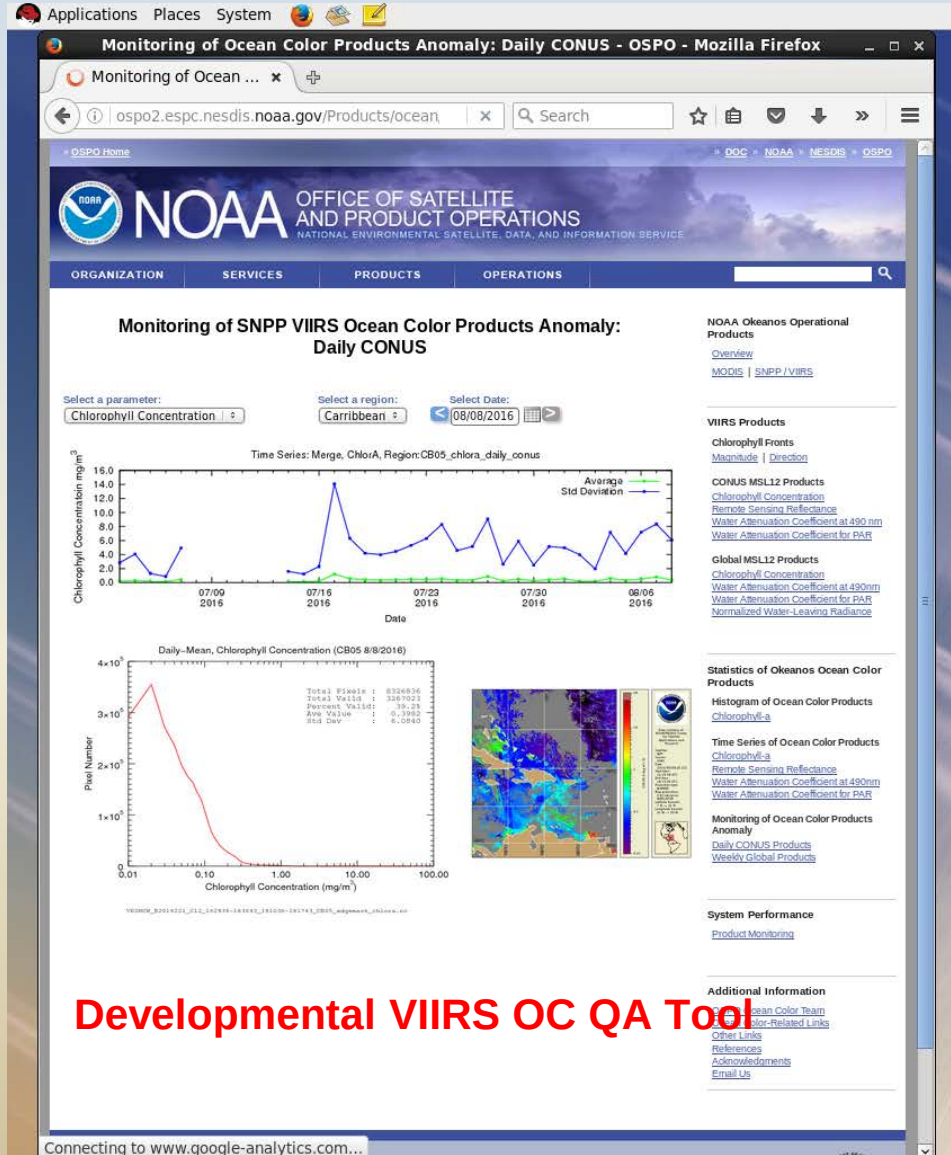
- Completed the installation of the CWAPS-SNPP VIIRS Software Package on the new Okeanos PTS in July 2016
- Pre-operational SNPP-VIIRS OC Products are available in ftp://cw-okeanos.noaa.gov/pub/data1/VIIRS_test/ for users' test and validation (Products are only saved one week)
- New Okeanos OPS is still in development
  - – New Okeanos OPS is expected to be done in early September 2016
  - –Pre-operational products from new Okeanos OPS are expected to be available in September
  - –ORR of new Okeanos OPS is expected to be done in October 2016

# Examples of SNPP VIIRS OC Products Generated in New Okeanos PTS

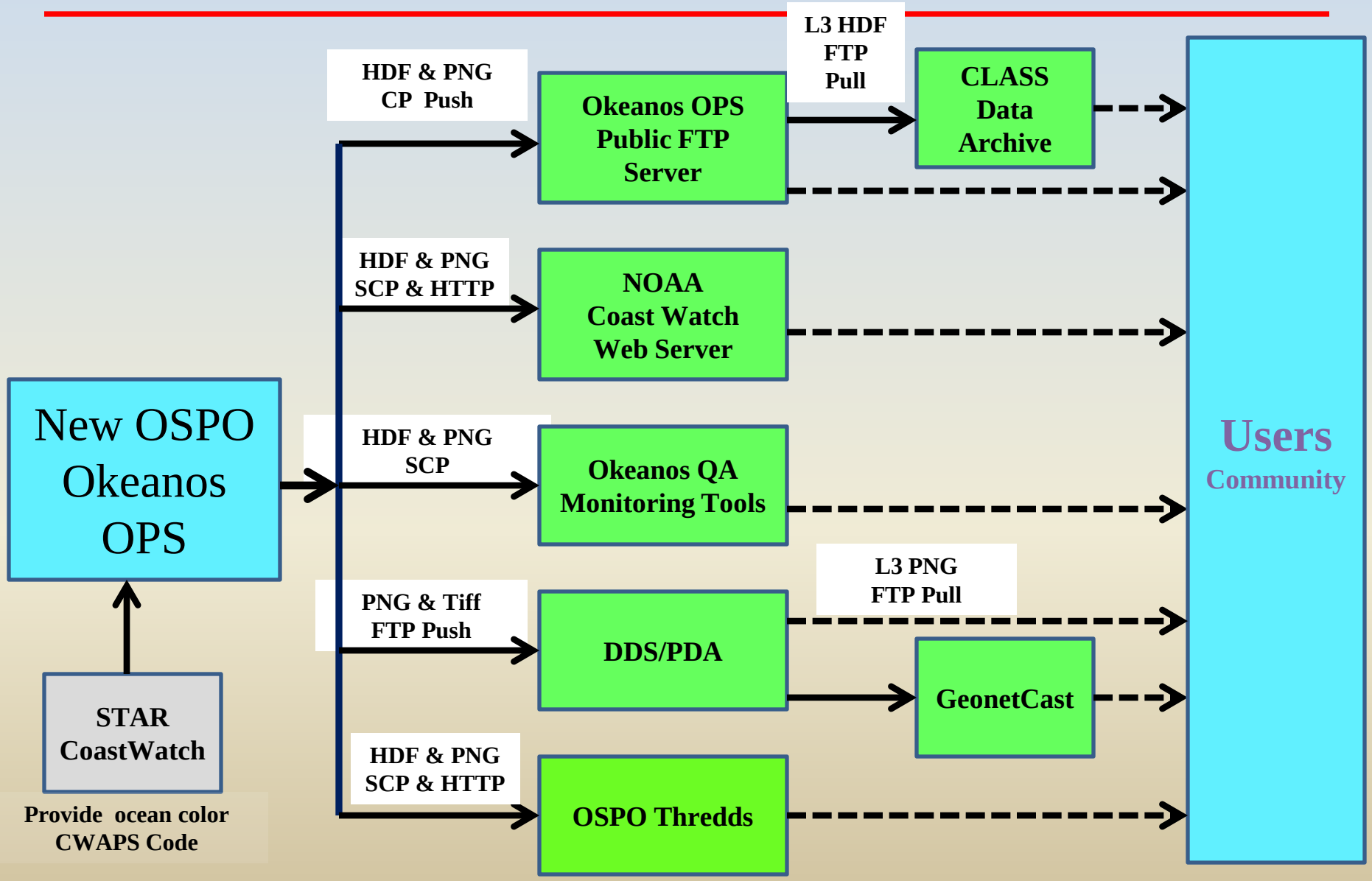


# Okeanos Ocean Color Products QA Monitoring Tool Update for VIIRS Products

- Monitor the quality of SNPP VIIRS OC product imagery at L2, L3, and L4
- Monitor the quality of SNPP VIIRS products at L3 and L4 (statistics analysis)
- Identify any suspicious VIIRS OC Products and send alert emails to the system operators and PAL
- Monitor the availability of SNPP VIIRS at L3 with time
- Monitor the stability of new Okeanos OPS with time



# SNPP-VIIRS Operational Ocean Color NUPS Data Dissemination Flow Chart



# Distribution of NOAA MODIS/Aqua and VIIRS/SNPP Operational Ocean Color Products

- **Products Distributions**
  - Okeanos ftp site (ftp://cw-okeanos.noaa.gov/pub/data1/ subject to change)
  - Okeanos Thredds Server (DAR submission is required from users)
  - OSPO Ocean Color Product QA Monitoring Web Service (http://www.ospo.noaa.gov/Products/ocean/color/index.html)
  - STAR CoastWatch Web Server
  - OSPO DDS/PDA (DAR submission is required from users)
  - NOAA/CLASS
- **Schedule for VIIRS/SNPP OC Products Distribution**
  - July 2016: Pre-operational products
  - Oct 2016: operational products

# NOAA activities in support of in situ validation observations for satellite ocean color products

Veronica P. Lance*
With contributions from Mike Ondrusek
and VIIRS Cal/Val Cruise Team Members

*Global Science & Technology, Inc.

2016 STAR/JPSS Annual Science Meeting
College Park, MD, 8-12 August 2016

# VIIRS Cal/Val Cruises

## Acknowledgements


- NOAA/JPSS Ocean Color Cal/Val team
- Officers and crew of the NOAA Ship *Nancy Foster*
- NOAA OMAO
- NOAA JPSS program
- NOAA STAR Ocean Color EDR team
- NOAA CoastWatch/OceanWatch Central

# VIIRS Cal/Val Cruises

## Outline

- NOAA dedicated to VIIRS Cal/Val cruises: 2014, 2015, upcoming 2016 (and beyond)
- Collaborations and other cruises of opportunity
- NOAA Optical Instrument Calibration Lab
- NOAA support of MOBY and four AERONET-OC sites
- Data assembly, distribution and archiving

# VIIRS Cal/Val Cruises

NOAA dedicated to VIIRS Cal/Val cruises: 2014, 2015, upcoming 2016 (and beyond)

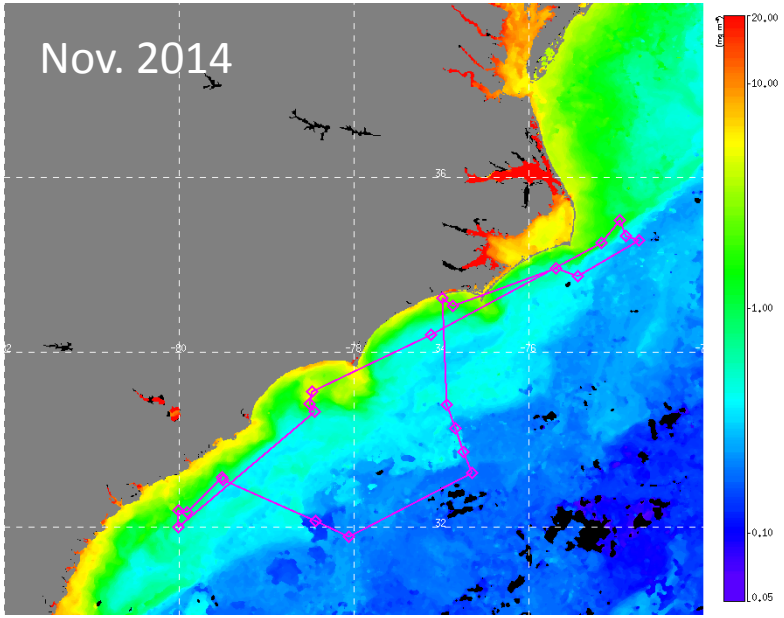


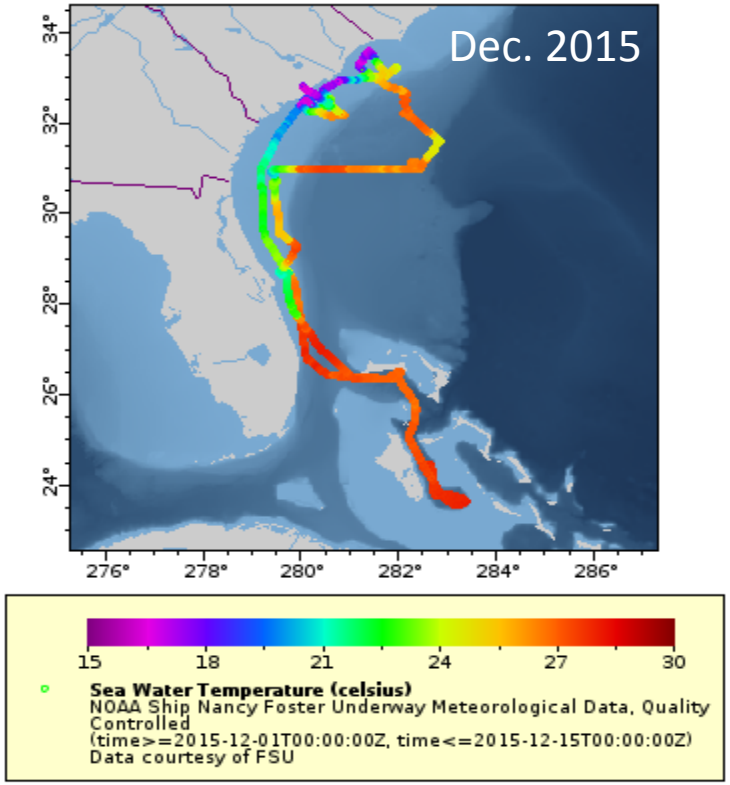
NOAA Ship *Nancy Foster*

# VIIRS Cal/Val Cruises

## Cruise Tracks

### Both 2014 (November) and 2015 (December) cruises departed from *Foster's* home port of Charleston, SC



# VIIRS Cal/Val Cruises

**Next Cruise:**

3-21 October 2016

14 days at sea (+5 days staging, destaging)

NOAA Ship *Nancy Foster*

From Charleston, SC

NF-16-08

# VIIRS Cal/Val Cruises

## Participating Institutions

**US Agencies:**

NOAA/STAR
NASA/GSFC
National Institute of Standards and Technology (NIST)
Naval Research Lab (Stennis)

**Universities:**

U. Southern Mississippi
U. Miami
U. South Florida
U. Massachusetts – Boston
City College of NY
LDEO at Columbia

**International:**

Joint Research Centre of the European Commission (2014)

# VIIRS Cal/Val Cruises

## Representative Measurements

**In water profiling, surface floating and above water ocean radiometry**



**Apparent Optical Properties (AOPs) –** Remote sensing reflectance - Simultaneous profiles with several instruments (e.g. HyperPro; MicroPro (2014 only); C-OPS; also several handheld and deck-mounted instruments)

## Representative Measurements

### In water profiling, surface floating and above water ocean radiometry





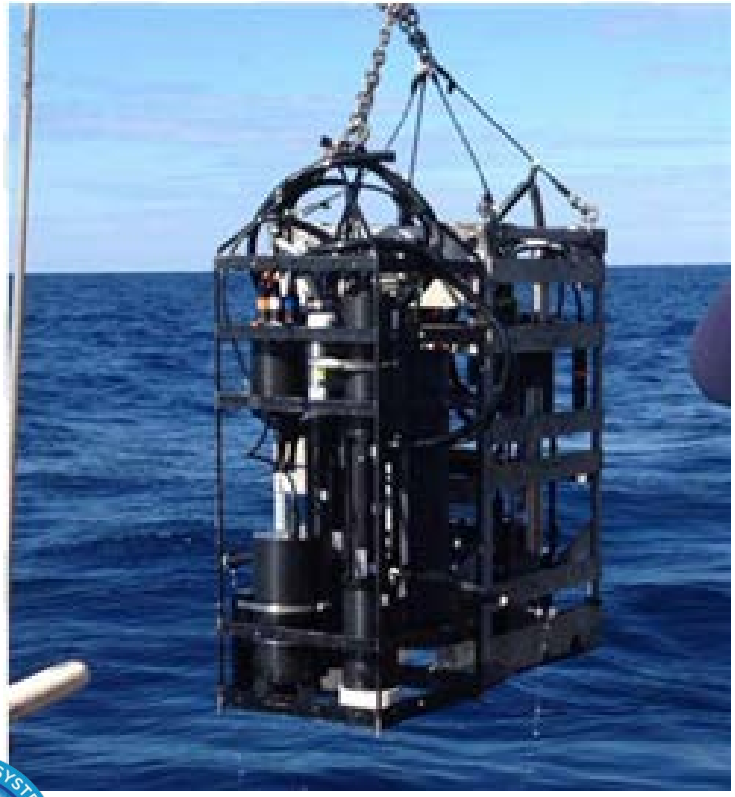




# VIIRS Cal/Val Cruises

## Representative Measurements

### In water profiling, surface floating and above water ocean radiometry



**Inherent Optical Properties ( IOPs) -**Total absorption; CDOM absorption; scatter and backscatter; fluorometry (chlorophyll, CDOM, phycoerythrin)

# VIIRS Cal/Val Cruises

## Representative Measurements

### Flow-through continuous measurements

- **IOPs -** Beam attenuation/scattering; backscatter; CDOM and chlorophyll fluorescence
- **Phytoplankton characterization** - Dynamic imaging particle analysis (FlowCam); phytoplankton functional groups; chlorophyll and phycobilipigments; photosynthetic efficiency (2014 only)



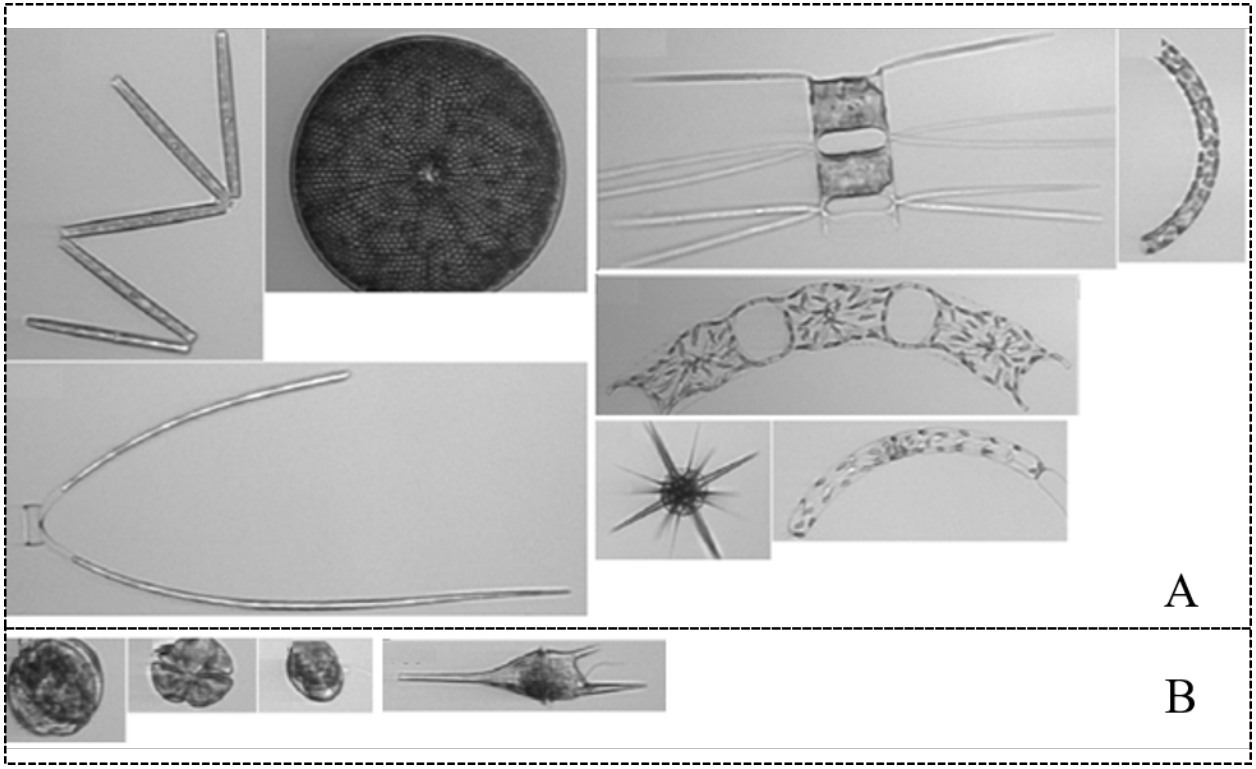
# VIIRS Cal/Val Cruises

## Representative Measurements

**Discrete water sampling and analyses**

Filter pad spectral absorption
HPLC phytoplankton pigment analyses
CDOM absorption
Dissolved organic carbon
Particulate organic carbon and particulate nitrogen
Fluorometric extracted chlorophyll
Suspended particulate material
Particle fluorescence and digital imaging (FlowCam)
Variable fluorescence (2014 only)
Advanced Laser Fluorometer (ALF; 2014 only)
Phycobilipigment concentration (2014 only)

# VIIRS Cal/Val Cruises




Large (>10µm) Phytoplankton Cells

# VIIRS Cal/Val Cruises

## Data Submission and Archiving

- **2014 Cruise (NF-14-09) Data–** Initiated archive with NCEI with data on hand. Ascension number and DOI are TBD. Please submit outstanding datasets.

- **2014 Cruise (NF-15-13) Data–** Assembling datasets now – please submit your data.

# VIIRS Cal/Val Cruises

2014
Pg 1 of 2

Accounting of Cruise Data Submissions NF-14-09

| Group | Dataset | 2014 |
|---|---|---|
| NOAA/STAR (Mike) | Hyperpro profiling (Rrs, etc.) | only matchup stations (n=9) |
| NOAA/STAR (Mike) | ECO Pucks on Hyperpro 2x triplets (Chl, CDOM, phycoerythrin, bb at 443, 450 860) | |
| NOAA/STAR (Mike) | chl-a fluorometric (method?) | |
| NOAA/STAR (Mike) | Microtops | |
| NOAA/STAR (Mike) | ASD (Rrs - above water) | |
| NOAA/STAR (Eric) | TSM | |
| Stennis (Ryan - USM) | ASD (Rrs - above water) | only matchup stations (n=9 this might be everything for handheld) |
| Stennis (NRL) | ASD (Rrs - above water) | ? |
| Stennis (Ryan) | Hyperpro (Rrs - floating) | only matchup stations (n=9; check on whether more stations for floating) |
| Stennis (Bob) | Flowthrough ac9 unfiltered (a, b, c) | x |
| Stennis (Bob) | Flowthrough ac9 filtered (ag, ap, | x |
| Stennis (Bob) | Flowthrough (bb) | x |
| Stennis (?) | Microtops | |
| UMB (Jianwei) | SBA floating hyperpro (Rrs) | x |
| UMB (Jianwei) | IOP BB9 (bb) | x |
| UMB (Jianwei) | IOP ACS180 filtered and unfiltered (apg, cpg) | x |
| UMB (Junfang) | Spectral Evolution Handheld | |
| USF (David) | Filter Pad Absorption (ap, ad, aph) | x |
| USF (David) | Chlorophyll (Welschmeyer) | x |
| USF (David) | Chlorophyll (Acidification) | x |
| USF (David) | ASD HandHeld above water (Rrs) | 7 stations - (this is probably everything they have?) |
| USF (?) | Microtops | |
| USF (?) | Hyperpro | |

# VIIRS Cal/Val Cruises

2014
Pg 2 of 2

| Group | Dataset | 2014 |
|---|---|---|
| CCNY | Hypersas-POL | |
| CCNY | GER | |
| CCNY | Microtops | |
| JRC (Giuseppe) | Micropro (profiling; Es, Ed, Lu, Kl?, Kd, Eu, Ku, R, Q, Rrs nLw | x |
| JRC (Giuseppe) | IOPs in same file, maybe calculated?? | x |
| JRC (Giuseppe) | TRIoS- he says most data no good - good at 5 stations) | |
| NASA(Scott) | C-OPS (profilling Rrs: Ed, Lu, Es, | x |
| NASA(Scott) | IOPS (acs, unfiltered: cgp, agp, ag, ) | x |
| NASA(Scott) | IOPS (ac9, filtered: ag) | x |
| NASA(Scott) | IOPS (bb3: bbp) | x |
| NASA(Scott) | IOPS (VSF-9: VSF) | x |
| NASA(Scott) | HyperSAS | |
| NASA (Aimee) | POC | |
| NASA (Aimee) | DOC | |
| NASA (Aimee) | CDOM | |
| NASA (Aimee/Crystal) | HPLC | x |
| LDEO (Joaquim) | ALF | |
| LDEO (Joaquim) | FIRe | |
| LDEO (Joaquim) | bbe | |
| LDEO (Joaquim) | phyocobilipigments | |
| LDEO (Joaquim) | Flow Cam | |
| LDEO (Joaquim) | microscopy | |
| U. Miami (Ken) | NURADS (8 stations) | X |
| NIST | n/a | |

# VIIRS Cal/Val Cruises

Accounting of Cruise Data Submissions NF-15-13

2015

Pg 1 of 2

| Group | Dataset | Dec-15 |
|---|---|---|
| NOAA/STAR (Mike) | Hyperpro profiling (Rrs) | |
| NOAA/STAR (Mike) | ECO Pucks on Hyperpro 2x triplets (Chl, CDOM, phycoerythrin, bb at 443, 450 860) | |
| NOAA/STAR (Mike) | chl-a fluorometric (Welschmeyer) | |
| NOAA/STAR (Mike) | ASD (Rrs - above water) | check for completeness |
| NOAA/STAR (Eric) | TSM | |
| Stennis (Ryan - USM) | ASD (Rrs - above water) | check for completeness |
| Stennis (NRL) | ASD (Rrs - above water) | check for completeness |
| Stennis (Ryan) | Hyperpro (Rrs - floating) | |
| Stennis (Bob) | Flowthrough ac9 unfiltered (a, b, c) | |
| Stennis (Bob) | Flowthrough ac9 filtered (ag, ap, | |
| Stennis (Bob) | Flowthrough (bb) | |
| UMB (Jianwei) | RISBA (was SBA) floating hyperpro (Rrs) | |
| UMB (Jianwei) | IOP BB7FL2 (bb at 412, 440, 488, 532, 595, 695, 715; CDOM fl; Chl fl) | |
| UMB (Jianwei) | IOP ACS180 filtered and unfiltered (apg, cpg) | |
| UMB (Guoqing) | Flow Cytobot | |
| UMB (Junfang) | Spectral Evolution Handheld | check for completeness |
| USF (David) | Filter Pad Absorption (ap, ad, aph) | x (rec'd but trouble unzipping) |
| USF (David) | Chlorophyll (Welschmeyer) | x (rec'd but trouble unzipping) |
| USF (David) | Chlorophyll (Acidification) | x (rec'd but trouble unzipping) |
| USF (David) | CDOM absorption (new for 2015 from ap sampling) | x (rec'd but trouble unzipping) |
| USF (David) | ASD HandHeld above water (Rrs) | check for completeness |
| USF (?) | Microtops | ? |
| USF (?) | Hyperpro - profiling | x (rec'd but trouble unzipping) |

# VIIRS Cal/Val Cruises

2015
Pg 2 of 2

| Group | Dataset | Dec-15 |
|---|---|---|
| CCNY | Hypersas-POL | only for matchup stations; only at VIIRS channels |
| CCNY | ASD | only for matchup stations; only at VIIRS channels |
| CCNY | GER | only for matchup stations; only at VIIRS channels |
| OSU (Nick) | Hyperpro - profiling | x |
| OSU (Nick) | Spectral Evolution Handheld | check for completeness |
| NASA(Scott) | C-OPS (profilling Rrs: Ed, Lu, Es, | |
| NASA(Scott) | C-OPS (profilling Rrs: Ed, Lu, Es, | |
| NASA(Scott) | IOPS (acs, unfiltered: cgp, agp, ag, ) | |
| NASA(Scott) | IOPS (ac9, filtered: ag) | |
| NASA(Scott) | IOPS (bb3: bbp) | |
| NASA(Scott) | IOPS (VSF-9: VSF) | |
| NASA(Scott) | HyperSAS | |
| NASA (Joaquin C.) | POC | |
| NASA (Joaquin C.) | DOC | |
| NASA (Joaquin C.) | CDOM | |
| NASA (Joaquin C.) | HPLC | X |
| LDEO (Joaquim G.) | Nutrients (N, P, Si) | |
| LDEO (Joaquim G.) | Flow Cam | |
| U. Miami (Ken) | NURADS (8 stations) | X |
| NIST | n/a | |

# VIIRS Cal/Val Etc.

## Collaborations and cruises of opportunity

### NOAA

- **JPSS/VIIRS external cal/val teams (ongoing)**
  - **Puerto Rico; Hawaii; Gulf of Mexico; West Coast/California; Chesapeake Bay; etc.**
- **NOAA OAR Ocean Acidification Program**
  - **ECOA – East Coast US**
  - **WCOA – West Coast US**
- **NOAA Coral Reef Watch**
  - **Puerto Rico; Hawaii; Australia**
- **NOAA/STAR research**
  - **Chesapeake Bay, etc.**

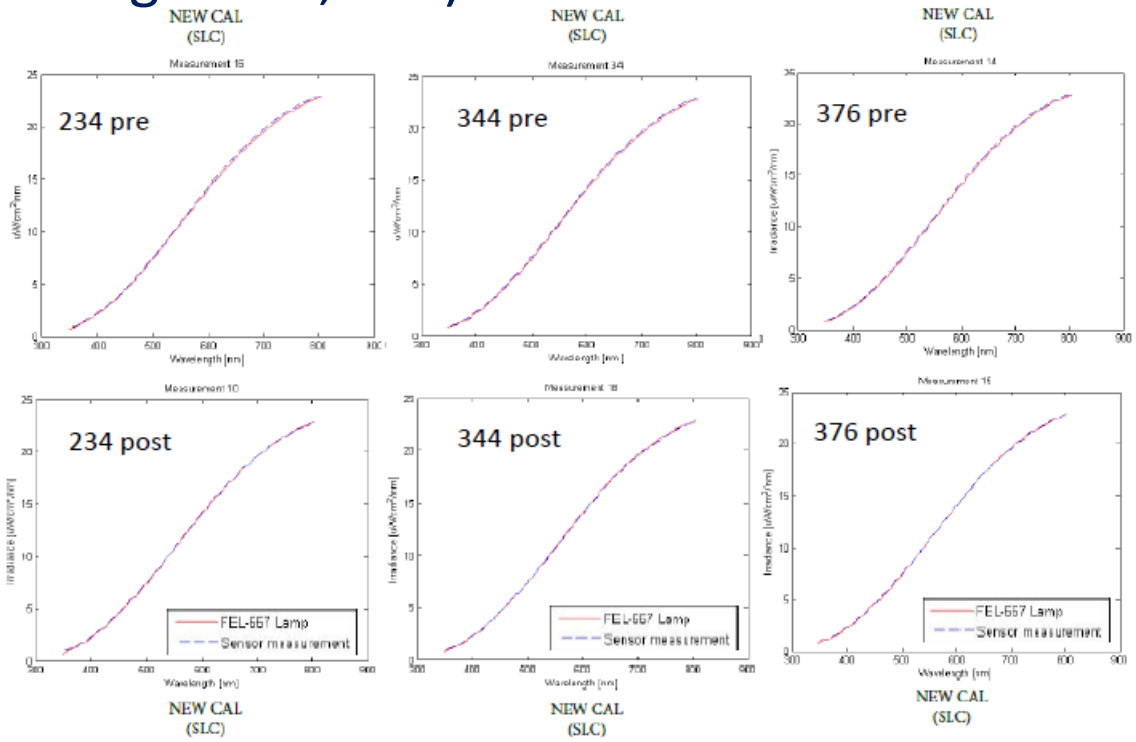
### **NASA/South Korea** ("KORUS" May-June 2016)

### Australia

- **CSIRO** – June-July 2016
- **CORAL** – Upcoming Late Aug – Oct 2016

## NOAA Optical Instrument Calibration Laboratory

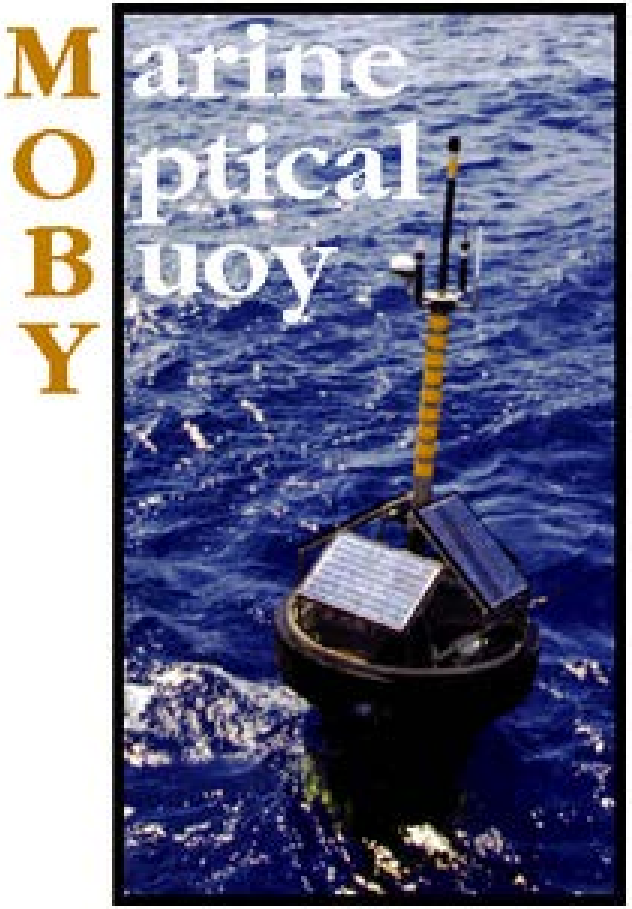
(NCWCP, College Park, MD)




In collaboration with NIST

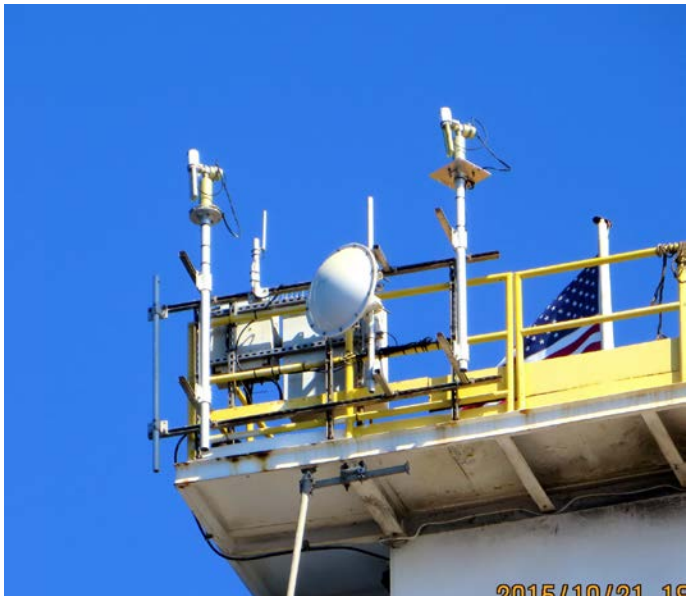
# VIIRS Cal/Val Etc.

## NOAA support of MOBY



# VIIRS Cal/Val Etc.

## NOAA support of 4 AERONET-OC Sites



- **WavCIS**
  Stennis, Gulf of Mexico
- **Eureka**
  OSU & USC, US West Coast
- **LISCO**
- CCNY, Long Island Sound
- **Lake Erie**
  NOAA/GLERL and UNH

# VIIRS Cal/Val Etc.

## Summary

- Successful 2014 and 2015 cruises
- Next cruise NF-16-08: 3-21 October 2016 (14 days)
- Participants, please submit outstanding datasets for 2014 & 2015

# STAR JPSS 2016 Annual Science Team Meeting

VIIRS Ocean Color Breakout
Wednesday , 10 August 2016

## Optical Measurements in Support of JPSS Cal/Val

Michael Ondrusek, Eric Stengel and Charle Kovach
Bob Arnone, Zhongping Lee, Eric Stengel, Ryan Vandermeulen, 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, Carlos Carrizo, Guoqiang Wang, Veronica Lance, Menghua Wang.

Primary Objectives:

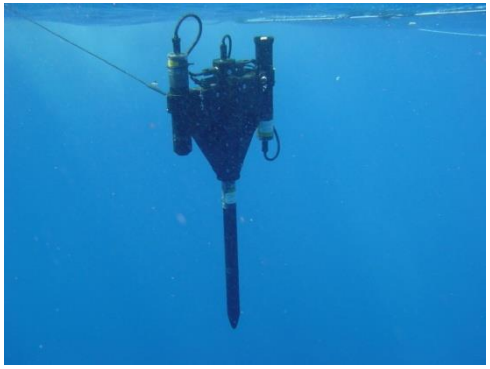
- Provide in situ ocean color data to be used for calibration and validation of the JPSS Cal/Val effort.
- Define protocols and uncertainties in validation data collection.
- Coordinate ocean color validation cruises.

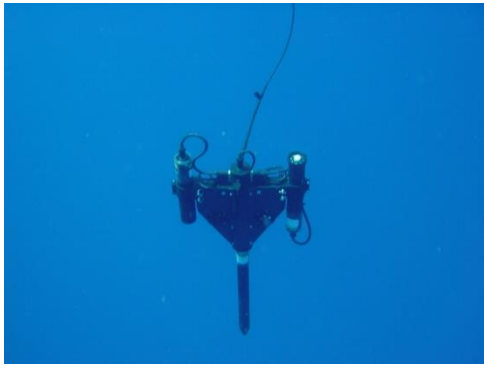
- **Validation of satellite ocean color sensors :**
  - Requires accurate and traceable in situ measurements
  - Hyperspectral to match all sensors
  - Many matchups and water types

- **Satlantic Profiler II (Hyperpro) in-water radiometer:**
  - Hyperspectral
  - Profiling
  - Lu, Ed, and Es





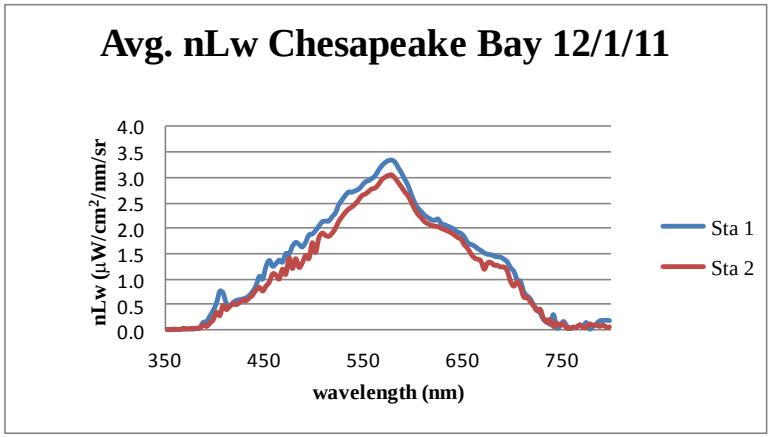




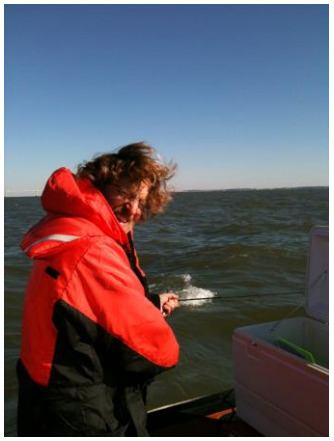
- **Validation capabilities**
  - Lwn/Rrs (in- and above-water)
  - Chlorophyll/pigments
  - Backscatter/Absorption
  - TSM
  - Aerosol Optical Depth

# Validation Measurements since VIIRS launch

# Dec. 1, 2011 VIIRS Intialization - Conducted Clear Sky Hyperpro ocean color validation measurements on the Chesapeake Bay.





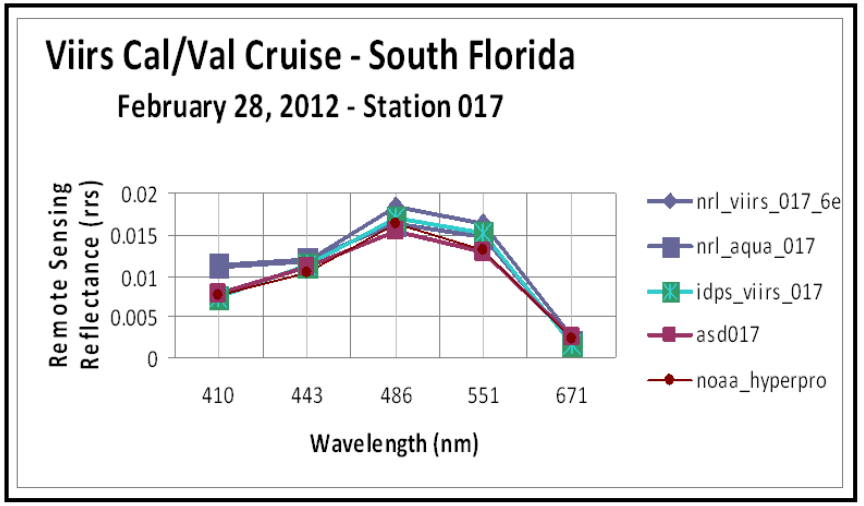
Chesapeake Bay VIIRS Ocean Color Validation: Conducted routine in-water Hyperpro and above-water ASD validation measurements in the Chesapeake Bay. Over 45 days with approximately 150 - 200 Stations in the Bay since Launch of VIIRS.





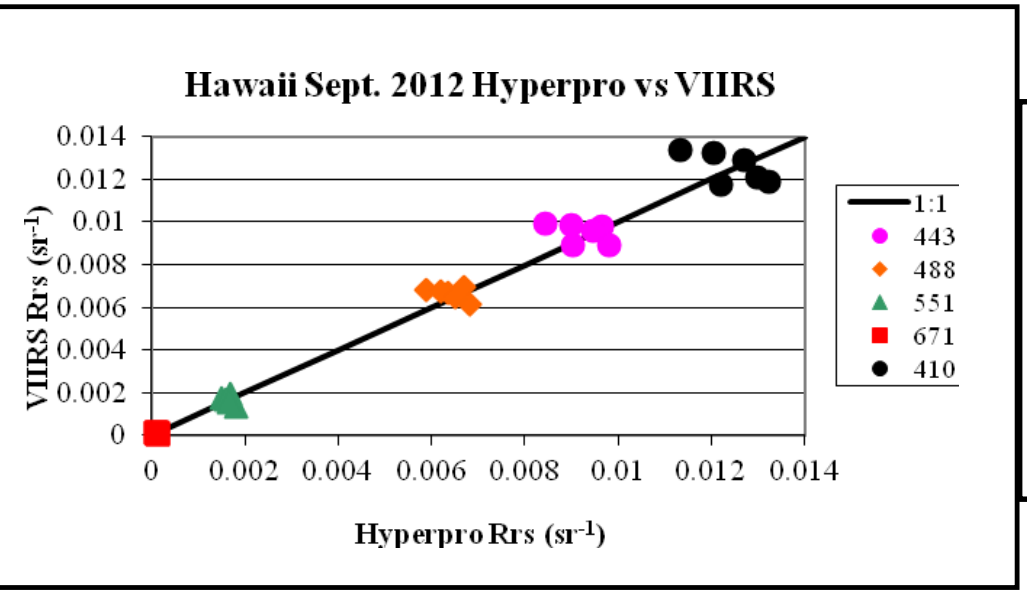
# South Florida Cruise Feb. – Mar. 2012, 16 Hyperpro and ASD Validation Stations.

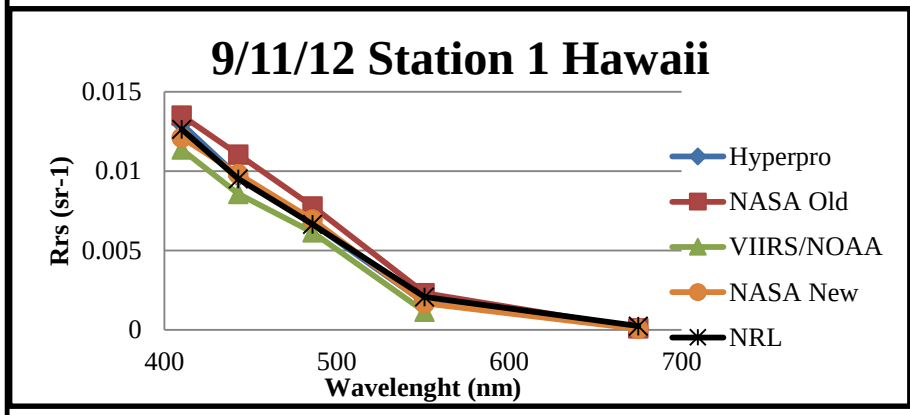


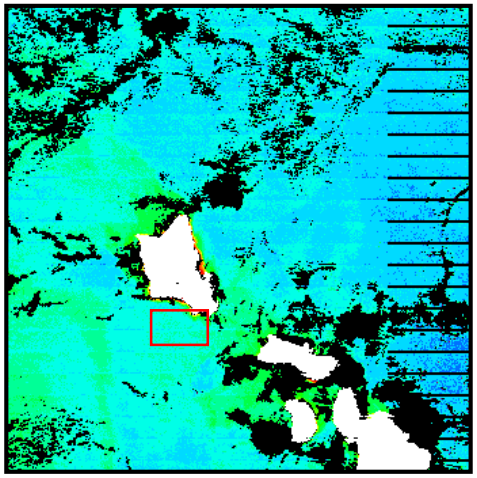

| | Hypro vs IDPS | | Hypro vs L2GEN | | ASD vs L2gen | | ASD vs IDPS | | ASD vs Aqua | | Hyperpro vsAqua | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ch | r2 | slope | r2 | slope | r2 | slope | r2 | slope | r2 | slope | r2 | slope |
| 410 | 0.8628 | 0.8752 | 0.9071 | 1.0177 | 0.8414 | 0.9639 | 0.8364 | 0.7994 | 0.5753 | 1.2016 | 0.4575 | 1.2782 |
| 443 | 0.9848 | 0.9329 | 0.9848 | 0.9058 | 0.9468 | 0.9072 | 0.9766 | 0.9125 | 0.9202 | 0.9692 | 0.8922 | 0.9796 |
| 488 | 0.9981 | 0.9772 | 0.9964 | 0.9762 | 0.9735 | 1.0503 | 0.9912 | 0.9964 | 0.9888 | 0.9115 | 0.9914 | 0.8727 |
| 551 | 0.9895 | 0.9603 | 0.9850 | 0.9838 | 0.9635 | 1.1198 | 0.9759 | 1.0767 | 0.9804 | 0.9281 | 0.9779 | 0.873 |
| 671 | 0.9953 | 0.7362 | 0.9959 | 0.9368 | 0.8992 | 1.0056 | 0.9613 | 0.7327 | 0.9712 | 0.576 | 0.9792 | 0.6486 |

# VIIRS validation using in situ Hyperpro measurements off Oahu, Hawaii collected in September, 2012 using NASA and NRL processings. The VIIRS data in the cross plot was processed using NASA data. 21 matchup stations

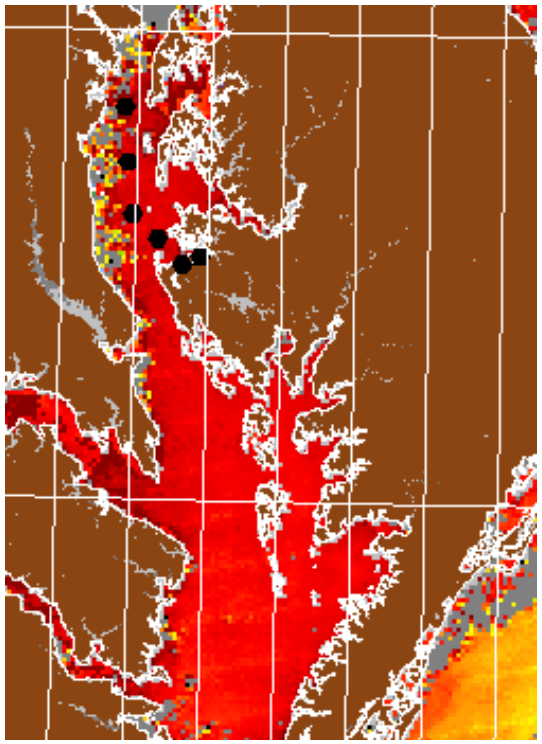


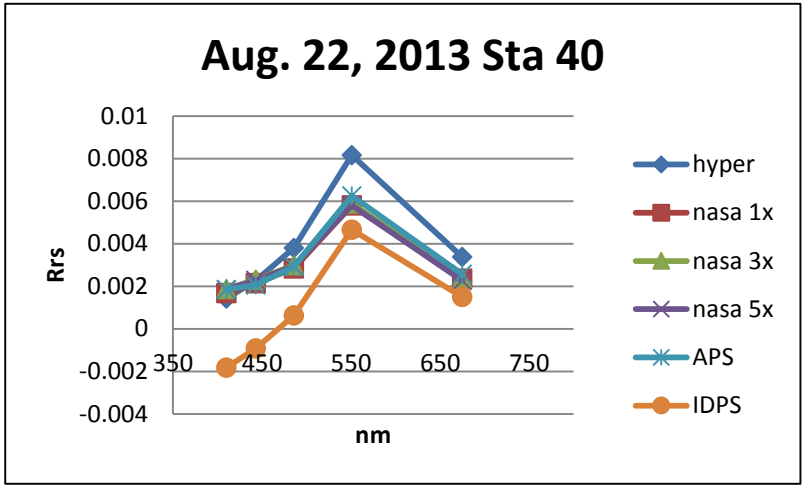



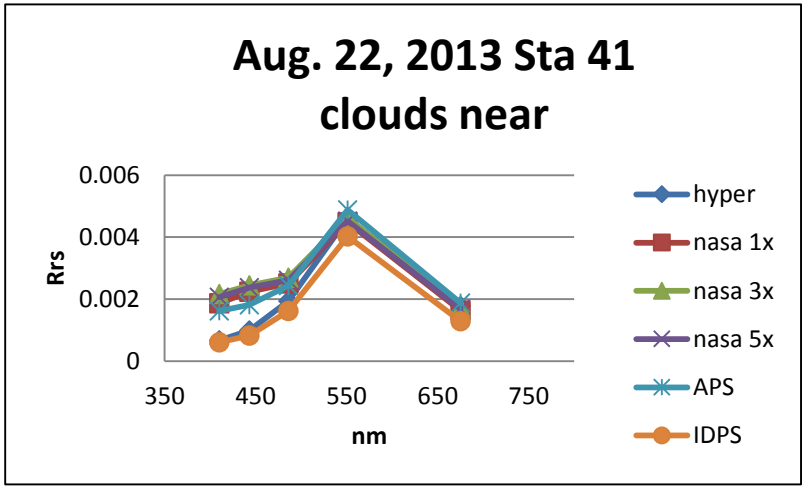

| Band | % Diff Hyperpro – NASA | Std Dev of % Diff Hyperpro |
|---|---|---|
| 410 | 1.50 | 3.48 |
| 443 | 3.18 | 1.05 |
| 488 | 3.93 | 3.38 |
| 551 | 1.40 | 36.27 |
| 671 | -8.81 | 158.79 |
| Average 410 to 551 | 2.50 | 11.05 |

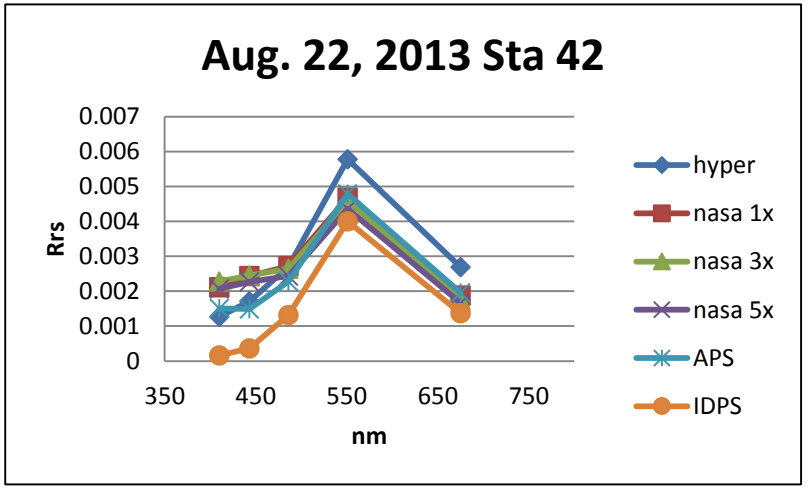


# Two week, August 2013 Cruise with CUNY/CREST covering entire Chesapeake Bay. Shown, Day 234, transect up the bay. 42 Stations total

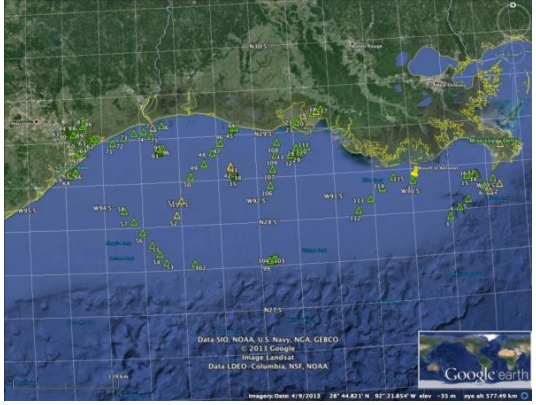




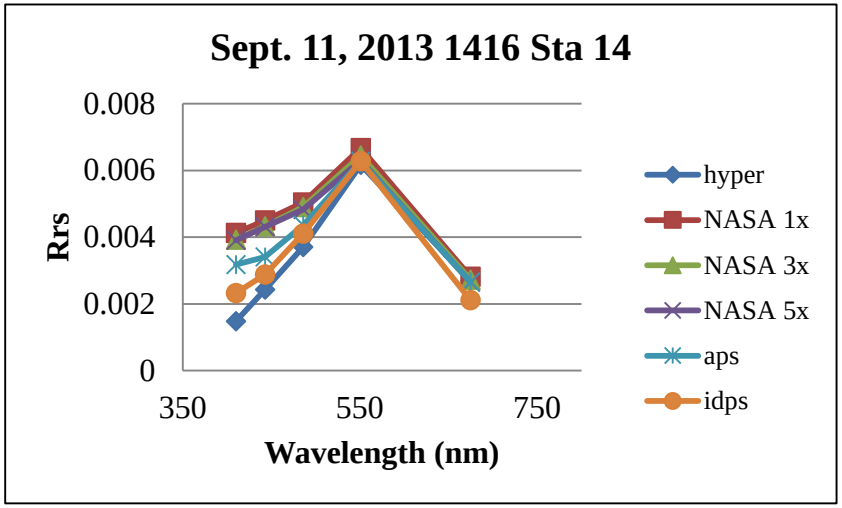



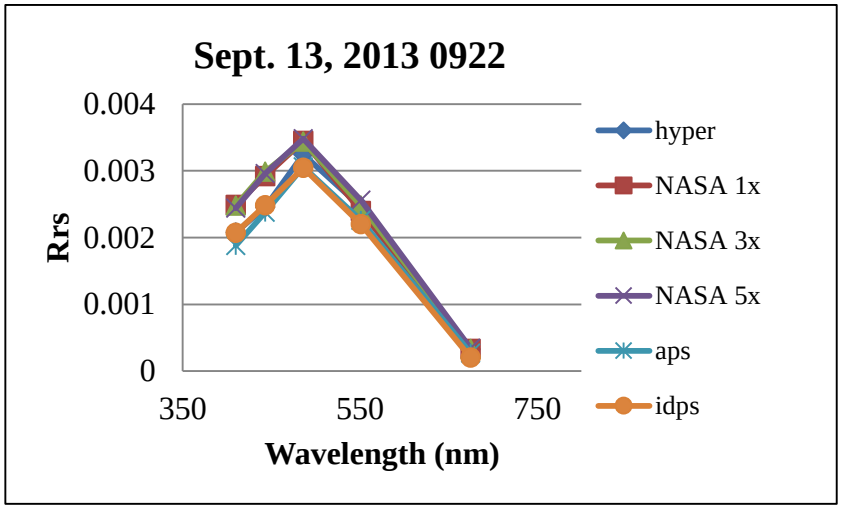



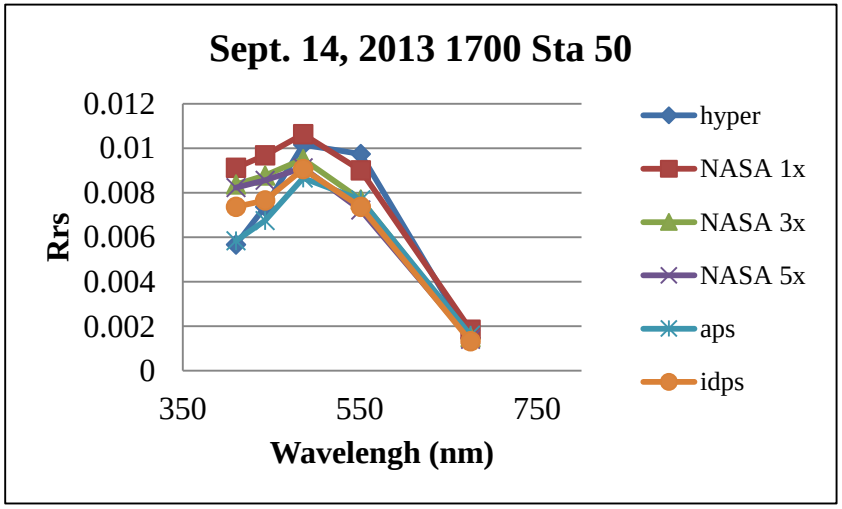
# Sept. 2013 Geocape Cruise 112 Stations Rrs Data shown from 9/11, 13, and 14, 2013 and Ecopuc backscatter validations are show in bottom right

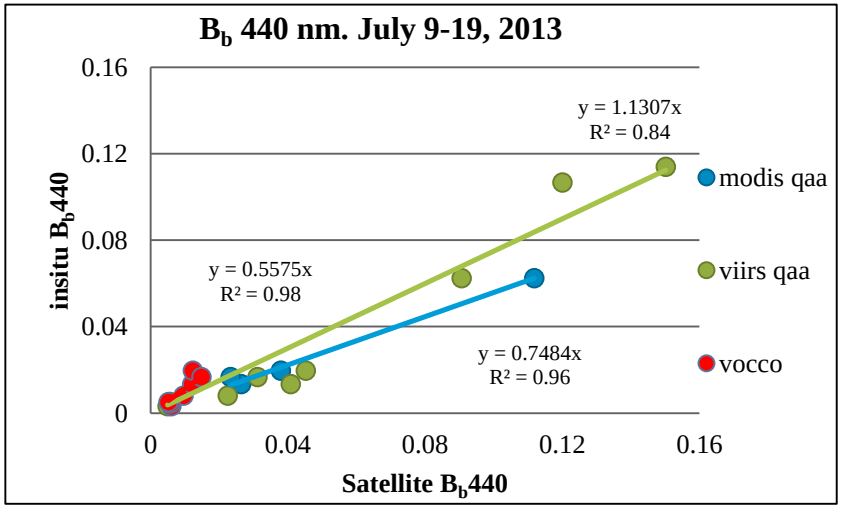




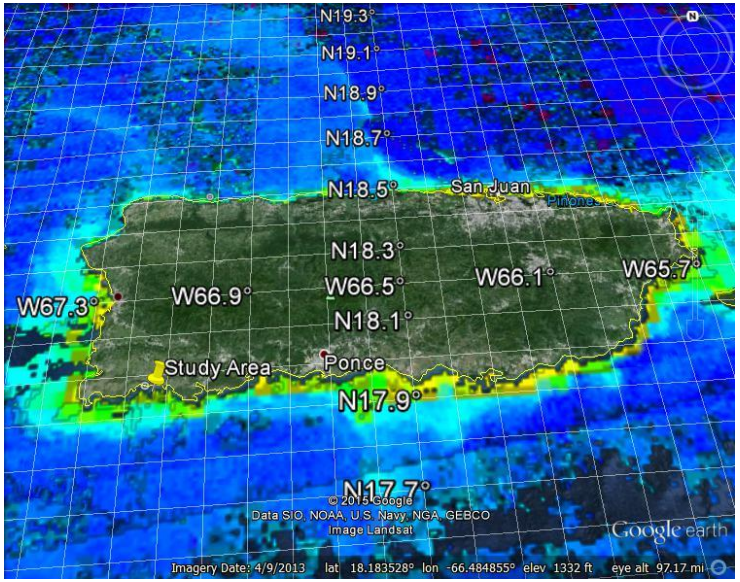



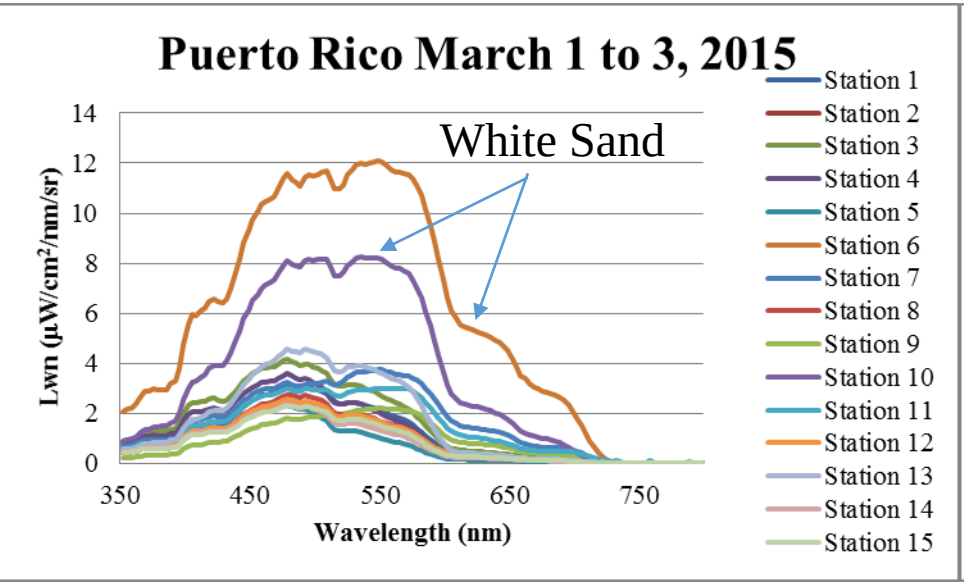



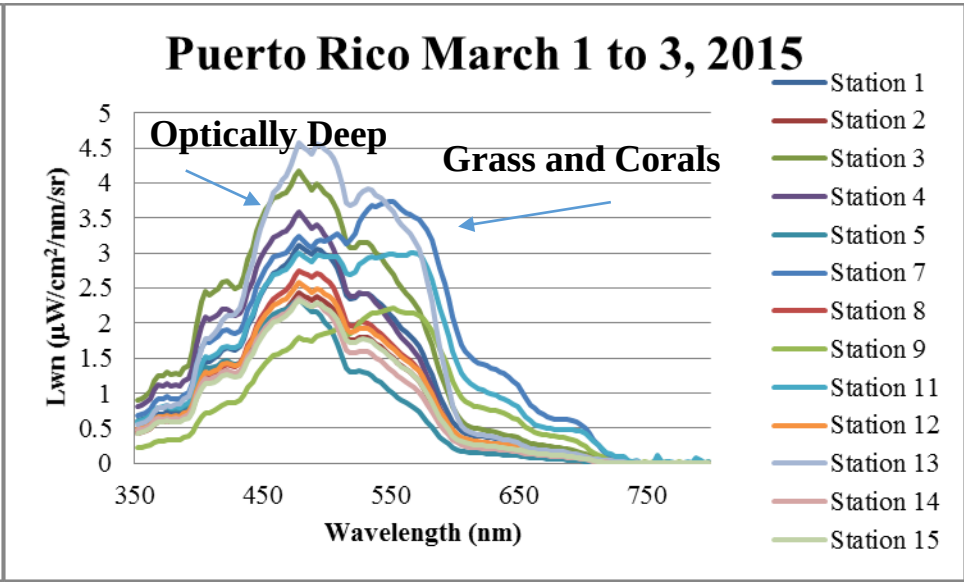



Conducted VIIRS Cal/Val cruises off Puerto Rico in May 2014 and March 2015 in collaboration with UMB, UPR, and EPA.. (image chl composite of March 1 to 6, 2015)




Occupied 15 stations each year in conditions ranging from shallow waters over sand and coral bottoms to optically deep waters



# Dedicated VIIRS Cal/Val Cruise
# NOAA Ship Nancy Foster
11-20 November 2014






## *International, Interagency and Academic Collaborations:*

**US Agencies**

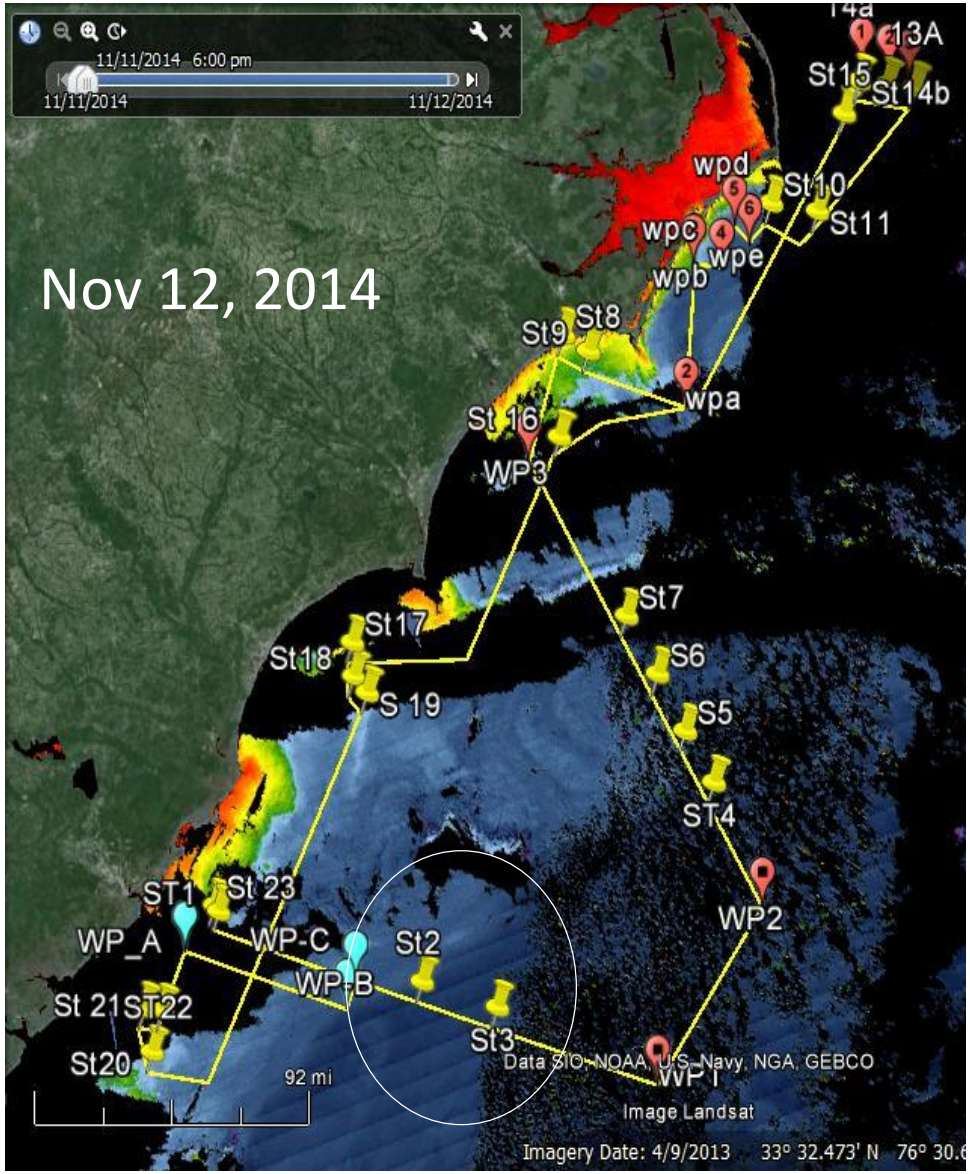
- **NOAA**/NESDIS/STAR (NOAA)
- Naval Research Laboratory, Stennis Space Center (**NRL**)
- NASA/Goddard Space Flight Center (**NASA**)
- National Institute of Standards and Technology (**NIST**)

**European Union**

- Joint Research Center of the European Commission (**JRC**)

**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



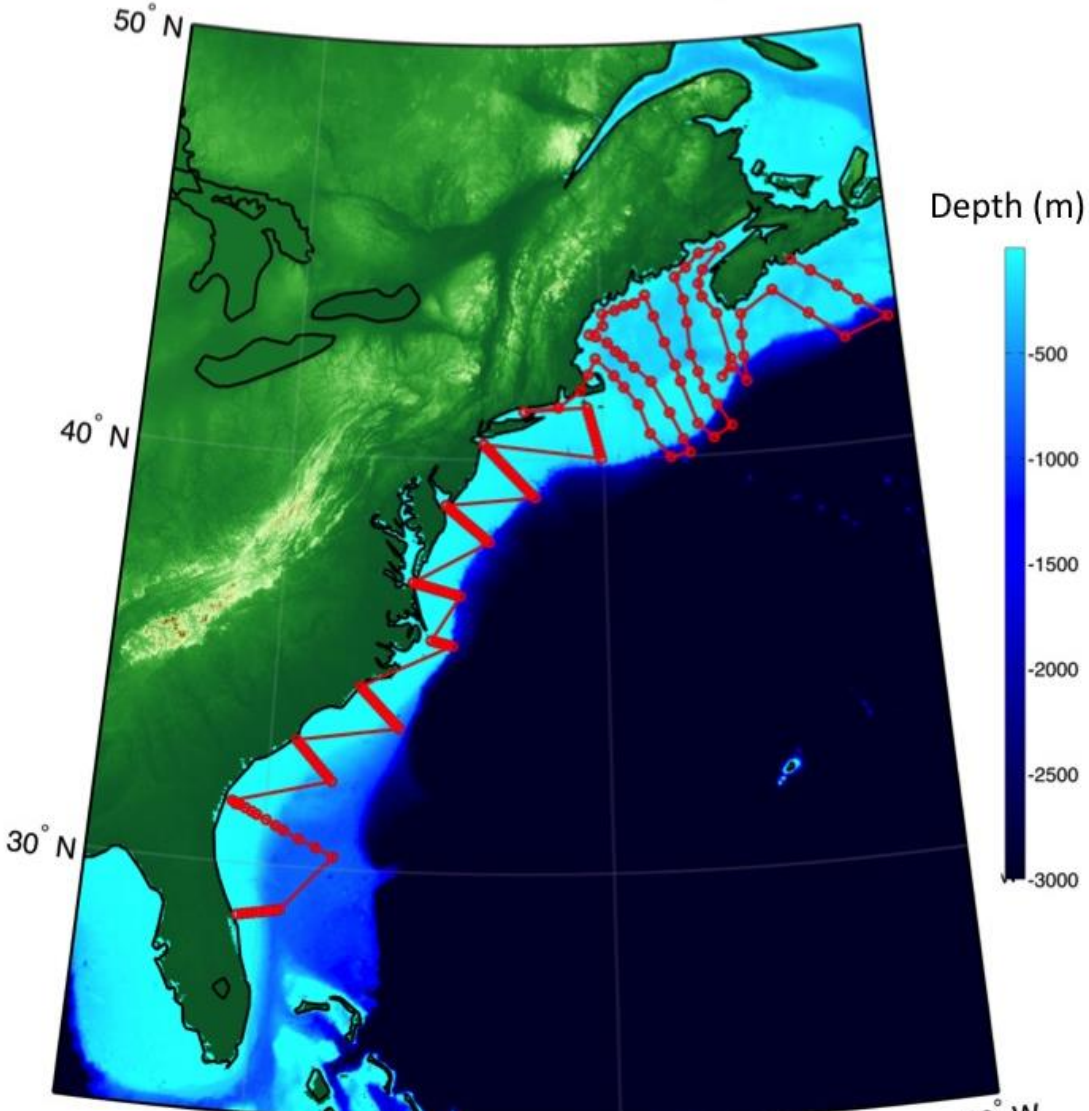

**November 12, 2014 Blue water validations**

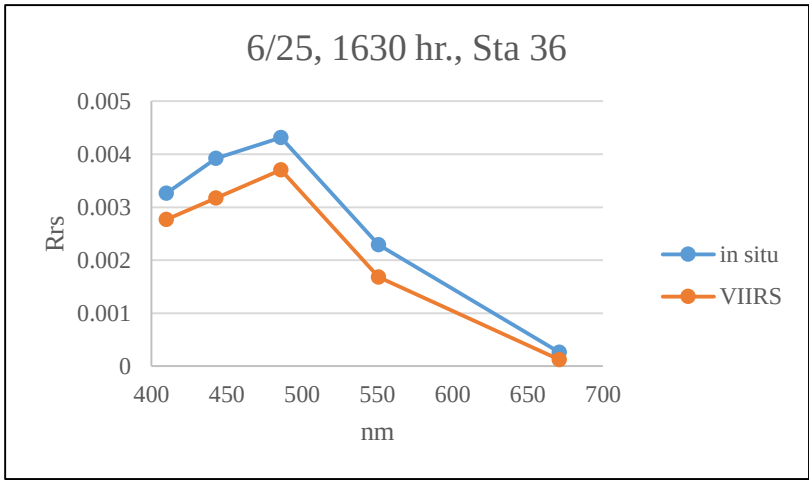
## ECOA 1- The East Coast Ocean Acidification Cruise 2015

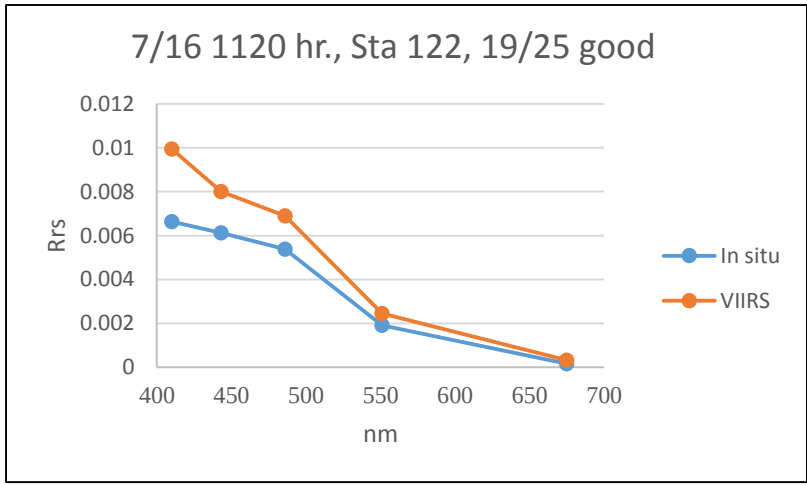
Leg 1 – June 17 to July 2, 2015 NNova Scotia to Norfolk, VA 21 optical stations

Leg 2 – July 8 to 24, 2015 53 optical stations from Chesapeake Bay to Miami

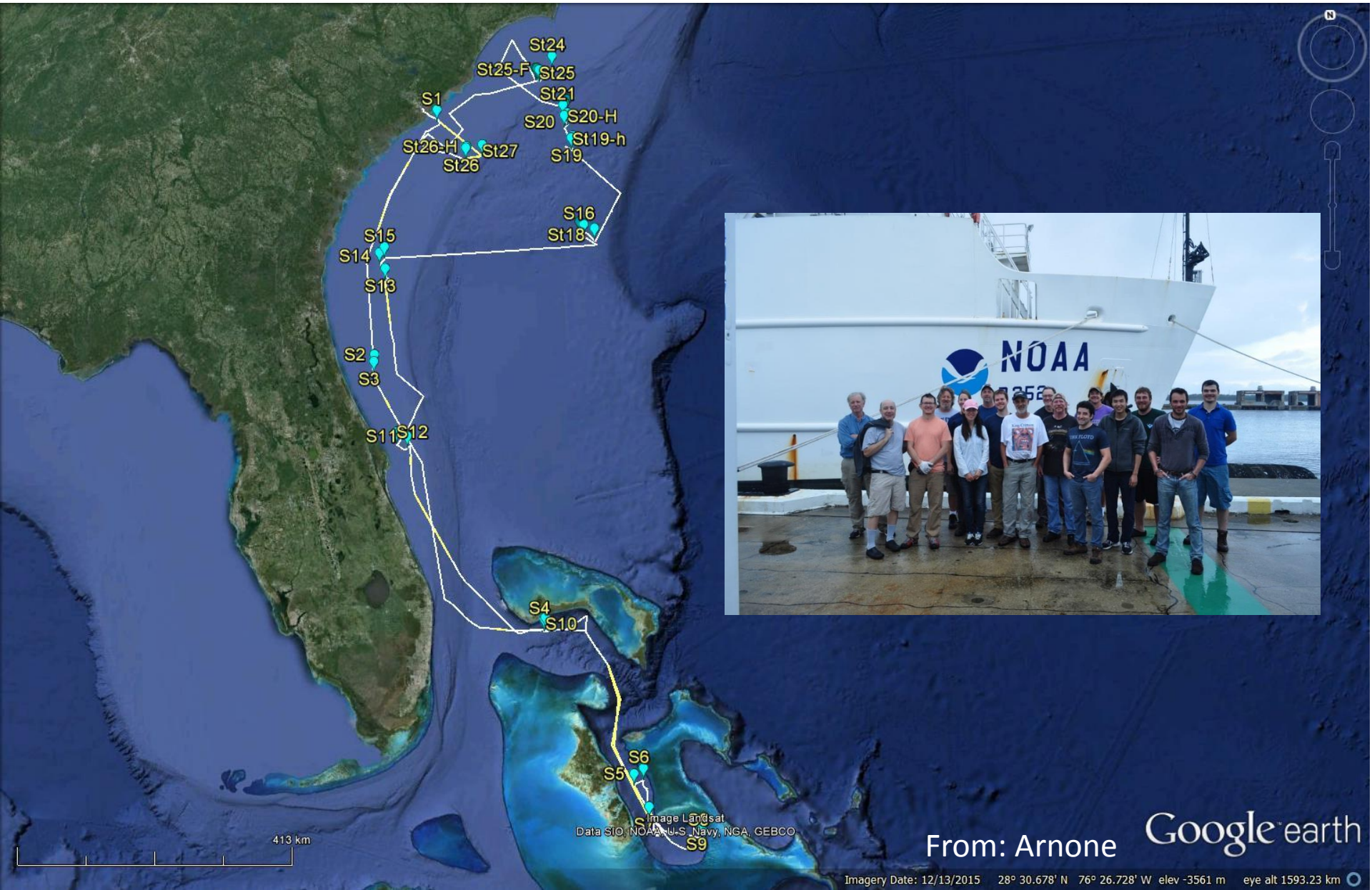
Figure 1. Tentative station plan



# December 2015 Cal/Val Cruise

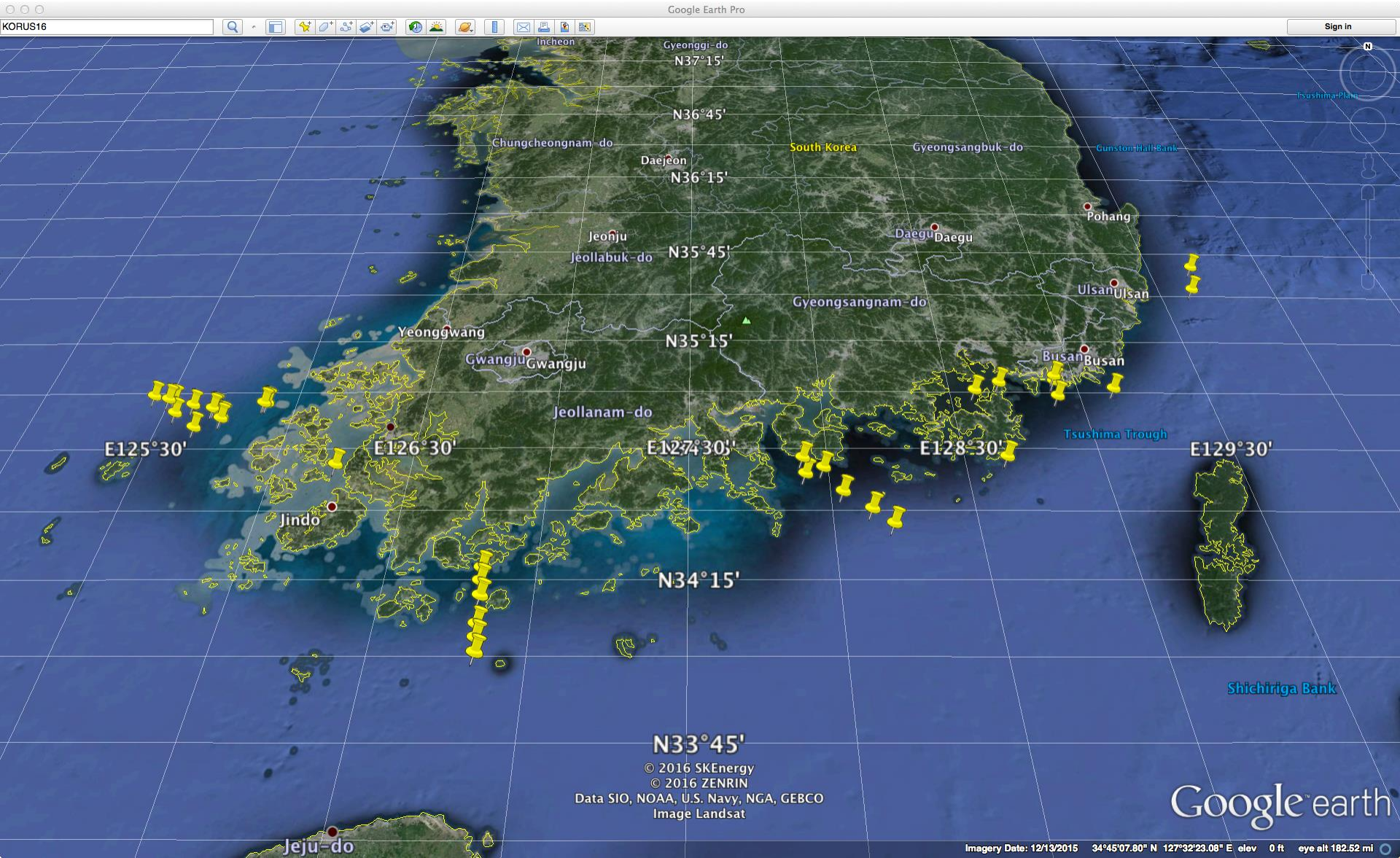




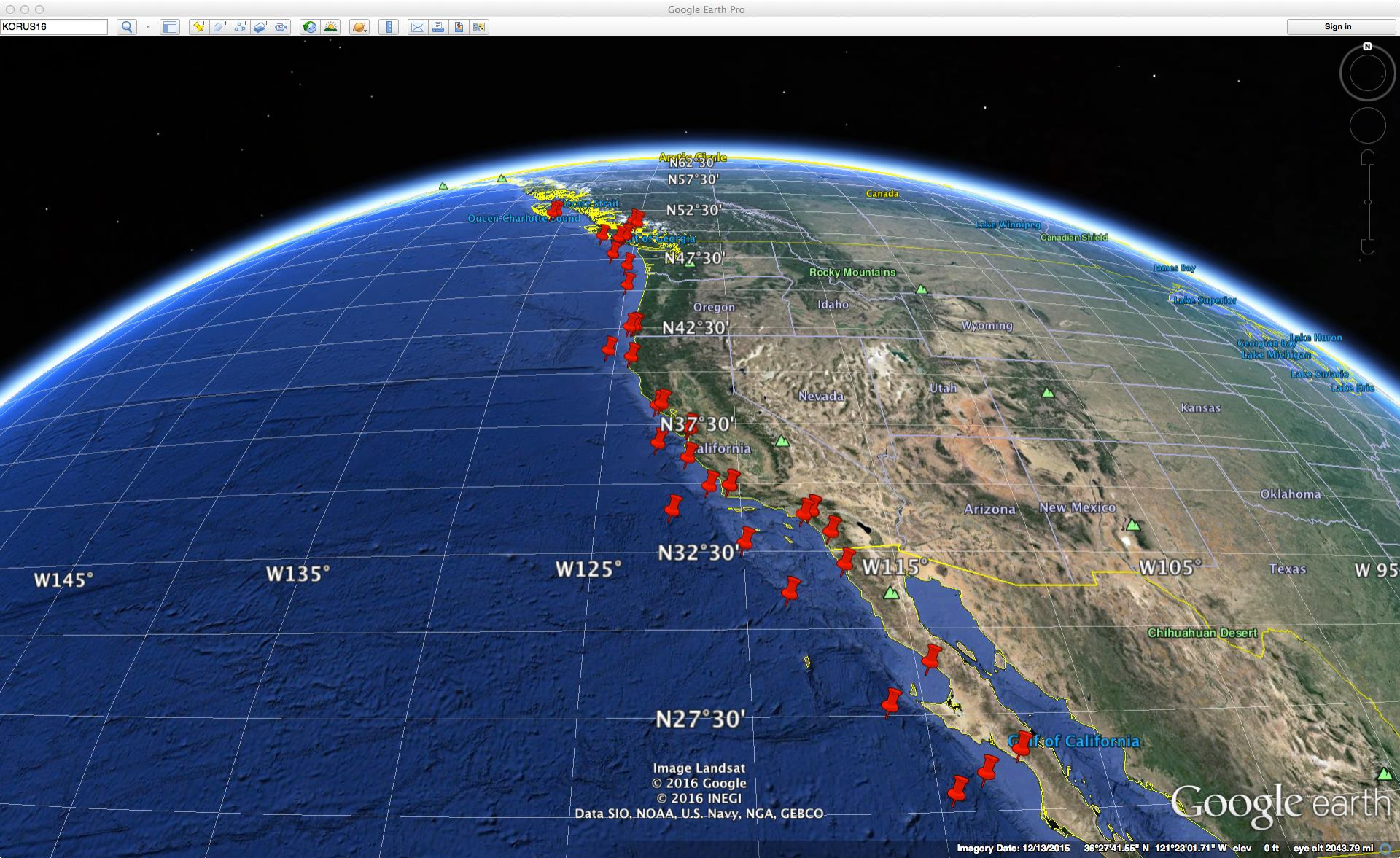


From: Arnone

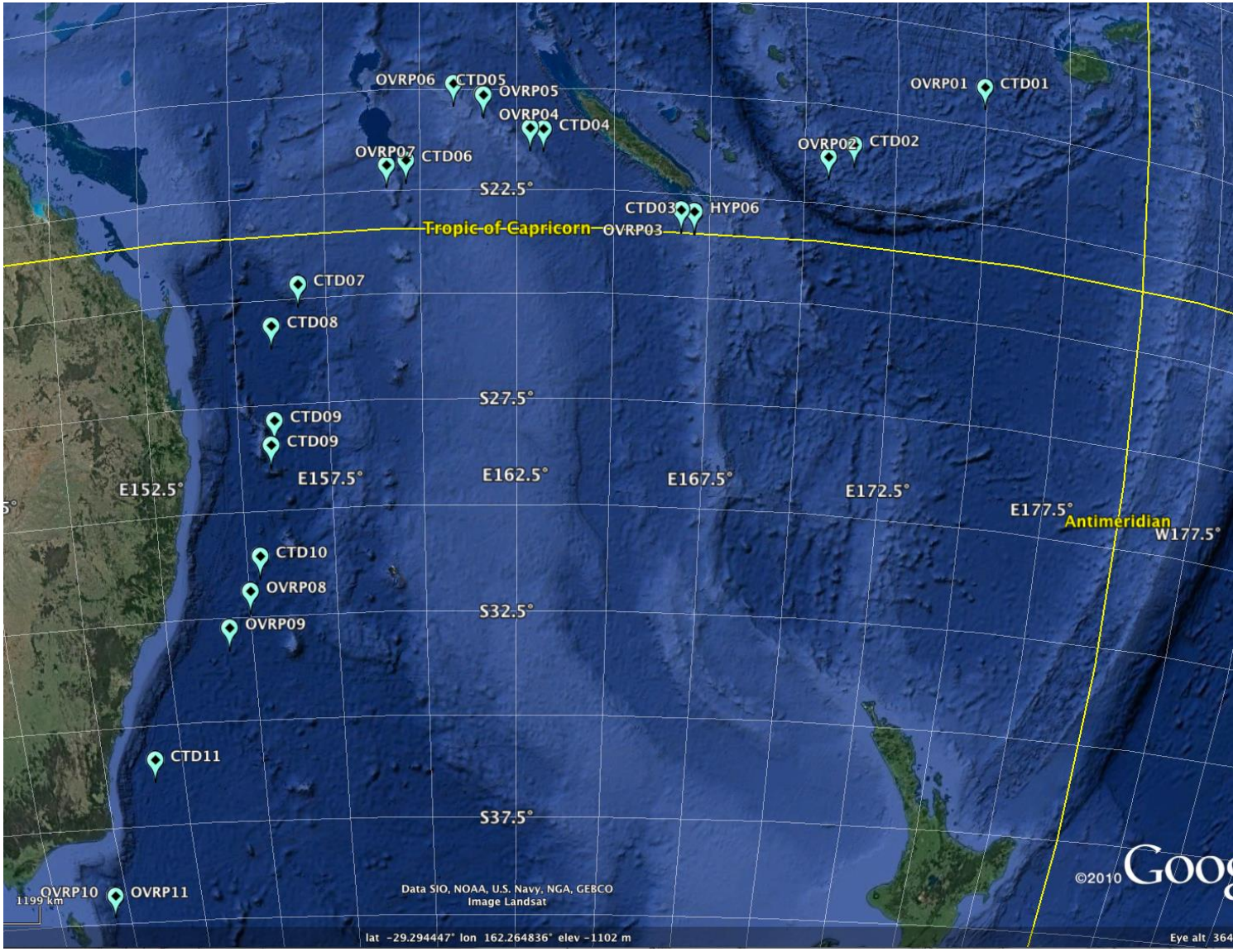
KORUS- off the coast of South Korea from May 20th to June 5th. Janmok conducted 35 stations. We measured Hyperpro, NURADS, Microtops, ASD Handheld II. Other groups measured pigments, IOPs and other relevant parameters.



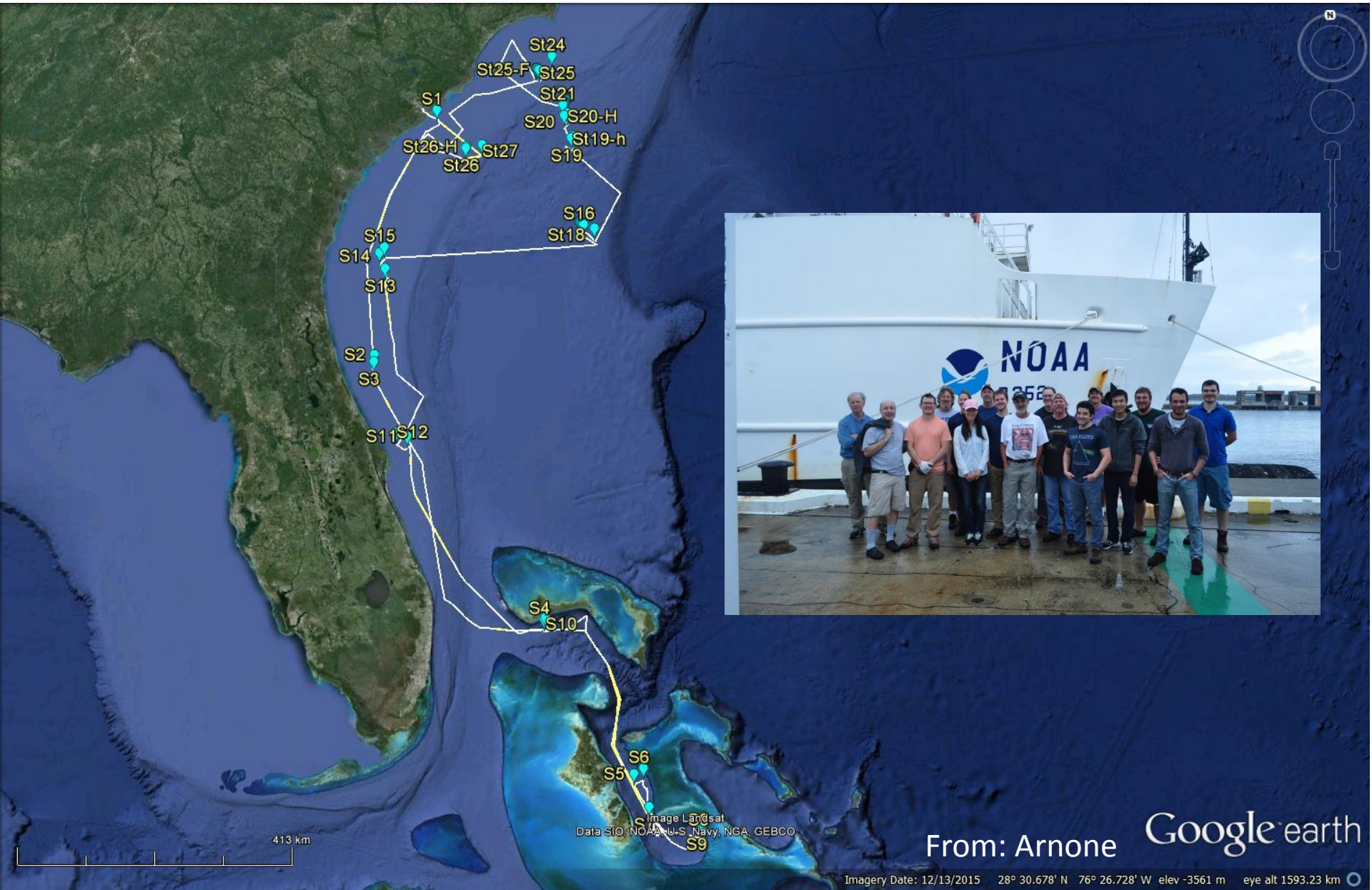
WCOA- From Baja, Mexico to Alaska from May 6th to June 5th. Aboard the NOAA Ship Ronald H. Brown. Measured Hyperpro, Microtops, pigments, Cdom, and particulate absorption. Other groups measured many other relevant parameters. 35 optical stations.



June – July 2016  CSIRO cruise – Fiji to Tasmania – 24 HyperPro II Stations with Microtops & ancillary chemistry & IOPs



# December 2015 Cal/Val Cruise







From: Arnone

# Science Objectives for the Cruise

**Goals**

**1) Validation of VIIRS JPSS Satellite Ocean Color products**

- **Occupied 27 Stations over 13 Days, 9 good station matchups with VIIRS**
- **Conducted pre- and post-cruise inter-cals**
- **Water-Leaving Radiance** - HyperPro, HyperTSRB, C-OPS, GER, SBA, HyperSAS, ASD Handheld 2
- **Aerosol Optical Depth** - Microtops
- **Bi-directional radiance distribution** - NURADS
- **Chlorophyll** - HPLC, Fluorometric, (in situ and extracted)
- **Absorption** - ACS, AC9, Spectrophotometric
- **Backscatter** - BB9, BB7, BB3, ECO Puck
- **Phytoplankton Physiology -** Imaging FlowCytobot
- **Carbon** - POC and DOC water analysis; plus CDOM
- **Total Suspended Matter** - Gravimetric

characterization of differences among the in situ ocean color measurements

# Science Objectives for the Cruise

**Goals (cont.)**

**2) Characterization of differences 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.

**3) Optical characterization of ocean variability (i.e. coastal, near-shore, cross-shelf, eddies, fronts, filaments, blue**

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

Principal investigators (PIs), participating institutions and institution abbreviations.

| PI Name (Last, First) | Participating Institutions | Research Group Abbreviation |
|---|---|---|
| Ondrusek, Michael* | NOAA/NESDIS Center for Satellite Applications and Research | NOAA/STAR |
| Ahmed, Sam | City College of New York | CCNY |
| Arnone, Robert | University of Southern Mississippi (USM) and Naval Research Center (NRL) | Stennis |
| Davis, Curtiss | Oregon State University | OSU |
| Gilerson, Alex | City College of New York | CCNY |
| Goes, Joaquim | Lamont-Doherty Earth Observatory at Columbia University | LDEO |
| Hu, Chuanmin | University of South Florida | USF |
| Johnson, B. Carol | National Institute of Standards and Technology | NIST |
| Lee, ZhongPing | University of Massachusetts, Boston | UMB |
| Mannino, Antonio | NASA Goddard Space Flight Center | NASA/GSFC |
| Voss, Kenneth | University of Miami | U. Miami |

List of science party personnel aboard the NOAA Ship *Nancy Foster* (alphabetical order).

| Name (Last, First) | Title | Research Group/Home Institution* |
|---|---|---|
| Arnone, Robert | Research Professor | Stennis/USM |
| Carrizo, Carlos | PhD Student | CCNY |
| Chavez, Joaquin | Staff Research Scientist | NASA/GSFC |
| Freeman, Scott | Staff Research Scientist | NASA/GSFC |
| el Habashi, Ahmed | PhD Student | CCNY |
| Kovach, Charles | Researcher | USF |
| Lin, Junfang | Postdoctoral Researcher | UMB |
| Ladner, Sherwin | Researcher | Stennis/NRL |
| Ondrusek, Michael | Chief Scientist | NOAA/STAR |
| Goode, Wesley | Researcher | Stennis/NRL |
| Ottaviani, Matteo | Researcher | CCNY |
| Stengel, Eric | Researcher | NOAA/STAR |
| Tufillaro, Nicholas | Researcher | OSU |
| Vandermeulen, Ryan | Remote Sensing Analyst | Stennis/USM |
| Wang, Guoqiang | PhD Student | UMB |

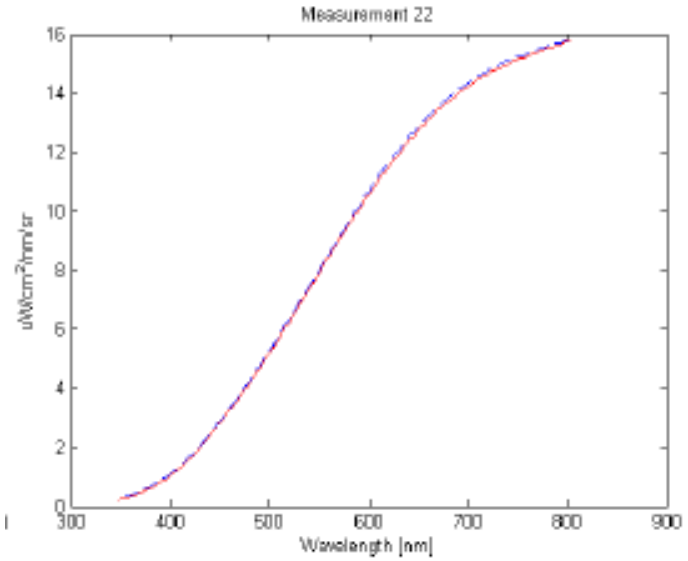
Pre-cruise calibrations done 11/19/15
Post-cruise calibrations done 1/5/16, 1/27/16 and 1/28/16

29 instrument calibrated
10 radiance
16 Irradiance
2 Par
1 ASD

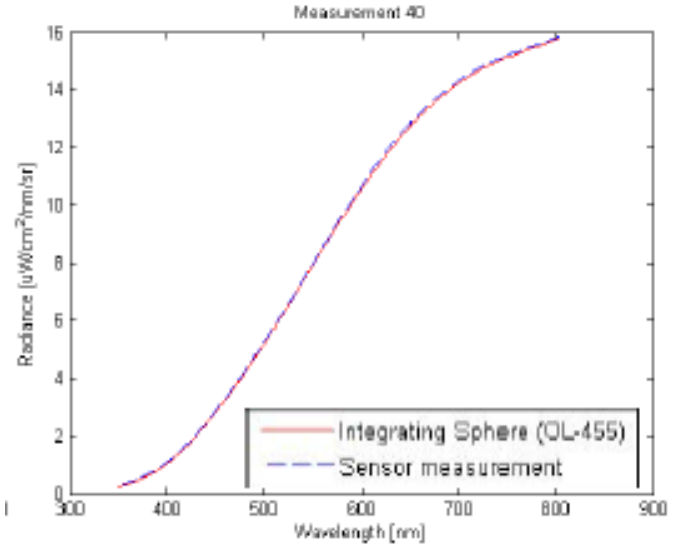
Radiance with plaque and integrating sphere
Irradiance directly with NIST Fel lamp

206 Lu Radiance

NEW CAL
(SLC)




BEFORE
CRUISE

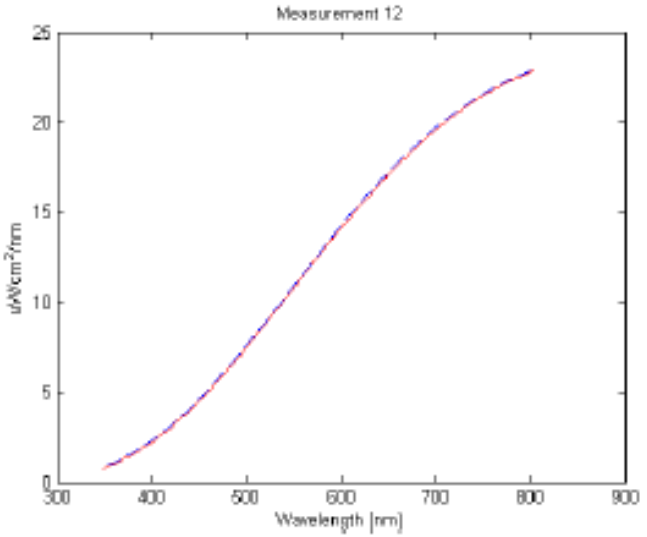



AFTER
CRUISE

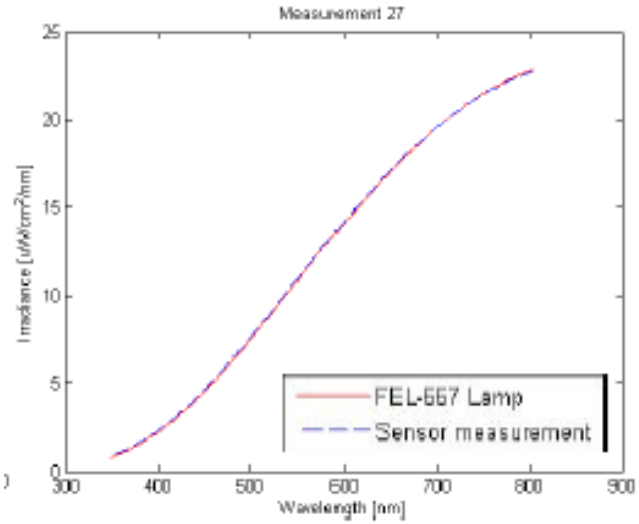
NEW CAL
(SLC)

233 Ed Irradiance

NEW CAL
(SLC)




BEFORE
CRUISE



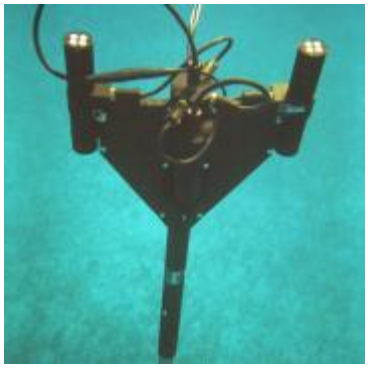

AFTER
CRUISE

NEW CAL
(SLC)

# Instruments used to measure Remote Sensing Reflectance

**Profilers**



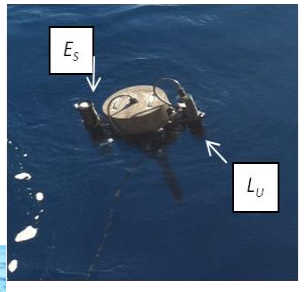


**3 HyperPro** (Satlantic) – free-falling hyperspectral optical profiler. 10 nm bands sampled every 3 nm. Radiance FOV 8.5 degrees.  Calibrated from 350 to 800 nm.

**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

**2 HyperTSRB** (Satlantic) – 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).

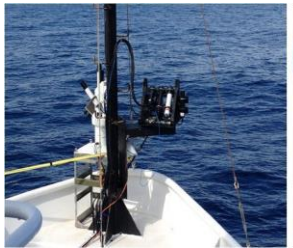
## Above-water



**3 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).

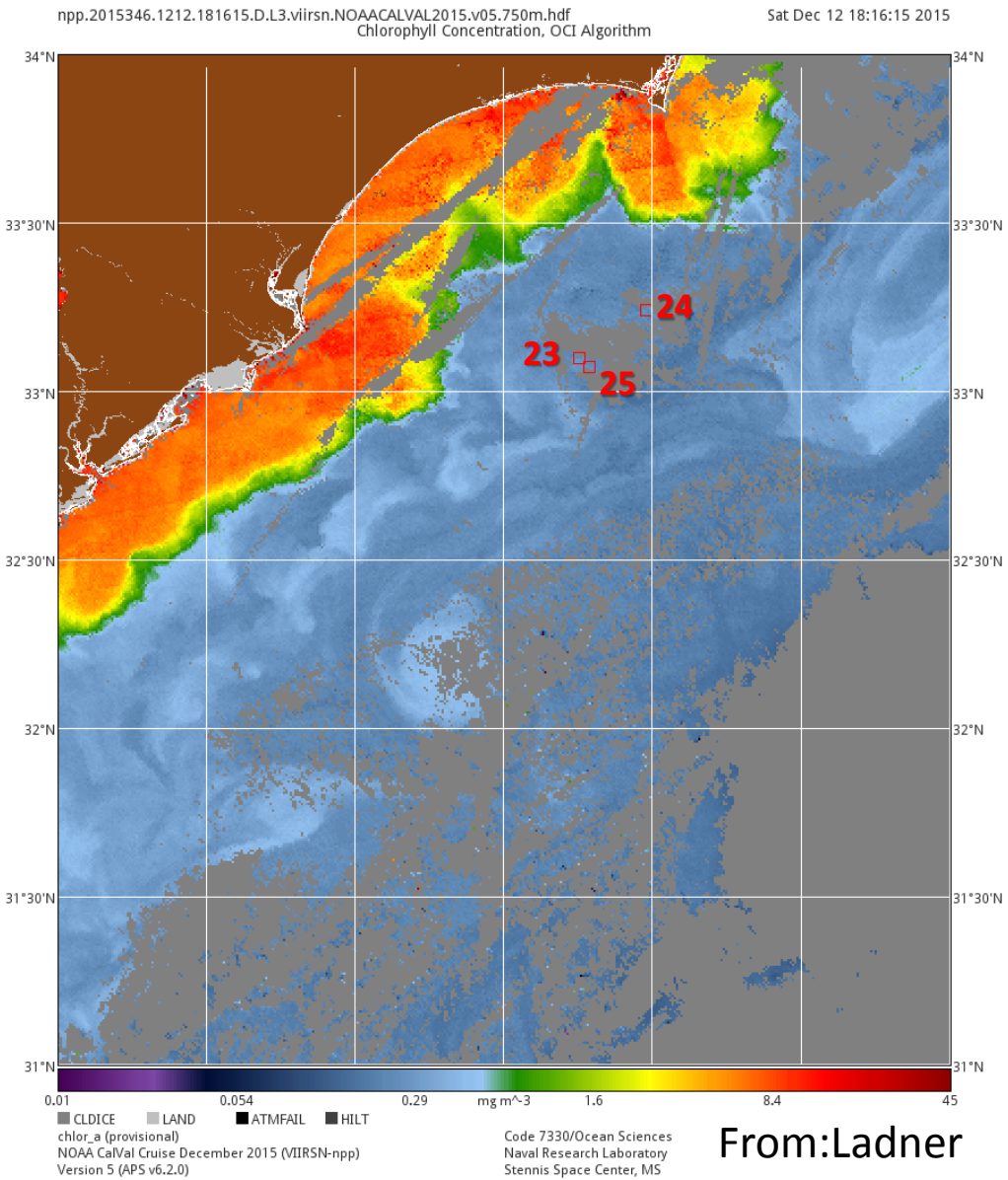




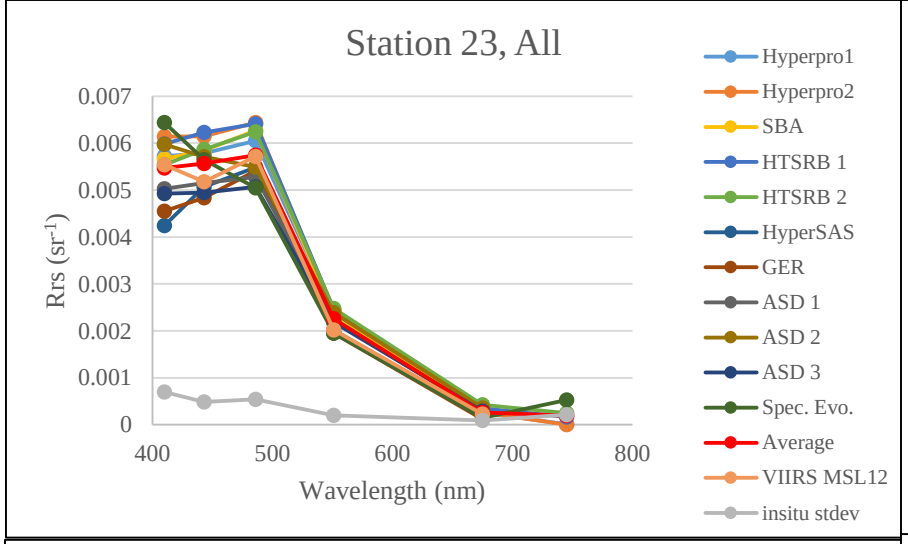
**2 HyperSAS** (Satlantic) – Autonomous above-water OCR's with narrow FOV of 3 degrees. Also set up to measure polarization

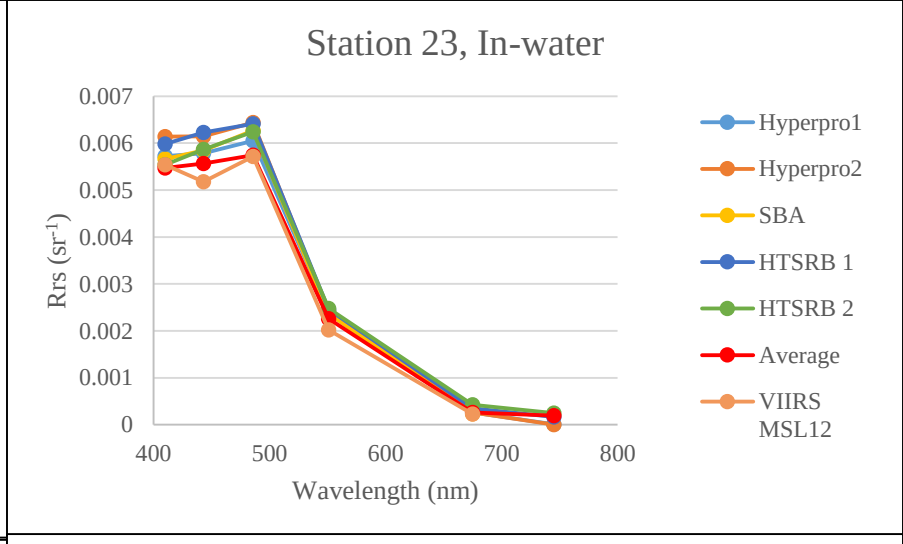
**Spectral Evolution –** 280 to 1900 nm handheld above water radiometer

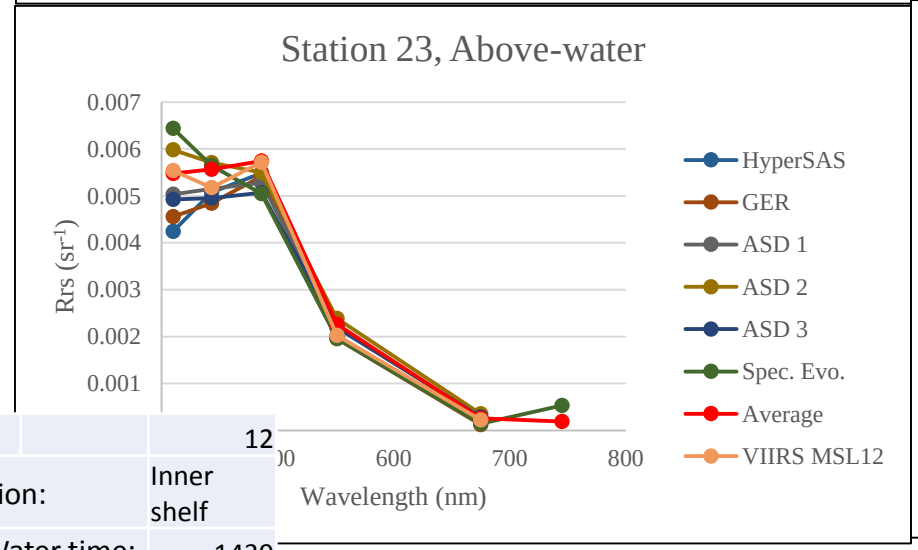
# 12/12/16 (1816 GMT)
# St. 23,24,25

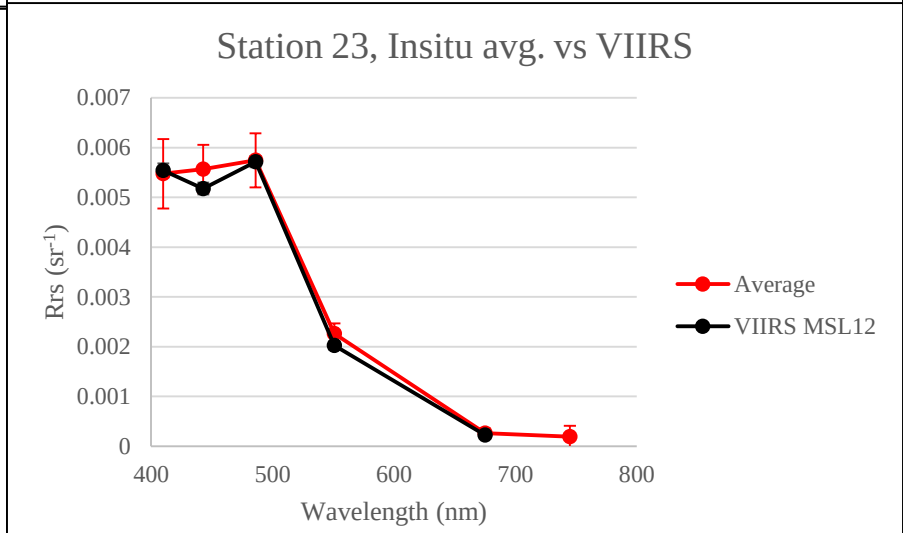



From:Ladner



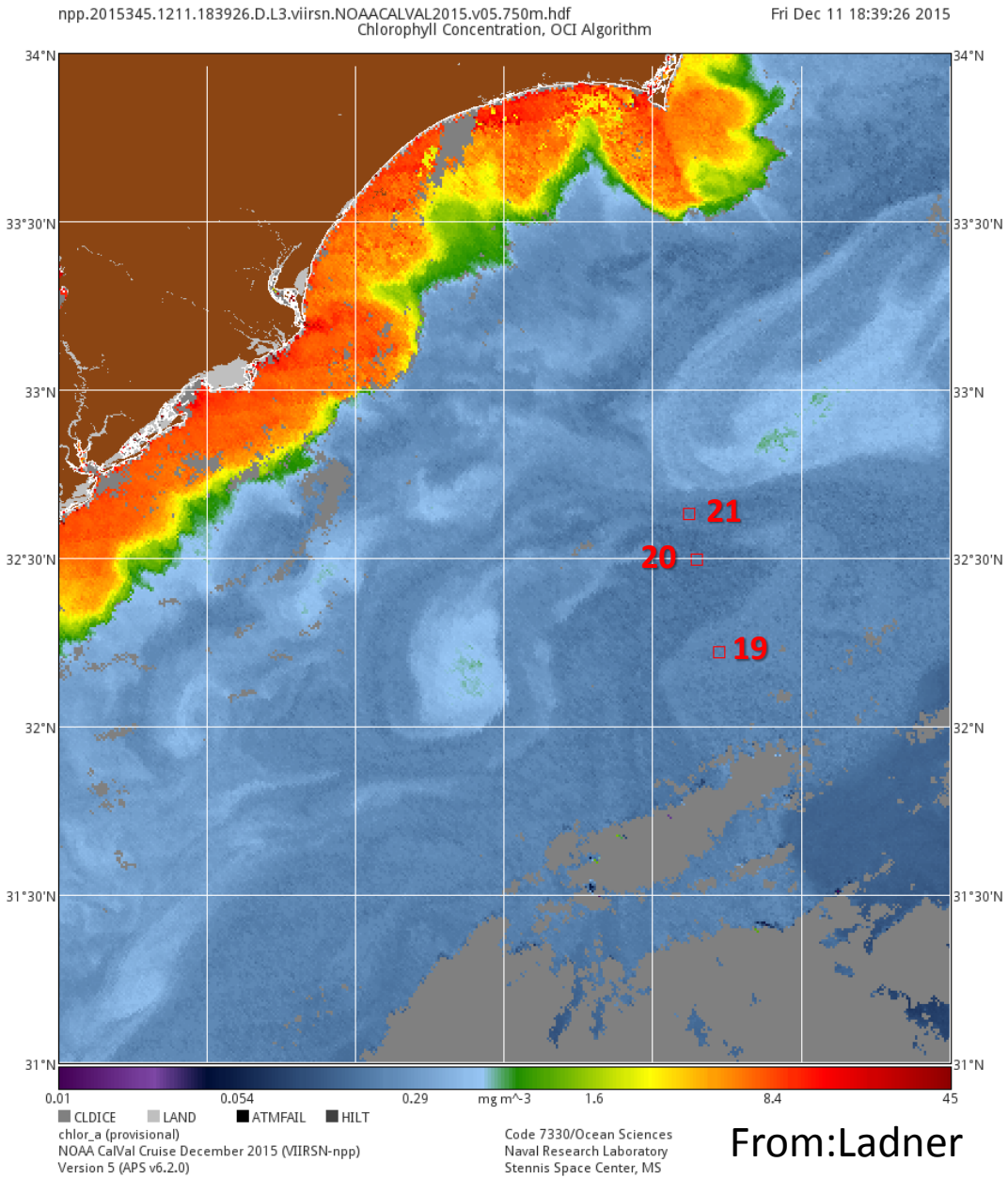




| | |
|---|---|
| Date: | 12 |
| Description: | Inner shelf |
| Above-Water time: | 1439 |
| Surface time: | 1345 |
| Profile time: | 1439 |
| Depth: | 50 |
| Cloud cover: | 0 |
| Wind speed: | 7 |
| Seas (ft.): | 2 |
| Chl (mg/m3) | 0.304 |
| # pixels in 5 x 5 | 22 |

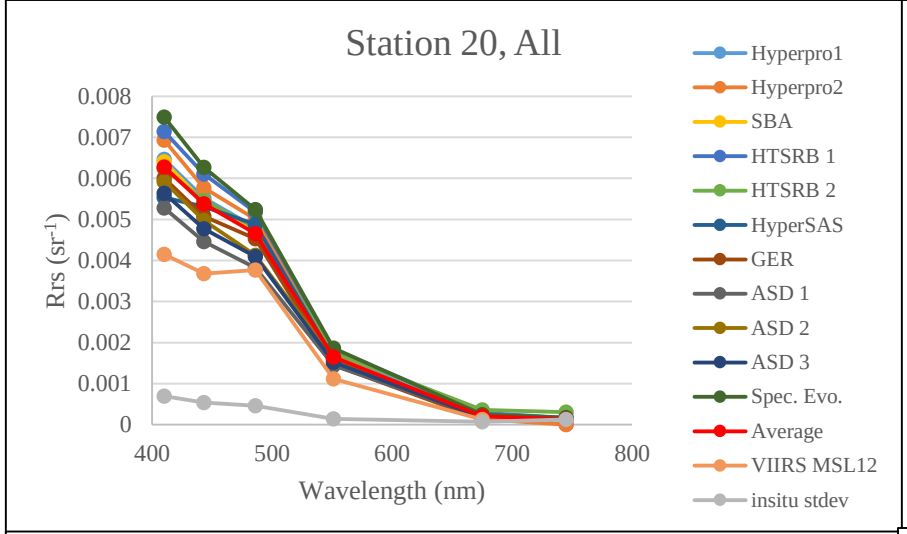
Percent Difference relative to Average

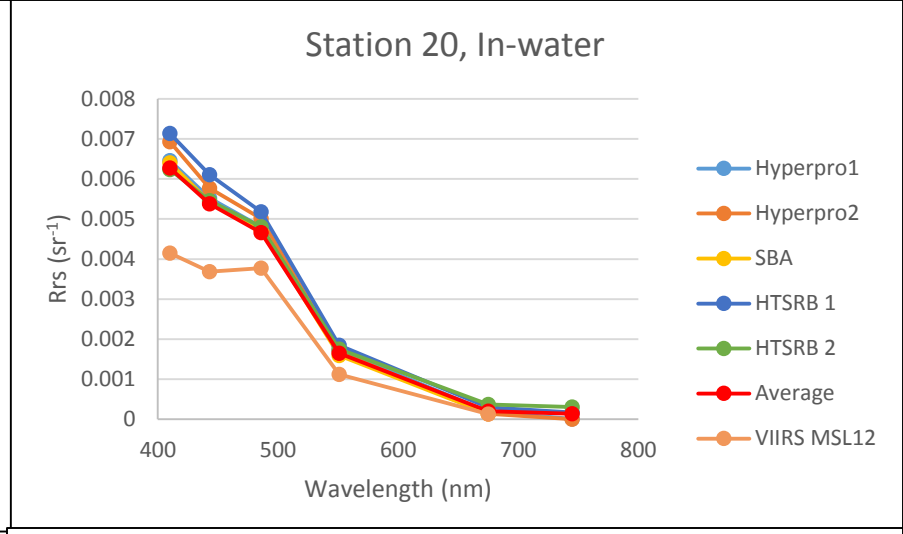
| Band | Hyperpro1 | Hyperpro2 | SBA | HTSRB 1 | HTSRB 2 | HyperSAS | GER | ASD 1 | ASD 2 | ASD 3 | Spec. Evo. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 410 | 4.52 | 12.19 | 3.47 | 9.27 | 1.16 | -22.51 | -16.83 | -8.10 | 9.20 | -10.01 | 17.63 |
| 443 | 3.95 | 10.44 | 4.99 | 11.85 | 5.41 | -8.92 | -13.08 | -7.52 | 2.55 | -11.12 | 1.45 |
| 486 | 5.27 | 12.05 | 9.14 | 11.59 | 8.66 | -4.54 | -5.79 | -8.13 | -4.37 | -11.78 | -12.11 |
| 551 | 6.61 | 7.00 | 4.88 | 8.58 | 9.72 | -10.75 | -13.51 | -1.39 | 5.60 | -3.25 | -13.50 |
| 675 | -1.35 | -0.17 | -9.57 | 33.91 | 62.03 | -33.80 | -54.18 | 1.07 | 35.78 | 10.22 | -43.94 |

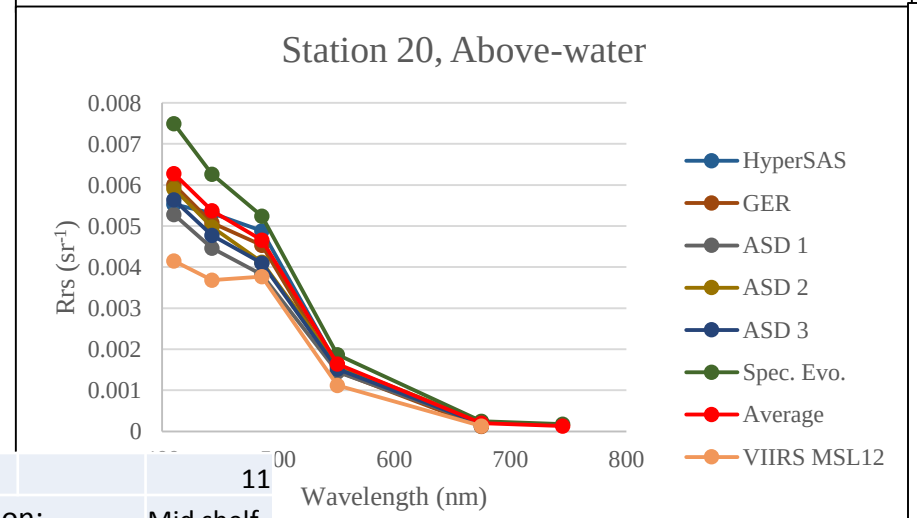
# 12/11/16 (1839 GMT)
# St. 19,20,21

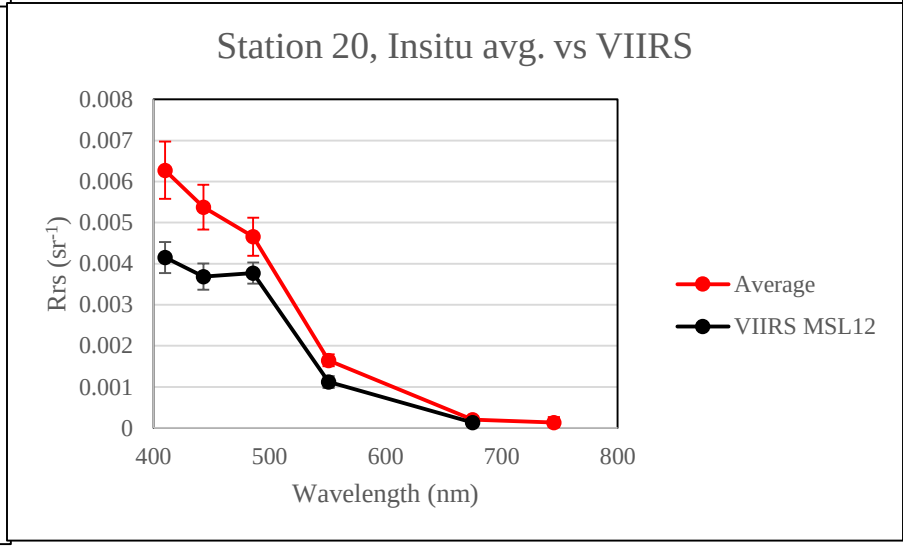



From:Ladner




| | |
|---|---|
| Date: | 11 |
| Description: | Mid shelf |
| Above-Water time: | 1643 |
| Surface time: | 1700 |
| Profile time: | 1731 |
| Depth: | 1000 |
| Cloud cover: | 0 |
| Wind speed: | 8.3 |
| Seas (ft.): | 2 |
| Chl (mg/m3) | 0.336 |
| # pixels in 5 x 5 | 23 |

Percent Difference relative to Average

| Band | Hyperpro1 | Hyperpro2 | SBA | HTSRB 1 | HTSRB 2 | HyperSAS | GER | ASD 1 | ASD 2 | ASD 3 | Spec. Evo. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 410 | 2.95 | 10.42 | 2.01 | 13.76 | -0.65 | -11.84 | -4.36 | -15.84 | -5.73 | -10.15 | 19.43 |
| 443 | 2.72 | 7.25 | 0.86 | 13.59 | 1.53 | -1.21 | -5.58 | -16.99 | -7.45 | -11.21 | 16.50 |
| 486 | 3.18 | 7.56 | 1.61 | 11.17 | 3.20 | 4.84 | -2.66 | -17.96 | -11.45 | -12.04 | 12.55 |
| 551 | 5.01 | 1.83 | -3.48 | 12.12 | 6.60 | -2.36 | -11.13 | -12.09 | -2.19 | -7.63 | 13.30 |
| 675 | -8.32 | -31.58 | -31.47 | 45.59 | 79.57 | -35.50 | -38.38 | -7.68 | 16.27 | -10.64 | 22.13 |

Instrument Percent difference relative to average of all instruments

## 2014 VIIRS Validation Cruise

| Band | Hyperpro | Hyperpro | Micropro | C-OPS | SBA | HyperTSRB | ASD | ASD | GER | HyperSAS |
|---|---|---|---|---|---|---|---|---|---|---|
| 410 | 4.83 | -0.41 | 1.93 | -1.49 | -9.01 | -4.29 | 6.47 | -1.82 | 4.04 | -0.75 |
| 443 | 6.84 | 3.12 | -0.35 | -4.21 | -8.90 | -0.28 | 1.34 | -3.30 | 6.19 | -1.31 |
| 486 | 4.83 | 3.81 | -0.37 | -2.19 | -9.86 | 1.01 | -4.71 | -2.21 | 10.38 | -0.75 |
| 551 | 5.22 | 4.14 | -1.86 | -7.24 | -9.12 | 5.52 | -0.11 | -4.75 | 8.53 | -1.16 |
| 675 | -9.18 | -14.02 | -14.91 | -17.22 | -8.57 | 36.15 | 38.47 | 0.24 | 5.46 | -11.25 |
| All | 2.51 | -0.67 | -3.11 | -6.47 | -9.09 | 7.62 | 8.29 | -2.37 | 6.92 | -3.04 |

## 2015 VIIRS Validation Cruise

| Band | Hyperpro | Hyperpro | Spec Evo | SBA | HTSRB 1 | HTSRB 2 | ASD 1 | ASD 2 | ASD 3 | GER | HyperSAS |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 410 | 3.88 | 13.32 | 14.46 | -1.04 | -0.97 | -1.68 | -6.04 | 2.29 | -12.15 | -7.30 | -17.42 |
| 443 | 4.97 | 10.15 | 10.09 | 0.48 | -1.31 | 0.41 | -10.97 | -3.32 | -12.94 | -4.97 | -4.86 |
| 486 | 6.45 | 9.93 | 4.84 | 1.37 | -2.34 | 3.36 | -15.05 | -8.95 | -14.12 | 1.09 | 0.92 |
| 551 | 7.39 | 3.18 | 6.46 | -2.70 | -2.06 | 6.48 | -10.68 | -2.11 | -8.75 | -5.98 | -3.61 |
| 675 | -5.43 | -17.26 | -3.61 | -33.49 | 50.99 | 72.27 | -5.04 | 9.29 | -7.03 | -44.38 | -35.22 |
| Average | 3.45 | 3.86 | 6.45 | -7.08 | 8.86 | 16.17 | -9.56 | -0.56 | -11.00 | -12.31 | -12.04 |

# MSL12 VIIRS Percent difference relative to in situ

## 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** |

**Going Forward:**

- **Third Annual VIIRS Cal/Val cruise aboard the Nancy Foster out of Charleston, SC.  Oct 5 to 19, 2016**

- **NASA/CSIRO CORAL cruise conducting optical characterizations over the Great Barrier Reef.**

Session 7

**2016 STAR JPSS Annual Science Team Meeting,**
**College Park, Maryland**
**August 8-12, 2016**

# Evaluation of VIIRS Ocean Color products and development of enhanced ocean products and applications

*Robert Arnone[1], Sherwin Ladner[2],Bill Gibson[3] , Ryan Vandermuelen[4], Wes Goode[2], Jen Bowers[2]*

1- University of Southern MS
2. Naval Research Laboratory
3. La State University
4. SSAI/NASA.GSFC

## Stennis - Cal val Team Annual Summary

# Cal Val Highlights of the Past year 2015 – 2016

**Outline**

**A. Foster Cruise – Dec 2015 - Tongue of Ocean / Gulf Stream Cruise**

1. Cruise track - Optical Shallow - Gulf Stream Crossing and Shingles
2. Protocols Floating HyperPro ,ASD, IOP Flow–

**B. VIIRS Validation in Gulf of Mexico**

**C. Diurnal changes in ocean color - VIIRS validation**

WavCis changes in Color

VIIRS orbital overlaps and Matchups

Processes shown in Diurnal changes

**D. WavCis -- status**

**Stennis - Cal val Team**

# Dec 2015 – Cal Val Cruise - Nancy Foster

## Gulf Stream and Tongue of Ocean

**Stennis Cal Val team**

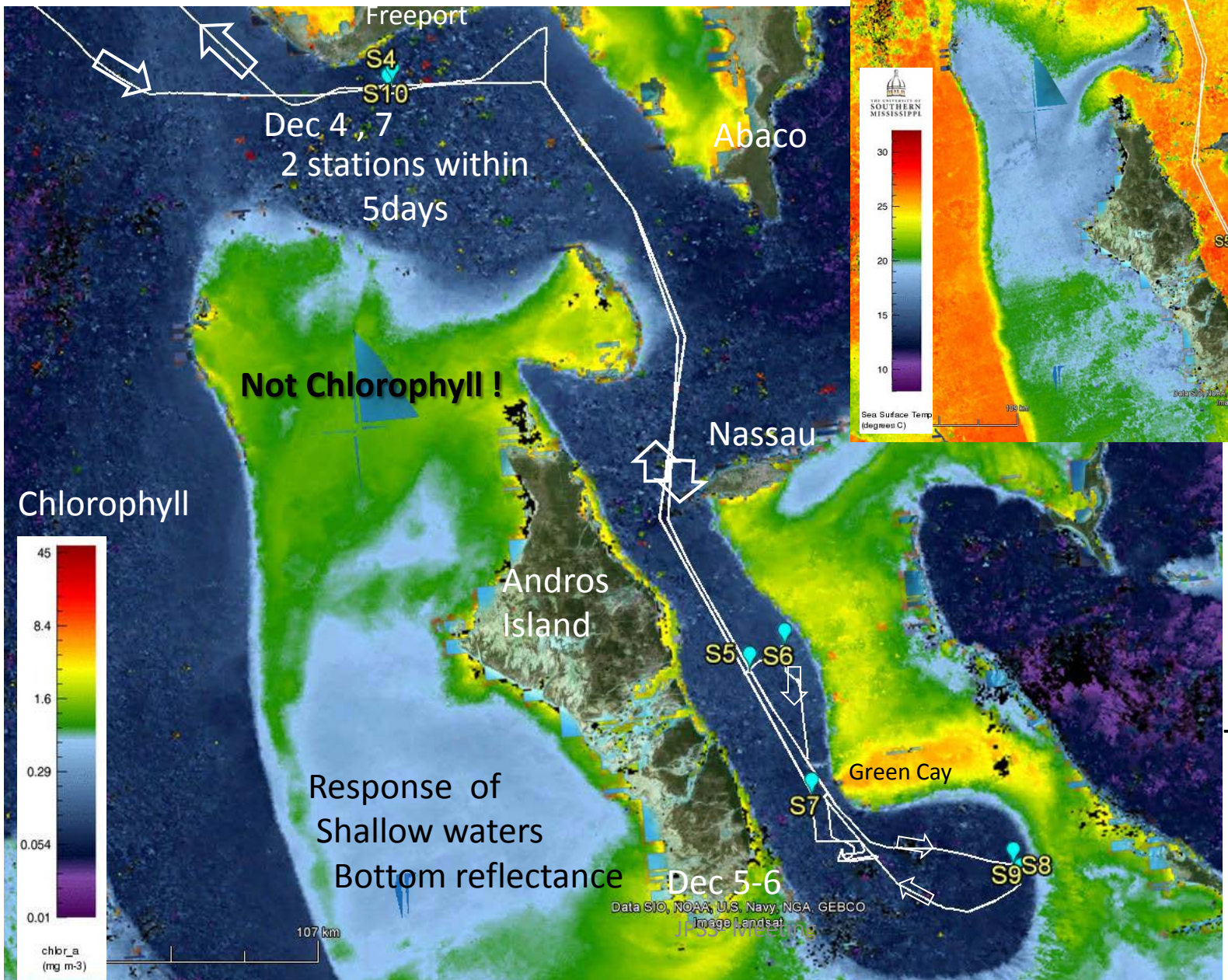
**GOALS:**

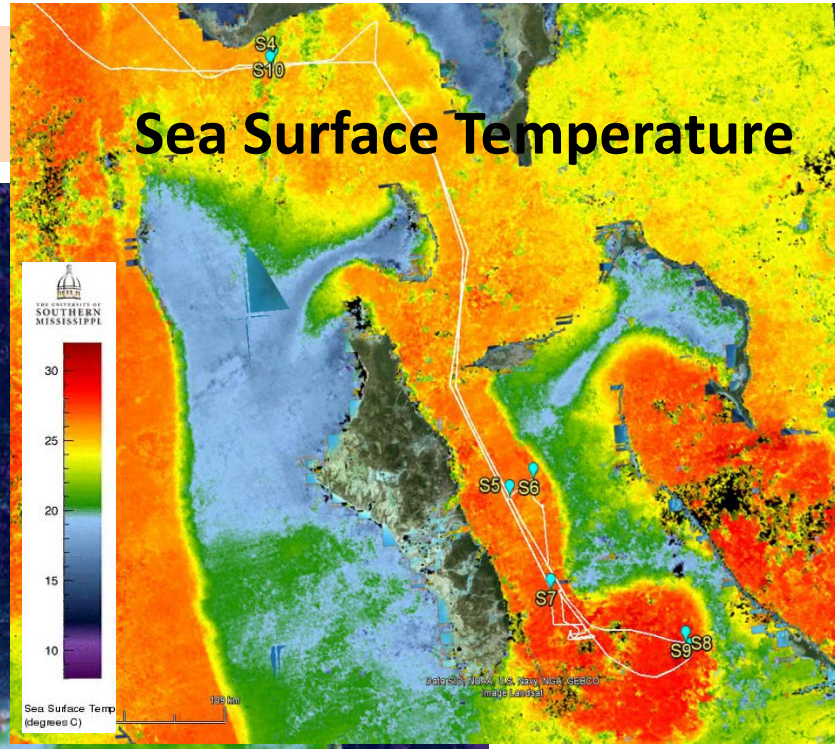
1. **Tongue of Ocean - Optically Shallow waters-**
   **Examine the changes in nLw in optically shallow waters in Tongue of Ocean**
2. **Compare optical measurements for nLw for VIIRS validation ASD/ Hyperpro**
3. **Protocols for insitu data collection**
4. **Validate VIIRS products to define Gulf Stream processes waters**
   **(Eddies, Shingles, Fronts)**

**Dec 2015 Cruise**

Tongue of the Ocean → 7 Stations

Water – Stable, Consistency,




Response
Of SST over
shallow Waters
- Cooler of
Shallow waters

Tongue waters
- Stable
- Low Winds
- Optically Clear

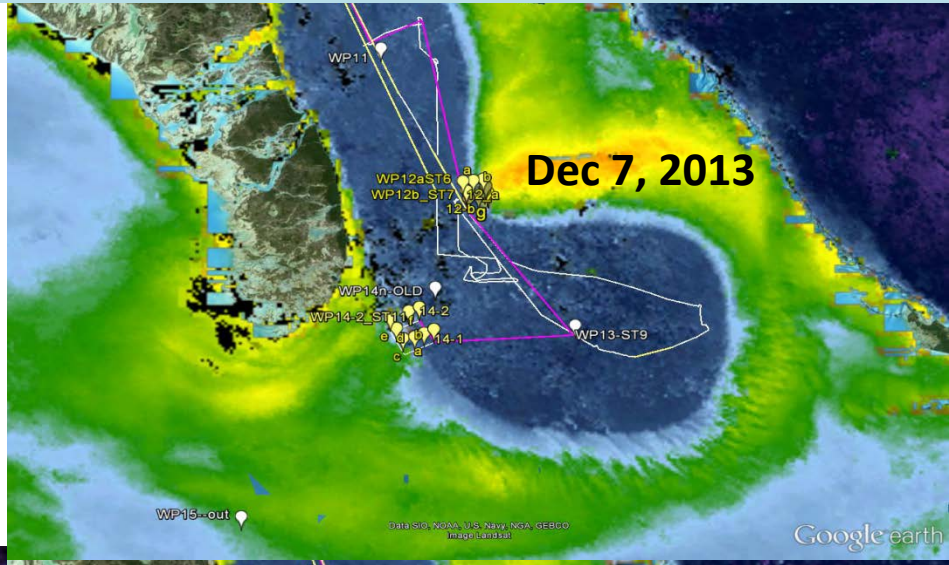
# Dec 2015 Cruise — Similar VIIRS Products in Optically Shallow waters !

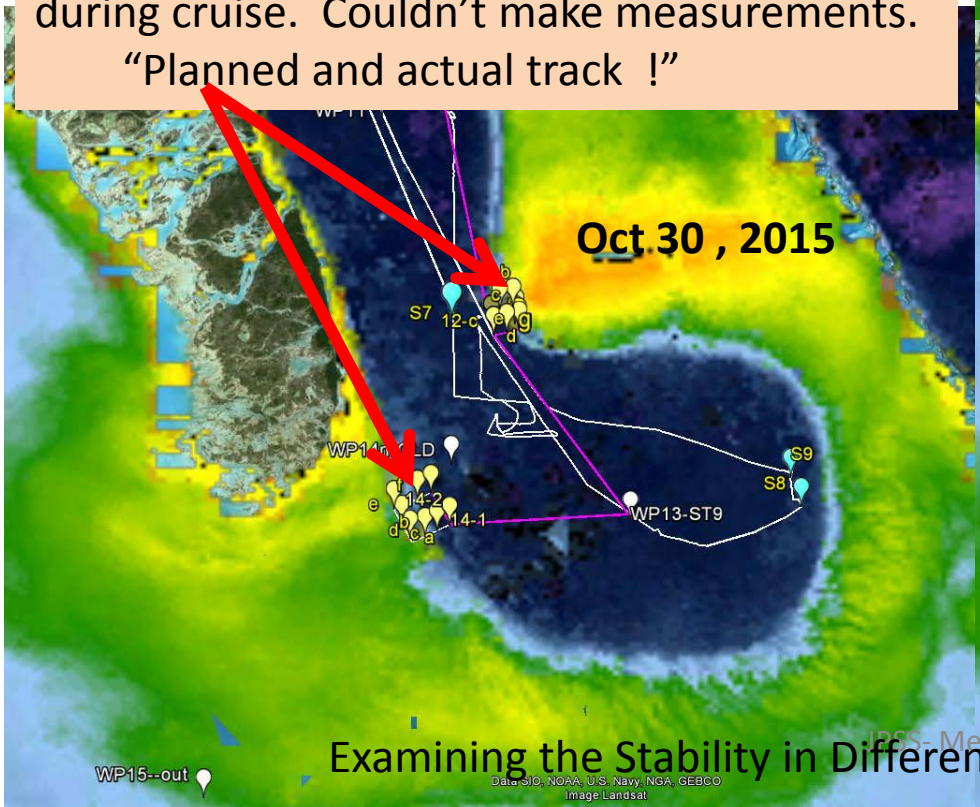
## Tongue of Ocean

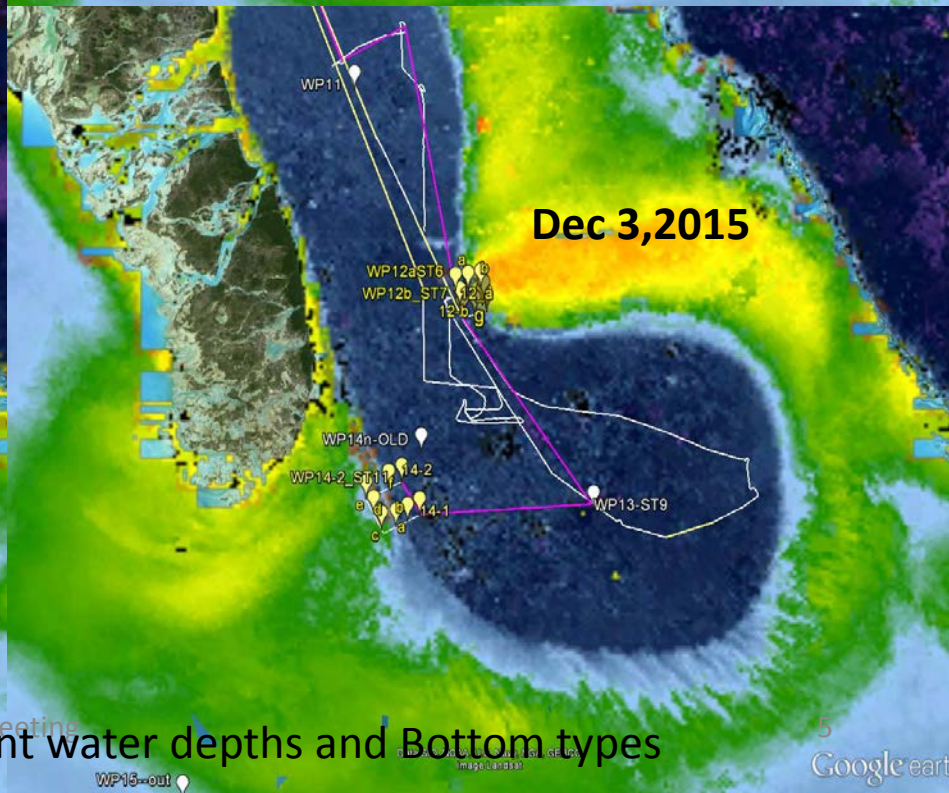
1- Optically Shallow waters Show similar nLw and Chl through the year. !
How stable are this RRS?
Stability in water depth and bottom reflectance

2- Can Stable Optically Shallow regions be used for VIIRS nLw validation?

Unfortunately
Had Bad weather conditions in Tongue during cruise. Couldn't make measurements.
"Planned and actual track !"



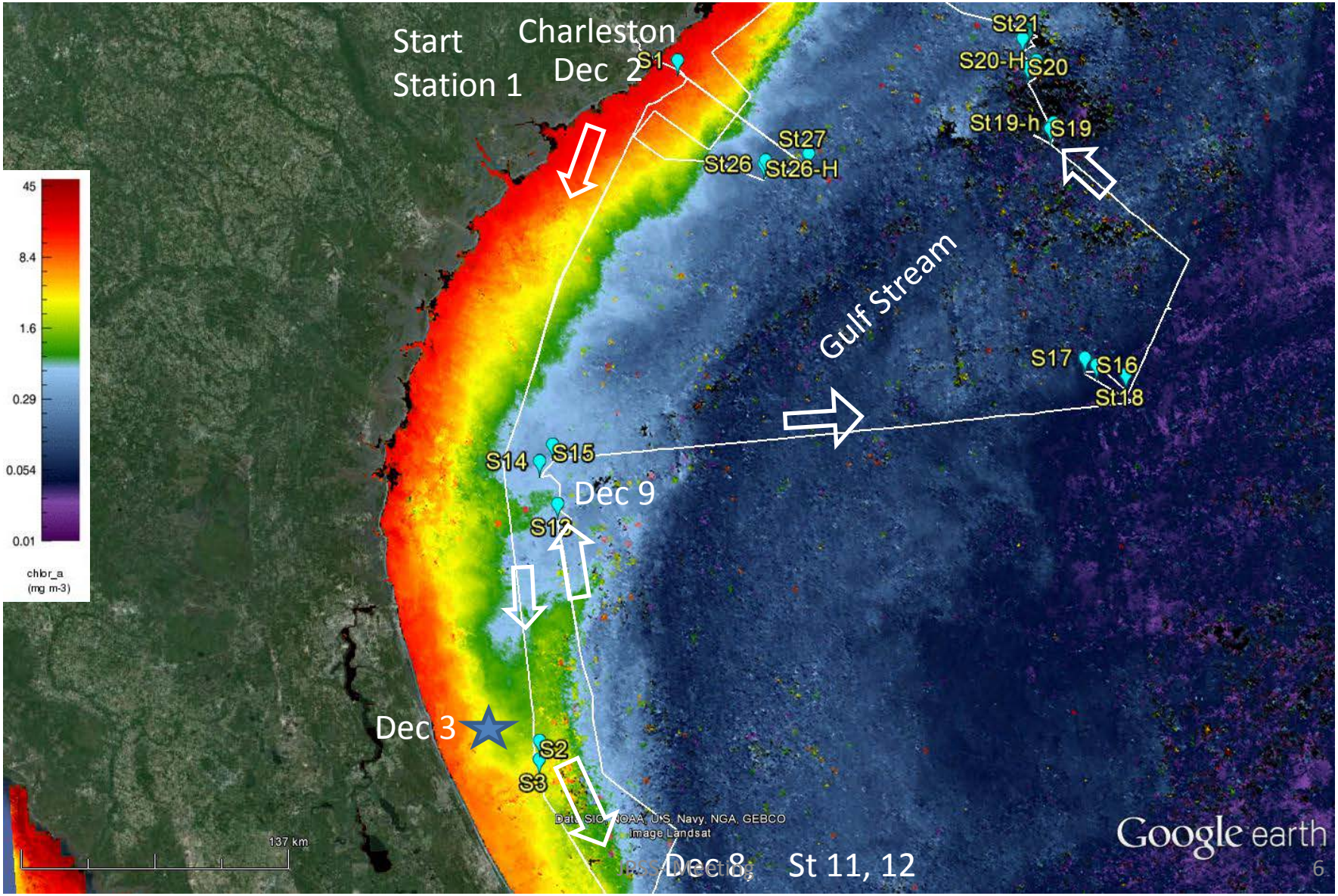

Examining the Stability in Different water depths and Bottom types

Dec 2015 Cruise

# Foster 2015 Cruise Track and Stations Selection

**Conditions improved Dec 8**

**Crossed Gulf Stream twice**



# Dec 2015 Cruise — Cruise Data Collected

UTC is +0500 local

Date - 2015
start time (UTC)
Julian -Day
Start time (GMT)
Julian date+time
Lat (degrees decimal min)
Lon (degrees decimal min)
Flowthrough hour Scan count(ship)
Sky cover (% clouds)
wind direction
wind speed (kt)
sea state (feet)
Water Depth
Secchi depth (Time same as Floaters)

**Station Specs**

**Optical Profilers** — 3

Ship Rossett - profiler- CTD, Chl-Fluorometer, O2
NASA -IOP Package , acs,ac9,bb9,vsf,SBE (Comments)
UMB - opticsPackage CTD, ACS,

**Hyperpro Profilers** — 4

GOOD VIIRS_MATCHUP - Mike
HyperPro - MIKE
C-Ops NASA (ELMO) 3(radiometers)
Hyperpro - USF
Hyperpro- OSU

**Floats** — 3

Hyperpro- Float (PUFF) USM
Hyperpro- Float ( NRL)
Hyperpro SBA- (BIG BIRD)

NURADS
Fiber - CUNY

**ABOVE WATER Radiometry** — 9

ASD - NOAA 1847
ASD - USM 1338
ASD - NRL 1707
ASD -USF 1007
ASD - CUNY 1075
ASD - Fiber CUNY
ASD Blue Card comparison
Specreal Evolution - OSU
Spectral Evolution - UMB
GER -CUNY
GER Fiber - CUNY
Cuny polarizatom Camera

**Bow mounts**

Microtops - NOAA
Microtops - NRL
Microtops - USF
Microtops - CUNY
Microtops - umb
HYPERsas - Bow CUNY
Hypersas - Bow Scott

**Water Samples** — 9

CHl_filted =Mike
Chlorophyll Filtered - NASA
HPLC Pigment
Nutrients
Particulate Org Carbon
CDOM
Dissolved Org Carbon
Pad absorption - USF
TSS- Stengel *
Flowcam ifcb
Samples - LUGOL'S

**Ship Flow** — 9

FLOWTHROUGH Data entire cruise
Ship Temperature
Ship Salinity
Ship Fluorescence volts chl and UV
IOP- Flowthrough acs- Filtered and Unfiltered
Flowthrough Backscattering (470,532,670 Nm)
PAR- 2

**Station Specs**

VIIRS Overpass Time (UTC)
Time off station
LATITUDE
LONGITUDE
Station Notes - drift

S- Meeting

etir

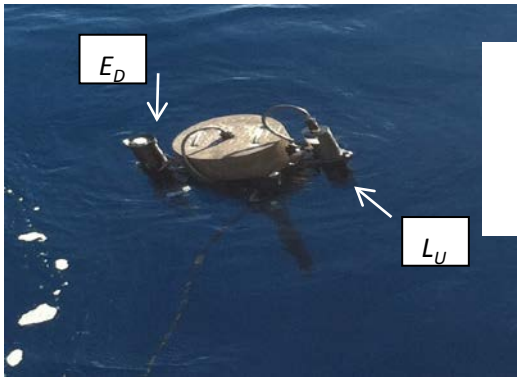
Dec 2015 Cruise

# Objective 2: Compare Variability in Insitu Data Radiometry for Cal Val of VIIRS

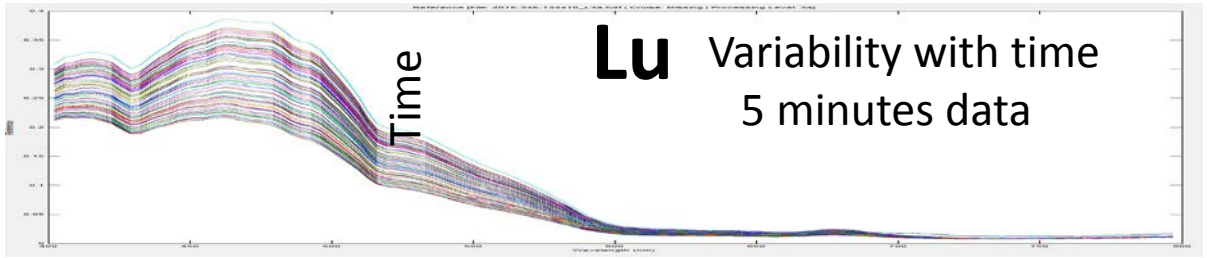
## Establish protocols

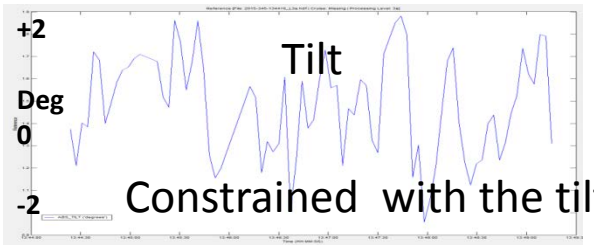
**" Floating Hyperpros" - Prosoft 8.1.4**

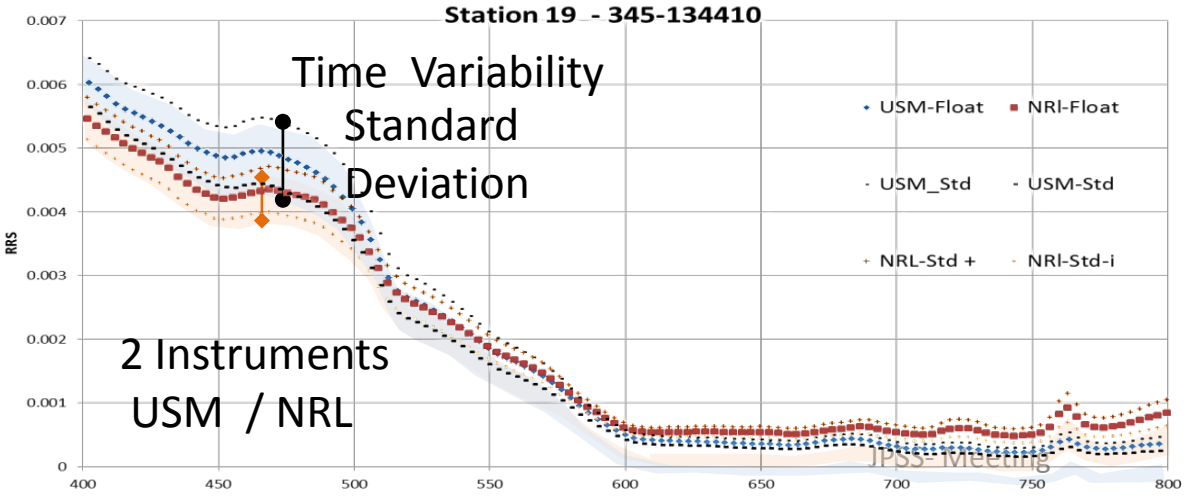
**Time changes of the Radiances - Constrained the tilt**




ES on Ship

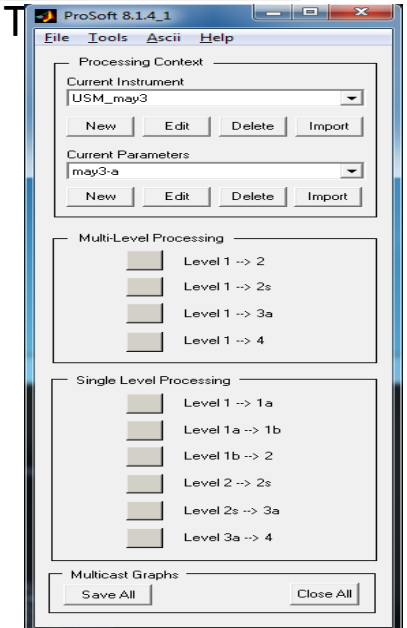



Prosoft Processing Details

Similar results For 2 Float Hyperpros



Dec 2015 Cruise

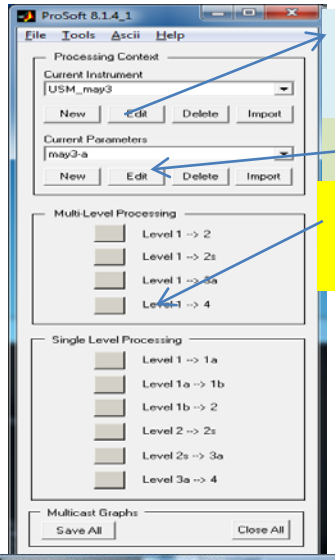
# Floating "Hyperpros" Protocols
# Prosoft 8.1.4.

From: Bob Arnone

Protocols used - for Post Processing

**Floating Hyperpro Protocols For RRS**

Steps




#1 Edit and load the cal
-

#2 - Edit to set up parameters

#3 Ready to process.
level 1→ Level 4

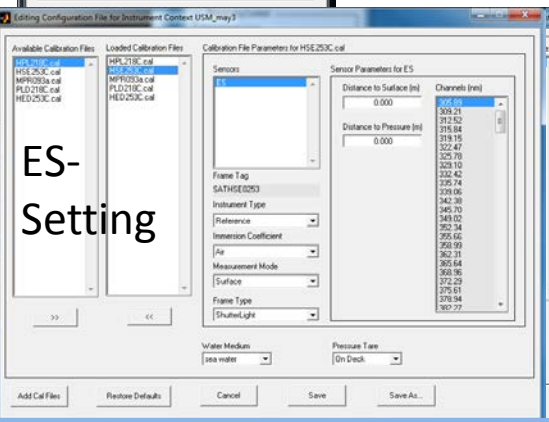
PROFILER : WET
REFERENCE : OFF
PRO-DARK : OFF
REF-DARK : OFF
PRO-ID : MPR0093
PROCESSING_LEVEL : 4
FILE_CREATION_TIME : 11-Mar-2016 17:27:47
DEGLITCH_PRODAT : OFF
DEGLITCH_REFDAT : OFF
STRAY_LIGHT_CORRECT : OFF
THERMAL_RESPONSIVITY_CORRECT : OFF
DEPTH_RESOLUTION : 0.01 m
BIN_INTERVAL : 0.05 m
BIN_WIDTH : 0.1 m
TIME_INTERVAL : 2 sec
TIME_WIDTH : 1 sec
WAVEL_INTERP : 0 nm
INTEGRATION_POINTS : 5
REFLECTION_ALBEDO : 0.043
REFLECTANCE_INDEX : 0.021
REFRACTIVE_INDEX : 1.345
ET_SOLAR_SPECTRUM : Thuillier
WATER_MEDIUM : sea water
LS_DISTANCE_SURF : 0.2

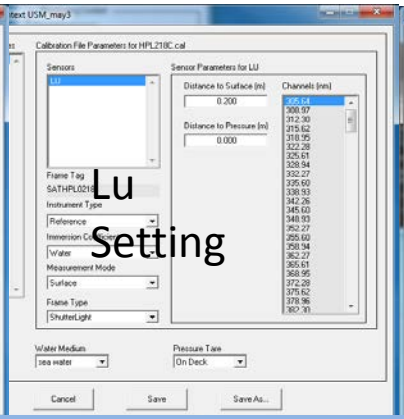
$$L_w(\lambda) = \frac{1-\rho}{n^2} L_u(0^-,\lambda)$$

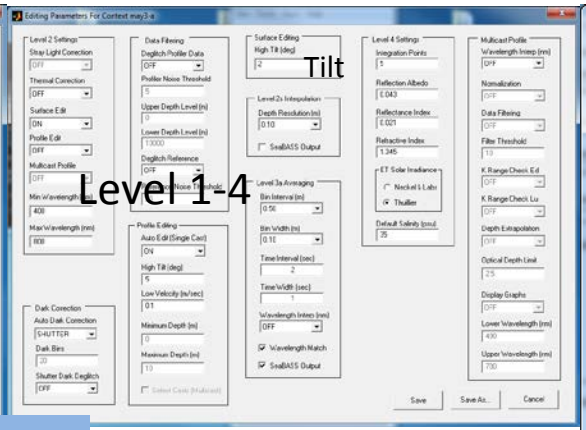
$\rho$ = 0.025 is the Fresnel reflectance of the air sea interface,
$n$ = 1.34 is the refractive index of seawater.

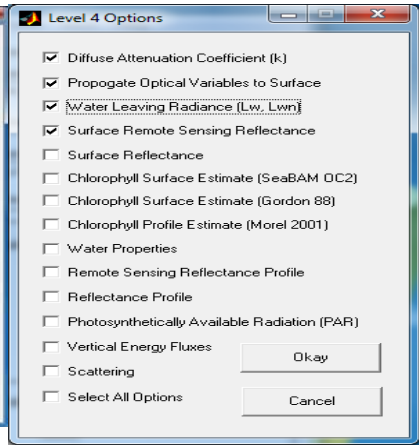
Remote sensing reflectance

$$R_{RS}(\lambda) = \frac{L_w(\lambda)}{E_S(\lambda)}$$



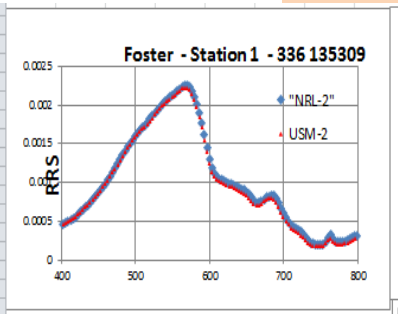

**Have details for Hyperpro Processing For anyone interested ?**

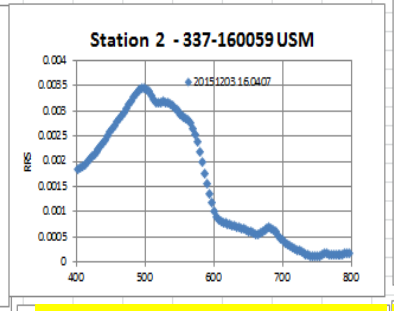
Dec 2015 Cruise

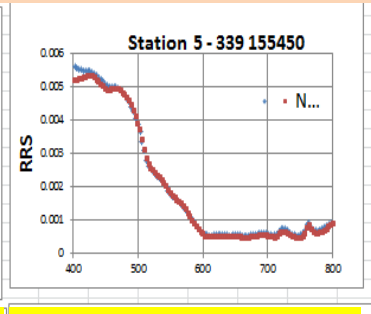
# Agreement of 2 Floating Hyperpro USM and NRL

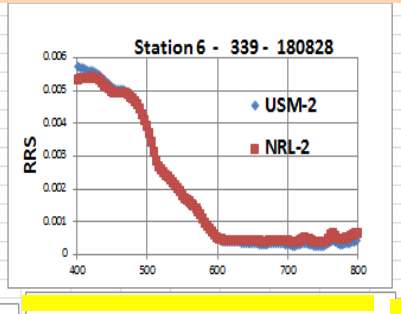
## Averaged Lu and Es Sensor filtered the 2deg Tilt

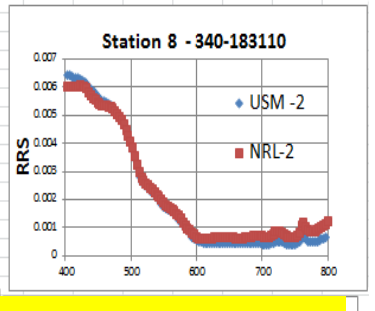
## Compared with the Above water ASD 14 Station Matchups

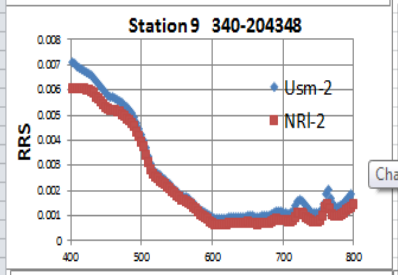


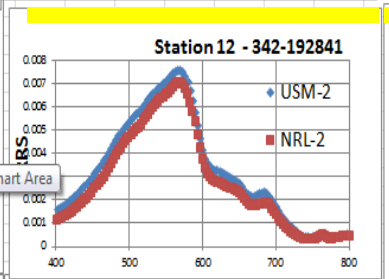



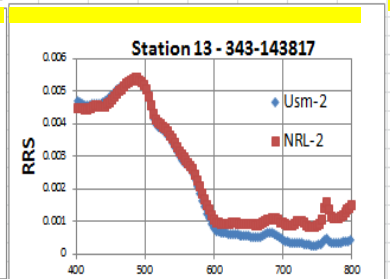



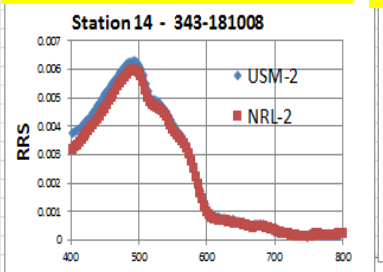



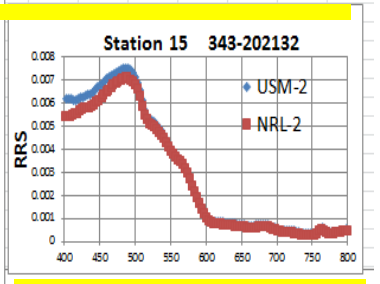



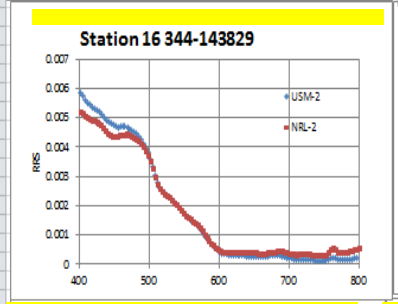



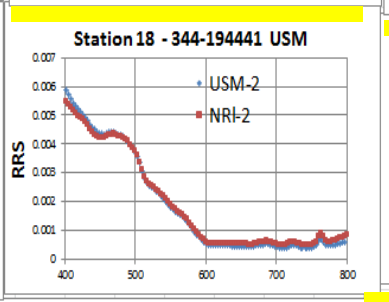



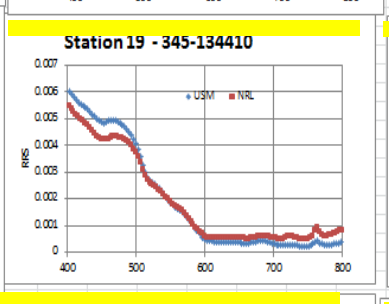



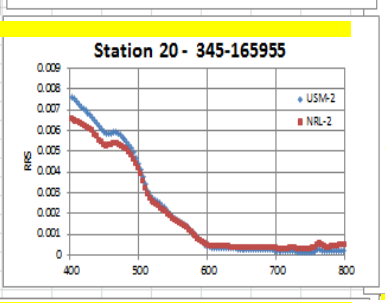



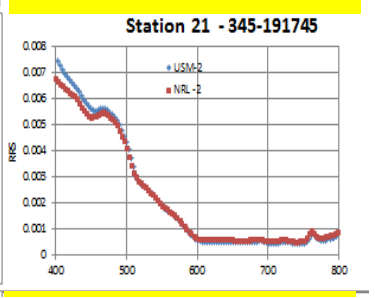



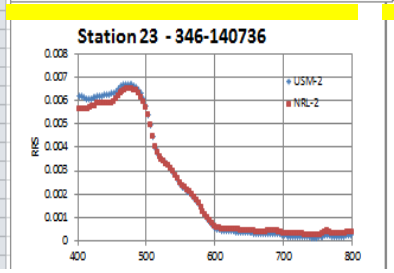



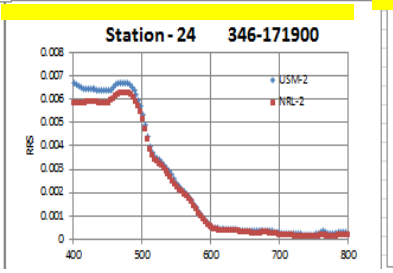



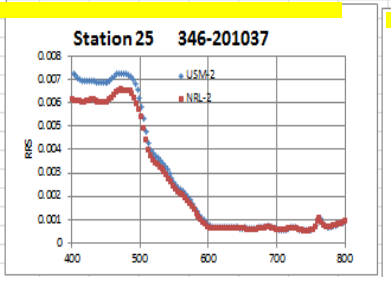



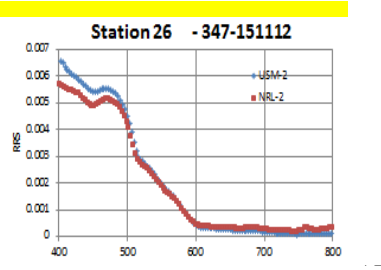



Dec 2015 Cruise

# Above water measurements of Rrs from ASD
# How does the distance above water affect the RRS ?

ASD Protocols For RRS

***Which deck on Foster should be used to collect ASD ?***

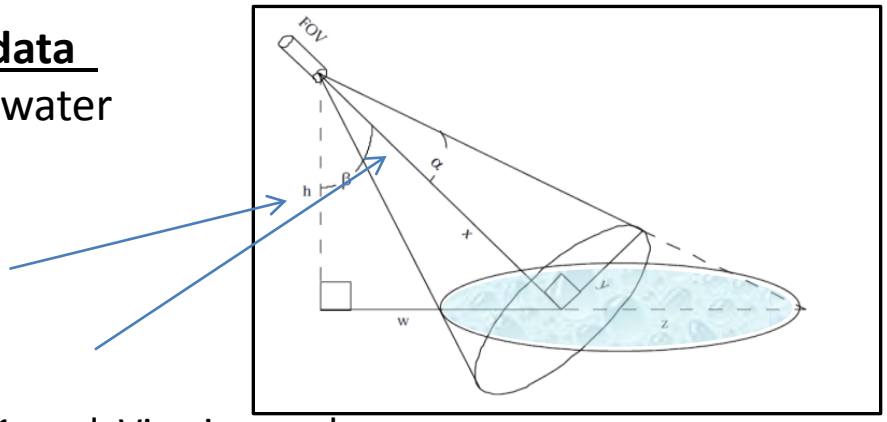
**ASD collected data**

Distance above water

Bow = 2m

01 deck = 5m

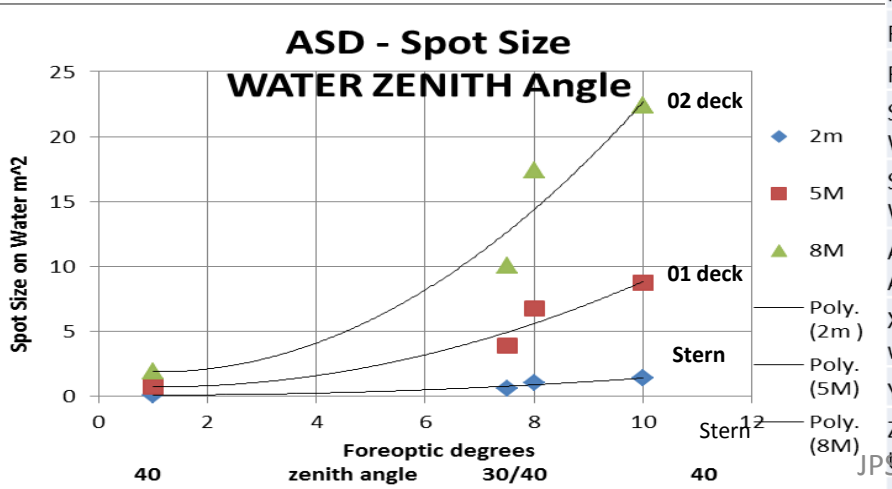
02 deck = 8m




**Comparison of Spot Size**

Fore optics 10 and 1 and Viewing angle

Top deck and large fore optics has largest Spot size




5 Above Water instruments have Differences

| Institution | USM | NRL | NOAA | USF | CUNY |
|---|---|---|---|---|---|
| Foreoptic (degrees) | 1 | 10 | 10 | 7.5 | 8 |
| Foreoptic (radians) | 0.01745329 | 0.17453293 | 0.17453293 | 0.13089969 | 0.13962634 |
| Sampling Zentih Angle - Water target (degrees) | 40 | 40 | 40 | 30 | 40 |
| Sampling Zentih Angle - Water target (radians) | 0.6981317 | 0.6981317 | 0.6981317 | 0.52359878 | 0.6981317 |
| Average Sampling Height Above Water (meters) | 2 | 2 | 2 | 2 | 2 |
| X, where x = SQRT(h^2 + w^2), and w = h tan b | 2.61081458 | 2.61081458 | 2.61081458 | 2.30940108 | 2.61081458 |
| Y, where y = x tan a | 0.02278423 | 0.22841668 | 0.22841668 | 0.15136614 | 0.18256594 |
| Z, where z=h [tan(b) + tan(b + a)] | 3.38636063 | 3.67819926 | 3.67819926 | 2.49105781 | 3.60957681 |
| AREA (m^2) | 0.12201122 | 1.40167848 | 1.40167848 | 0.62827694 | 1.0874876 |

**Dec 2015 Cruise**

# ASD protocol -

## Results - ASD Requires Spot Size from 2- 10 Meters!

## For the Foster – collect ASD on 01 deck !

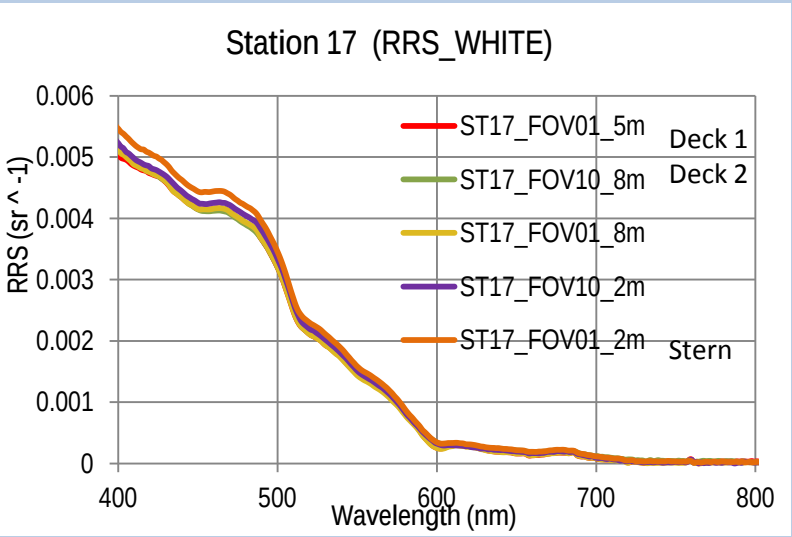
**ASD Protocols For RRS**

Shooting ASD from which deck ?

**2 m - stern**
**5m - O1 deck**
**8m - 02 Deck**

## Blue Water Matchups

$R_{RS}$ – Uncertainty in above-water spot size

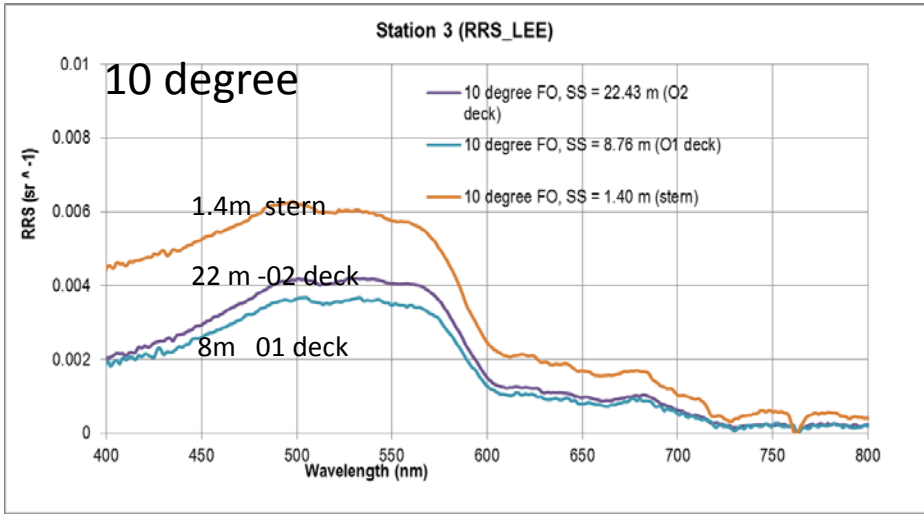


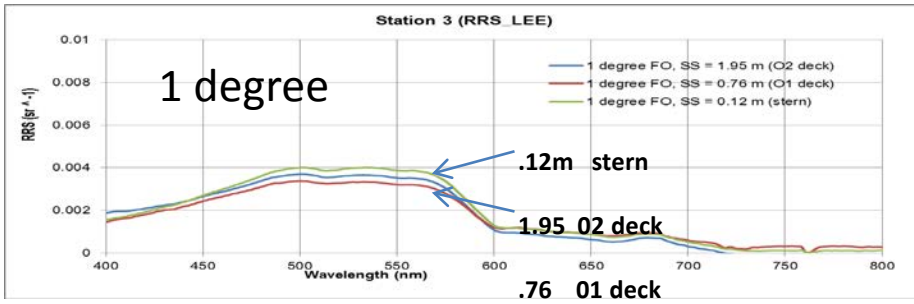

**No apparent trend in sampling height FOV and quality of returns**

***Very good agreement in blue waters for all stations!***

## Coastal Matchups

$R_{RS}$ – Uncertainty in above-water




**Stern – highest uncertainty 10 deg FOV - higher**

**O1 Deck is most consistent for 1 and 10 degree FOV 1.95 and 8m spot size Selected as the Protocol**

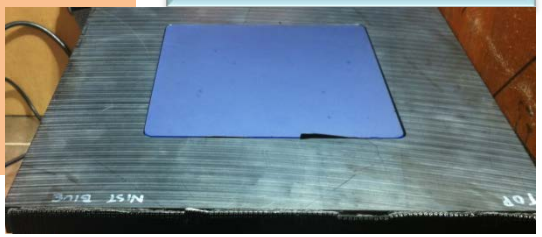
Dec 2015 Cruise

# Radiometer – NIST blue tile

## Instruments =*5 ASD 1 SpecEvol 1 GER*

**ShowS good agreement among different systems**

ASD Protocols For RRS



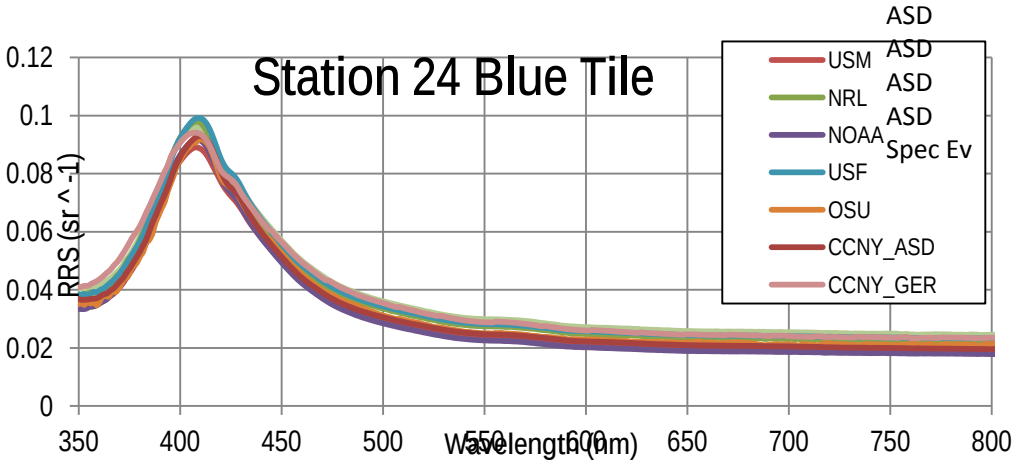
Several Blue tile Stations Collected These are best days!

## Similar Protocols

# files collected.
# dark Targets
Angles,
NRL Grey card
NRL processing

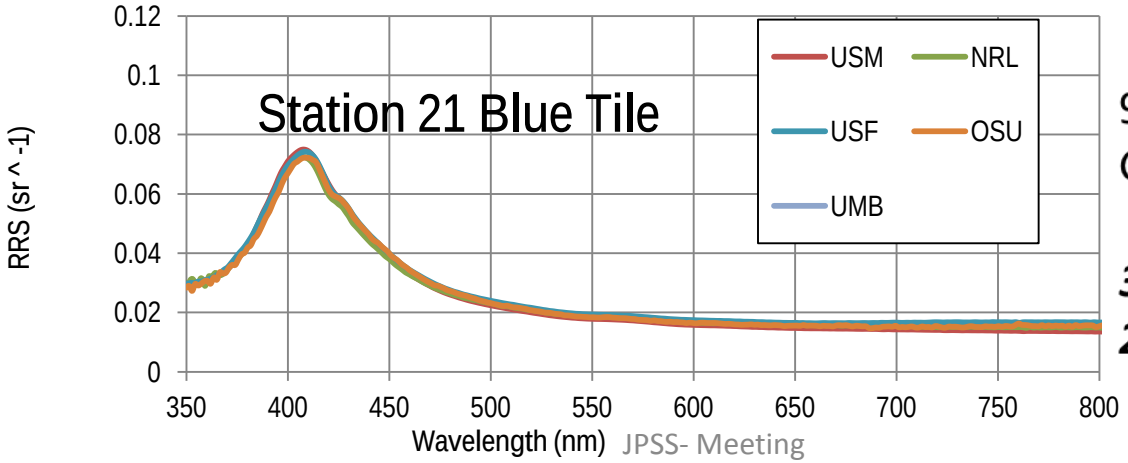
Different % Clouds

**Similar Processing on all Systems**




135 degree azimuth T1430 GMT

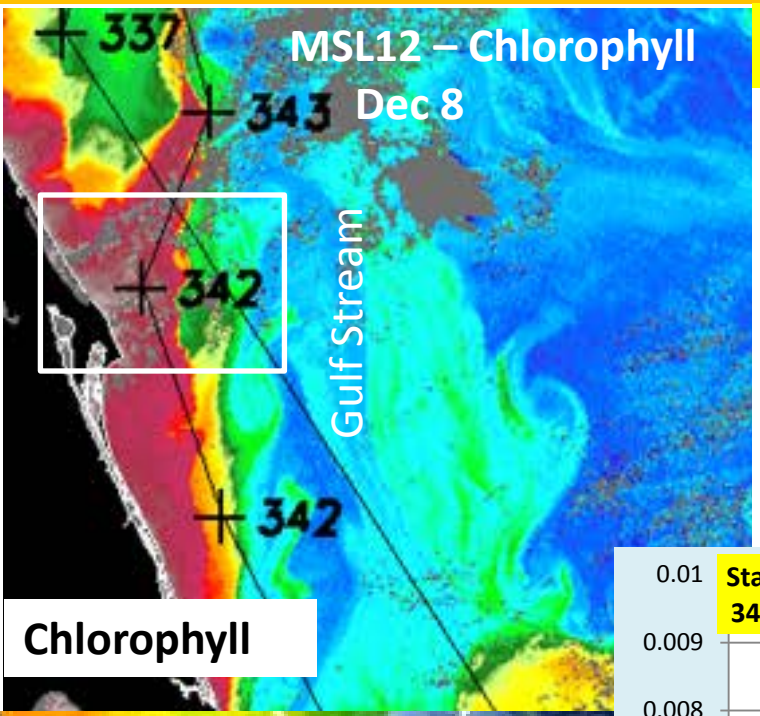
$$R_{tile}(\lambda) = R_g(\lambda)\frac{S_{tile}(\lambda)}{S_{ref}(\lambda)}$$

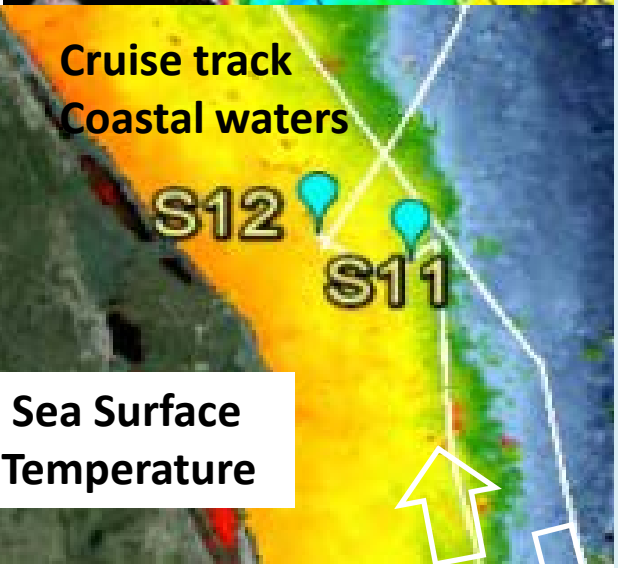



90 degree azimuth T1910 GMT

***3** ASD*
***2** SpecEvol*

# Dec 2015 Cruise VIIRS and Insitu Matchup - Floating Hyperpro -and ASD




## Station 12 – Dec 8, 2016 Coastal waters

***Uncertainty with VIIRS data***

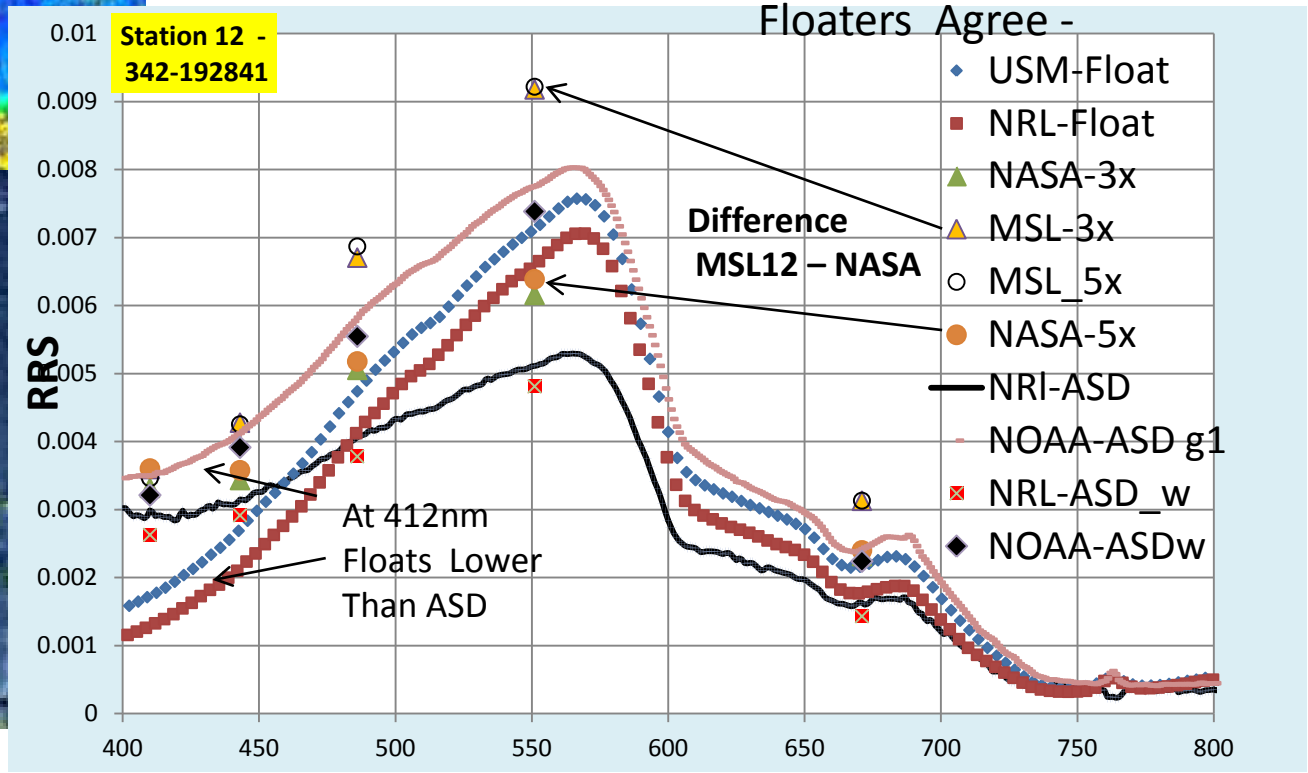
**Scattered Clouds VIIRS Satellite Matchup**

***No center pixel, only 3x3 , 5x5 mean***

***Require Protocol for VIIRS data – matchups***

ASD better agreement with VIIRS At 400 nm

Floaters Agree -



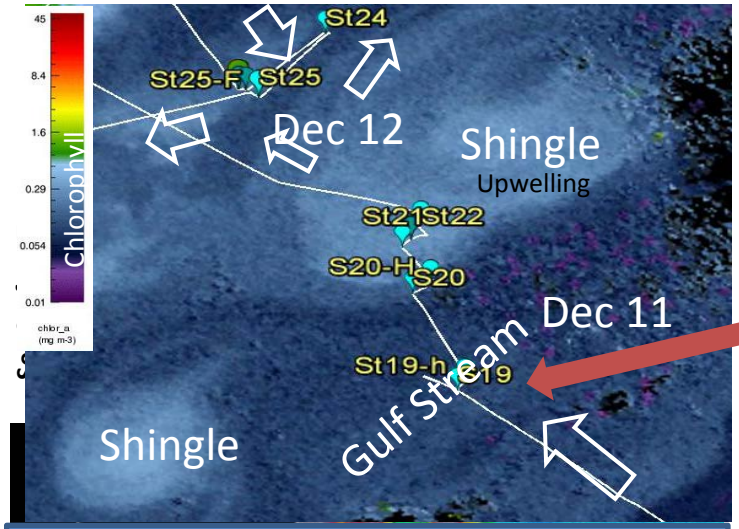
# Dec 2015 Cruise — VIIRS and Insitu Matchup - Floating Hyperpro -and ASD

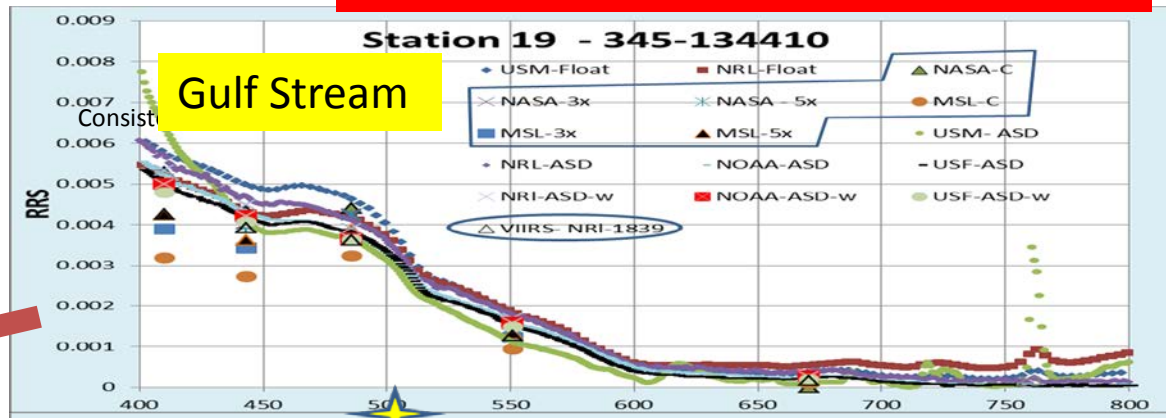
## Day 345 Dec 11, Station 19, 20, 21

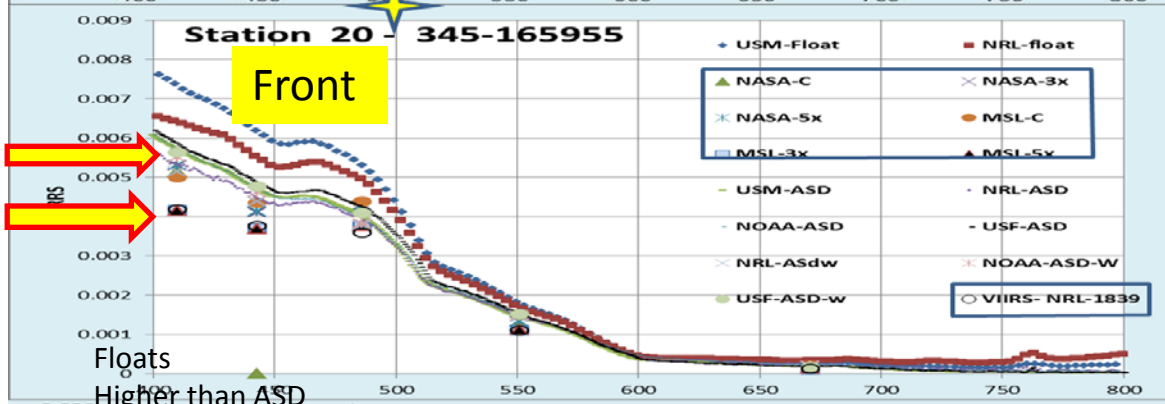
Clear Skies

Gulf Stream St 19 Shingle St 20 – 21

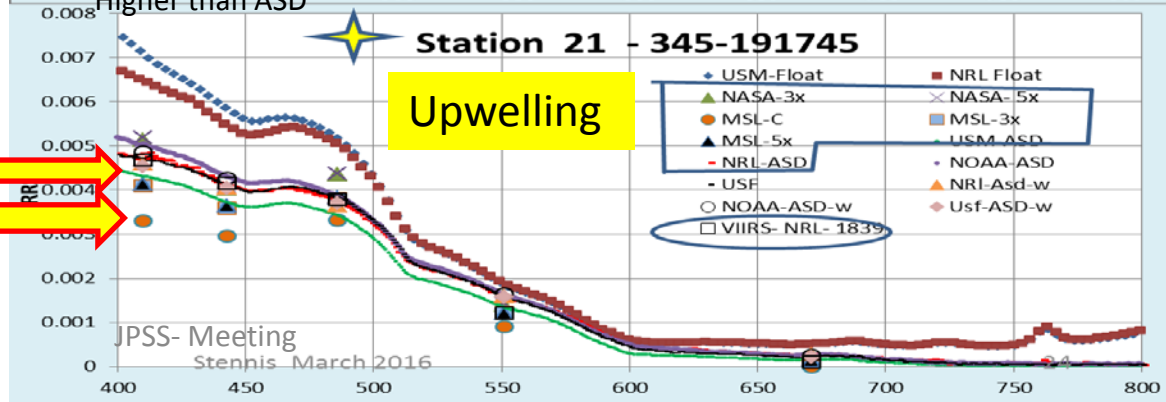
RRS from Floaters and ASD Consistent.




Floats Higher than ASD




**Suggests Protocols VIIRS Matchup**

Note Differences ~ 13% in Center Pixel,

3x3

5x5

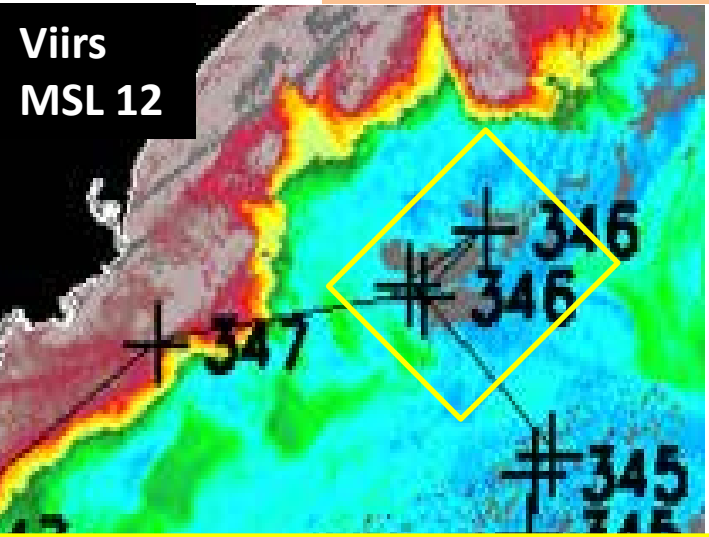
**Remove Cloud Shadows .**

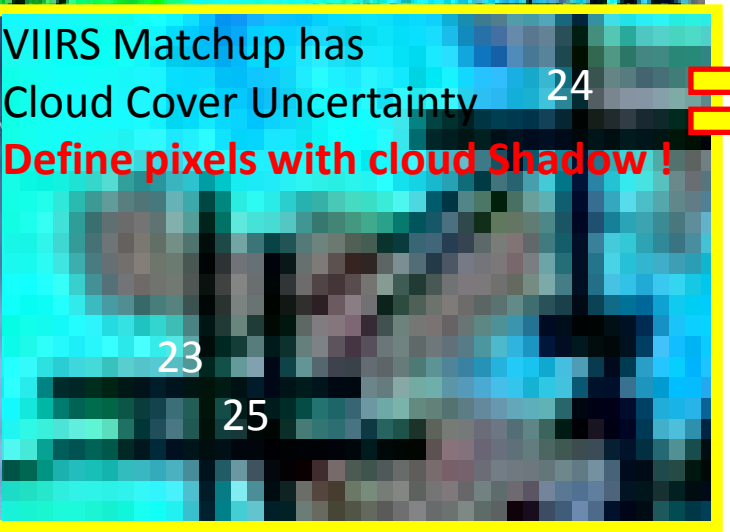
VIIRS MSL – and NASA = Low

VIIRS overpass at 1838 = St 21

# Dec 2015 Cruise — VIIRS and Insitu Matchup - Floating Hyperpro -and ASD

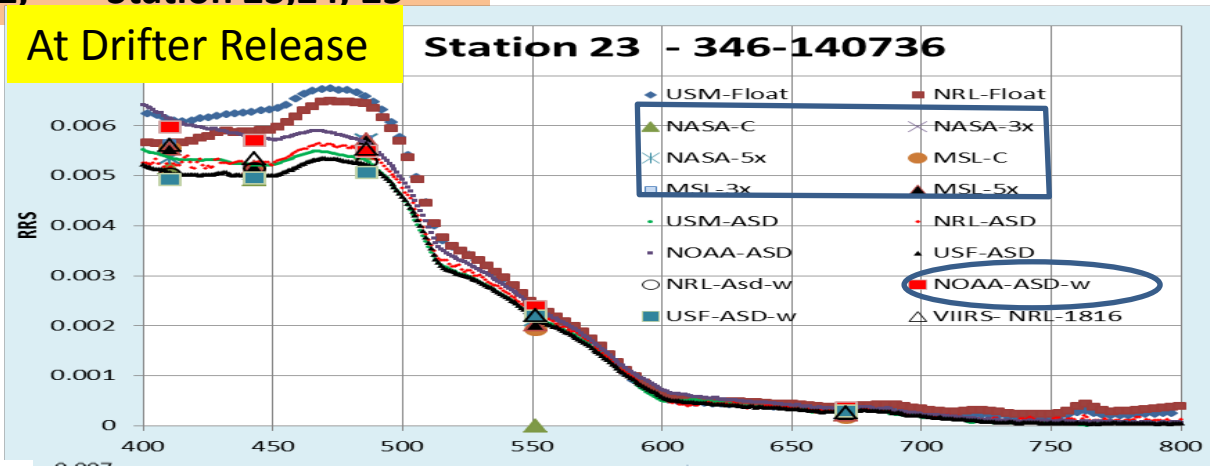
**Day 346 Dec 12, Station 23,24, 25**

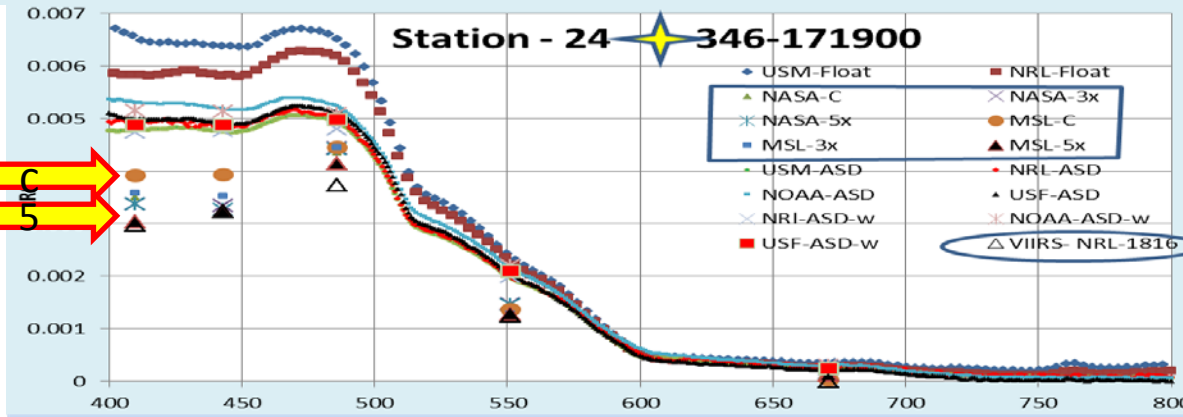


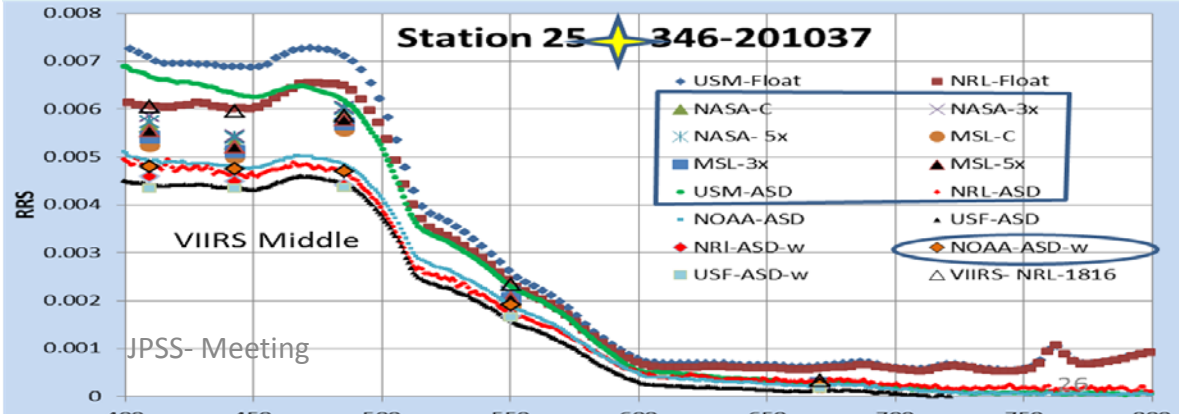




VIIRS Scattered Clouds
Has VIIRS Center Pixel
Along SST frontal boundary

At Drifter Release

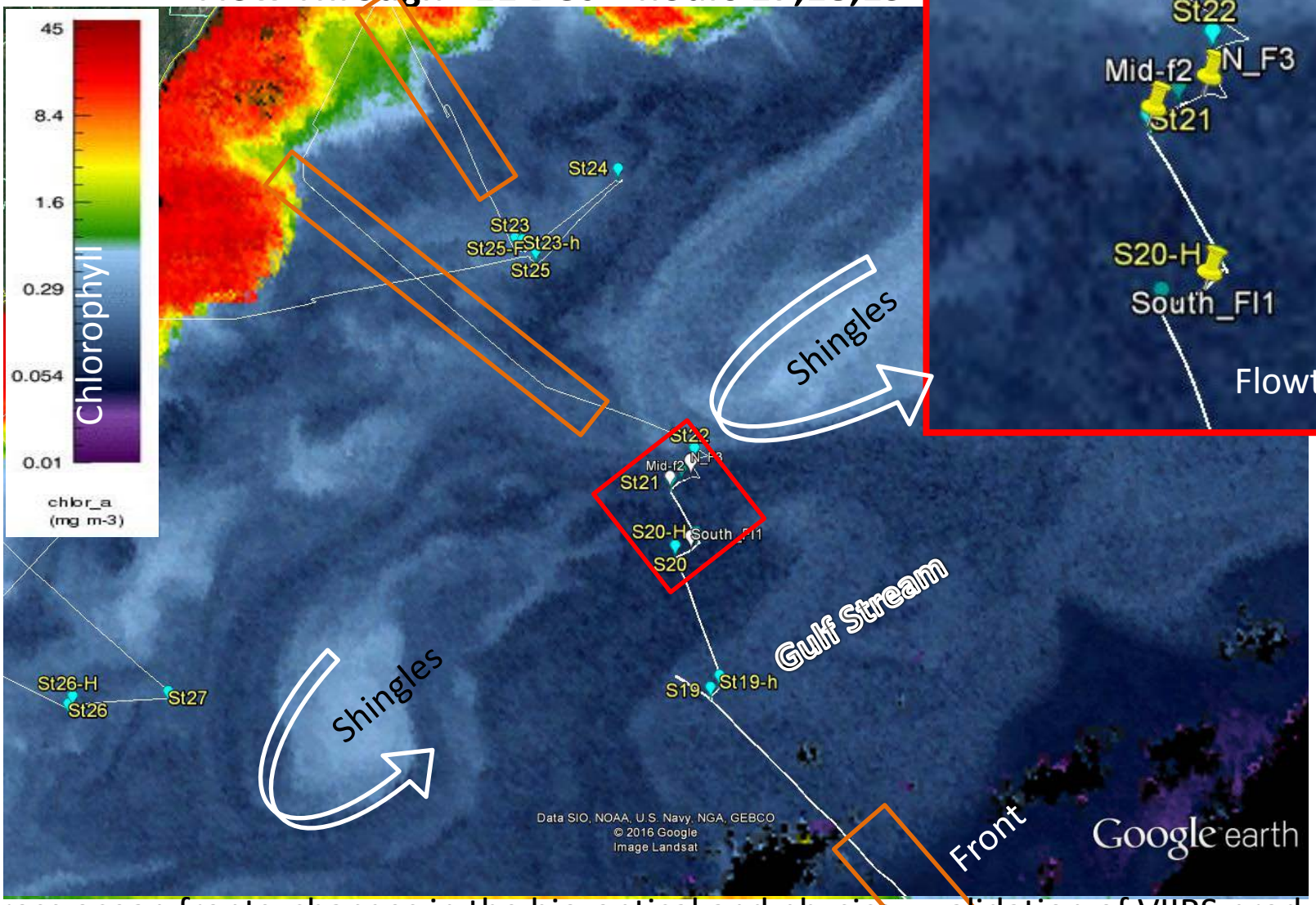


**Dec 2015 Cruise**

## Flow Through 11 Dec – hours 17,18,19





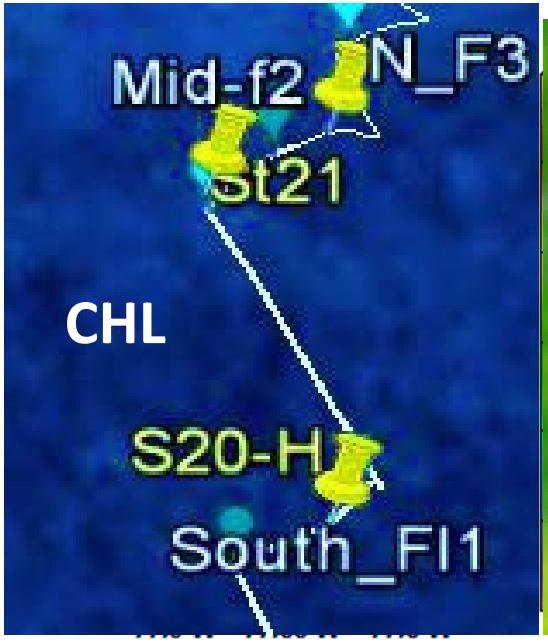


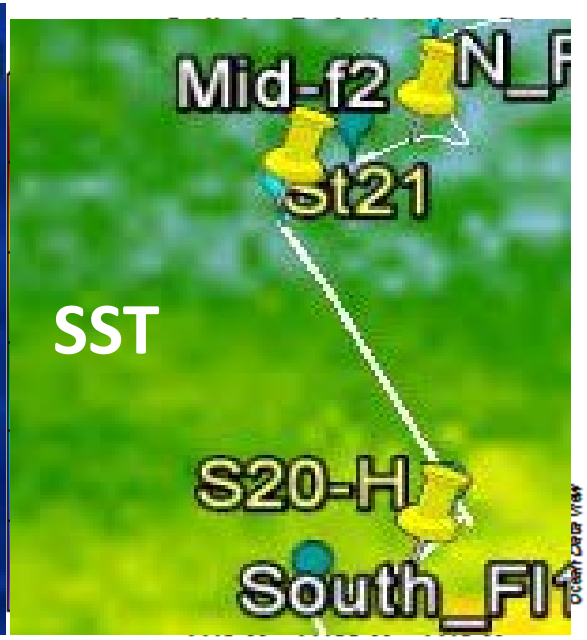
Cross ocean fronts changes in the bio-optical and physics – validation of VIIRS products

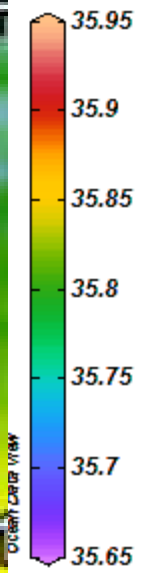
Flowthrough data -- Ship salinity , temperature

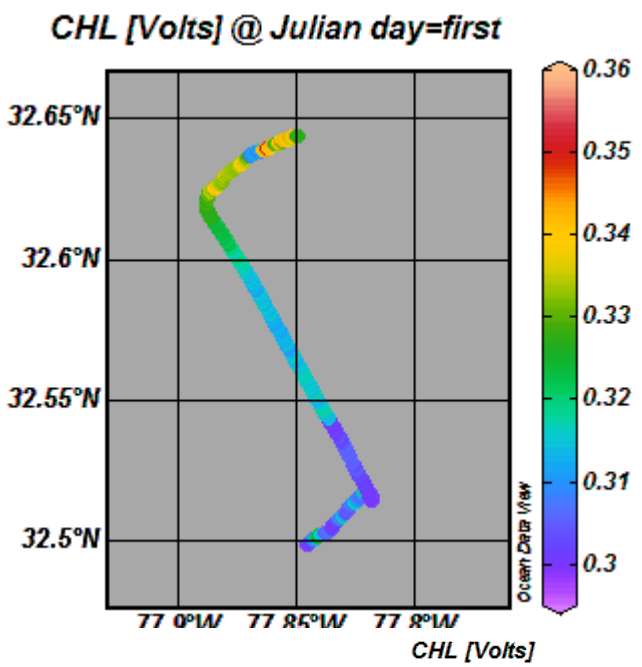
IOP- total and filtered absorption (λ) , scattering (λ), CDOM, spectral slope → particle size,

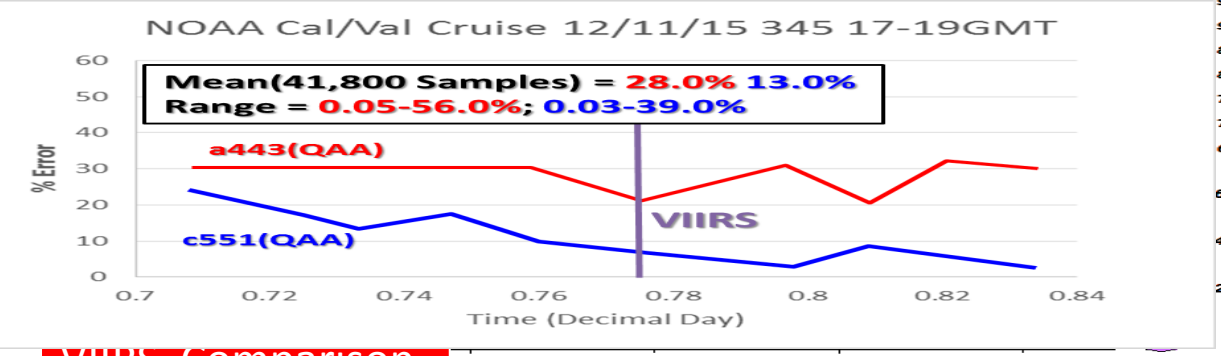
bb - backscattering

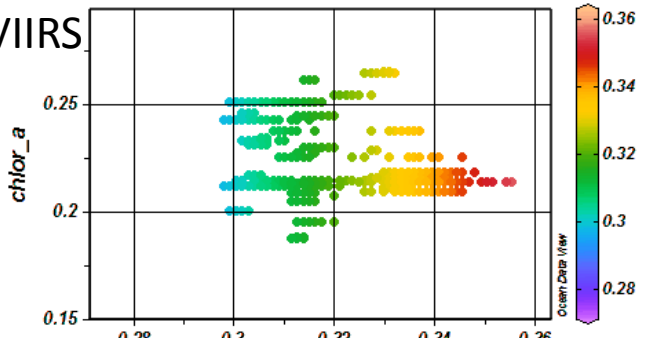


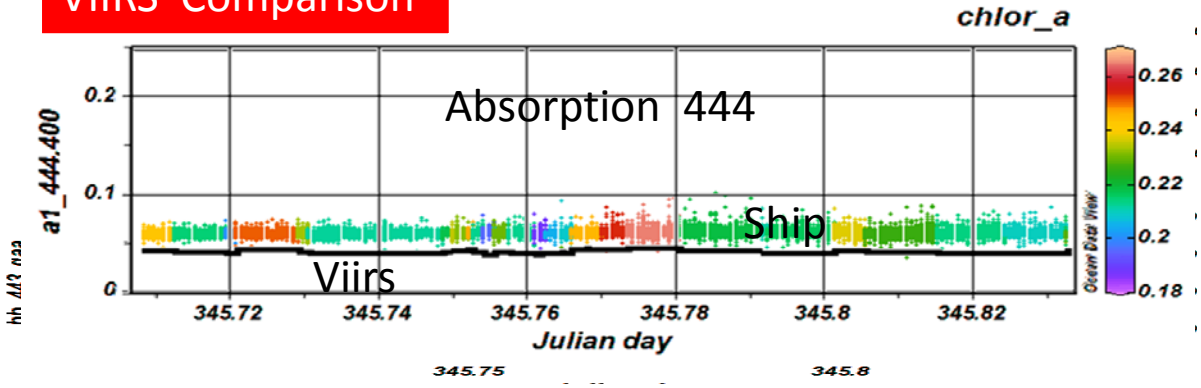



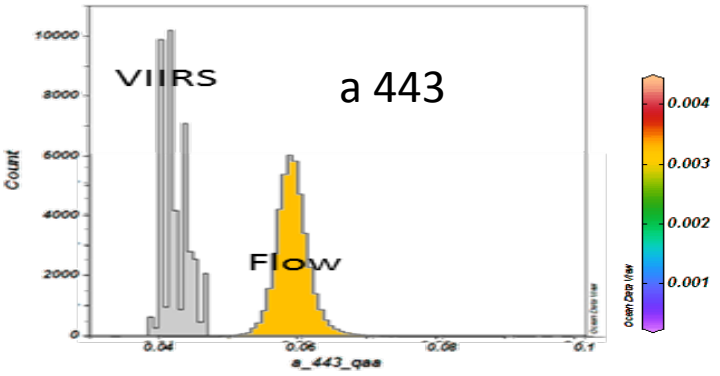




VIIRS Comparison



# Diurnal changes in ocean color in coastal waters

## How does Diurnal Changes in ocean color affect Cal – Val of VIIRS?

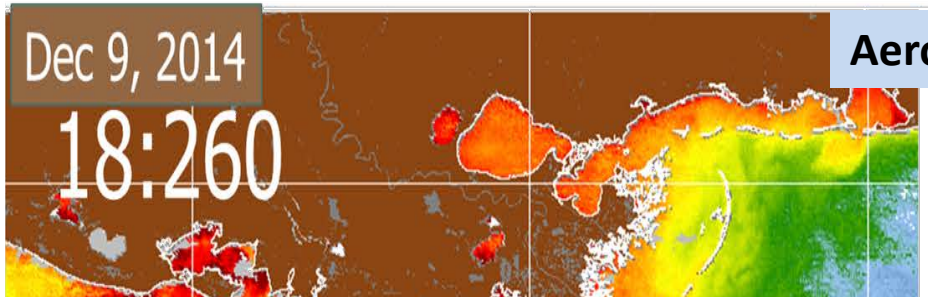
1. **How rapidly does ocean color change in the coastal ocean ?**
   **What is the spectral uncertainty of these changes?**
2. **Diurnal changes in ocean color can occur from:**
   a. Advection of water masses.
   b. Upwelling, downwelling of subsurface optical layers.
   c. Biological activity → Phytoplankton blooms and decay

4. **Can VIIRS 100 minute "orbital overlaps" detect diurnal changes?**
   a. Validate diurnal Ocean color signatures and define the temporal certainty.
   b. Diurnal ocean color can characterize coastal physical and bio-optical processes.
   c. New products can be developed from diurnal ocean color to define coastal processes
5. **Many examples from Aeronet showing the ocean color changes every 20 minutes .**

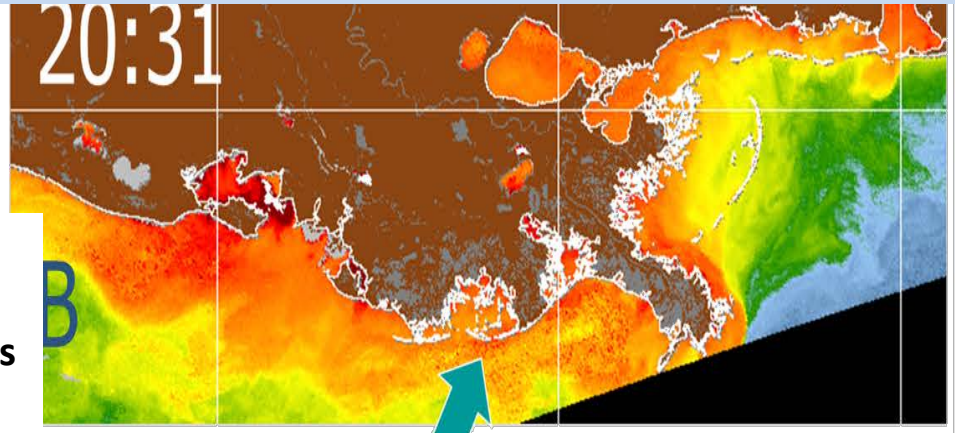
Citation: Robert Arnone ; Ryan Vandermeulen ; Sherwin Ladner ; Michael Ondrusek ; Charles Kovach, H. Yang, J.Salsbury: " Diurnal changes in ocean color in coastal waters ", *Proc. SPIE* 9827, Ocean Sensing and Monitoring VIII, 982711 (May 17, 2016); doi:10.1117/12.2241018; http://dx.doi.org/10.1117/12.2241018
http://proceedings.spiedigitallibrary.org/proceeding.aspx?articleid=2524464

# VIIRS Orbital overlap showing Diurnal Chlorophyll changes ~ 100 minutes.

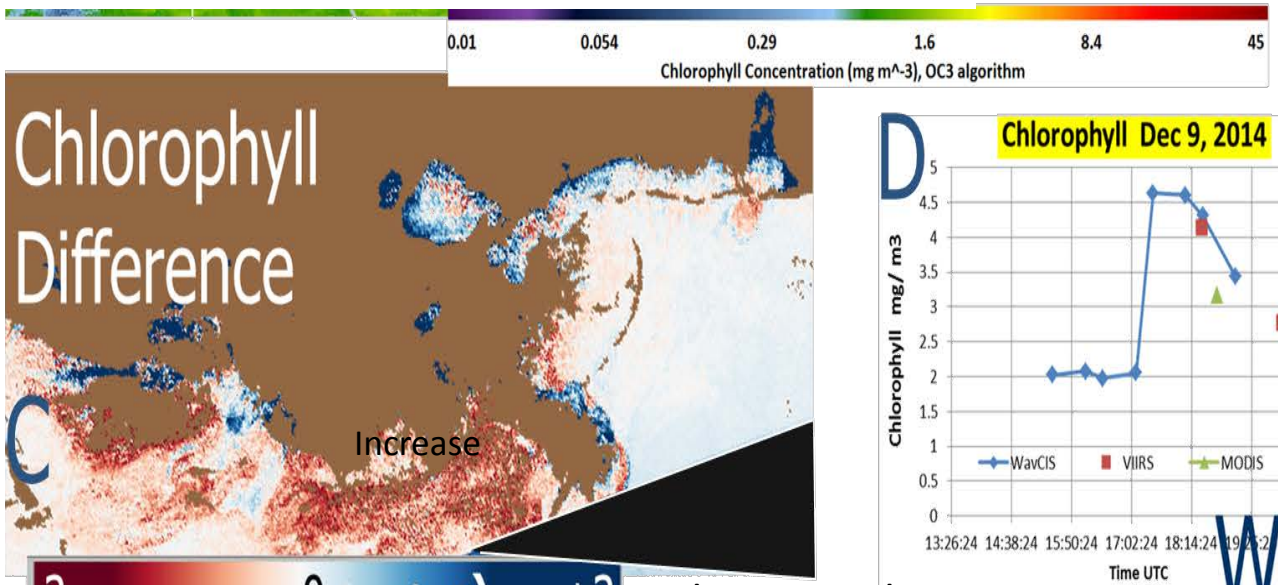
At ~30 Latitude - overlap Sensor angles ranges from 56 t0 70 degrees
VIIRS shows it can validate track rapid Diurnal changes at Aeronet



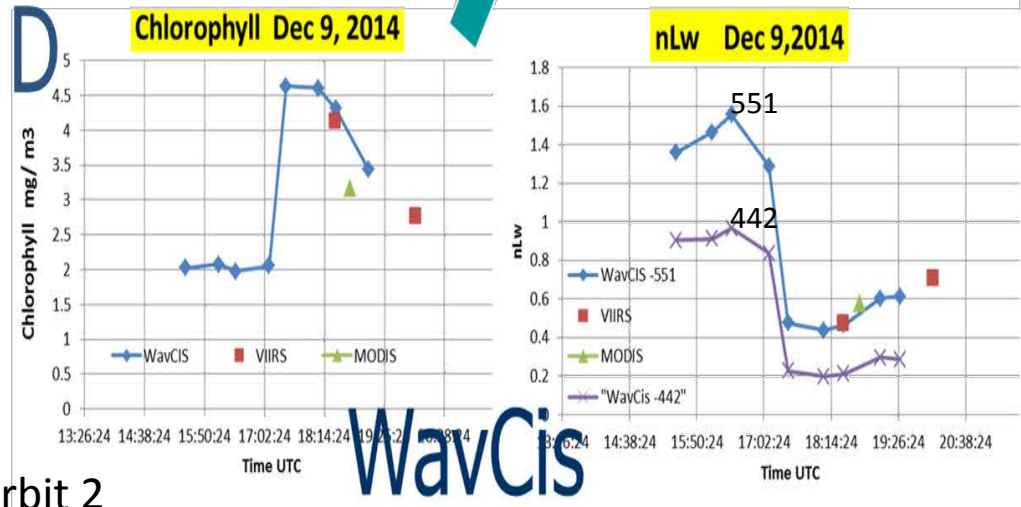

**Aeronet Shows the Diurnal changes in ocean color .**




**Diurnal Changes occur**
**1.Advection of Water Masses**
**2.Upwelling, downwelling of Subsurface optical layers**
**3. Biological Activity- Blooms and decay**

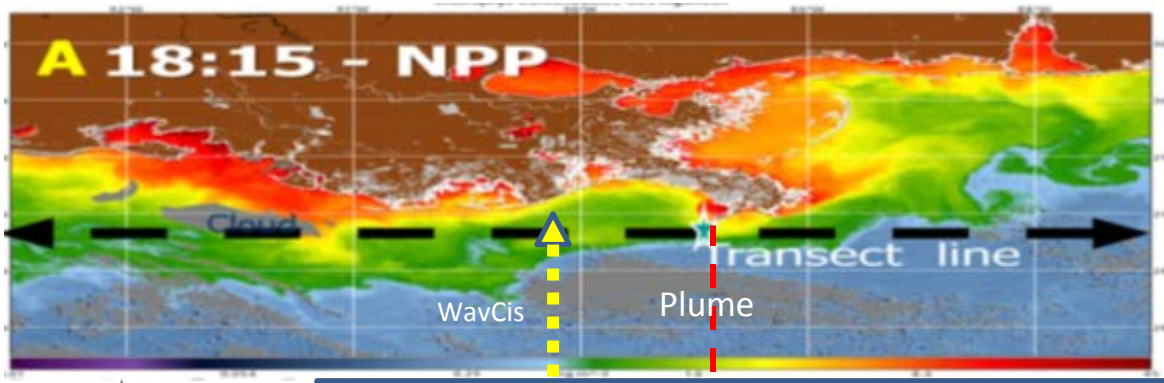



Orbit 1 – Orbit 2



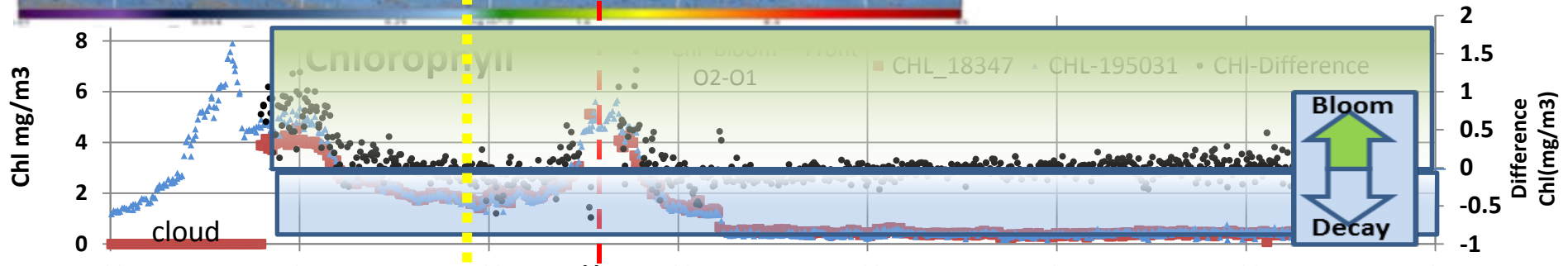

**VIIRS Following Trend**

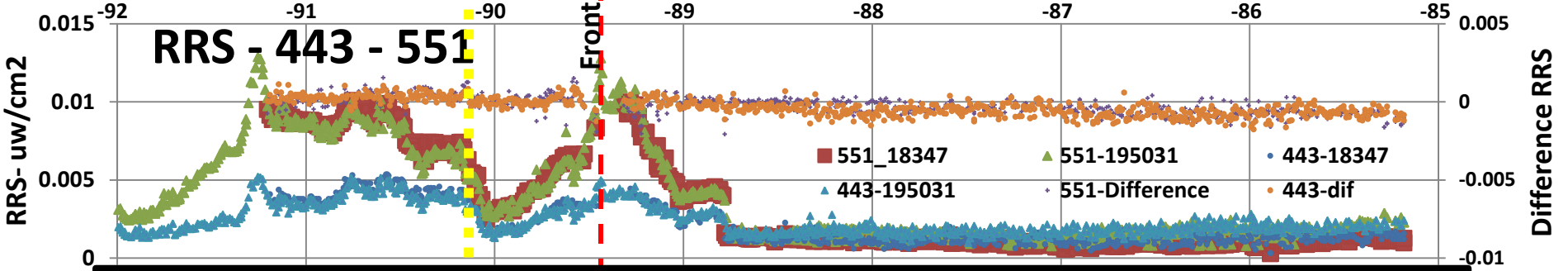
# Does VIIRS orbital overlap correctly handle the large sensor angles ?

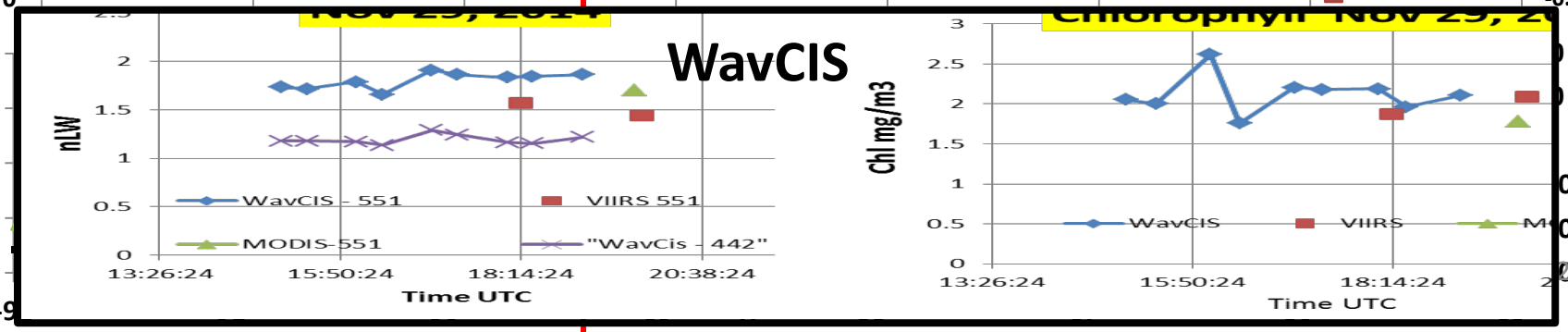



Overlap on Nov 29

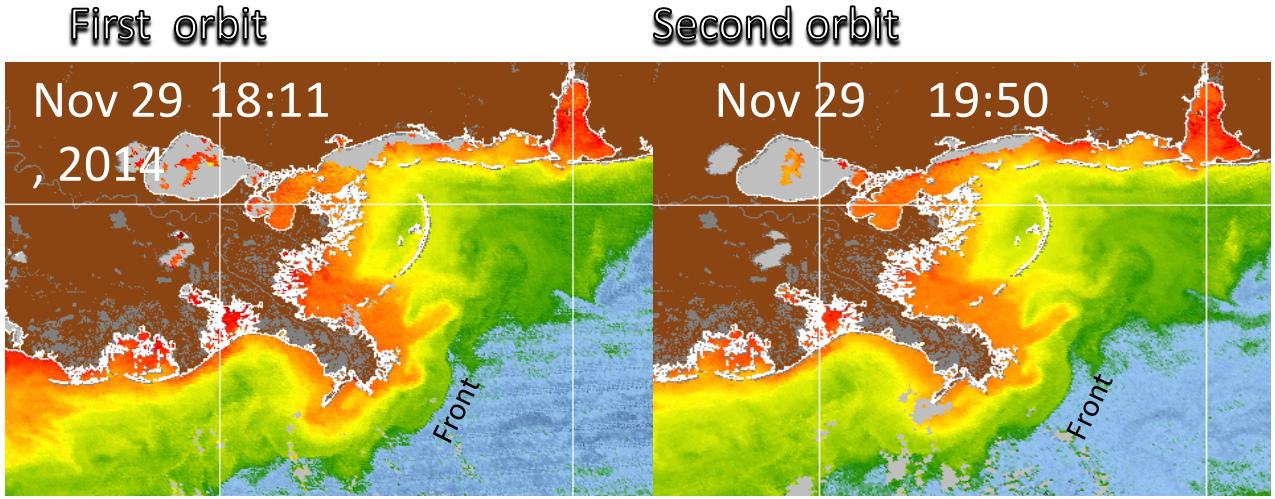
The Solar and Sensor angles Does not show a relationship to differences in VIIRS products. Is handling correctly angles.



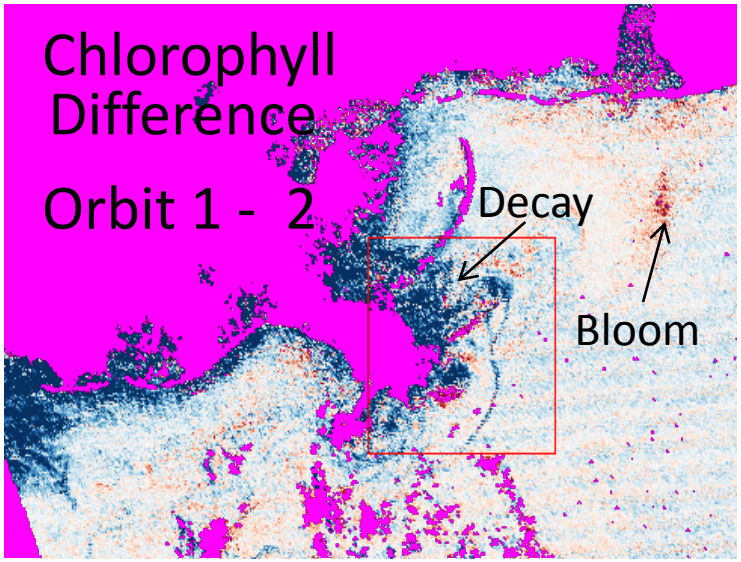
# VIIRS Diurnal Changes can identifies Surface Processes in the Ecosystem

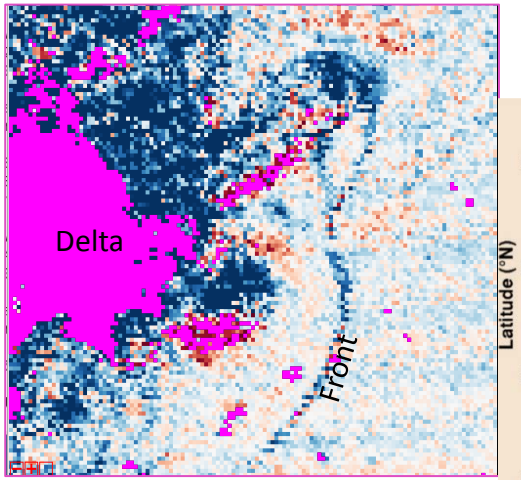


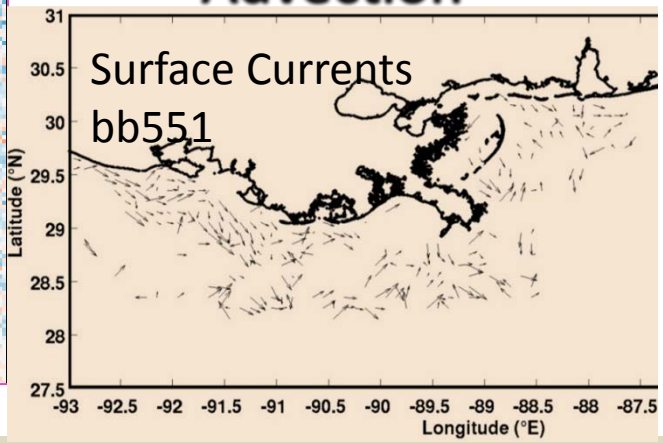

**Products**

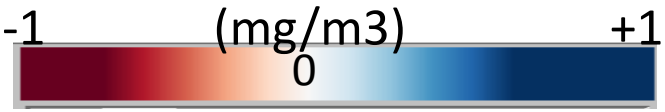
1) **Phytoplankton Blooms and Decay**
2) **Water Mass Advection surface Currents**

## Frontal Movement Advection



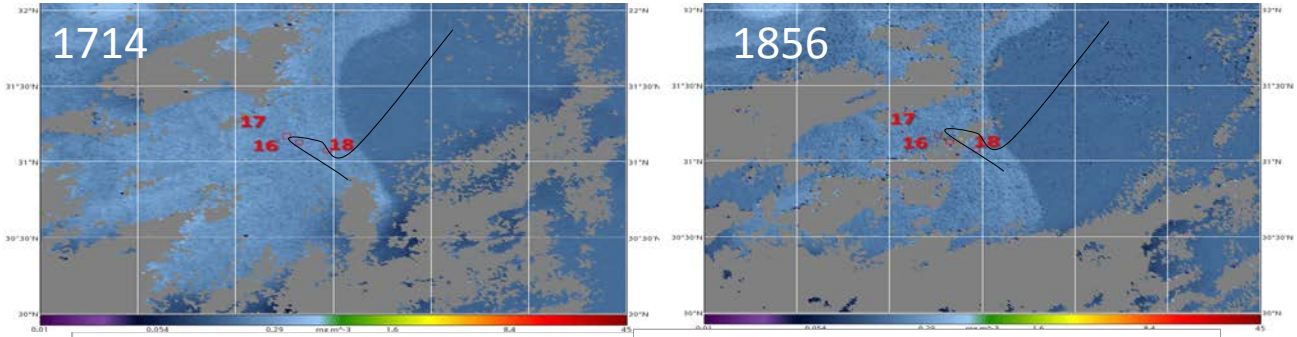



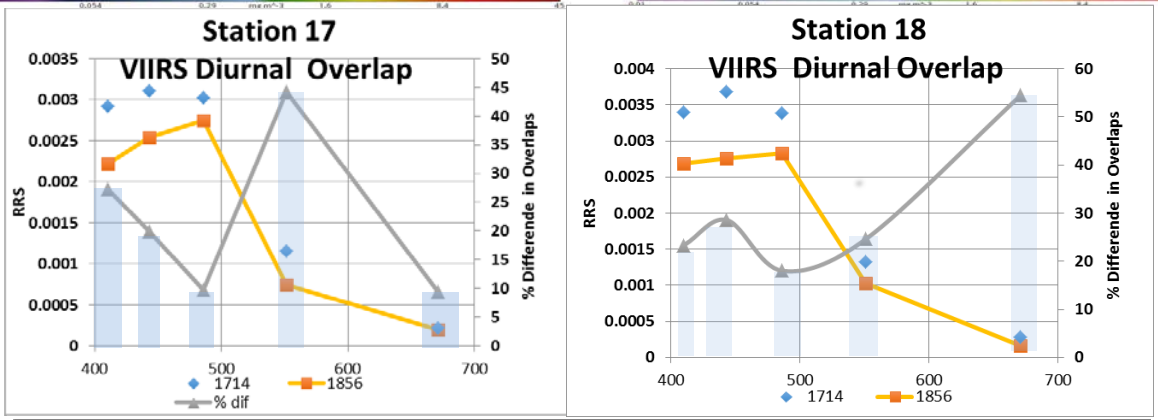

Bloom Second Pass Greater Decay

- **Maximum Cross Correlation used to estimate surface currents .**
- **Different Color Products used for surface advection vs Biology**

# How Rapidly did VIIRS Ocean Color Change for Dec Foster cruise?

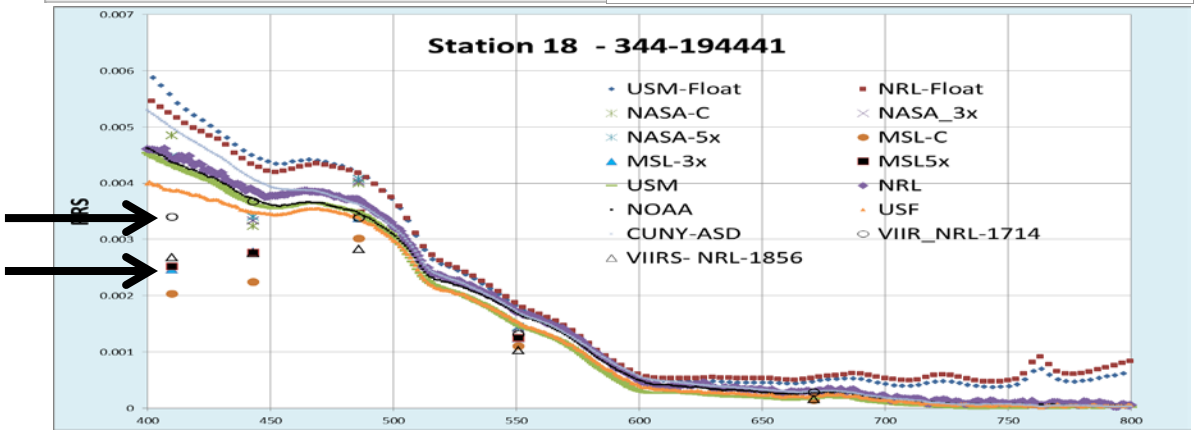
**Foster Dec 10, 2015**
**VIIRS – Diurnal Overlaps**










**Diurnal variability within 100 minutes at these Station locations.**

- **First Orbit is larger.**

**% change in RRS**

**% Change**

**410 – 25%**
**443 – 24%**
**486 – 14%**
**551 – 34%**
**671 – 32%**

**Spectrally different changes major 551 and 671**

**These spectral changes support the Variability in VIIRS matchup for these waters ?**

# Diurnal Changes in ocean color

- *Diurnal processes (hours) occur in coastal regions which impact the ocean color signatures.*
  - *WavCis SeaPrism shows hourly color response in the nLw*
- *VIIRS overlaps detected the diurnal hourly ocean color within 100 Minutes !!!*
- *Rapid ocean color changes "must " be accounted for in coastal satellite calibration/validation.*
- *New VIIRS ocean color Products – from Diurnal changes.*
  - *Water mass Advection →*
    *VIIRS OVERLAP ocean color can be used to derive surface currents!!!*
  - *Bio-optical changes*
    *VIIRS Chlorophyll DIFFERENCES identify BLOOM and DECAY regions !*

## Future VIIRS Cal Val Cruises

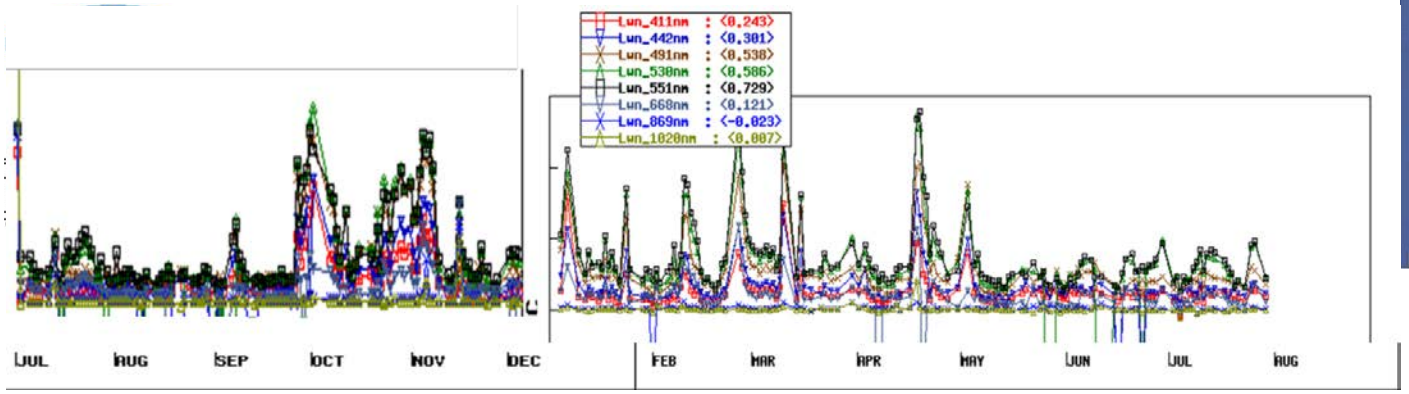
1. Diurnal Changes in Color - 6 hours per day -Overlaps
2. Optically Shallow waters – depth , bottom reflectance's
   - Stability of a ocean site
3. VIIRS Data matchup Protocols

# WavCIS SeaPrism Status
# SN 610






**1) WavCis SeaPrism has been operating successfully throughout the year and reporting to AERONET.**




**2) SeaPrism Calibration.**

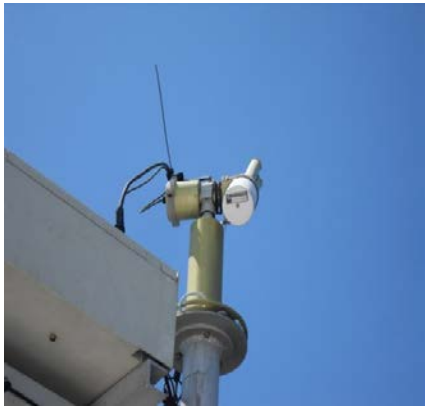
**On 7/28/2015, SN 610 re-installed and put back into operation.**

**Aug 2016, Next Scheduled Calibration, to include Robotic Arm.**

**Have Loaner & Robotic arm, waiting good weather & mostly sunny day.**

**3) Maintenance Summary**

- **Robotic Arm is scheduled to be replaced as it has been in operation since 2010. Because the optical cable being rapped around the elevation shaft last year, Goddard and Giuseppe are recommending we replace the Robotic Arm on the next calibration run.**







Likely cause was heavy winds from thunderstorms, reported 50 to 100 mph winds

# WavCIS SeaPrism Status
# SN 610



Maintenance past year

- **Aeronet was Down Oct 19th - Nov 6th of 2015 satellite Communications but no loss of data**
  - Power cycled on Nov 6th by Chevron Personnel resulting in the Satellite link being restored. Although no data was being transferred during that time period, it was being saved on the computer resulting in ***no loss of data.*** Once the Satellite link was back up, all data was then transferred and caught back up by the afternoon of Nov 6th. The cause of the outage was the repainting of the roof. Workers covered up the Satellite Dish, causing the link to shut down.
  - **The Dish was re-aligned in December 2015 to achieve optimal performance.**

- **Three inspection trips were made between December 2015 and June 2016 to the Sea Prism site**.
  - Clean the rain sensor as salt crystals do form on it and cause false rain errors,
  - Inspect the interior of box for water
  - Replace the desiccant that keeps the interior of the box dry and electrical connections corrosion free and to grease the gasket on the door to insure proper water tight seal.
  - Check computer for proper operation, Sea Prism data is backed up to an external hard drive, that data is then removed and disk maintenance is performed to insure reliability of the computer.

# Summary

1. Dec Foster cruise and Gulf of Mexico
   - Tongue can address - Optically Shallow areas for Cal Val
   - Developing protocols for Floating Hyperpro , ASD - Deck 02
   - Protocols for VIIRS satellite - cloud cover etc - Center Pixel.

2. Diurnal ocean color using VIIRS Orbital Overlaps - New products
   - Ocean Color Changes in coastal areas with time
   - Aeronet use for diurnal color changes can be significant
   - VIIRS Overlap shows the changes within 100 minutes.
   - Diurnal processes identified by Overlap Blooms and Decay
   - VIIRS overlaps provide support for a Geostationary Sensor

3. WavCis – Aeronet Operational and Calibrated at NASA

**Stennis - Cal val Team**
**Annual Summary**

**Thank You**

# Validation for Ocean Color satellites (LISCO and Ocean Cruises)

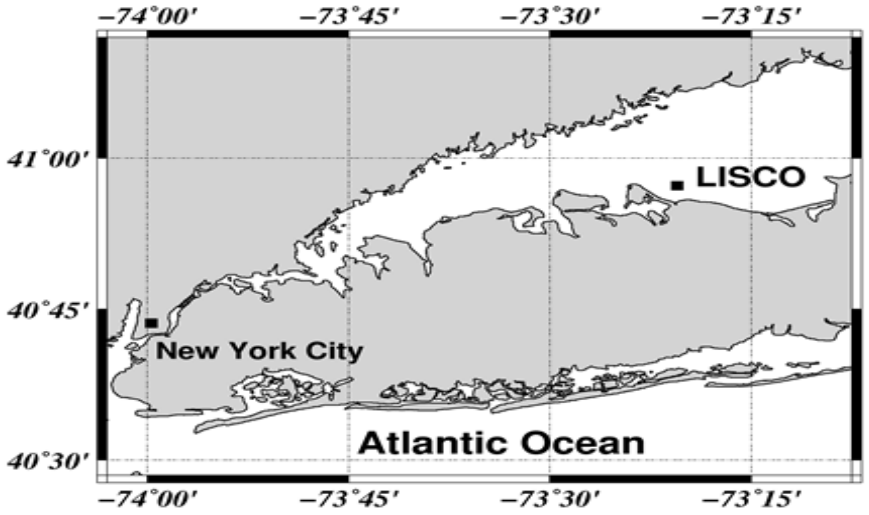
Alex Gilerson, Samir Ahmed, Matteo Ottaviani, Robert Foster, Ahmed El-Habashi, Carlos Carrizo, Eder Herrera

Optical Remote Sensing Laboratory,
The City College of the City University of New York





# Long Island Sound Coastal Observatory (LISCO)








Multi-spectral SeaPRISM instrument. Transmits data to NASA AERONET every hour.



HyperSAS-POL with polarimetric sensors. Transmitted data to CCNY server every hour. Was on the platform in 2009-2014. Currently used for the shipborne operations.

# Comparison of spectral Remote Sensing Reflectance (Rrs) using NASA and NOAA **MSL12** processing and AERONET data

Rrs are obtained from:

- MODIS (412, 443, 488, 547, and 667)
- VIIRS (410, 443, 486, 551, and 671)
- LISCO AERONET-OC, Level 1.5 (413, 442, 491, 551, 668)

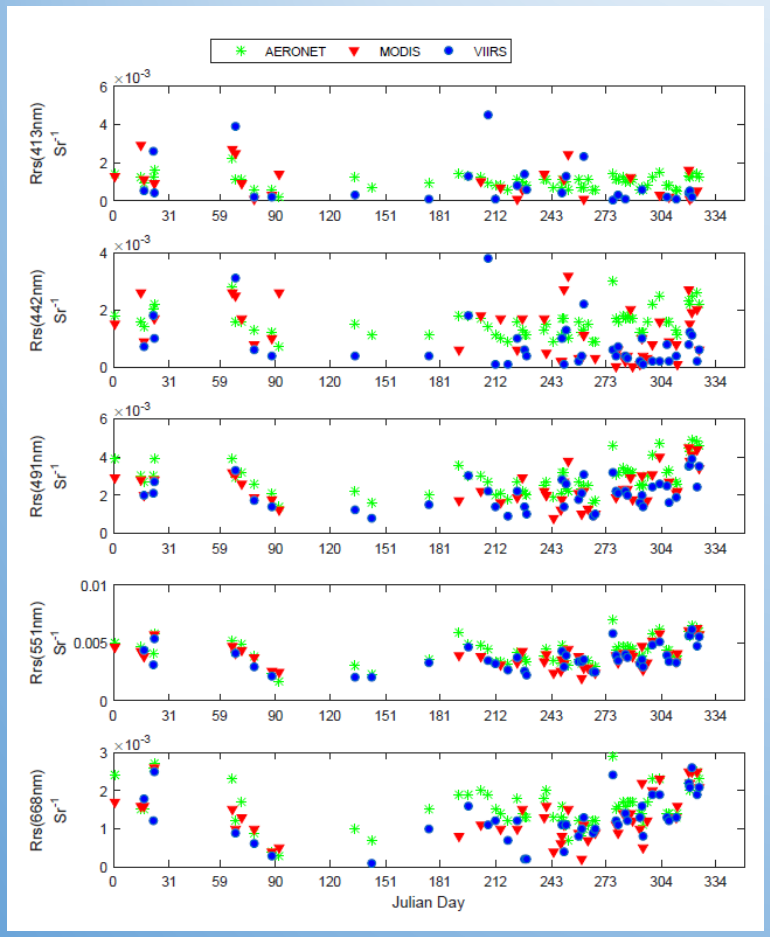
Satellite data are filtered for sunglint and clouds on a 3x3 grid centered at LISCO

Stray-light flag is suspended

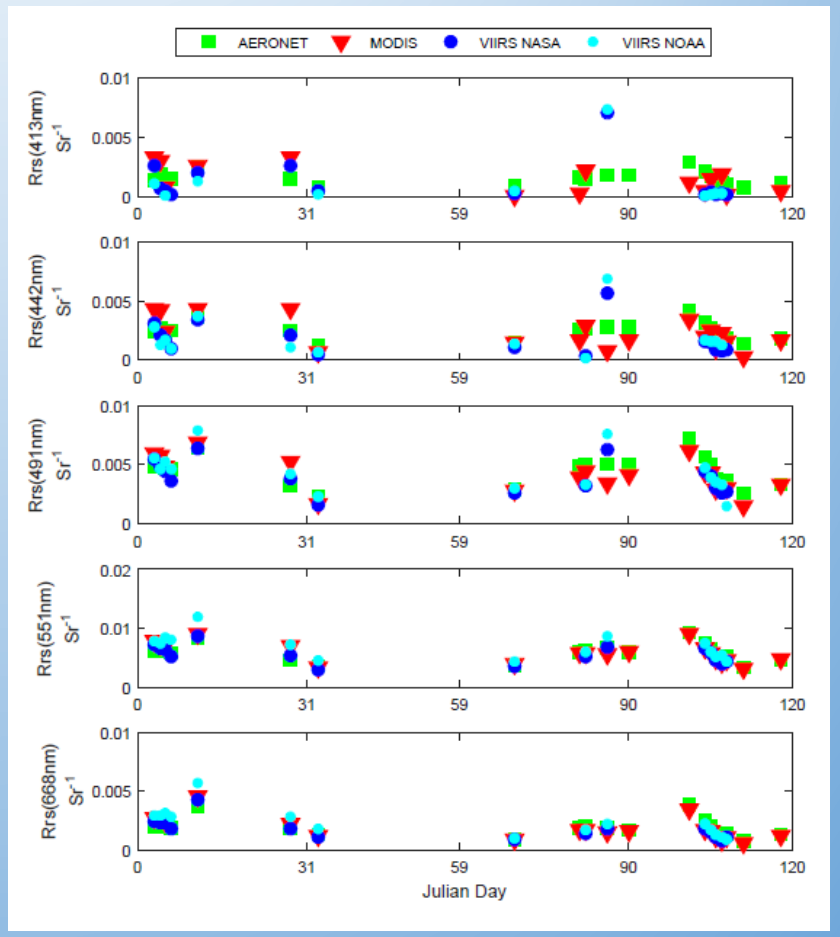
Temporal coincidence is sought with AERONET-OC measurements (±2h)

# Time series data for the LISCO site

## All 2015



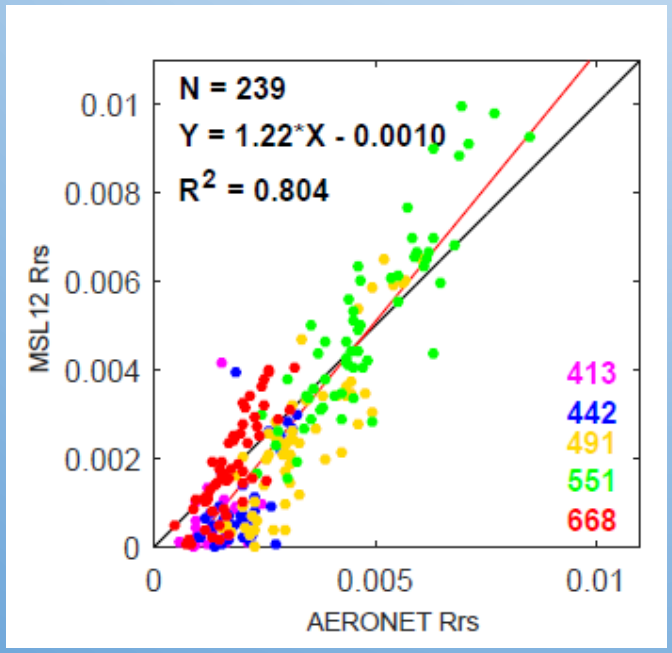

## 2016

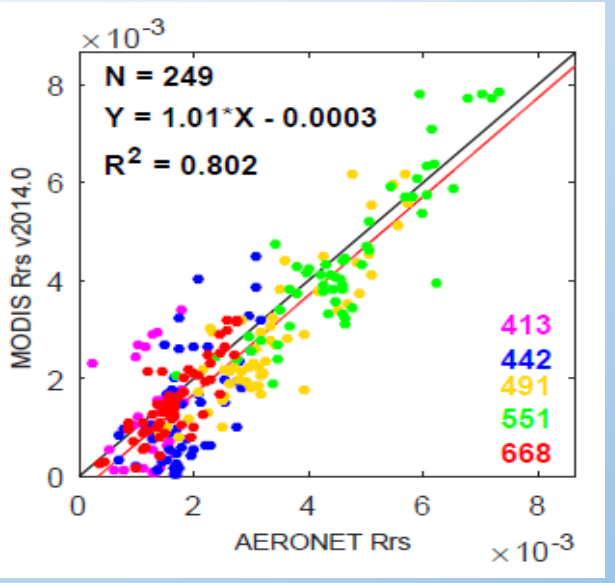


# Validation on the LISCO site (all 2015)

MODIS

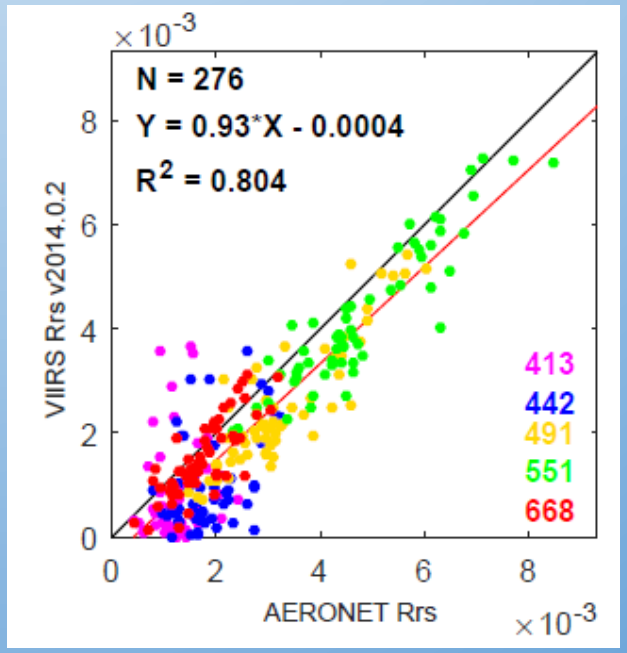
NOAA
MSL12




NASA

VIIRS




NASA

# Validation on the LISCO site (2016)

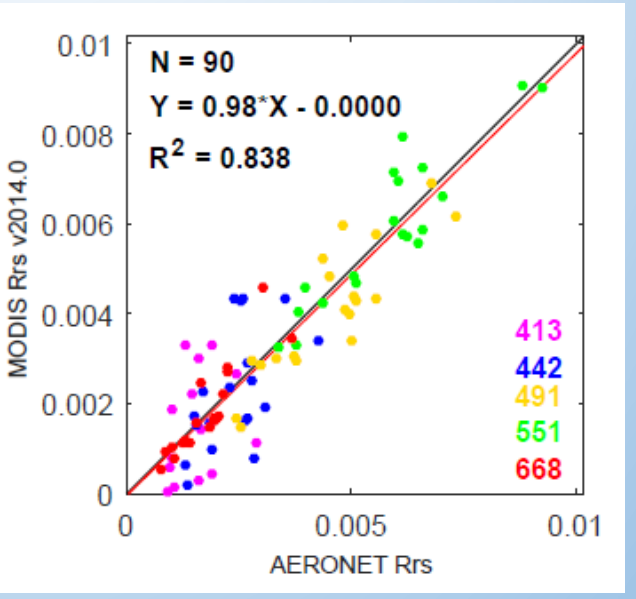
MODIS

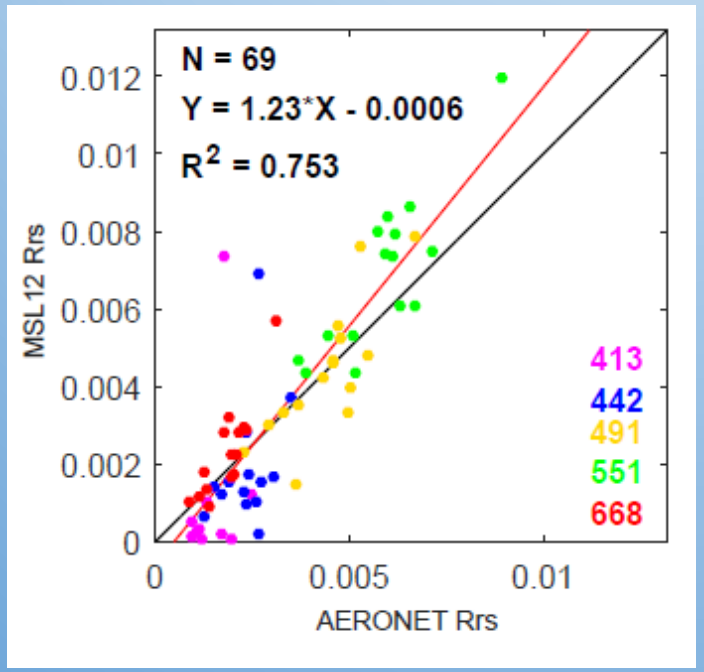
VIIRS

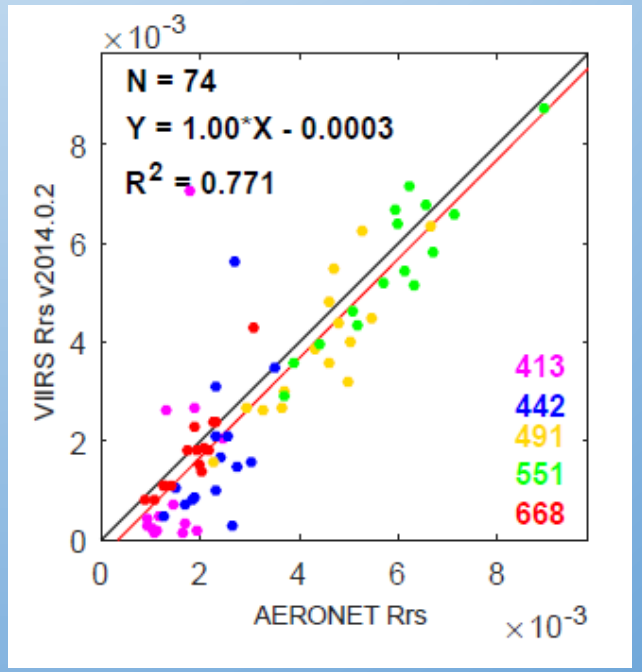
NOAA
MSL12

NASA

NASA



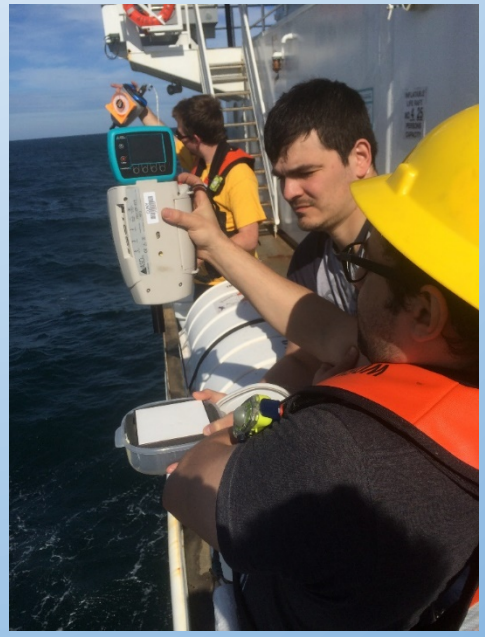
# Validation in ocean cruises

CCNY ocean group participated in two VIIRS validation ocean cruises on NOAA R/V Nancy Foster (Nov. 2014, Dec. 2015)

Other teams: NOAA/STAR, NASA, U. of South Florida, OSU, U. of Southern Mississippi, UMAS Boston





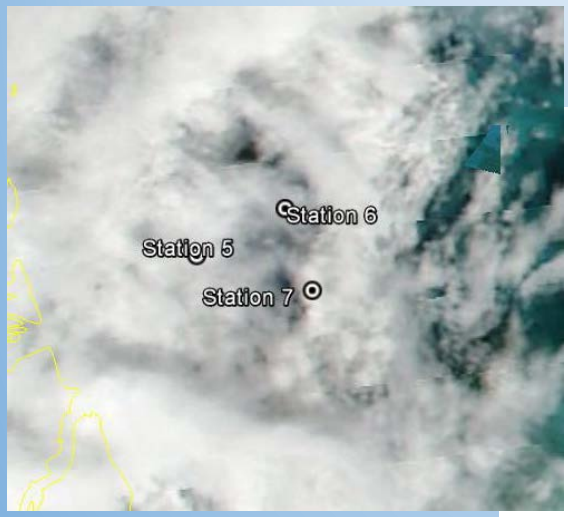


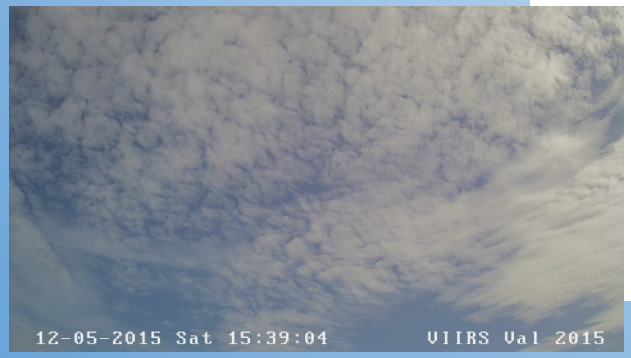
CCNY HyperSAS-POL (6 sensors) in front of the ship. Made underway measurements with continuous adjustment of its platform for Sun glint minimization

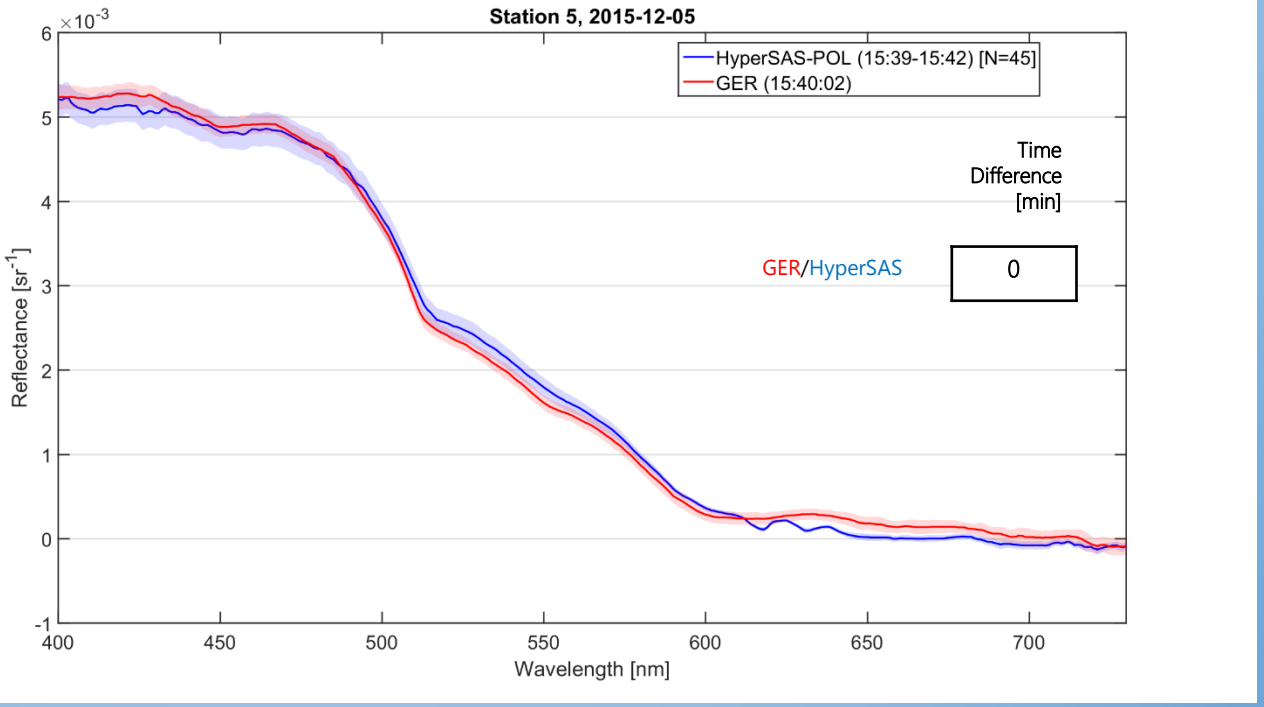
GER and ASD handheld spectroradiometers for manual operation

# Comparison of HyperSAS and GER (handheld) data (open ocean station)

## Station 5

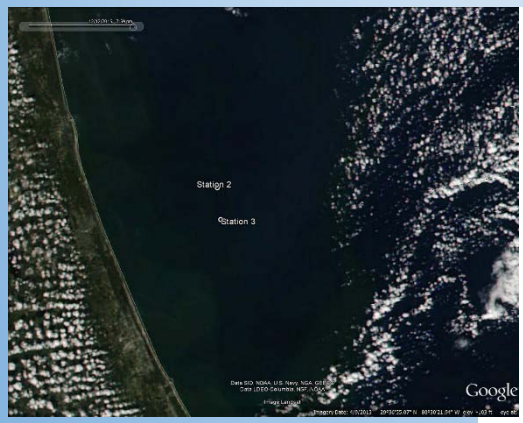


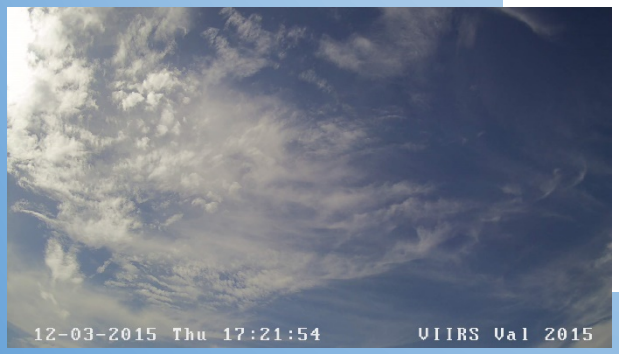



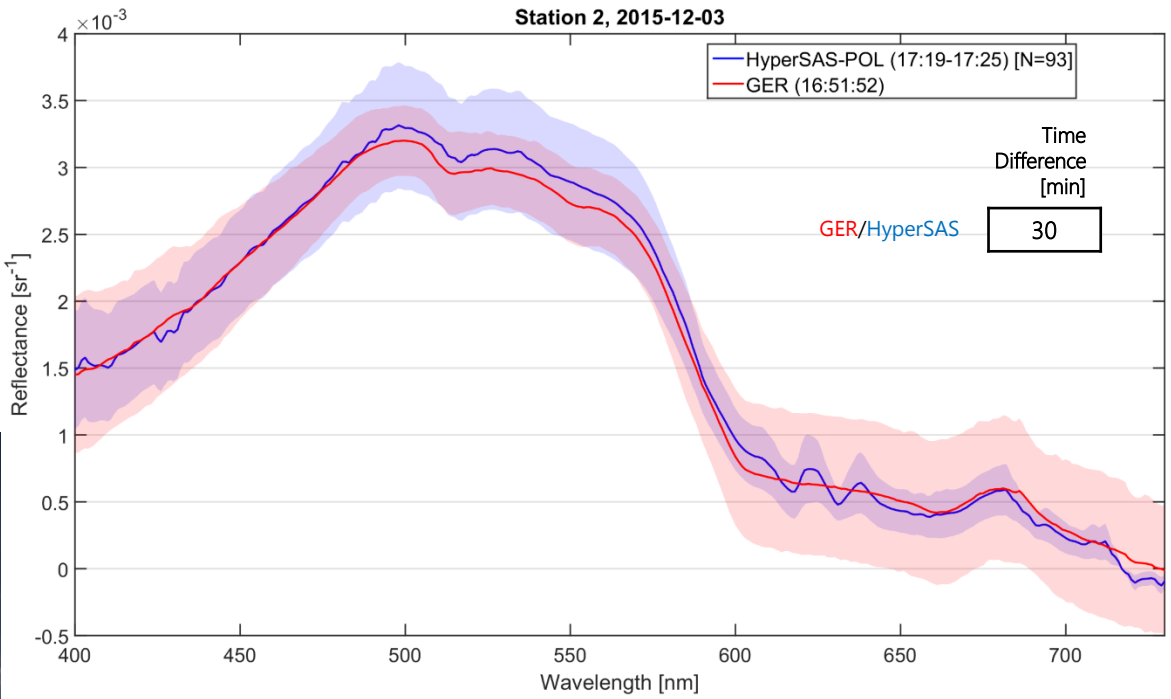



# Comparison of HyperSAS and GER (handheld) data (coastal water station)

## Station 2

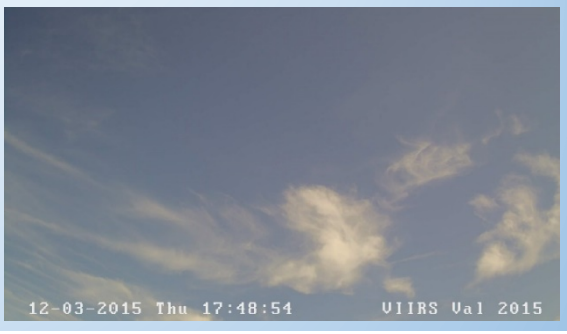


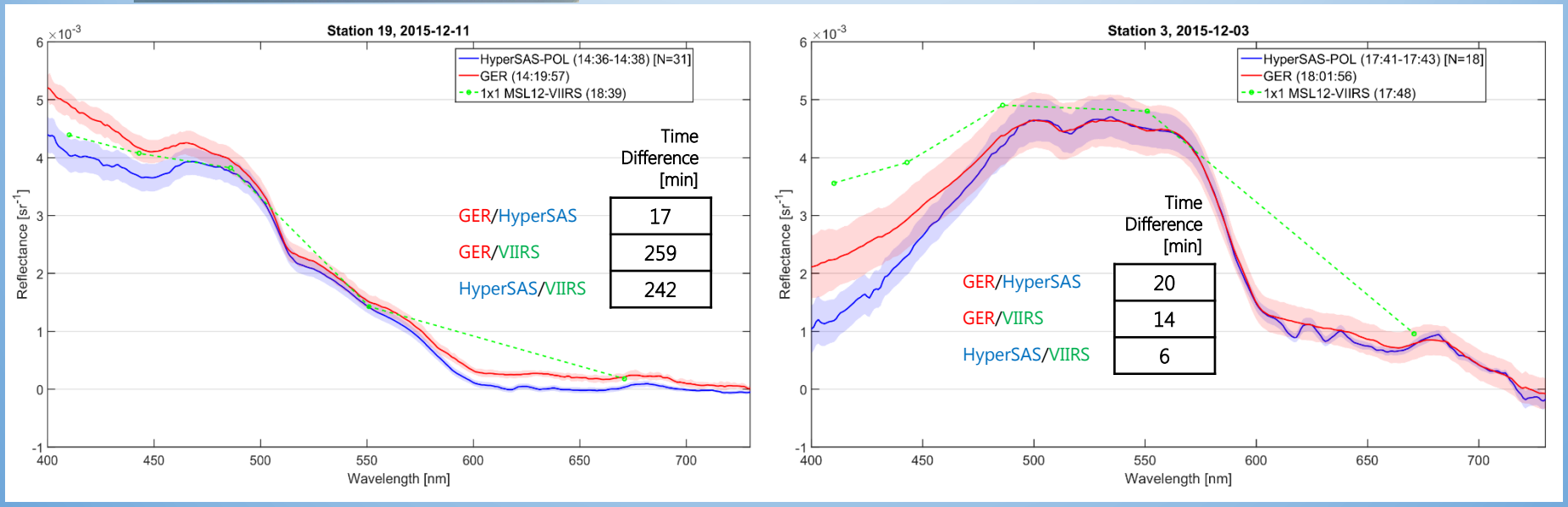



# Comparison of HyperSAS, GER (handheld) and VIIRS data




Open ocean station

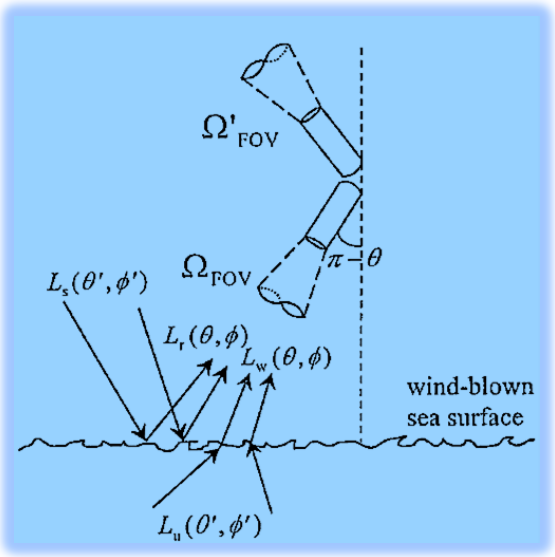
Coastal water station

HyperSAS showed very good performance in comparison with many other instruments on board and can be considered as a stable shipborne instrument for the validation of the satellite data

# Glint Correction

***How do we estimate polarized Remote Sensing Reflectance?***

For scalar reflectance:






For polarized reflectance:

We need to know the full polarization state of the light after interaction with the surface.

$$\bar{\rho} = \begin{bmatrix} \rho_{11} & \rho_{12} & \rho_{13} & \rho_{14} \\ \rho_{21} & \rho_{22} & \rho_{23} & \rho_{24} \\ \rho_{31} & \rho_{32} & \rho_{33} & \rho_{34} \\ \rho_{41} & \rho_{42} & \rho_{43} & \rho_{44} \end{bmatrix}$$

Goal: Determine $\bar{\rho}$

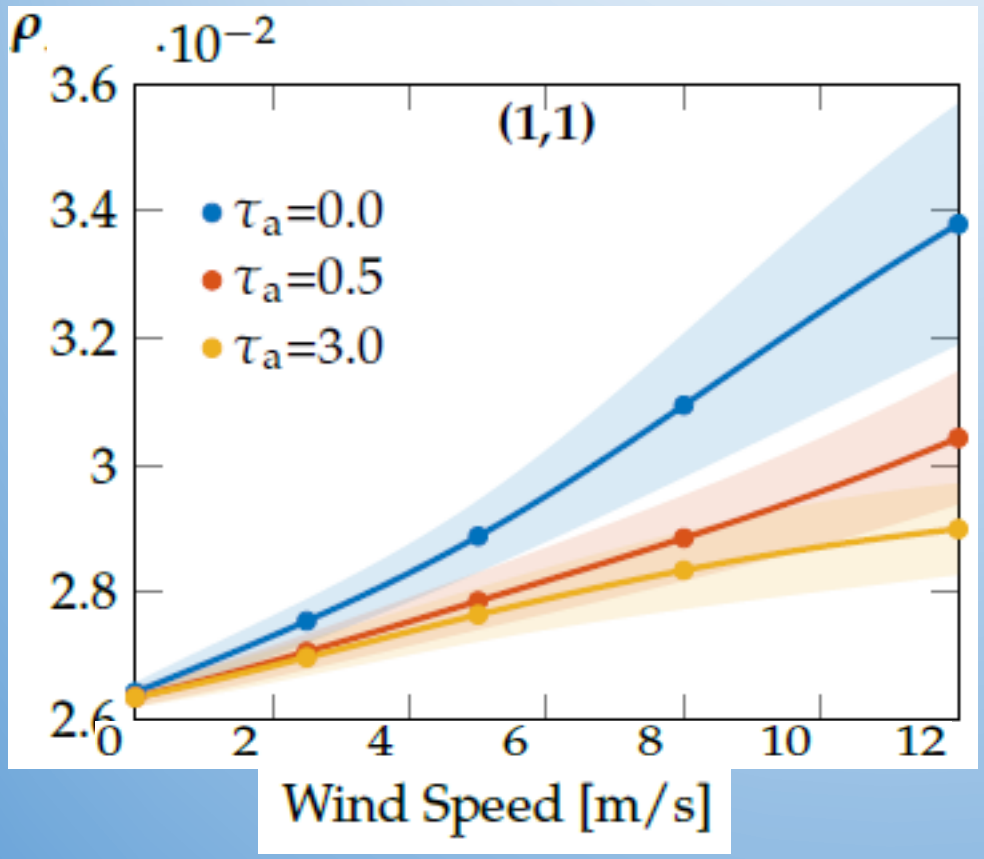
$$\rho = f\begin{pmatrix} \theta_s, \phi_s, \theta_v, \phi_v, n(\lambda), \Omega_{FOV}, \\ windspeed, sky\ illumination \end{pmatrix}$$

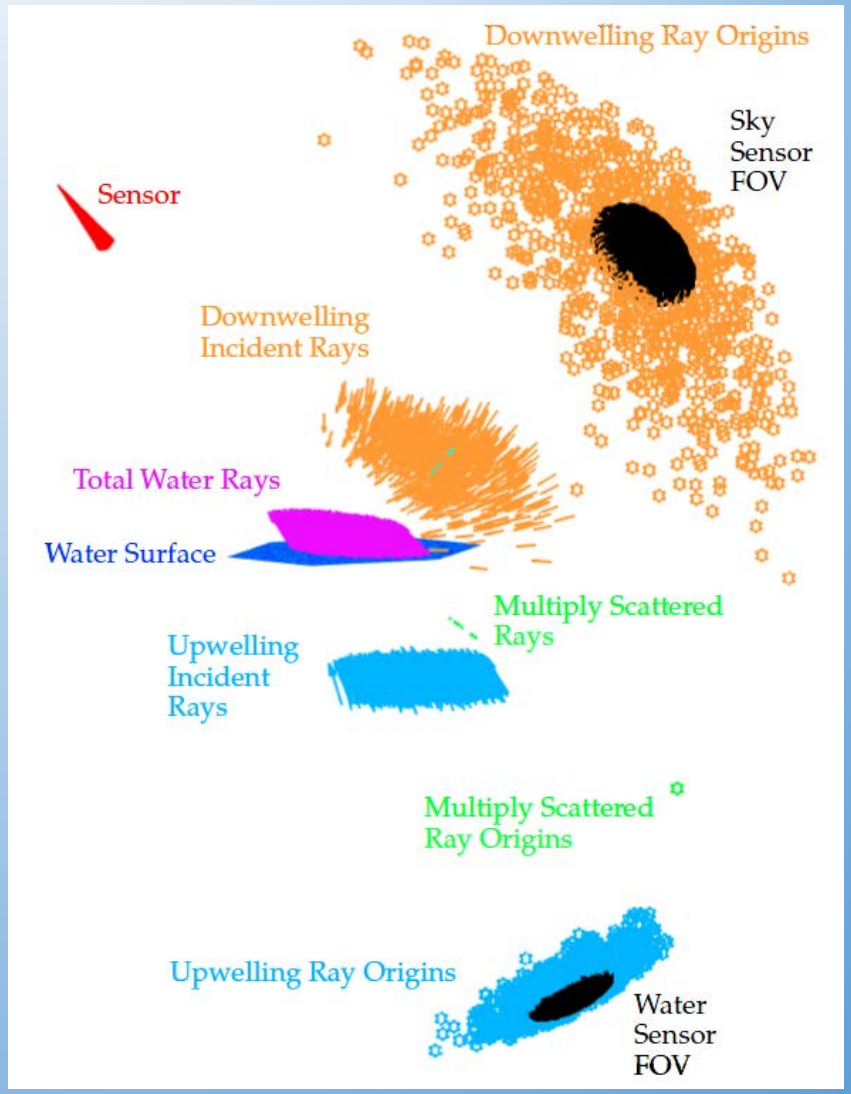
$$\overline{\boldsymbol{Rrs}} = (\bar{\boldsymbol{L}}_{\boldsymbol{t}} - \boldsymbol{\rho} \cdot \bar{\boldsymbol{L}}_{\boldsymbol{s}})/\bar{\boldsymbol{E}}_{\boldsymbol{d}}$$

$\rho$ estimates how much incident light is reflected from the surface.

$$R^p_{rs}(\theta_v, \phi_v, \lambda) = \frac{L^p_t(\theta_v, \phi_v, \lambda) - \bar{\rho} L^p_s(\pi - \theta_v, \phi_v, \lambda)}{E_d(\lambda)} \quad [sr^{-1}]$$

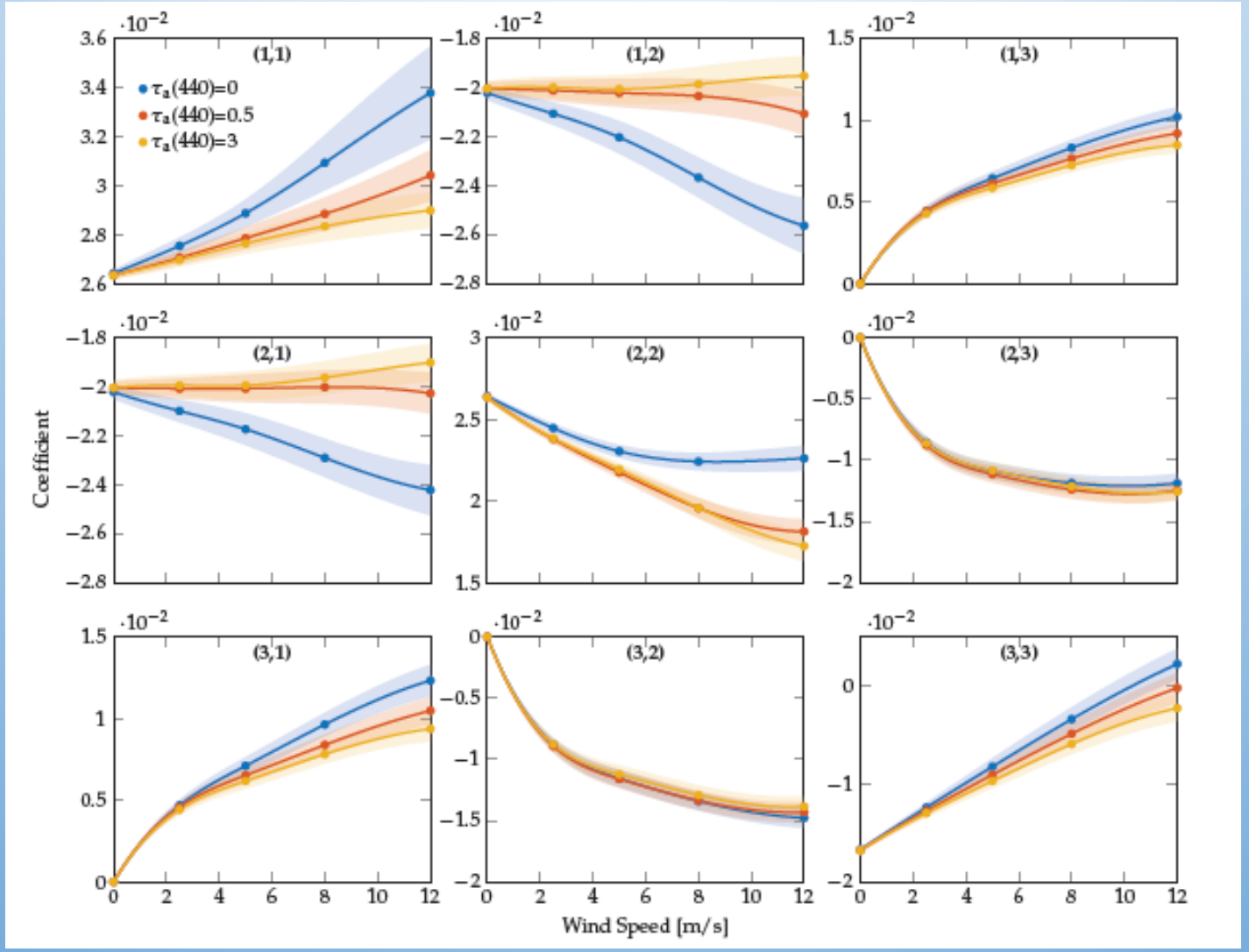
# Modeling of light reflection for wind driven ocean surfaces



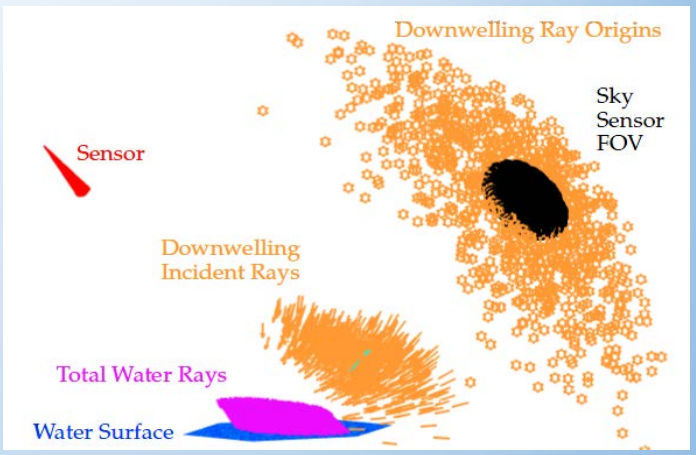

R. Foster et al, Appl. Opt. (in review)

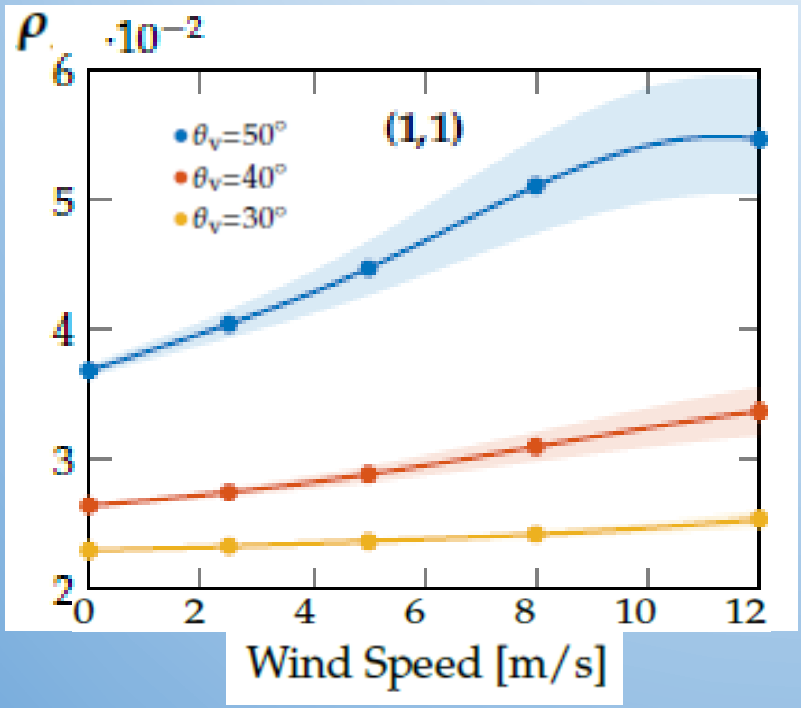
# Effective surface reflective matrix

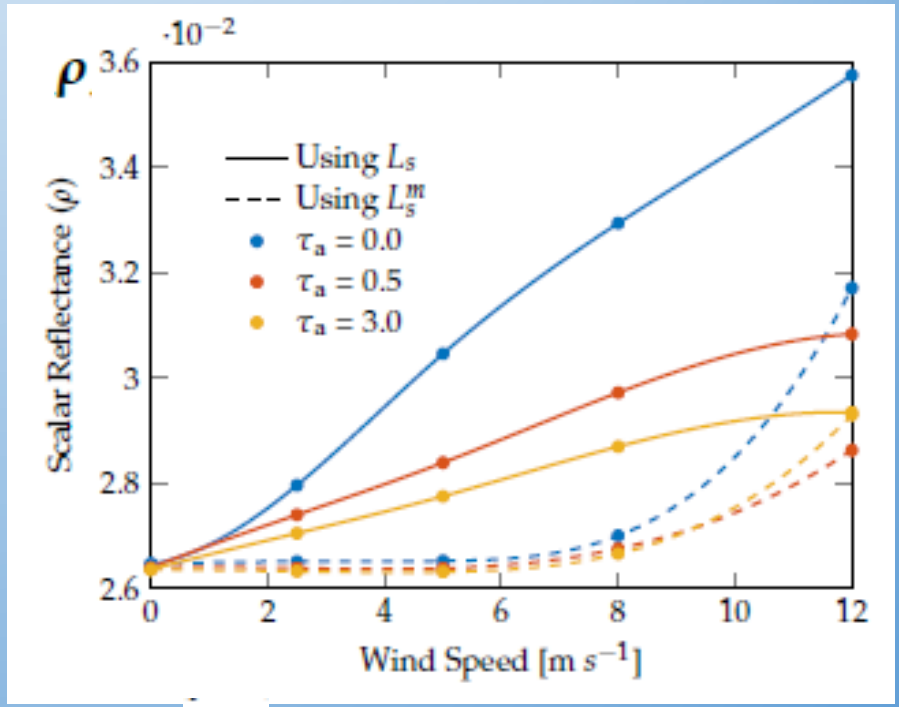



Sun angle 30 deg, viewing angle 40 deg, azimuth angle 90 deg

# Dependence of $\rho$ on the viewing angle and a field of view




Combination of accurate measurements and correct coefficients improves HyperSAS and other sensors data quality in above water measurements

$L_s^m$ is for the measurement of the radiometer with 5.75 deg half angle

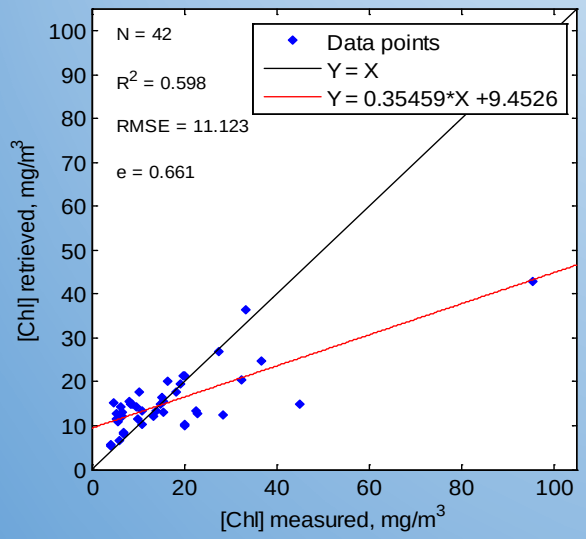
# Development of Algorithms for Retrieval of Chlorophyll-a in the Chesapeake Bay and other Coastal Waters Based on JPSS-VIIRS Bands

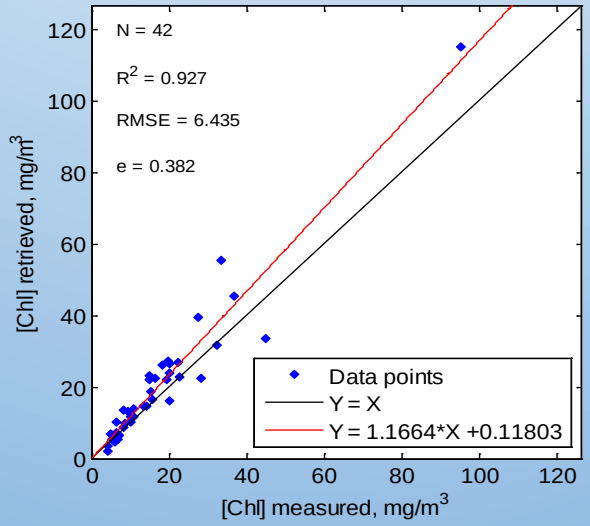
Evaluation on the field data, Chesapeake Bay, 2013

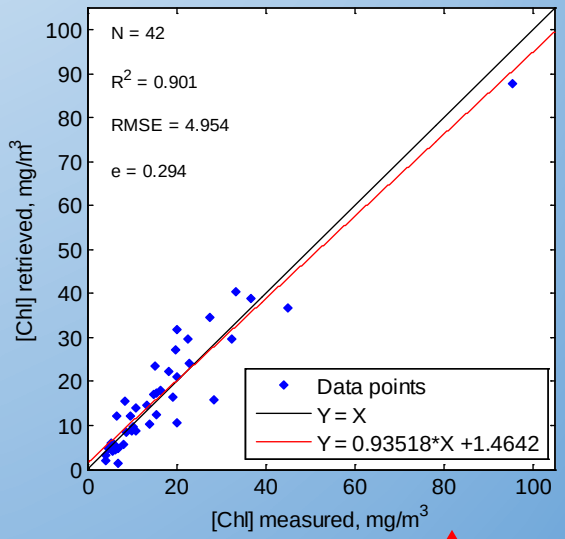
OC3V

[Chl] =(35.75*(Rrs708/Rrs665) - 19.30).^1.124 Gilerson et al 2010

very high data consistency; no 708nm band on VIIRS




**Algorithms which include 745nm band**

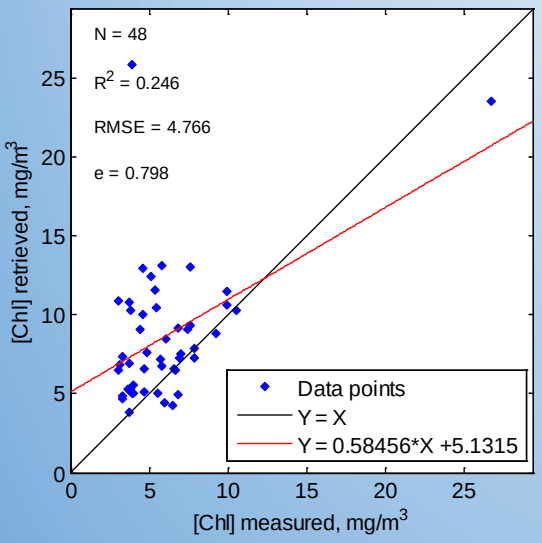
chl1 = 10^(a1 + a2*Rrs488/Rrs550 + a3*Rrs671/Rrs745 )

Similar results chl2 = ((2.459*(t1*Rrs745/Rrs671) - 0.439 + t2)/(0.022))^1.124

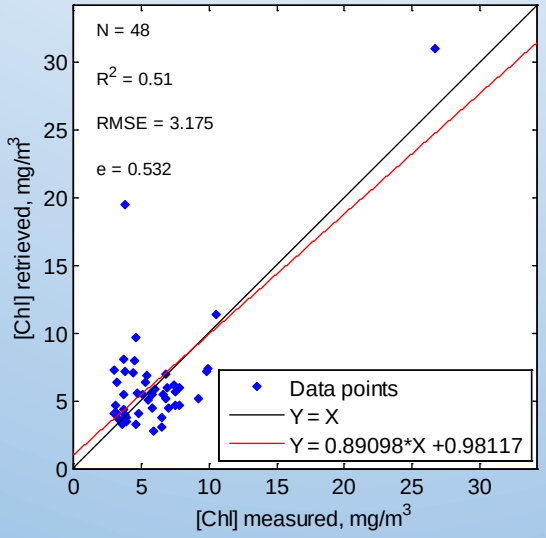
# Performance of the algorithms based on the satellite data

Evaluation on the satellite data VIIRS 2012-15, strict filtering, matchups with the in situ data of the Chesapeake Bay Program

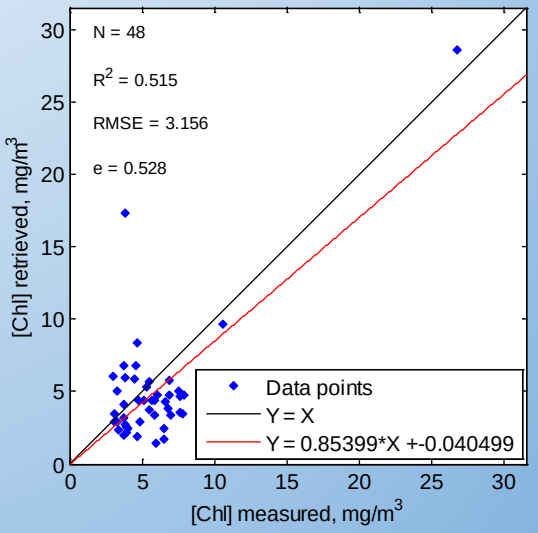
OC3V




Chl1 = 10 $^{(a1 + a2*R1 + a3*R2)}$




Chl2 = c1*(1/R2) $^{c2}$ - c3




R1=Rrs486/Rrs550;  R2= Rrs671/Rrs745 )

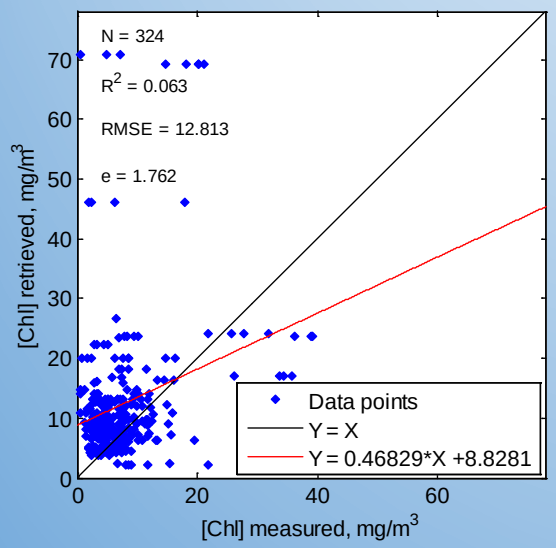
- Good performance of the algorithms which use 745nm band in comparison with OC3V on VIIRS.
- Small amount of data because of the strict filtering

# Performance of the algorithms based on the satellite data

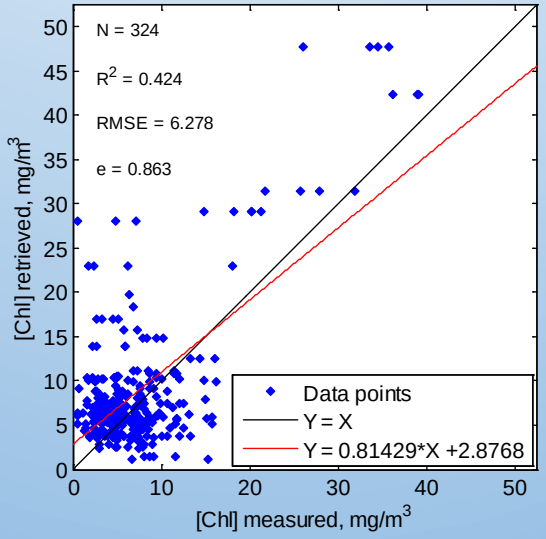
**Stray light flag is suspended**

Evaluation on the satellite data VIIRS 2012-15, strict filtering, matchups with the in situ data of the Chesapeake Bay Program

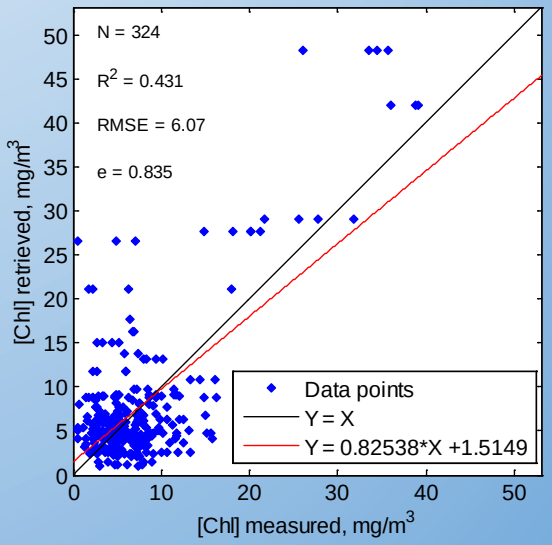
OC3V




Chl1 = 10 $^{(a1 + a2*R1 + a3*R2)}$




Chl2 = c1*(1/R2) $^{c2}$ - c3




R1=Rrs486/Rrs550;  R2= Rrs671/Rrs745 )

While few outliers are present, new algorithms significantly outperform OC3V algorithm

# Conclusions

- Based on the comparison of the satellite and AERONET-OC data on the LISCO site 412 and 443nm bands for MODIS and VIIRS do not perform well in coastal environment, atmospheric data should be further analyzed.
- HyperSAS instrument performs well in the shipborne mode and can be considered for the validation at the stations and underway.
- Accurate reflection coefficients were simulated for various wind and observation conditions and can be used for the improvement of the sky correction in above water measurements.
- Chlorophyll algorithms for the Chesapeake Bay with VIIRS bands have been developed based on the Rrs671/Rrs745 ratio which significantly outperform standard OC3V algorithms.

- We acknowledge support from the JPSS program and NOAA-CREST.

# Evaluation of VIIRS performance over coastal waters and its capacity to detect dark water and algal blooms

Chuanmin Hu, Brian Barnes, Jennifer Cannizzaro, David English, Lin Qi

Univ. South Florida, huc@usf.edu

NOAA JPSS/VIIRS Team Meeting, August 8 - 11, 2016

# Objectives

- Evaluate/Validate VIIRS ocean color data products
- Demonstrate VIIRS capacity in studying coastal oceans (water quality, algal blooms, oil spills)
- Share data and results with community to advance science and mission planning

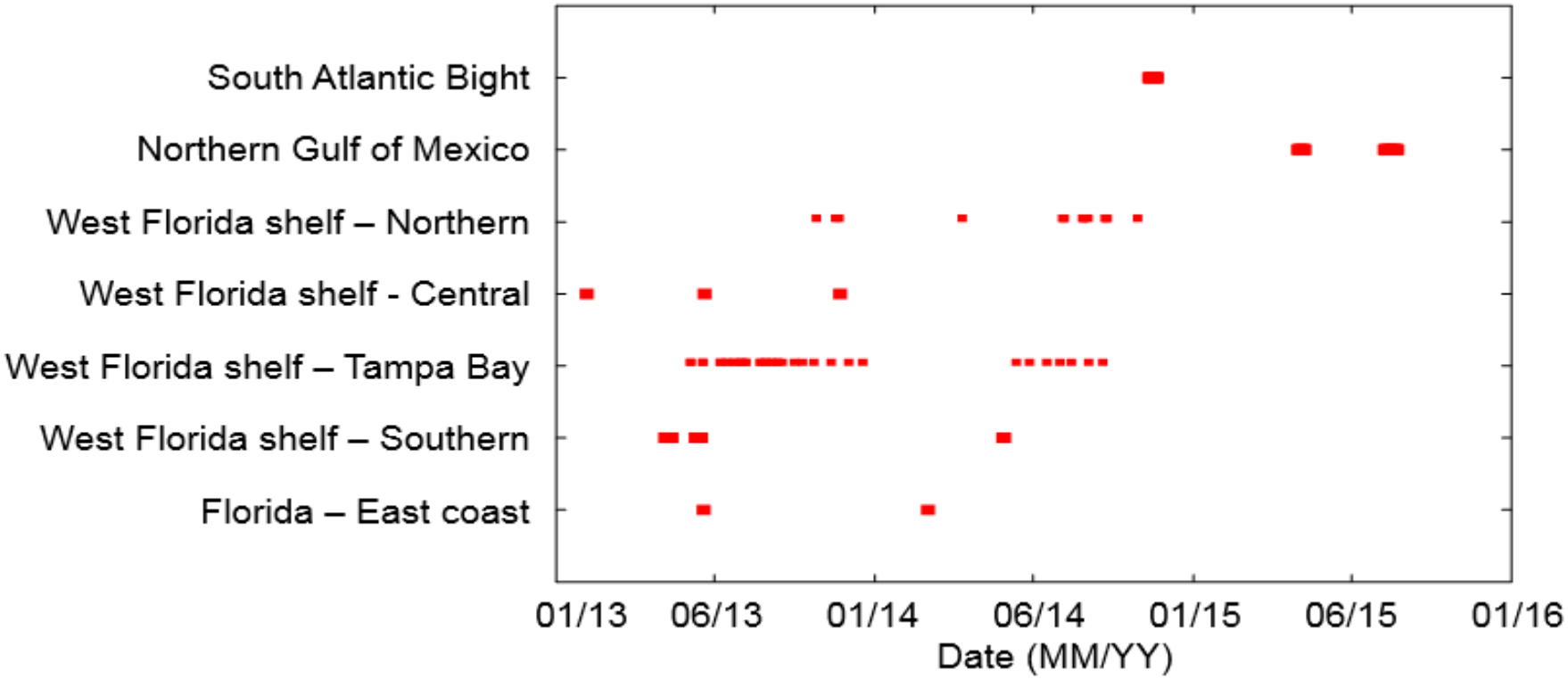
# How?

- Field measurements following community-accepted protocols
- Satellite data analysis and comparison with field measurements
- Communication with science team and the community
- Technical reports and publications

# Field Measurements

Conducted by USF Optical Oceanography Lab in collaboration with other groups.

All measurements have filter-pads absorptions and CDOM absorptions. Most measurements also have scattering and reflectance IOPs. Some have taxonomy and profiling data.

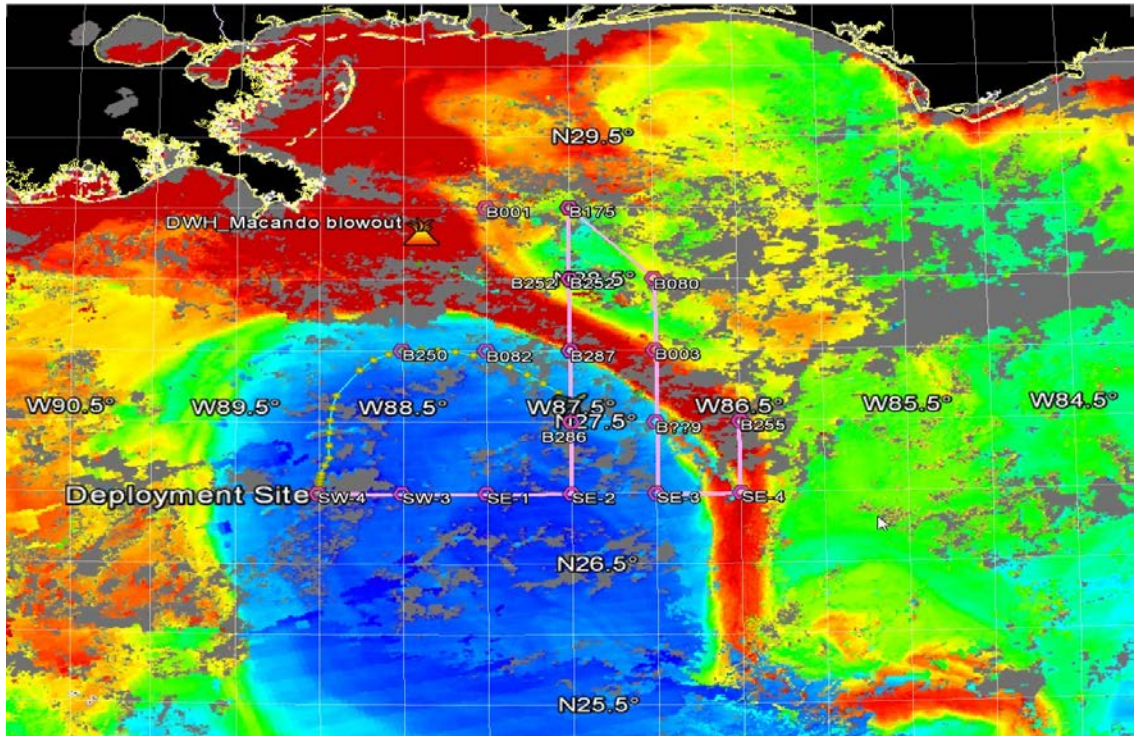



Note: NOAA VIIRS cruises not plotted here

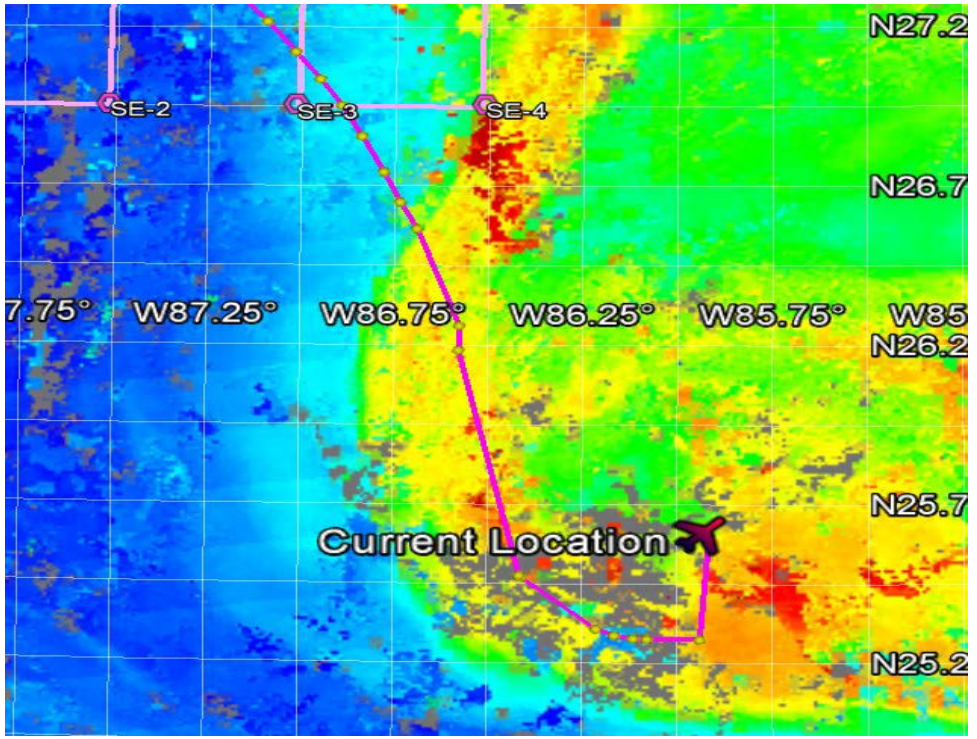
# Field Measurements

An example from the DEEPEND02 cruise (Aug 8 – 22, 2015)

MODIS 5-day composite ending Aug 12, overlaid with cruise stations and glider track to Aug 12

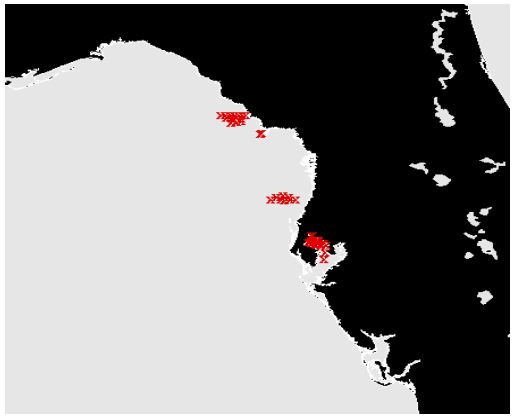


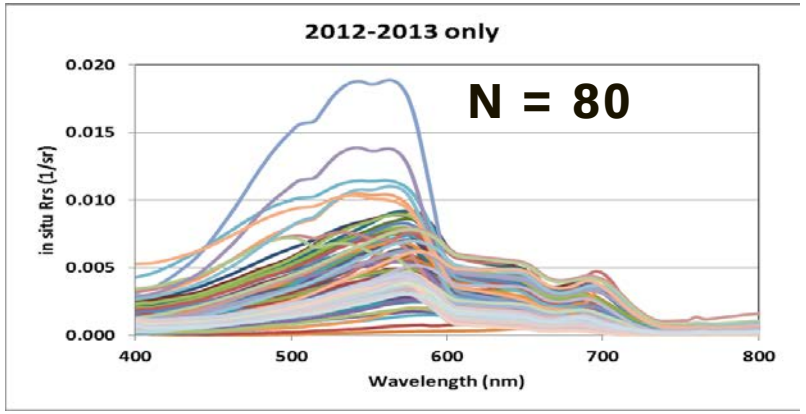

MODIS 3-day composite showing glider track up to Aug 18

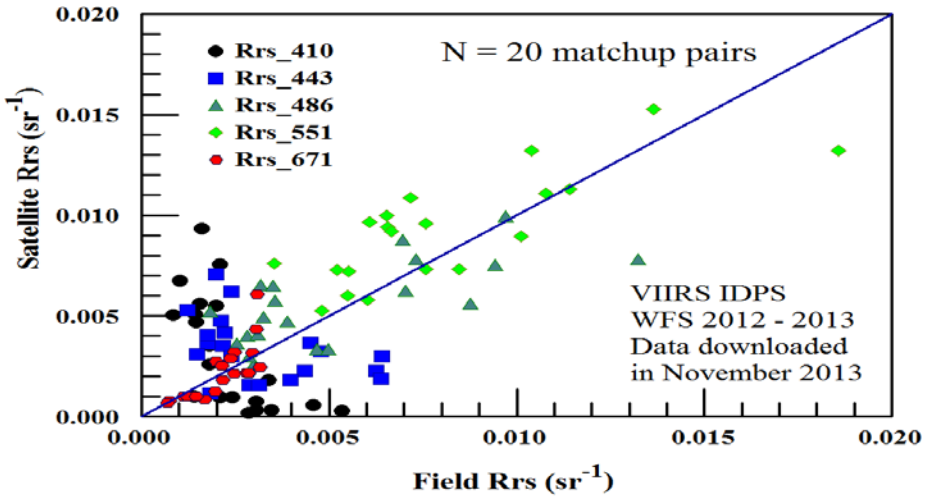


# NOAA VIIRS Validation Results

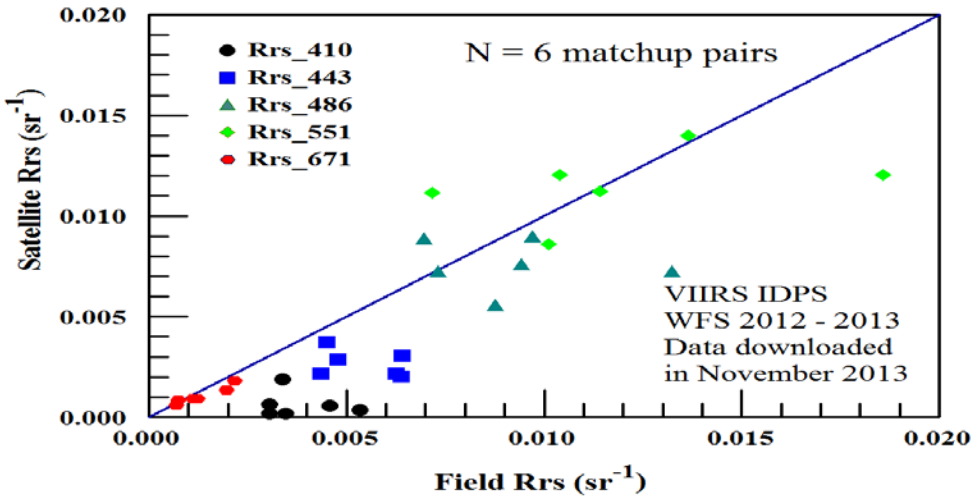
# Initial Validation (IDPS processing) in 2014





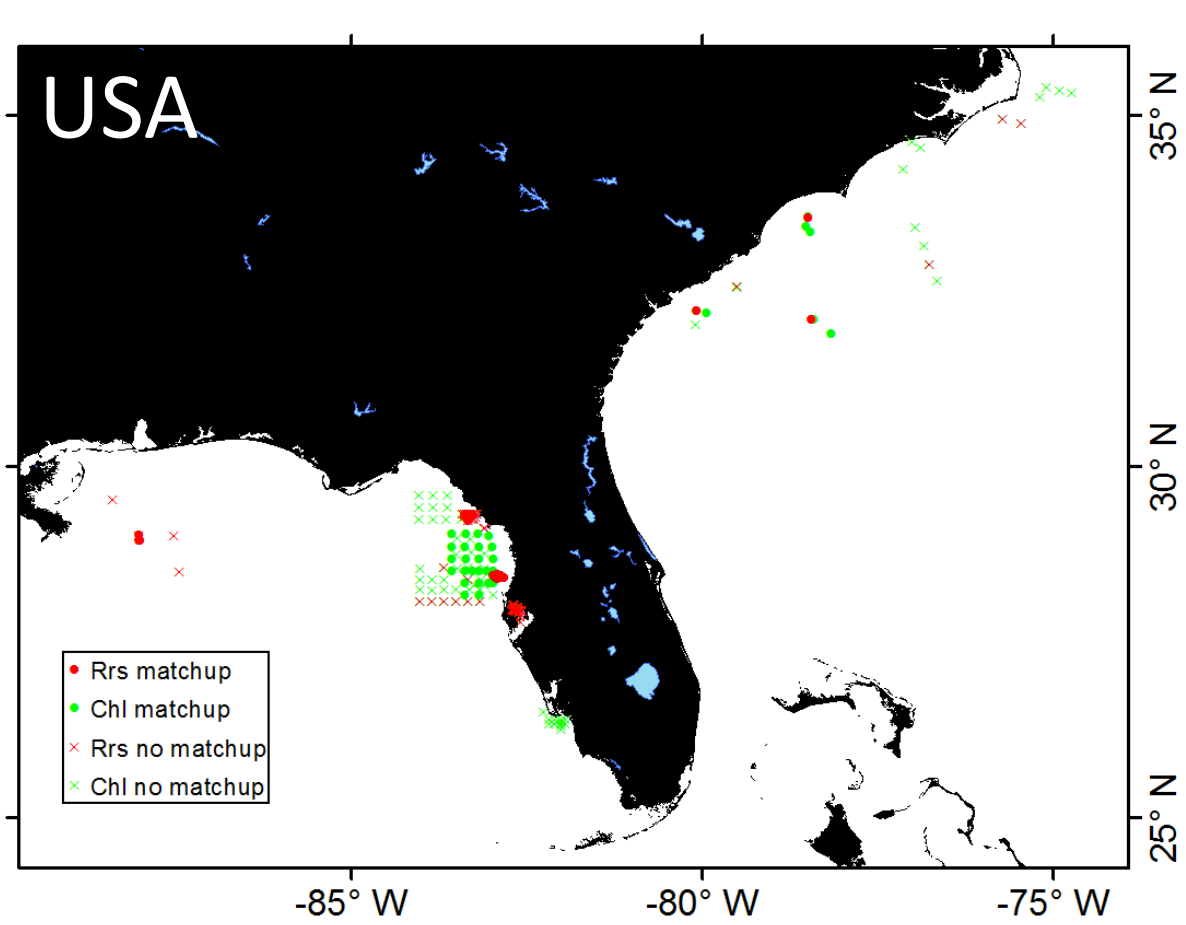

QF Flags not applied

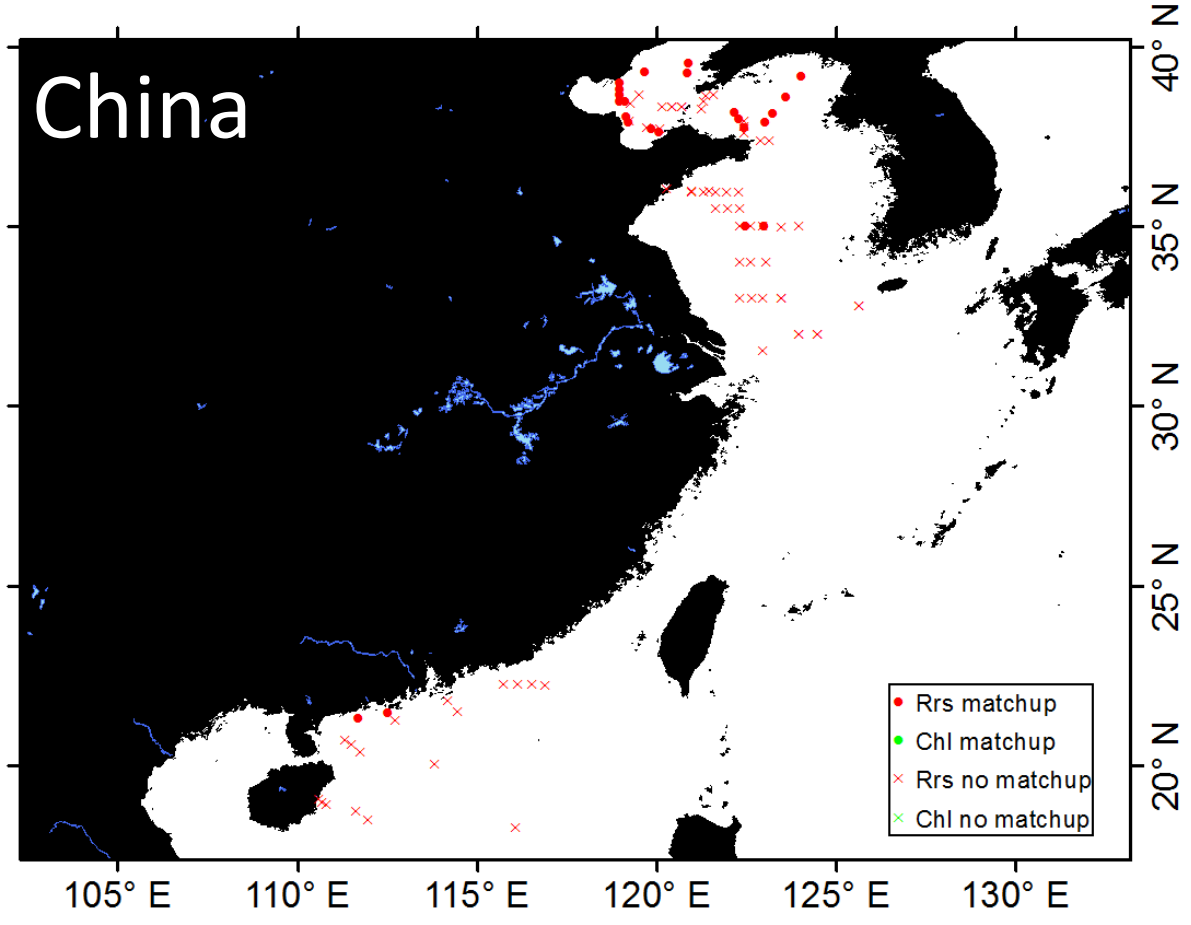



QF Flags applied

# New Validation (MSL12 processing)

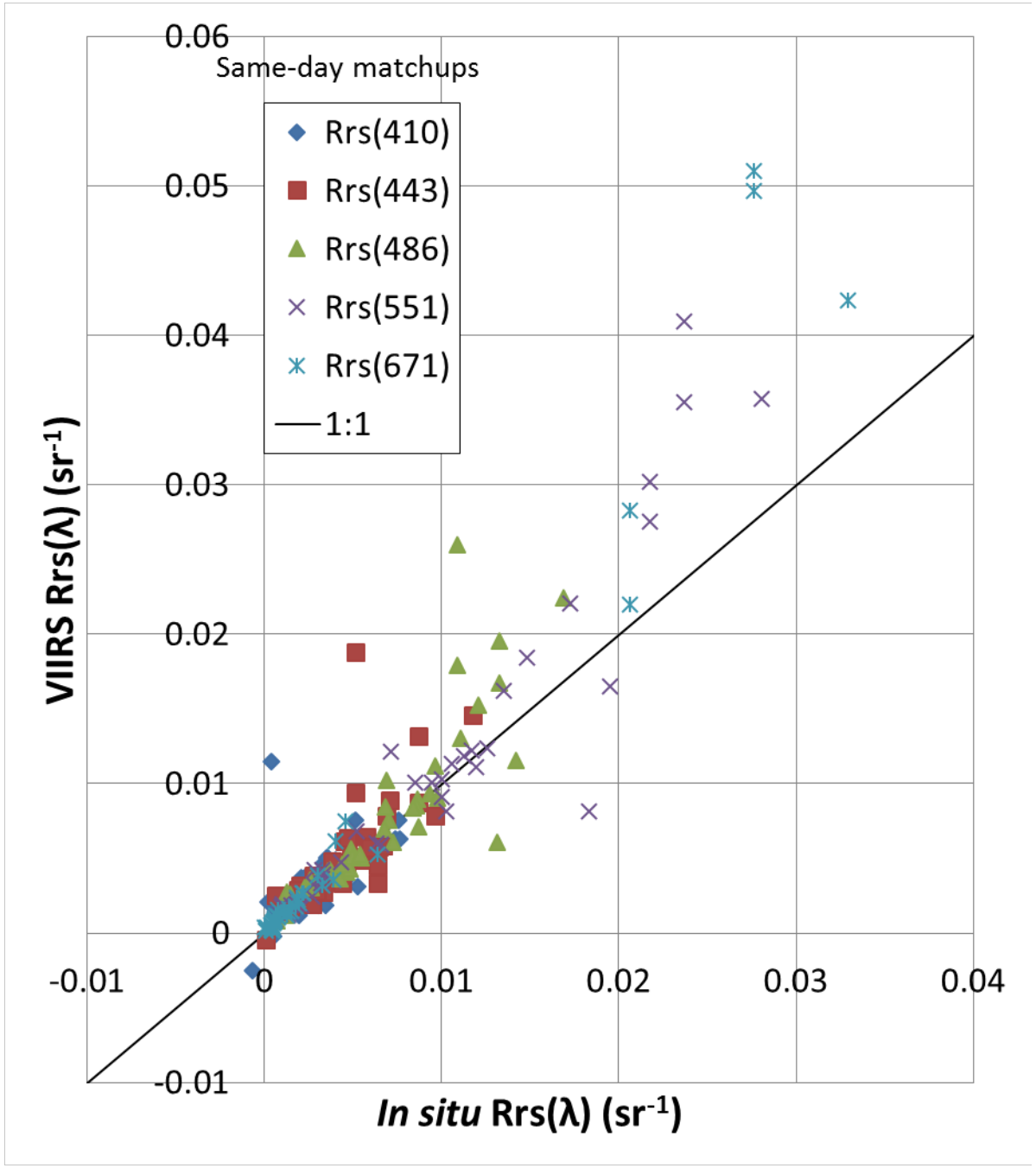
**VIIRS data downloaded from NOAA/NESDIS ftp site in July 2016**
**Field data collected between 2012 and 2015 from different cruises**



# NOAA VIIRS

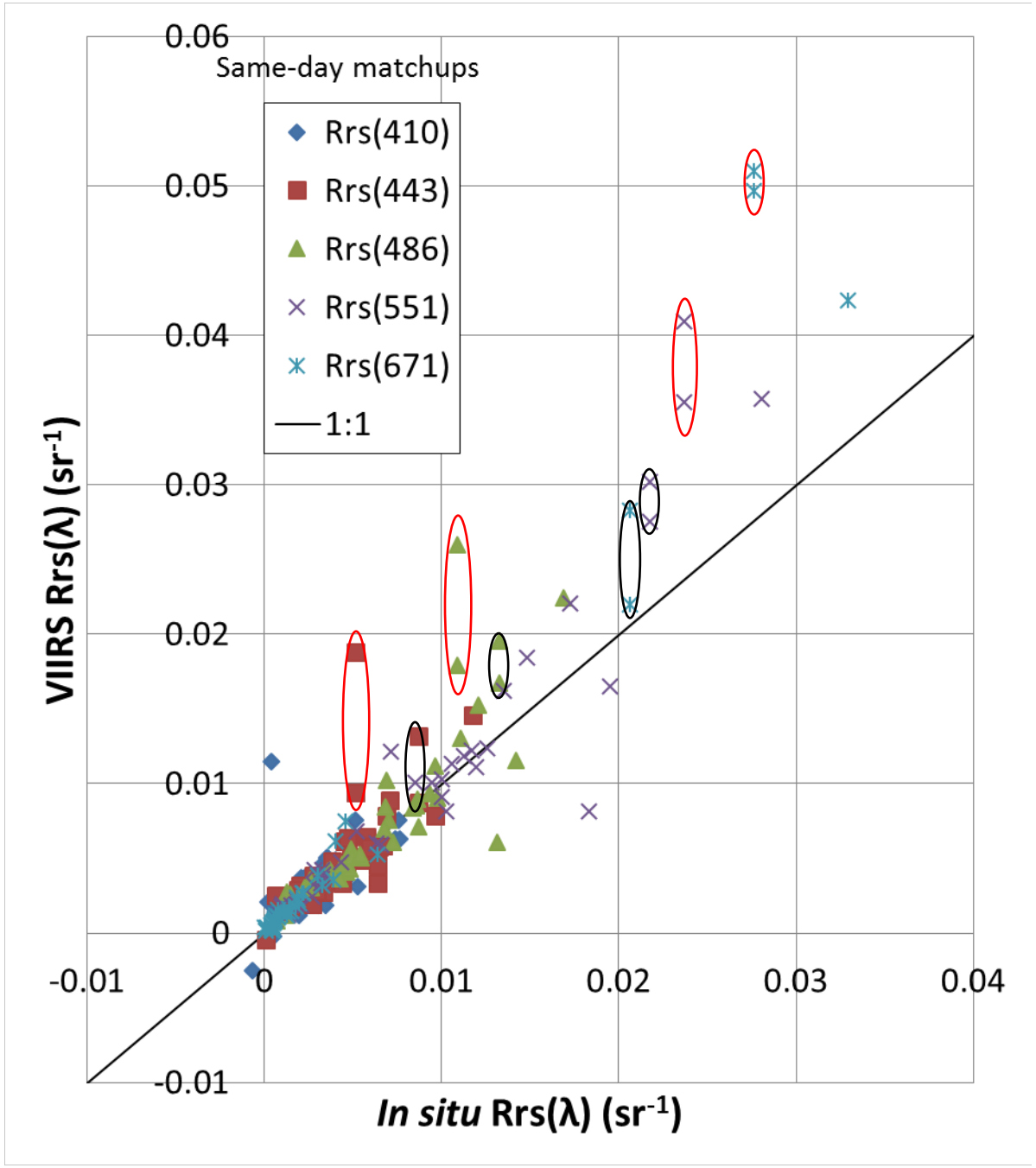
Linear-scale same-day matchups between *in situ* and VIIRS Rrs(λ).




| | UPD (%) | MAD ($sr^{-1}$) | N |
|---|---|---|---|
| Rrs(410) | 63.7 | 0.00118 | 38 |
| Rrs(443) | 18.5 | 0.00140 | 39 |
| Rrs(486) | 20.9 | 0.00185 | 40 |
| Rrs(551) | 21.4 | 0.00232 | 43 |
| Rrs(671) | 37.1 | 0.00184 | 43 |

# NOAA VIIRS

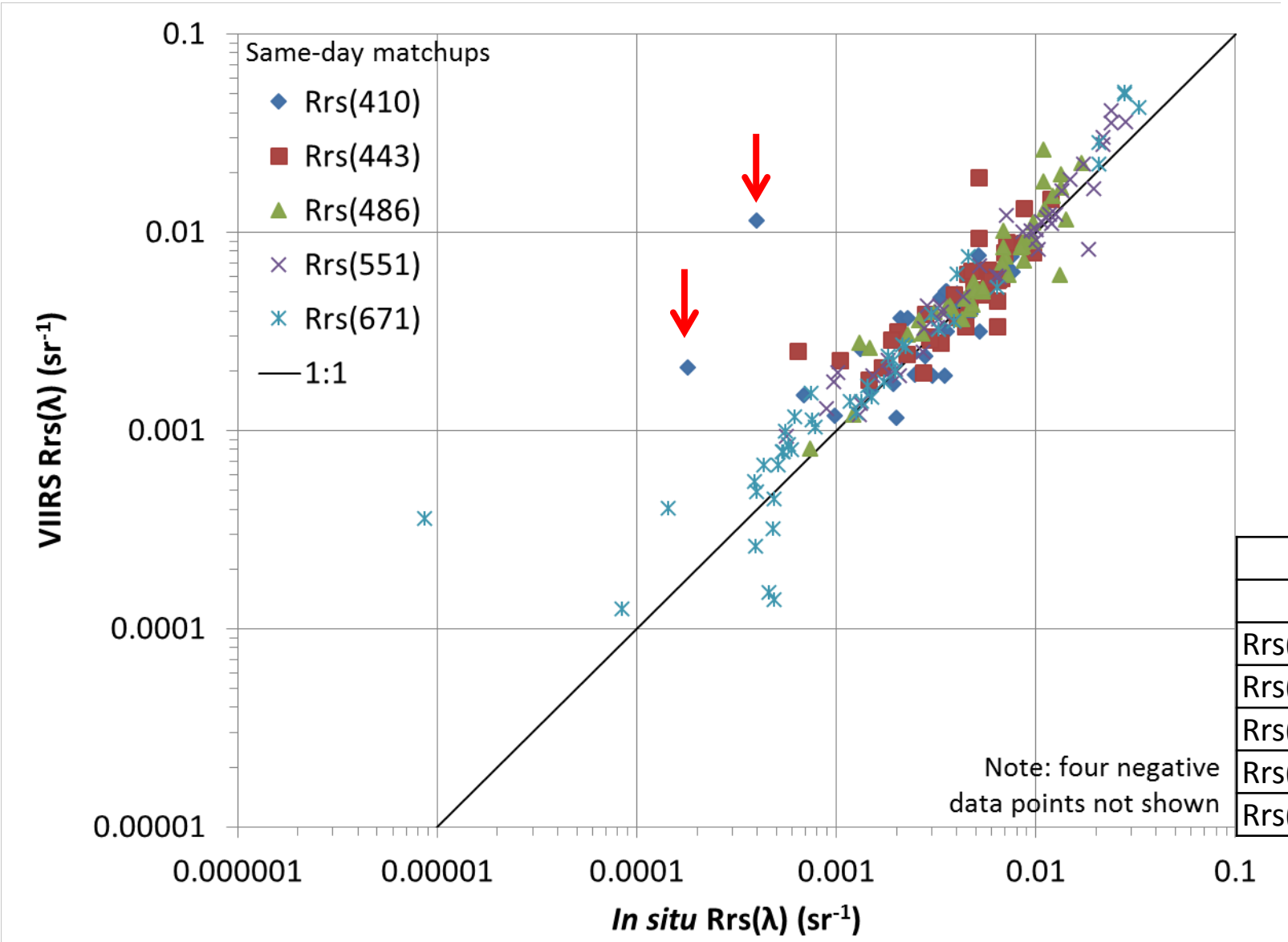
Two *in situ* spectra had replicate same-day VIIRS matchups (i.e., 2 valid VIIRS measurements for that location and date). One outlined in red and the other outlined in black. Rrs values for both spectra are higher than in situ values, thus they're easily identified in this graph.




| | UPD (%) | MAD ($sr^{-1}$) | N |
|---|---|---|---|
| Rrs(410) | 63.7 | 0.00118 | 38 |
| Rrs(443) | 18.5 | 0.00140 | 39 |
| Rrs(486) | 20.9 | 0.00185 | 40 |
| Rrs(551) | 21.4 | 0.00232 | 43 |
| Rrs(671) | 37.1 | 0.00184 | 43 |

# NOAA VIIRS

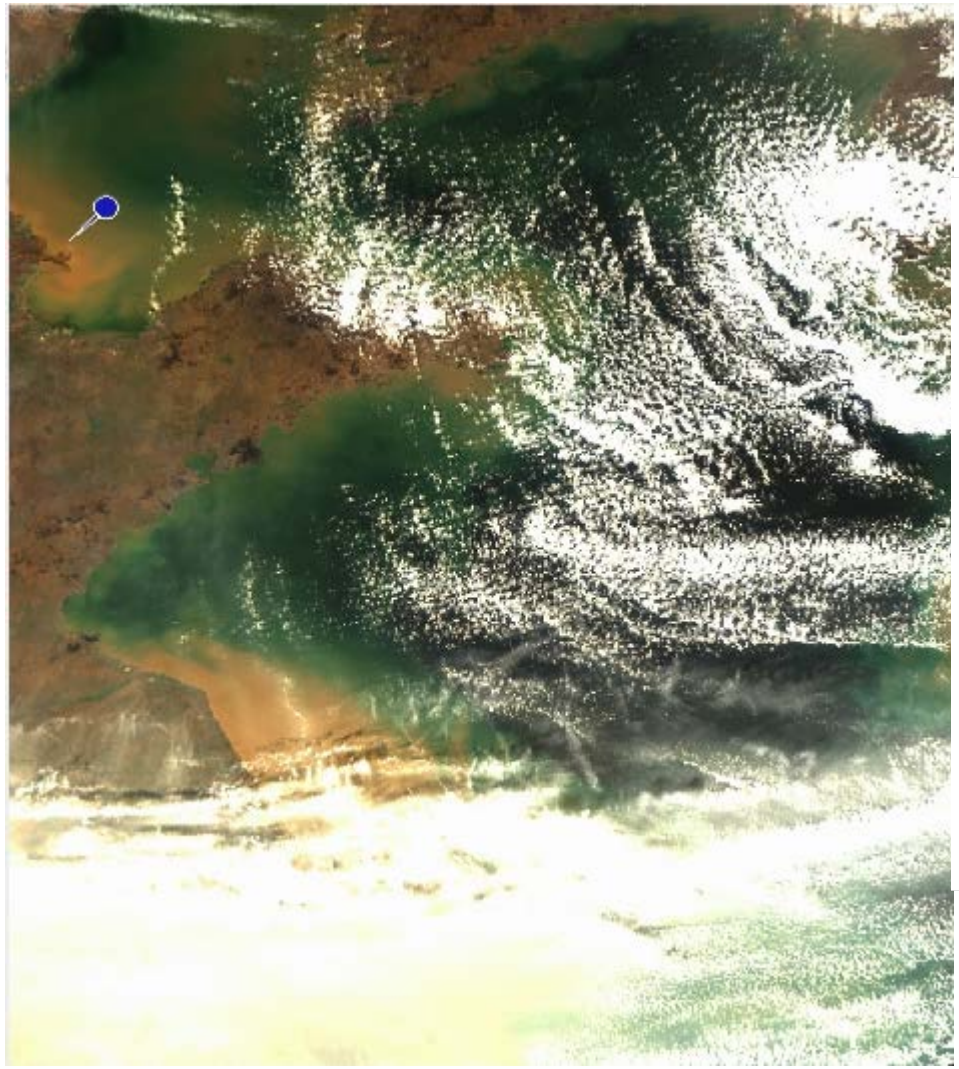
Log-scale same-day matchups between *in situ* and VIIRS Rrs(λ).

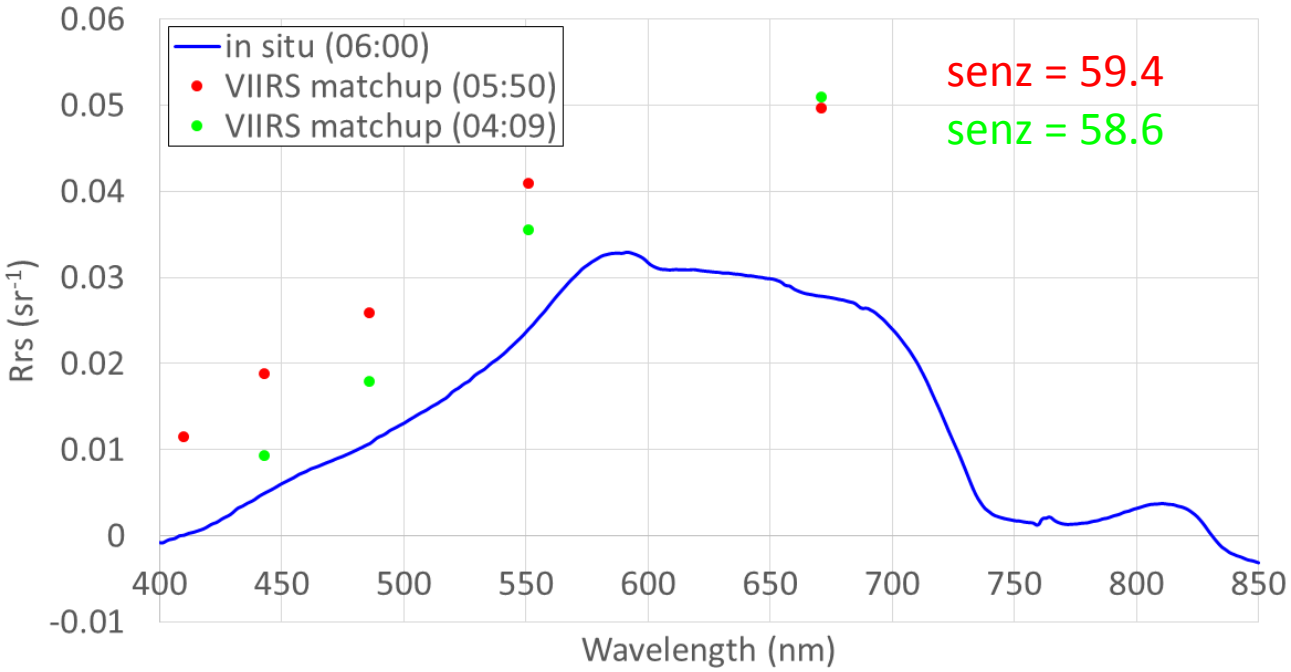



| | All data | | | Without 2 outliers | | |
|---|---|---|---|---|---|---|
| | UPD (%) | MAD ($sr^{-1}$) | N | UPD (%) | MAD ($sr^{-1}$) | N |
| Rrs(410) | 63.7 | 0.00118 | 38 | 57.4 | 0.00088 | 36 |
| Rrs(443) | 18.5 | 0.00140 | 39 | 13.2 | 0.00105 | 37 |
| Rrs(486) | 20.9 | 0.00185 | 40 | 18.0 | 0.00151 | 38 |
| Rrs(551) | 21.4 | 0.00232 | 43 | 19.6 | 0.00199 | 41 |
| Rrs(671) | 37.1 | 0.00184 | 43 | 35.2 | 0.00140 | 41 |

# NOAA VIIRS

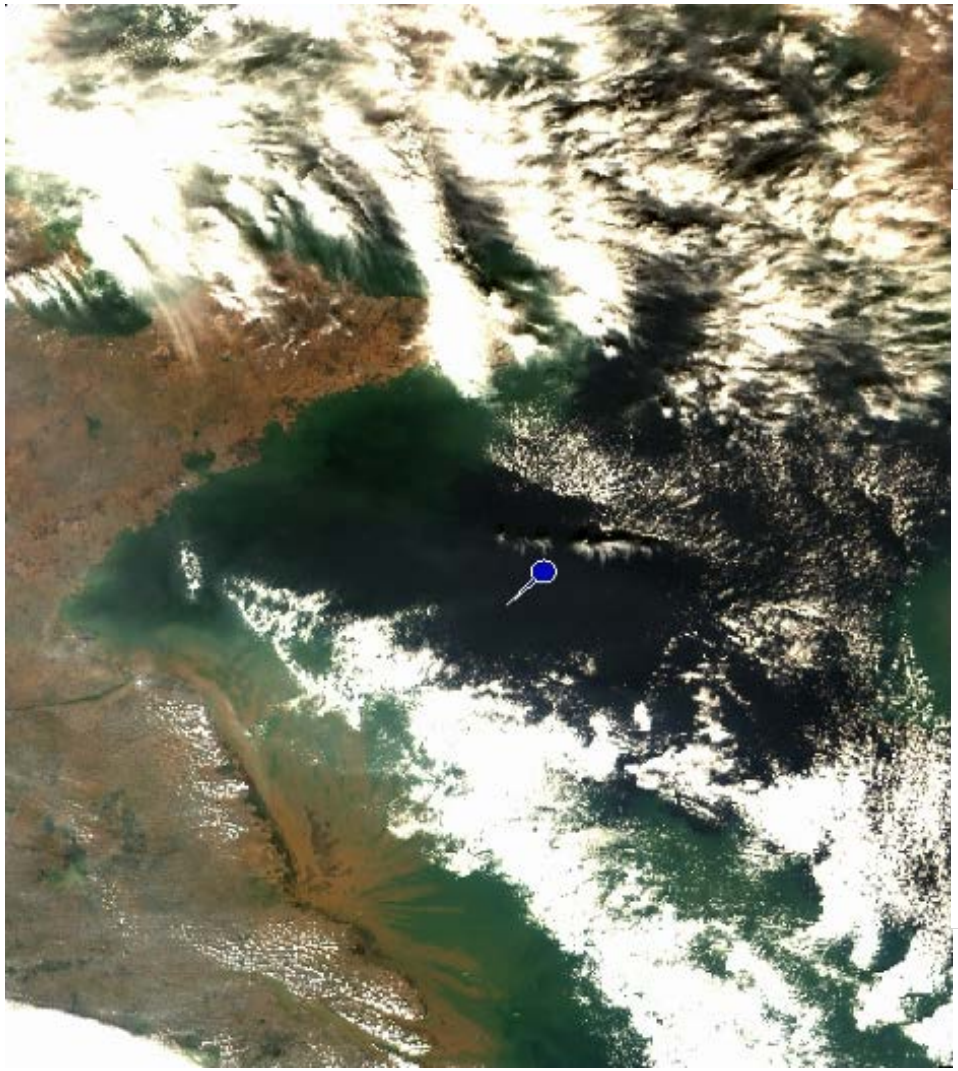
V20123240406

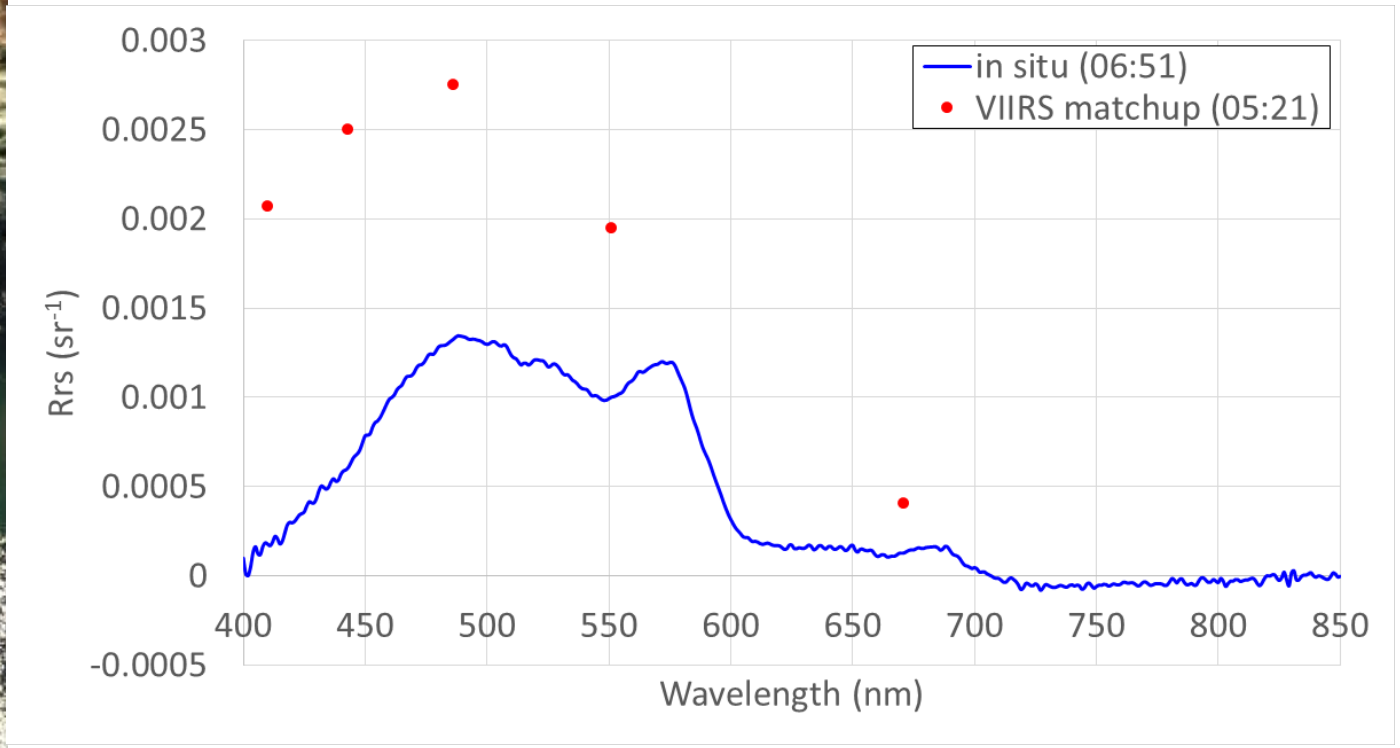




# NOAA VIIRS

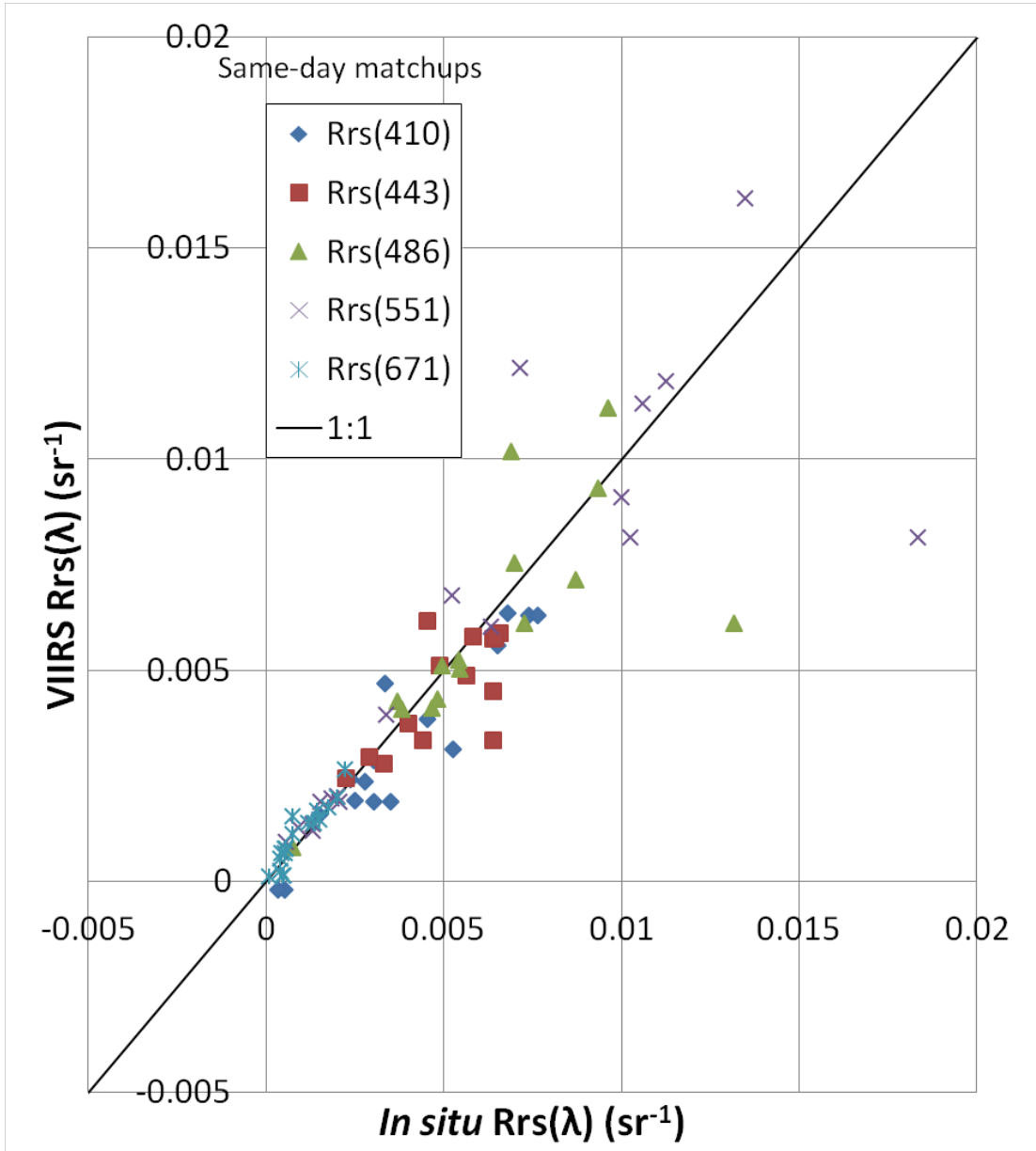
V20133170518

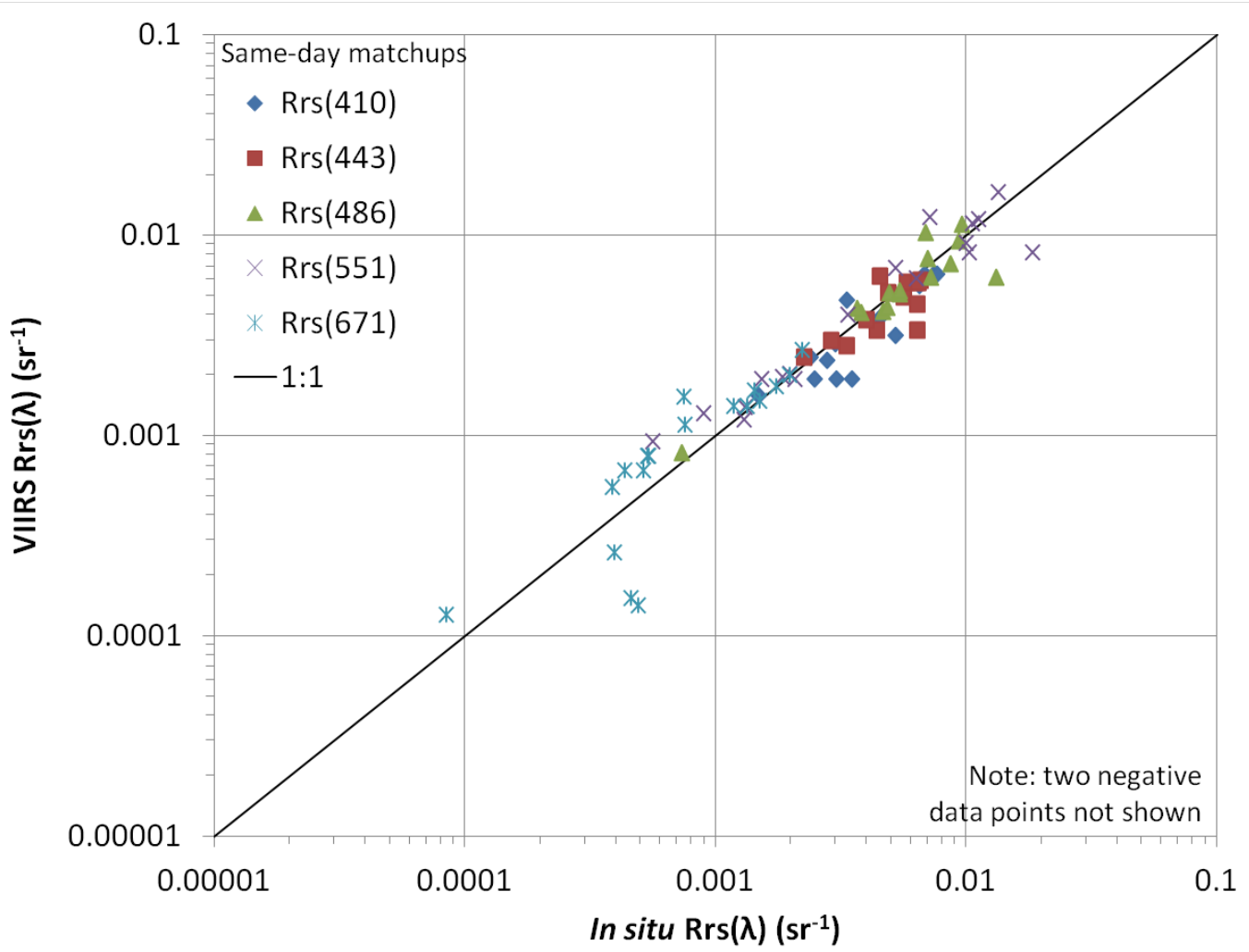




# NOAA VIIRS

## USA only

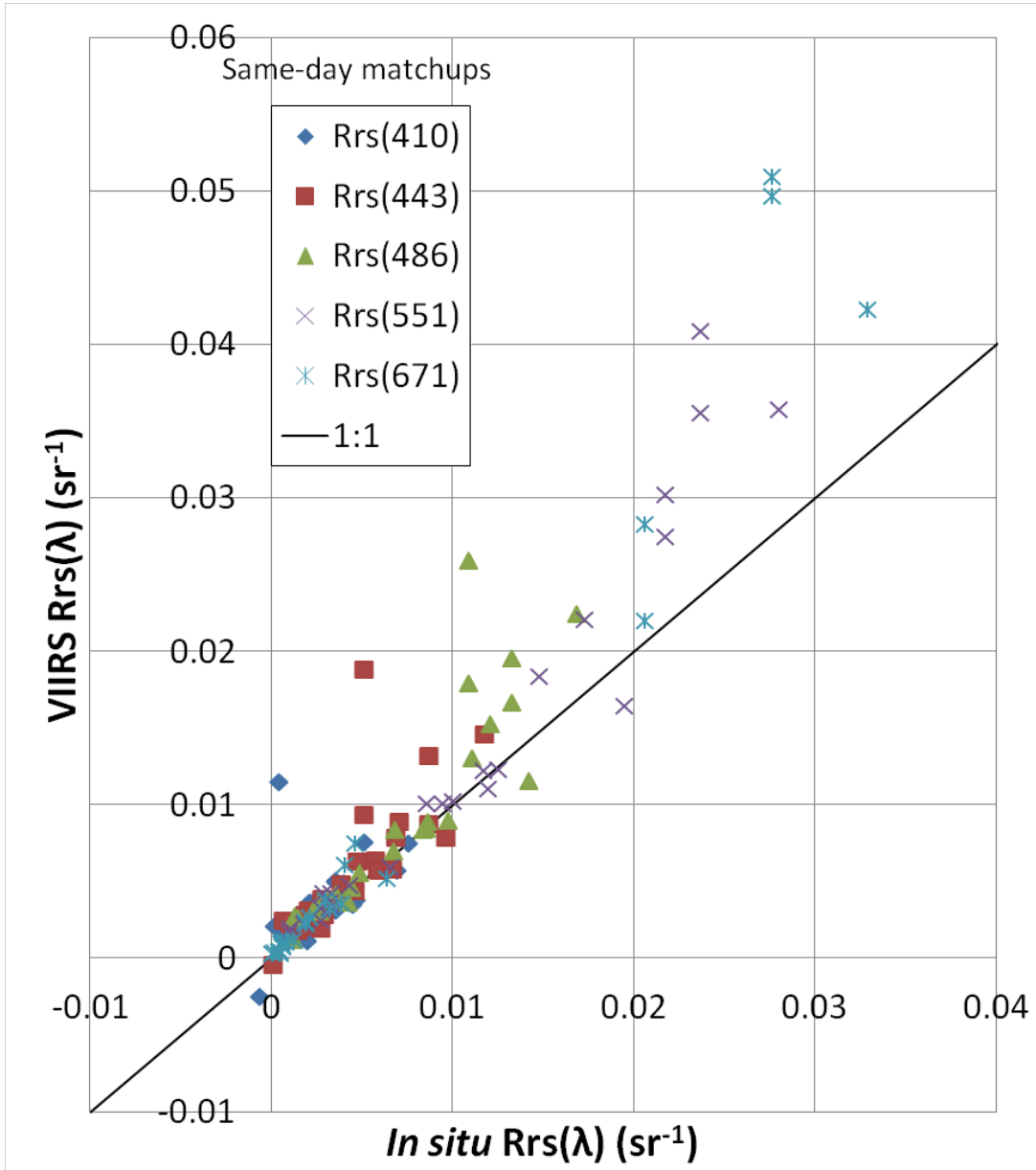


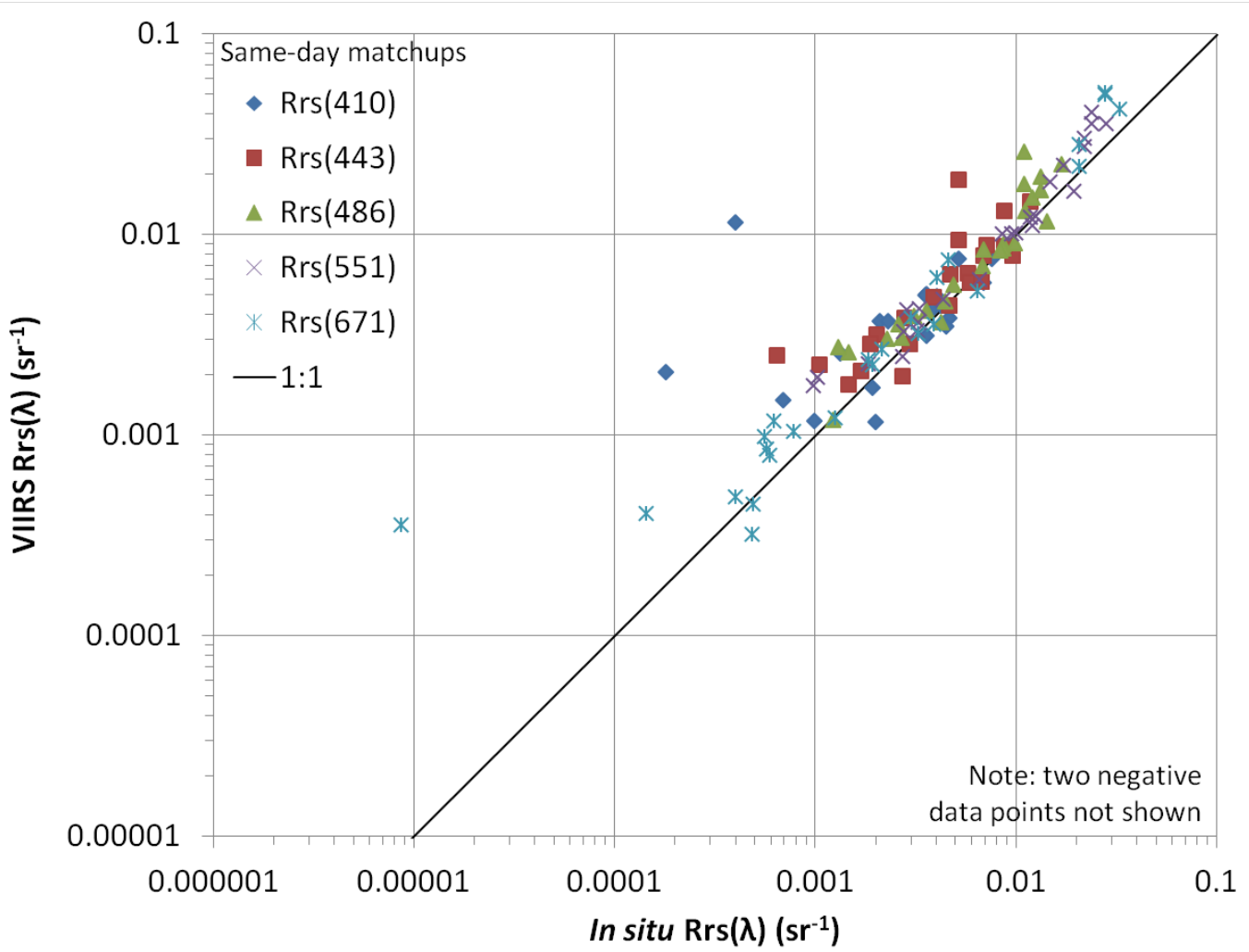




| | UPD (%) | MAD ($sr^{-1}$) | N |
|---|---|---|---|
| Rrs(410) | 102.4 | 0.00082 | 16 |
| Rrs(443) | 17.4 | 0.00084 | 14 |
| Rrs(486) | 16.1 | 0.00120 | 15 |
| Rrs(551) | 20.8 | 0.00146 | 18 |
| Rrs(671) | 35.3 | 0.00022 | 18 |

# NOAA VIIRS

## China only

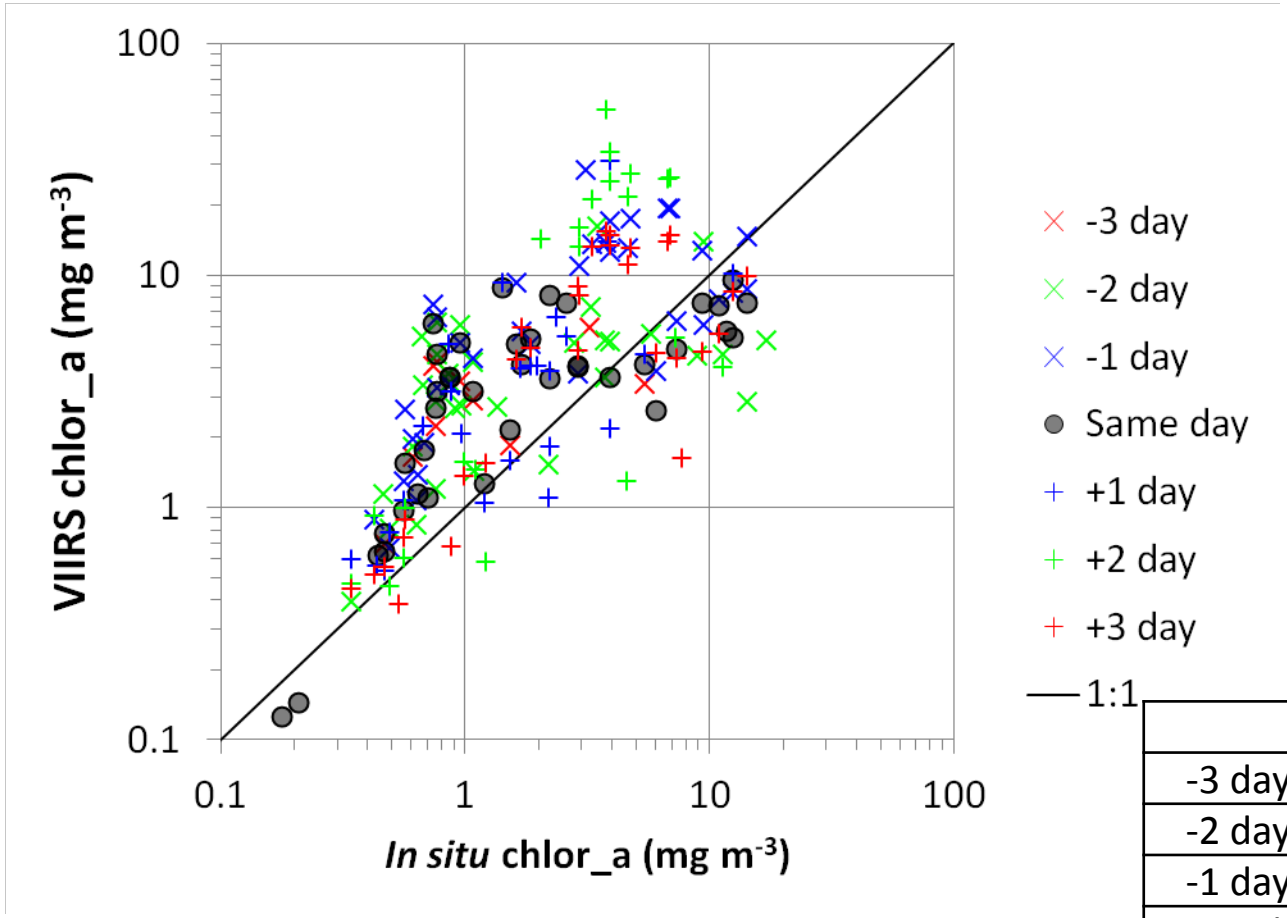



| | UPD (%) | MAD ($sr^{-1}$) | N |
|---|---|---|---|
| Rrs(410) | 35.6 | 0.00144 | 22 |
| Rrs(443) | 19.1 | 0.00171 | 25 |
| Rrs(486) | 23.8 | 0.00224 | 25 |
| Rrs(551) | 21.7 | 0.00293 | 25 |
| Rrs(671) | 38.5 | 0.00301 | 25 |

# NOAA VIIRS

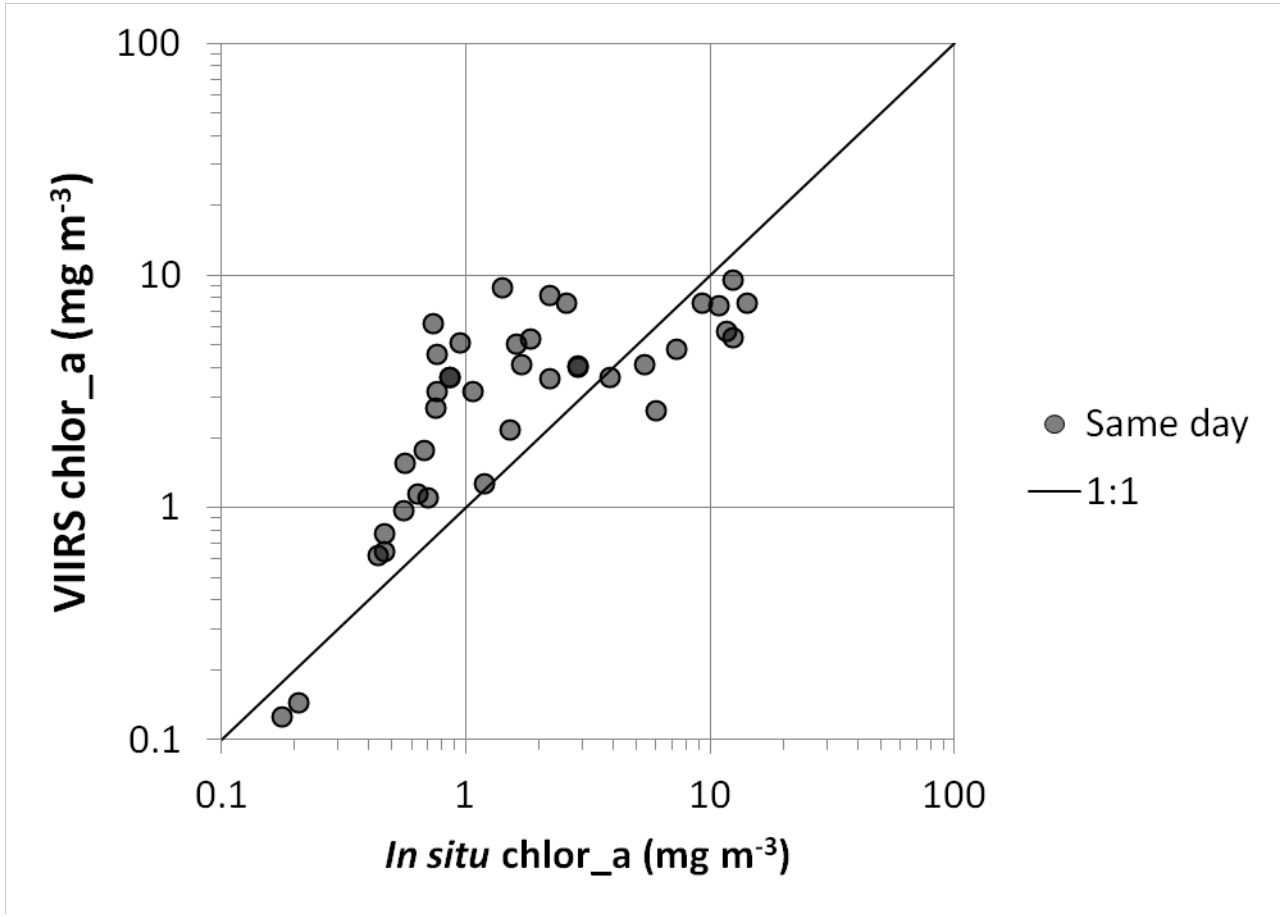
log-scale matchups between *in situ* and VIIRS chlor_a.



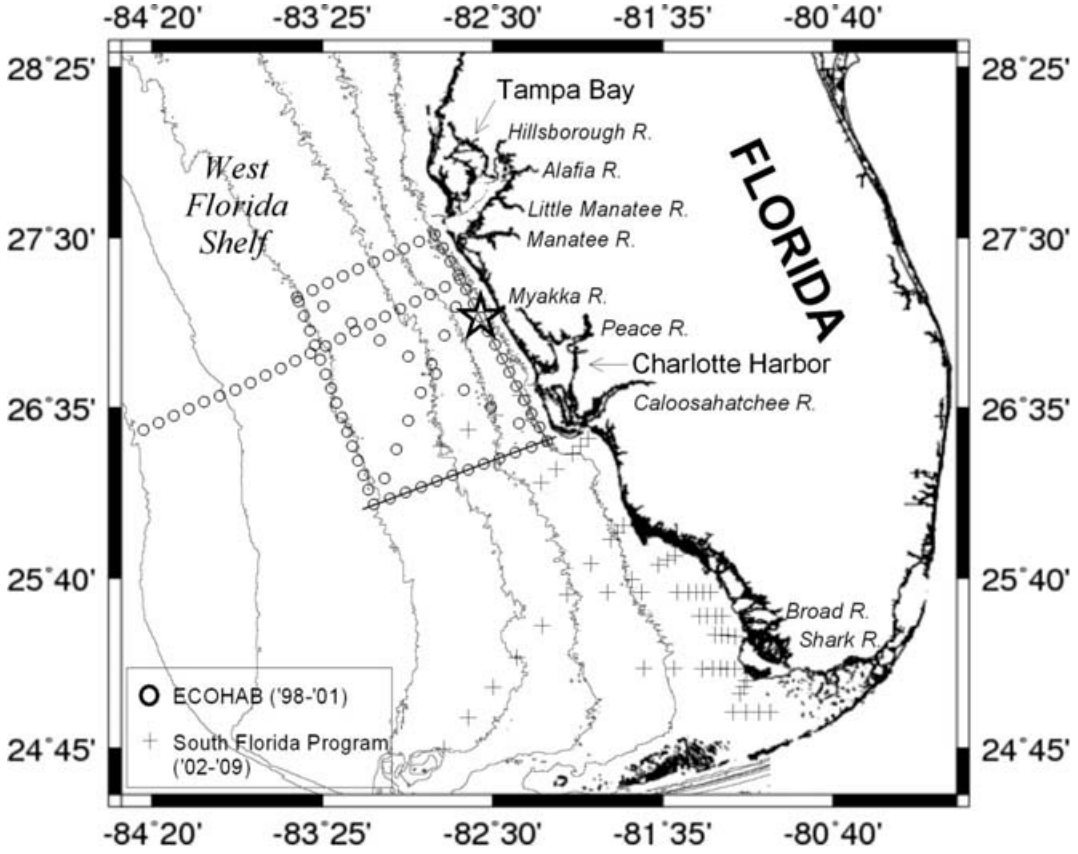

| | UPD (%) | MAD (mg $m^{-3}$) | N |
|---|---|---|---|
| -3 day | 83.5 | 1.9 | 10 |
| -2 day | 83.1 | 3.2 | 33 |
| -1 day | 90.2 | 5.3 | 37 |
| Same day | 71.2 | 2.5 | 39 |
| +1 day | 67.7 | 3.1 | 25 |
| +2 day | 95.4 | 11.2 | 22 |
| +3 day | 65.9 | 4.2 | 30 |

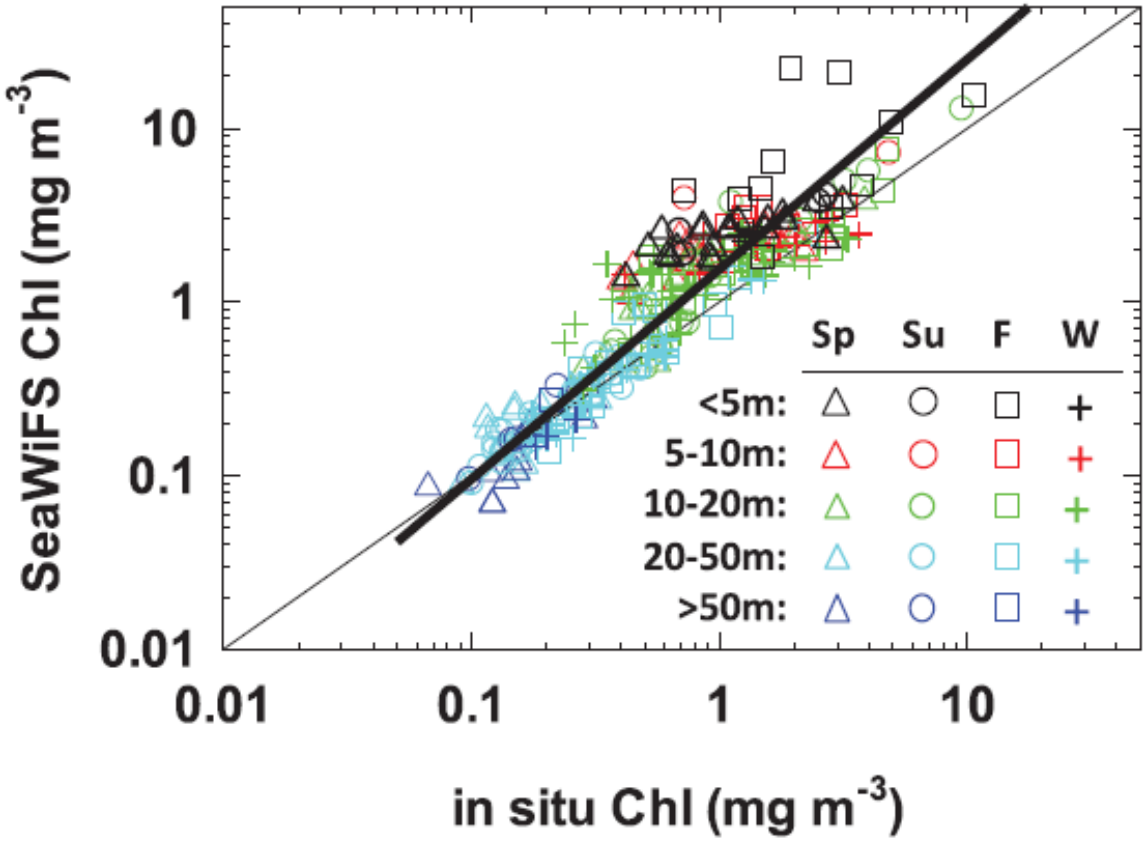
# NOAA VIIRS

log-scale matchups between *in situ* and VIIRS chlor_a. Only same-day. Note that MOST of these points come from 2 consecutive dates of sampling within a HAB.



# Typical algorithm problems over shallow waters



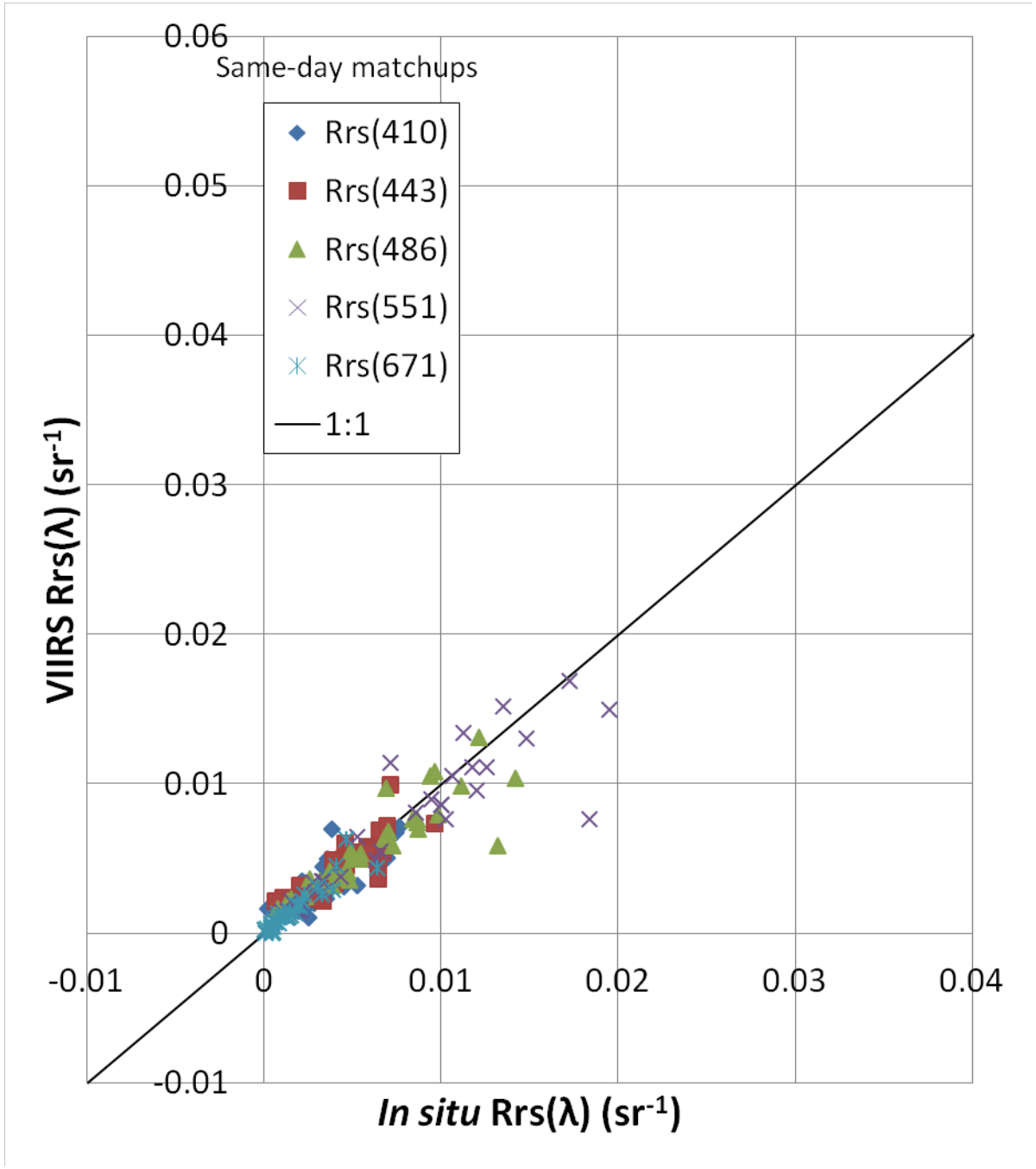




From Cannizzaro et al. (2013, JCR)

# NASA VIIRS

# NASA VIIRS

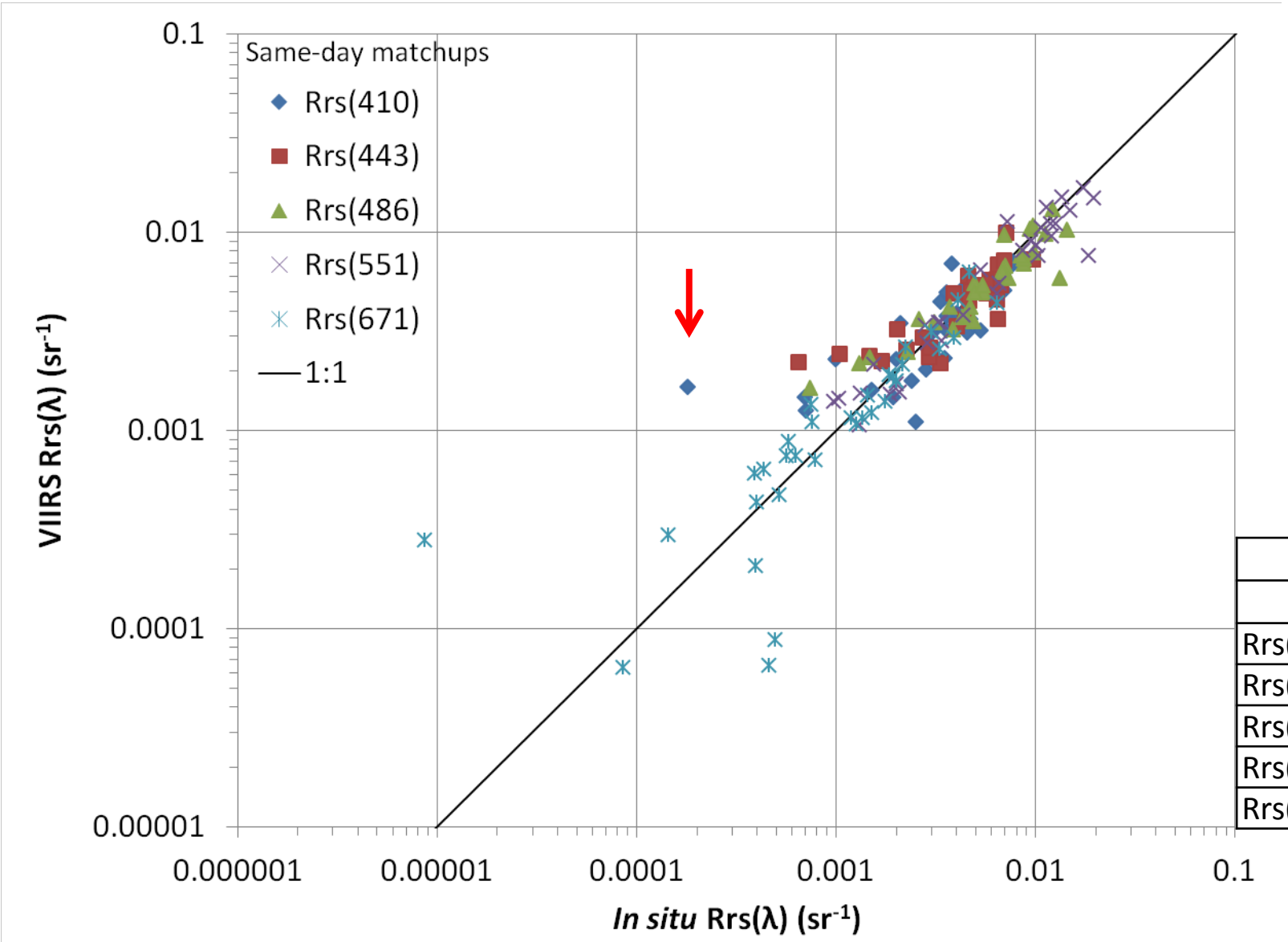
Linear-scale same-day matchups between *in situ* and VIIRS Rrs(λ). Note that there are fewer matchups (8-10 per band) for NASA data relative to NOAA. Much of this is due to spatial consistency.




| | UPD (%) | MAD ($sr^{-1}$) | N |
|---|---|---|---|
| Rrs(410) | 33 | 0.00089 | 31 |
| Rrs(443) | 23.8 | 0.00088 | 31 |
| Rrs(486) | 20.2 | 0.00115 | 32 |
| Rrs(551) | 19.4 | 0.00136 | 33 |
| Rrs(671) | 35.8 | 0.00035 | 33 |

# NASA VIIRS

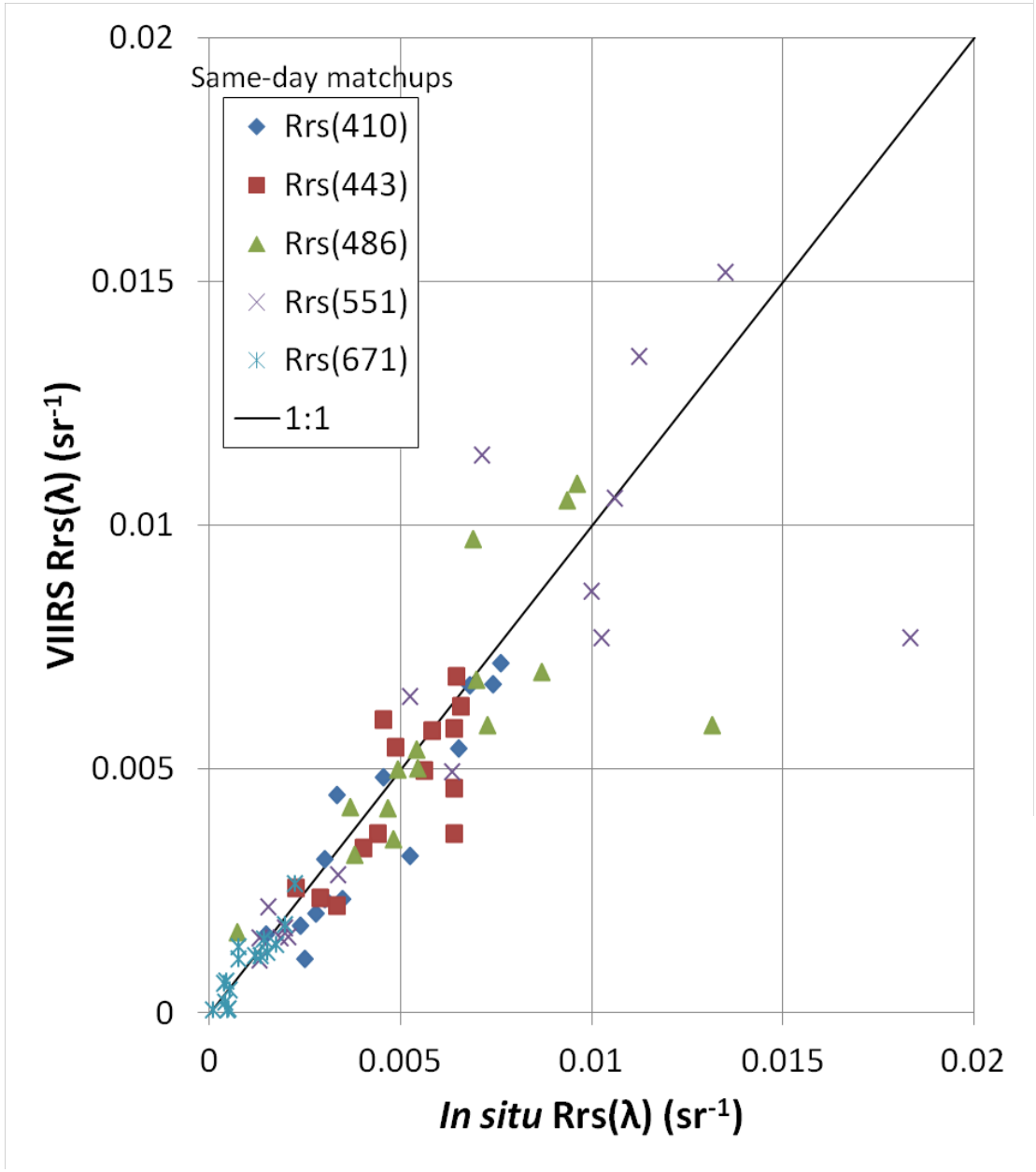
Log-scale same-day matchups between *in situ* and VIIRS Rrs(λ).

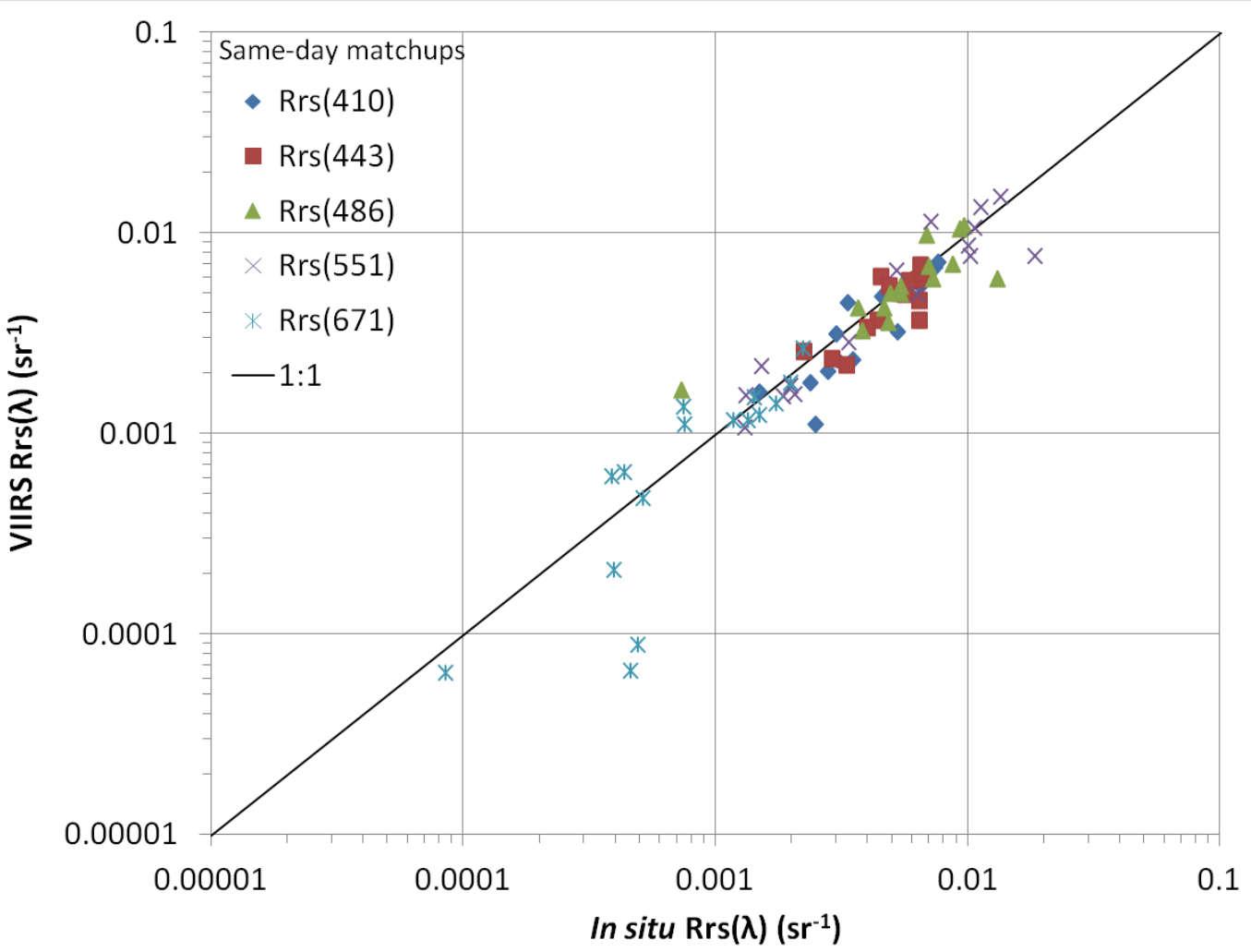



| | All data | | | Without 1 outlier | | |
|---|---|---|---|---|---|---|
| | UPD (%) | MAD ($sr^{-1}$) | N | UPD (%) | MAD ($sr^{-1}$) | N |
| Rrs(410) | 33 | 0.00089 | 31 | 28.8 | 0.00087 | 30 |
| Rrs(443) | 23.8 | 0.00088 | 31 | 21 | 0.00086 | 30 |
| Rrs(486) | 20.2 | 0.00115 | 32 | 19.2 | 0.00115 | 31 |
| Rrs(551) | 19.4 | 0.00136 | 33 | 18.8 | 0.00139 | 32 |
| Rrs(671) | 35.8 | 0.00035 | 33 | 34.7 | 0.00035 | 32 |

# NASA VIIRS

## USA only

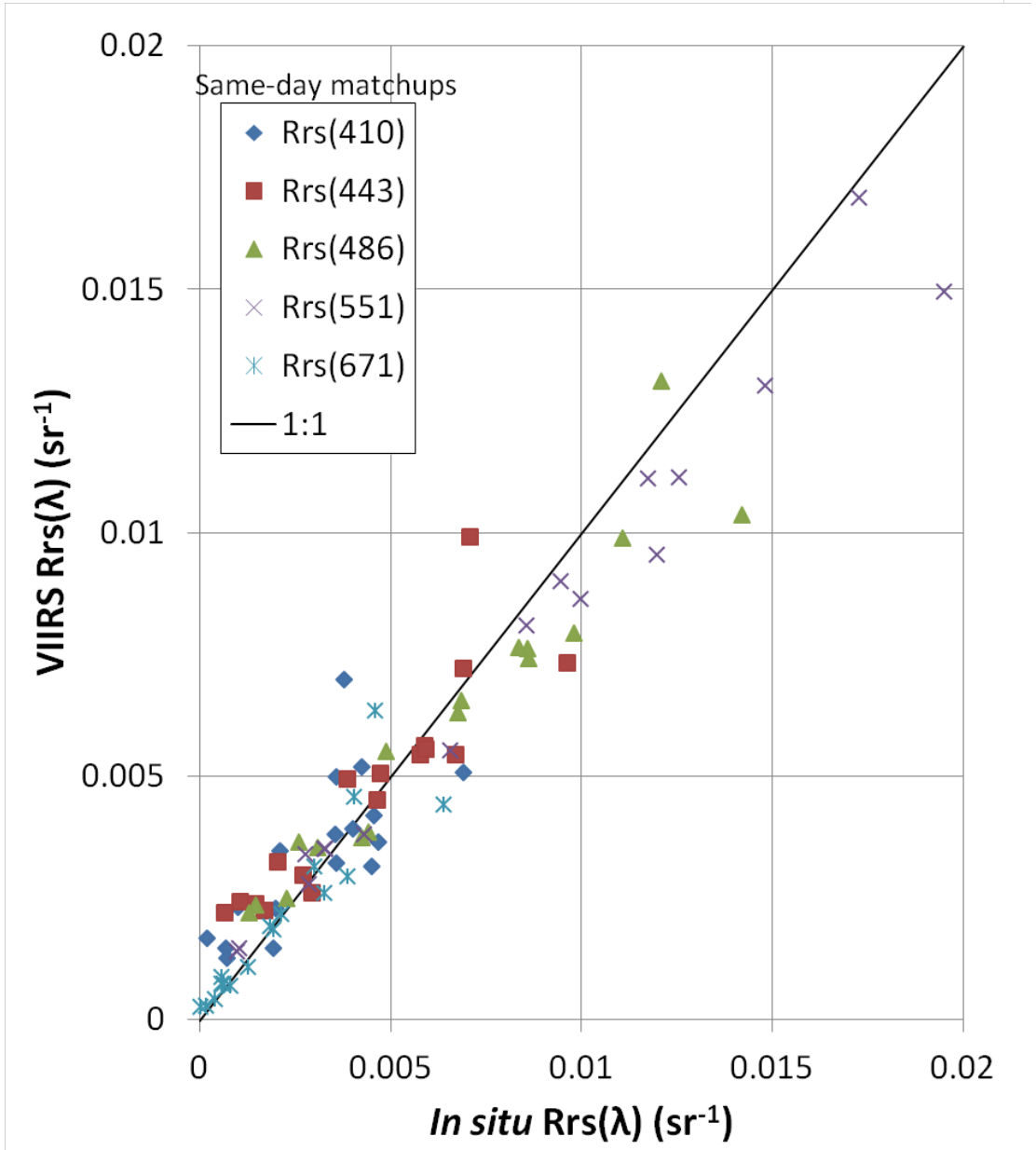


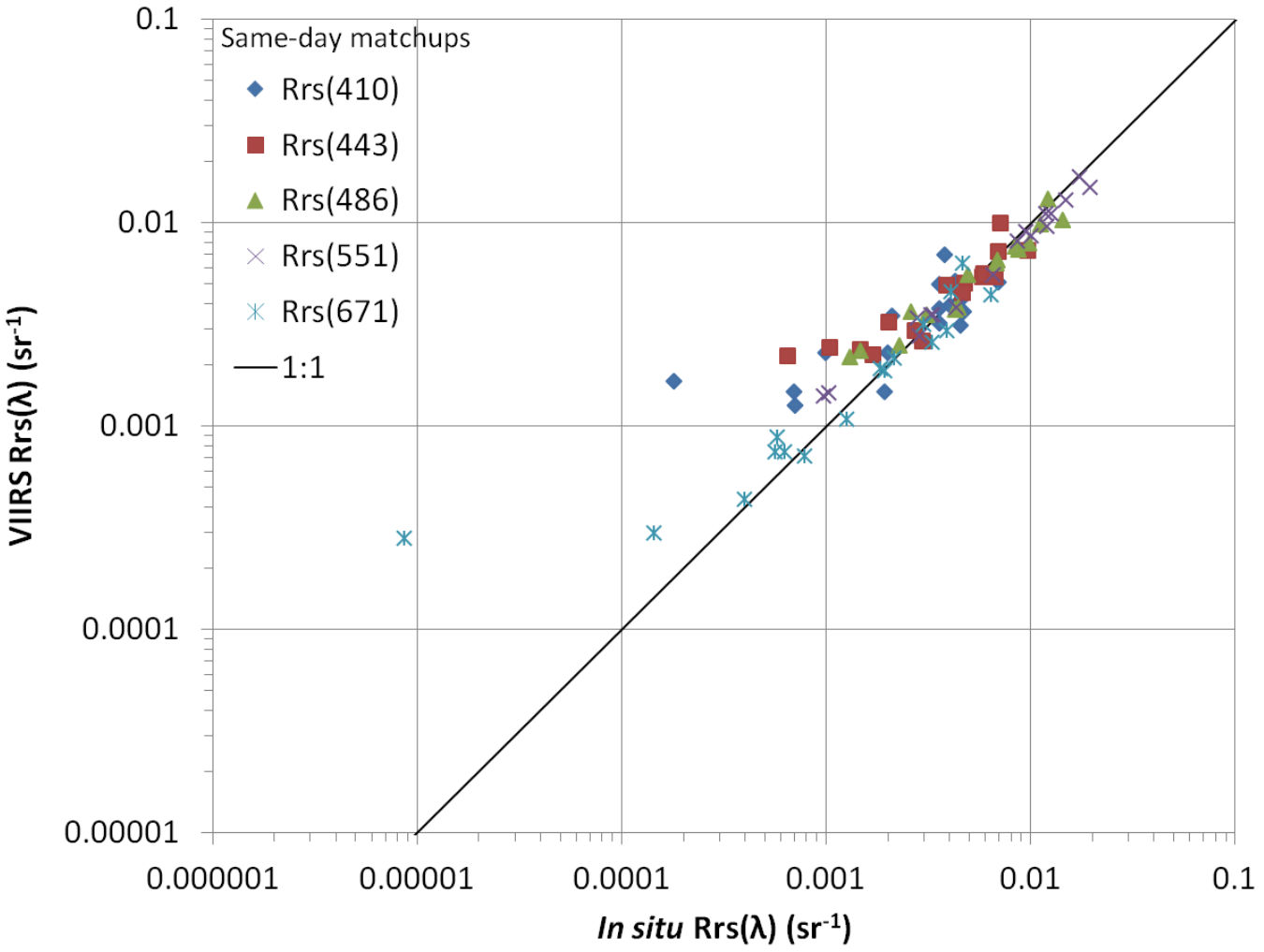




| | UPD (%) | MAD ($sr^{-1}$) | N |
|---|---|---|---|
| Rrs(410) | 23.8 | 0.00076 | 14 |
| Rrs(443) | 19.2 | 0.00085 | 14 |
| Rrs(486) | 22.4 | 0.00133 | 15 |
| Rrs(551) | 24.7 | 0.00176 | 16 |
| Rrs(671) | 40.8 | 0.00024 | 16 |

# NASA VIIRS

China only

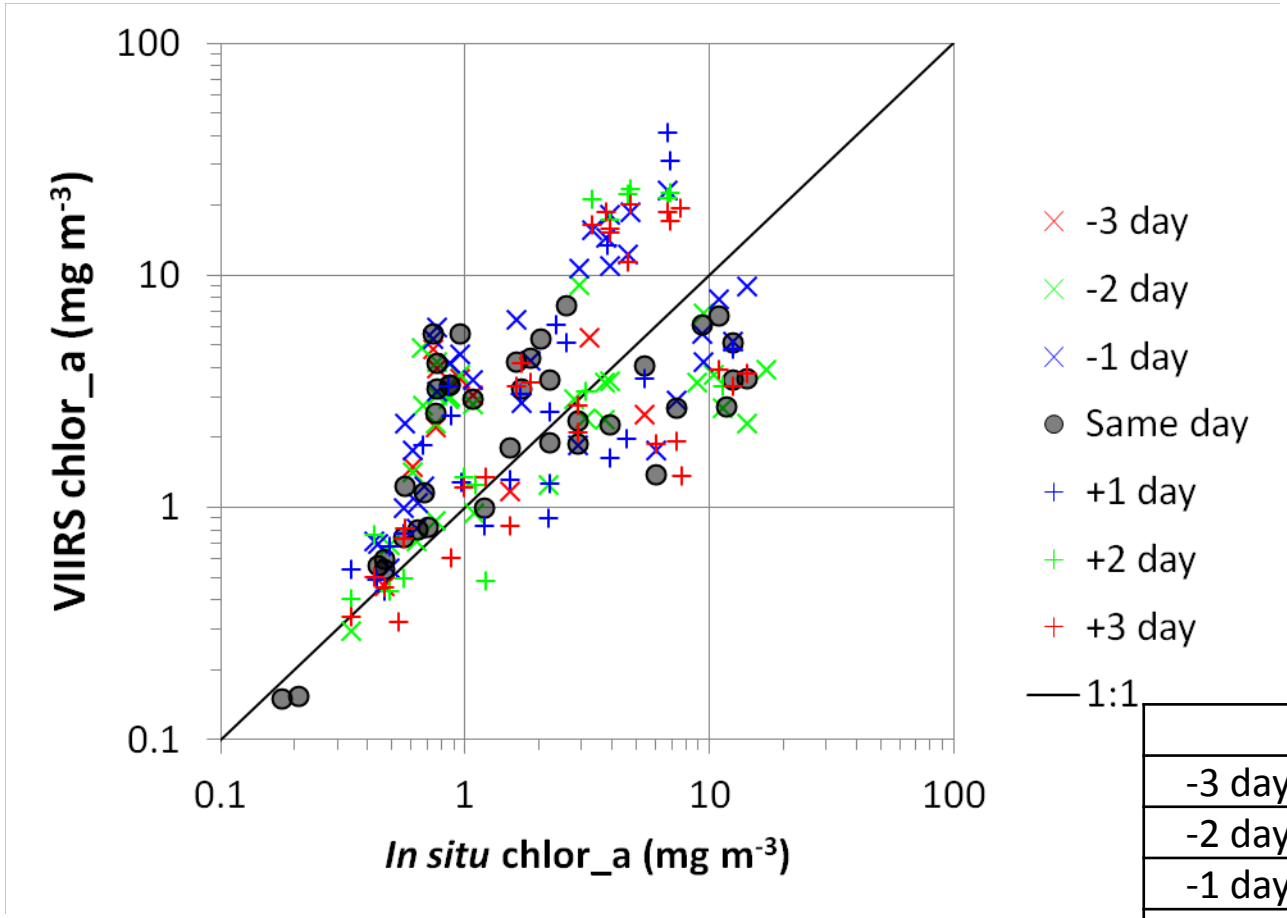



| | UPD (%) | MAD ($sr^{-1}$) | N |
|---|---|---|---|
| Rrs(410) | 40.7 | 0.00101 | 17 |
| Rrs(443) | 27.6 | 0.00091 | 17 |
| Rrs(486) | 18.4 | 0.00098 | 17 |
| Rrs(551) | 14.4 | 0.00099 | 17 |
| Rrs(671) | 31.1 | 0.00044 | 17 |

# NASA VIIRS

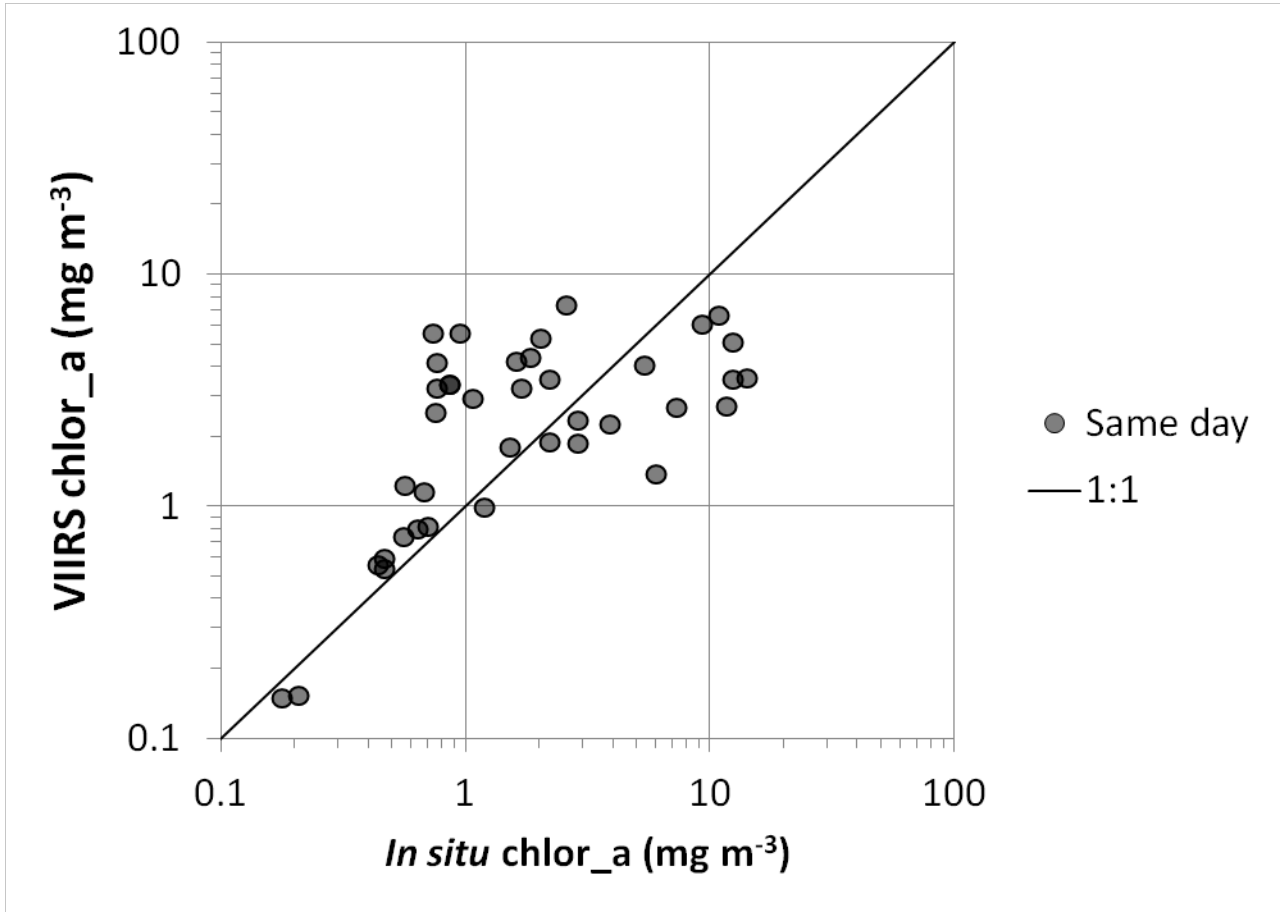
log-scale matchups between *in situ* and VIIRS chlor_a.




| | UPD (%) | MAD (mg $m^{-3}$) | N |
|---|---|---|---|
| -3 day | 82.7 | 2.0 | 10 |
| -2 day | 75.6 | 2.9 | 29 |
| -1 day | 88.9 | 4.6 | 35 |
| Same day | 69.2 | 2.6 | 39 |
| +1 day | 64.8 | 4.1 | 24 |
| +2 day | 70 | 6.8 | 16 |
| +3 day | 72.4 | 5.3 | 30 |

# NASA VIIRS

log-scale matchups between *in situ* and VIIRS chlor_a. Only same-day. Note that MOST of these points come from 2 consecutive dates of sampling within a HAB.



# COMMON MATCHUPS

These tables include only the matchups that are in both the NOAA and NASA datasets. “Extra Matchups” is a count of the matchups unique to that dataset (e.g., NOAA captured 8 Rrs(410) matchups that were excluded by NASA, while 1 NASA Rrs(410) matchup was excluded by NOAA).

| Chlor_a | | UPD (%) | | MAD (mg $m^{-3}$) | | Extra Matchups | |
|---|---|---|---|---|---|---|---|
| | N | NASA | NOAA | NASA | NOAA | NASA | NOAA |
| -3 day | 10 | 82.7 | 83.5 | 2 | 1.9 | 0 | 0 |
| -2 day | 26 | 75.8 | 84.1 | 2.7 | 3.2 | 3 | 7 |
| -1 day | 34 | 90.2 | 89.2 | 4.8 | 4.5 | 1 | 3 |
| Same day | 38 | 68.7 | 69.3 | 2.6 | 2.4 | 1 | 1 |
| +1 day | 21 | 57.3 | 59.3 | 1.8 | 1.8 | 3 | 4 |
| +2 day | 15 | 74.6 | 80.7 | 7.2 | 8.5 | 1 | 7 |
| +3 day | 28 | 72.4 | 64.9 | 5.2 | 4.1 | 2 | 2 |

| All Rrs | | UPD | | MAD | | Extra Matchups | |
|---|---|---|---|---|---|---|---|
| | N | NASA | NOAA | NASA | NOAA | NASA | NOAA |
| Rrs(410) | 30 | 32.2 | 29.4 | 0.0009 | 0.00085 | 1 | 8 |
| Rrs(443) | 31 | 23.8 | 22.5 | 0.00088 | 0.00086 | 0 | 8 |
| Rrs(486) | 32 | 20.2 | 18.3 | 0.00115 | 0.00111 | 0 | 8 |
| Rrs(551) | 33 | 19.4 | 19 | 0.00136 | 0.00143 | 0 | 10 |
| Rrs(671) | 33 | 35.8 | 38.3 | 0.00035 | 0.00044 | 0 | 10 |

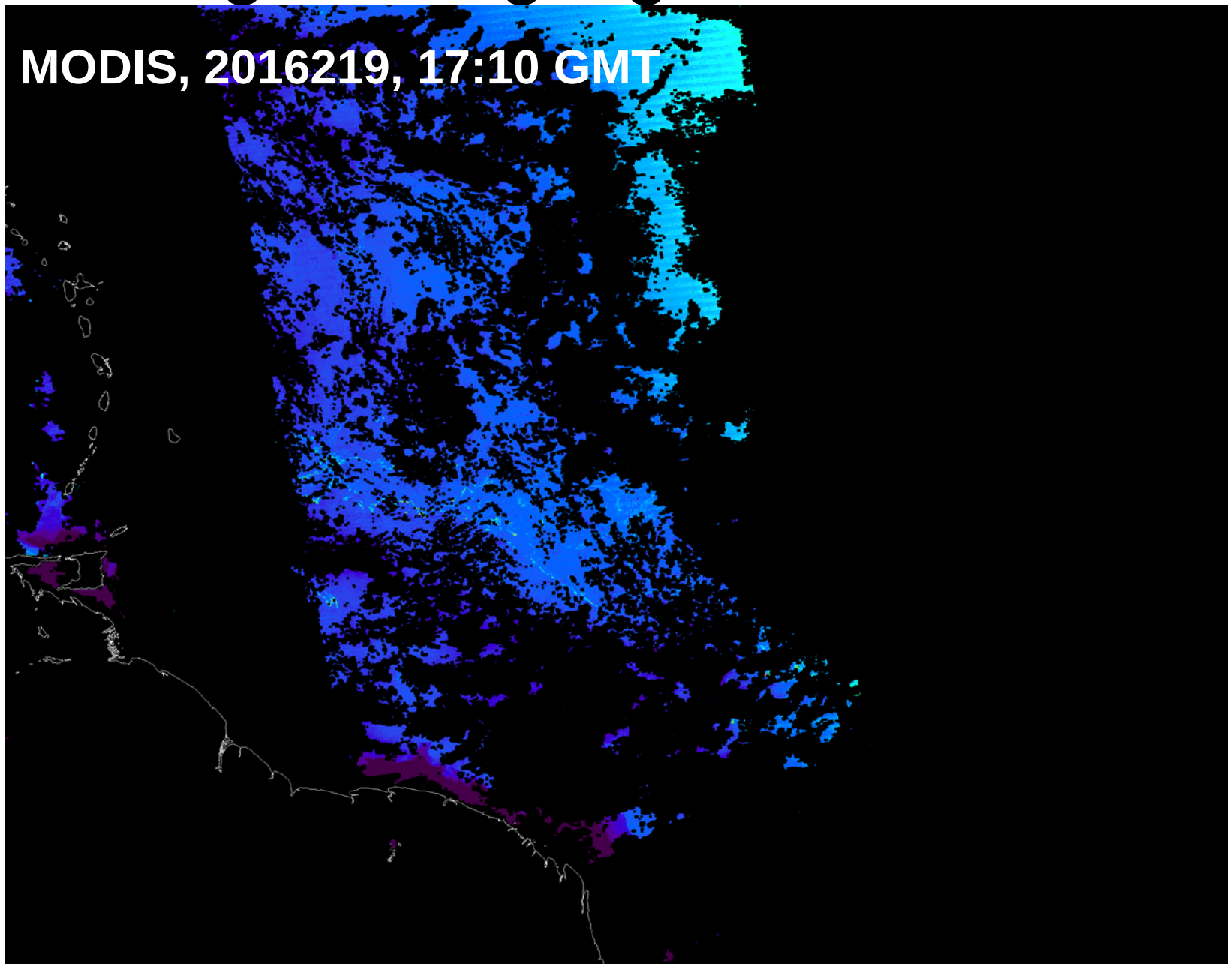
| USA Rrs | | UPD | | MAD | | Extra Matchups | |
|---|---|---|---|---|---|---|---|
| | N | NASA | NOAA | NASA | NOAA | NASA | NOAA |
| Rrs(410) | 30 | 23.8 | 22.8 | 0.00076 | 0.00085 | 0 | 2 |
| Rrs(443) | 31 | 19.2 | 17.4 | 0.00085 | 0.00084 | 0 | 0 |
| Rrs(486) | 32 | 22.4 | 16.1 | 0.00133 | 0.0012 | 0 | 0 |
| Rrs(551) | 33 | 24.7 | 18.1 | 0.00176 | 0.0016 | 0 | 2 |
| Rrs(671) | 33 | 40.8 | 35 | 0.00024 | 0.00022 | 0 | 2 |

| China Rrs | | UPD | | MAD | | Extra Matchups | |
|---|---|---|---|---|---|---|---|
| | N | NASA | NOAA | NASA | NOAA | NASA | NOAA |
| Rrs(410) | 30 | 39.7 | 35.1 | 0.00103 | 0.00085 | 1 | 6 |
| Rrs(443) | 31 | 27.6 | 26.7 | 0.00091 | 0.00088 | 0 | 8 |
| Rrs(486) | 32 | 18.4 | 20.2 | 0.00098 | 0.00103 | 0 | 8 |
| Rrs(551) | 33 | 14.4 | 19.8 | 0.00099 | 0.00127 | 0 | 8 |
| Rrs(671) | 33 | 31.1 | 41.5 | 0.00044 | 0.00065 | 0 | 8 |

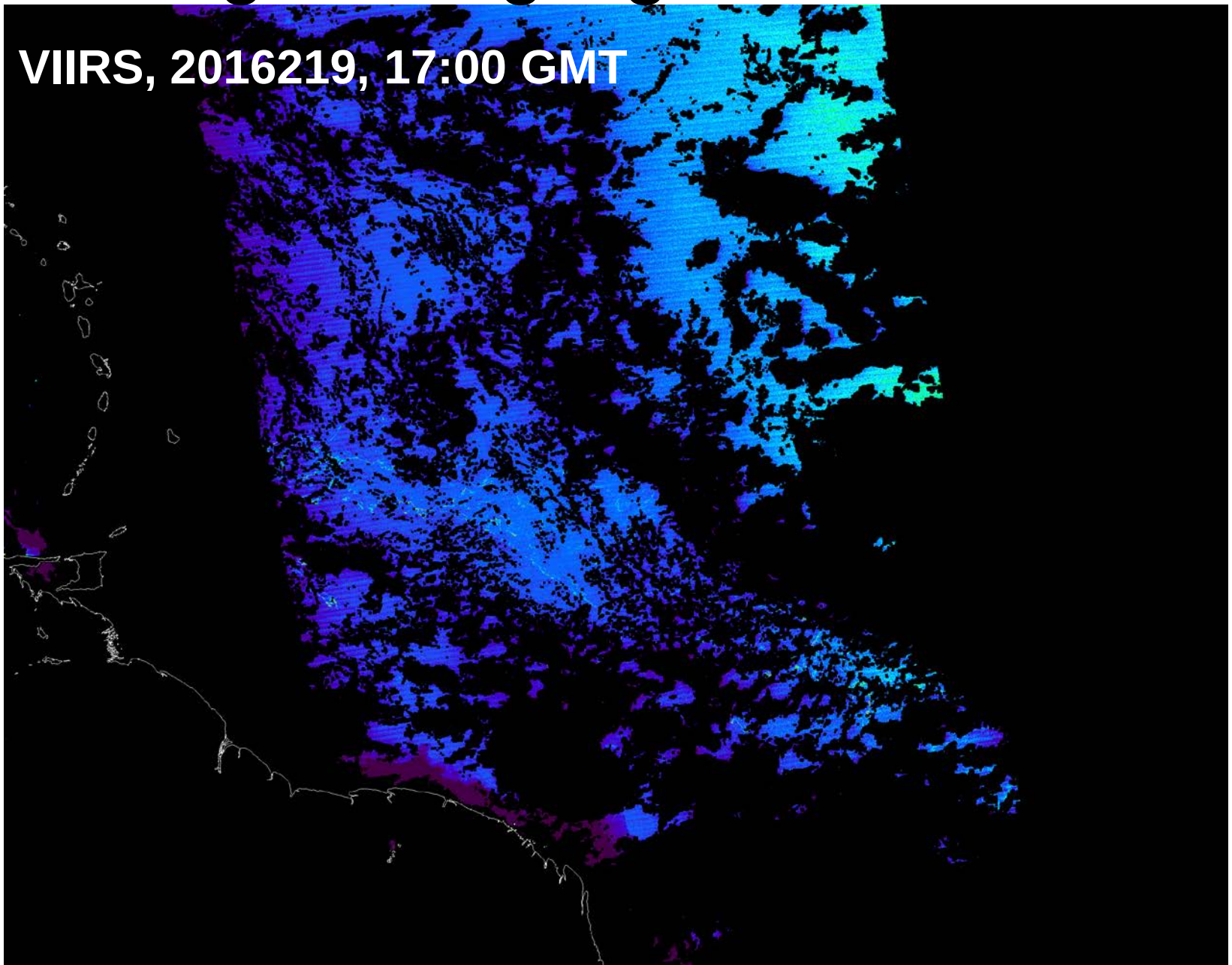
# Conclusions from validation results

- MSL12 Rrs performance generally satisfactory in coastal waters (comparable to published MODIS results)
- Bio-optical inversion algorithms still need improvements
- MSL12 Rrs slightly better than L2gen Rrs for the same pixels
- MSL12 shows more retrievals than L2gen

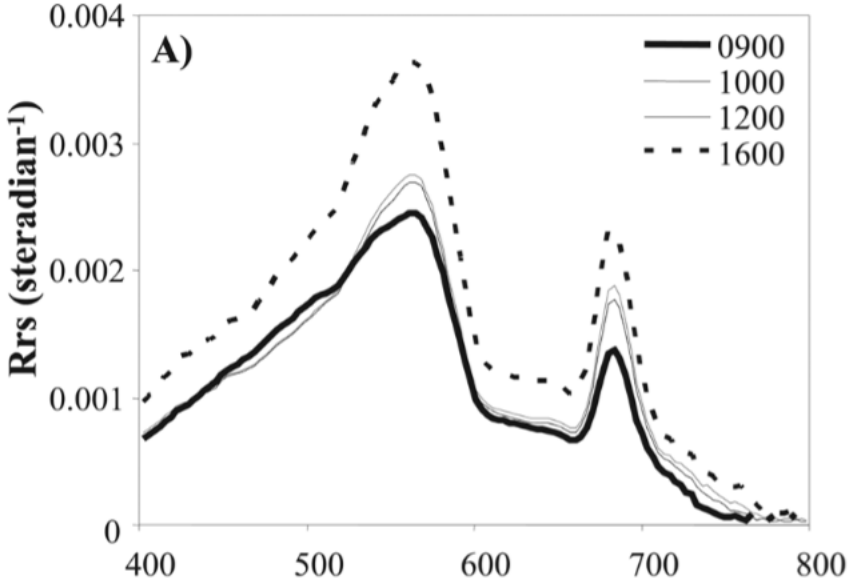
# Detecting floating algae

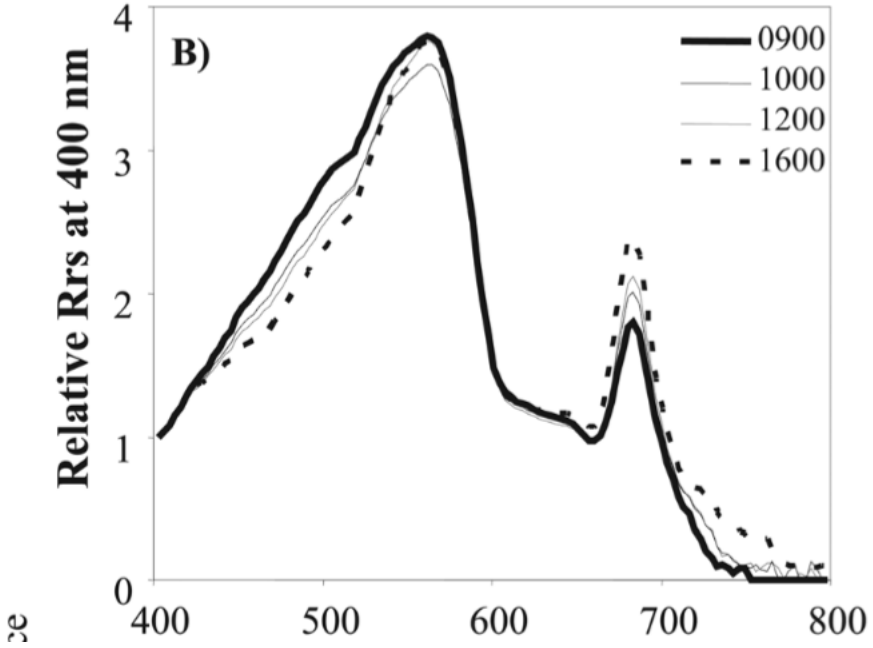


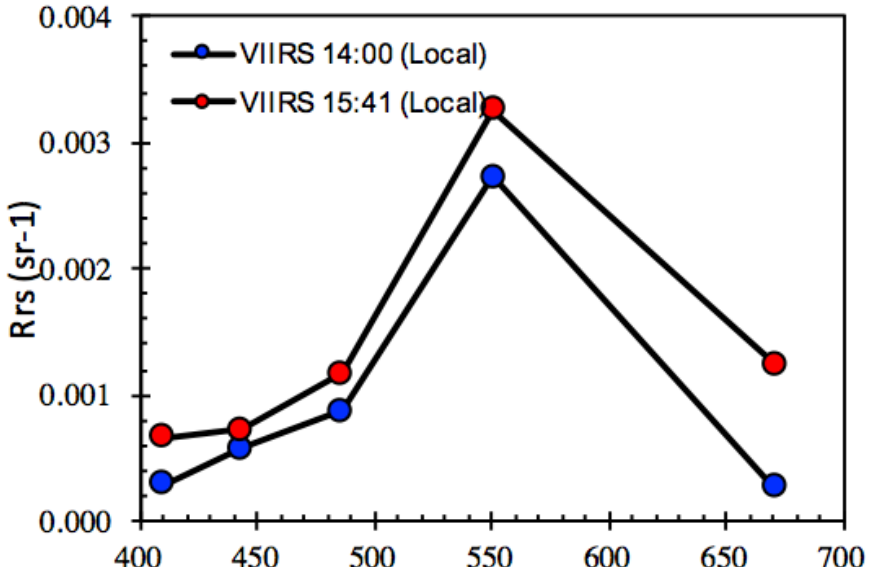
# Detecting floating algae

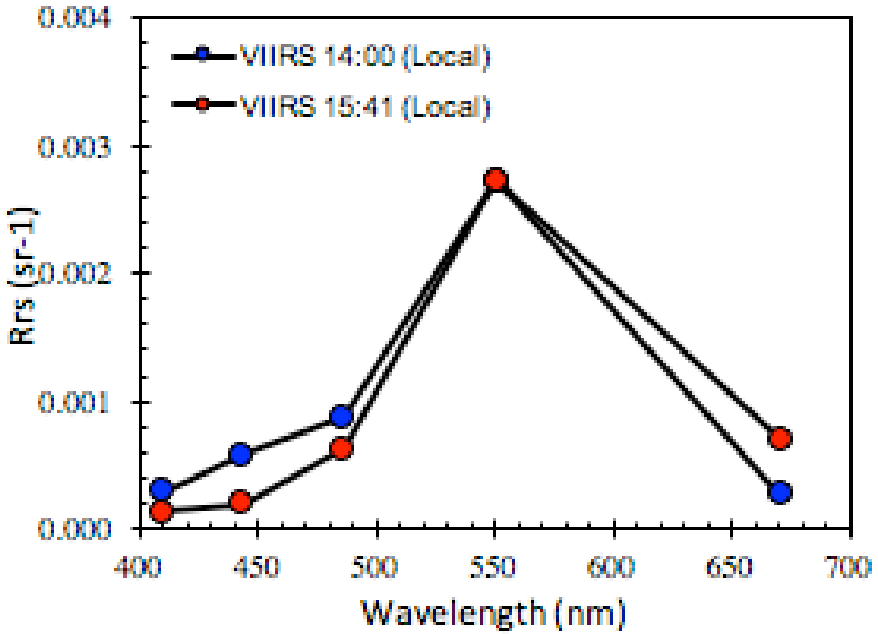


# Vertical migration of dinoflagellates



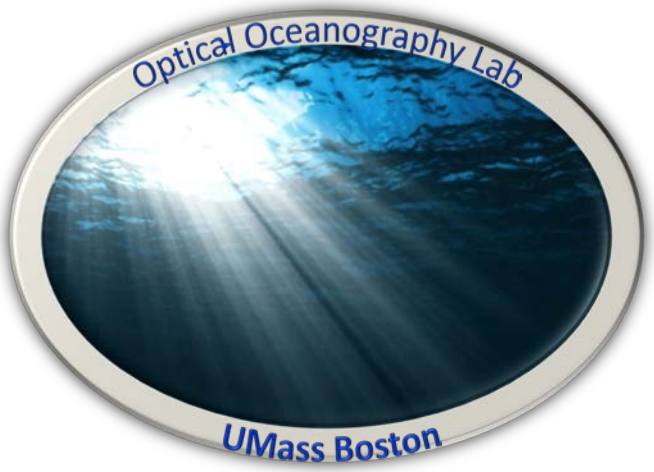



# Towards consistent VIIRS AOP and IOP products

ZhongPing Lee, JunFang Lin, JianWei Wei

University of Massachusetts Boston

UMASS BOSTON



# Acknowledgements:

NOAA/STAR

# UMB activities:

## 1. Evaluation of VIIRS Rrs products

**1a. Compare VIIRS Rrs with climatological Rrs of gyre waters**

**1b. Compare VIIRS Rrs with in situ measurements in MassBay**

**1c. Participate NOAA Cal/Val cruise and other cruises**

## 2. Development of new products

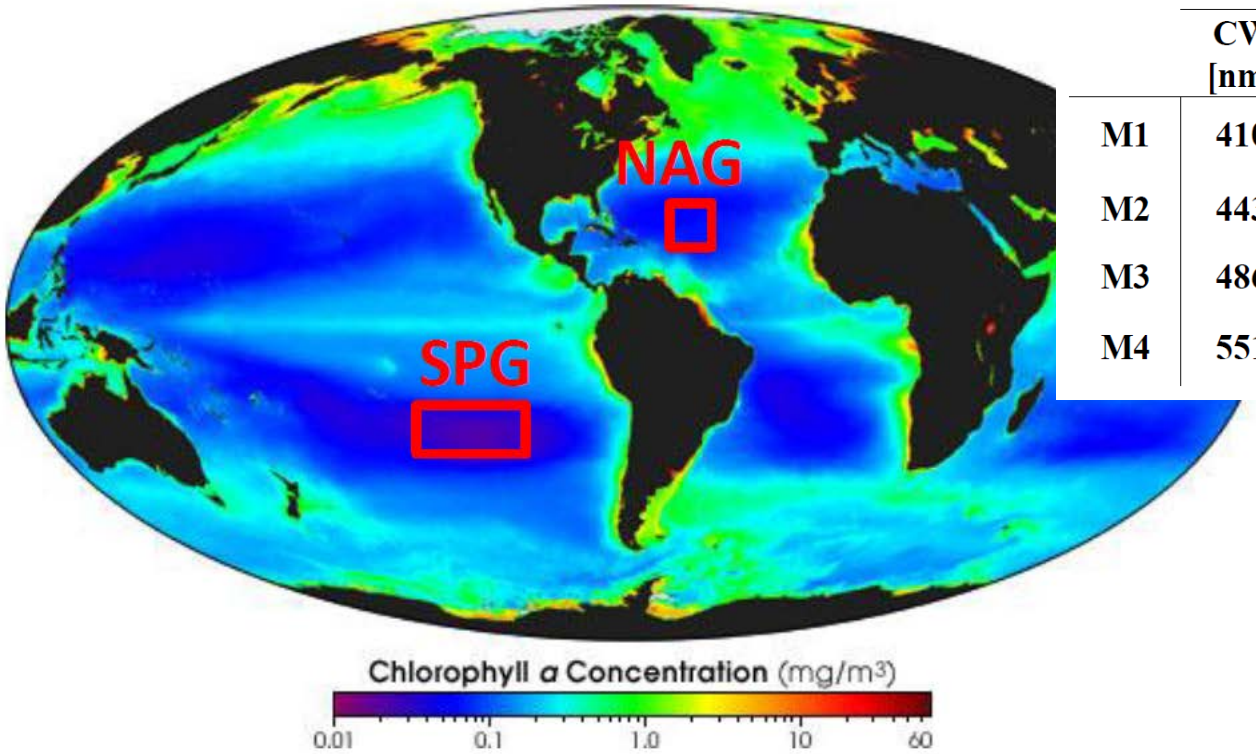
**2a. Quality Assurance System for Rrs**

**2b. IOPs from in situ AOPs**

**2c. Secchi disk depth ($Z_{SD}$) for VIIRS**

# 1. Evaluation of VIIRS Rrs products

## 1a. Compare VIIRS Rrs with MODIS climatological Rrs of gyre waters




### Band characteristics

| | VIIRS | | MODISA | |
|---|---|---|---|---|
| | CW [nm] | Bandwidth [nm] | CW [nm] | Bandwidth [nm] |
| M1 | 410 | 20 | 412 | 15 |
| M2 | 443 | 15 | 442 | 10 |
| M3 | 486 | 19 | 488 | 10 |
| M4 | 551 | 19 | 547 | 10 |

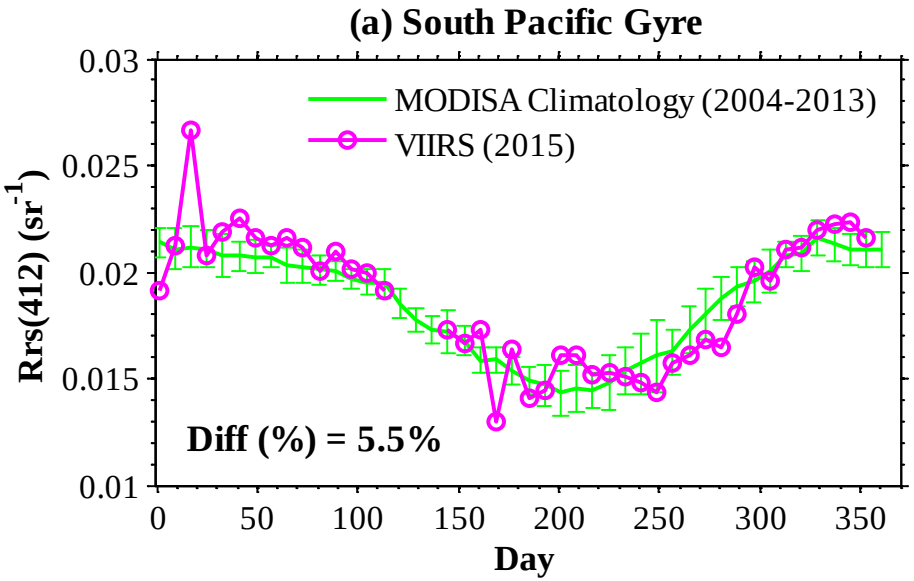
**Location: South Pacific Gyre (SPG) and North Atlantic Gyre (NAG)**

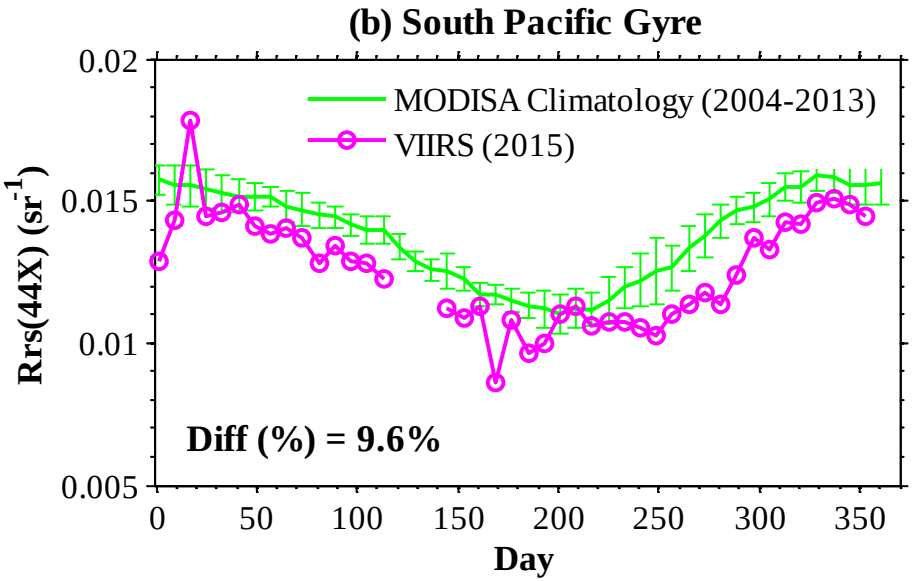
**Data (8-day composite): VIIRS: latest reprocessing (from CoastWatch)**

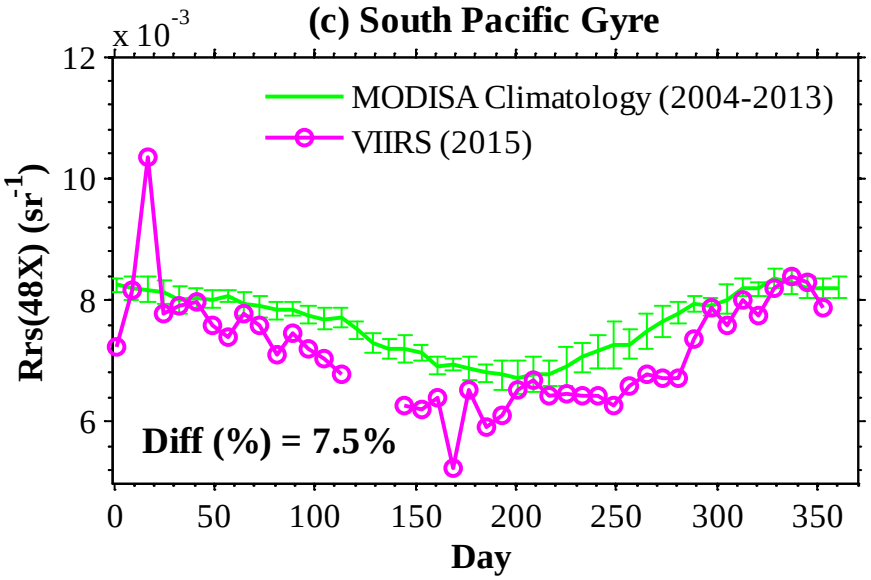
**MODIS_Aqua (from OBPG; 8-day climatology)**

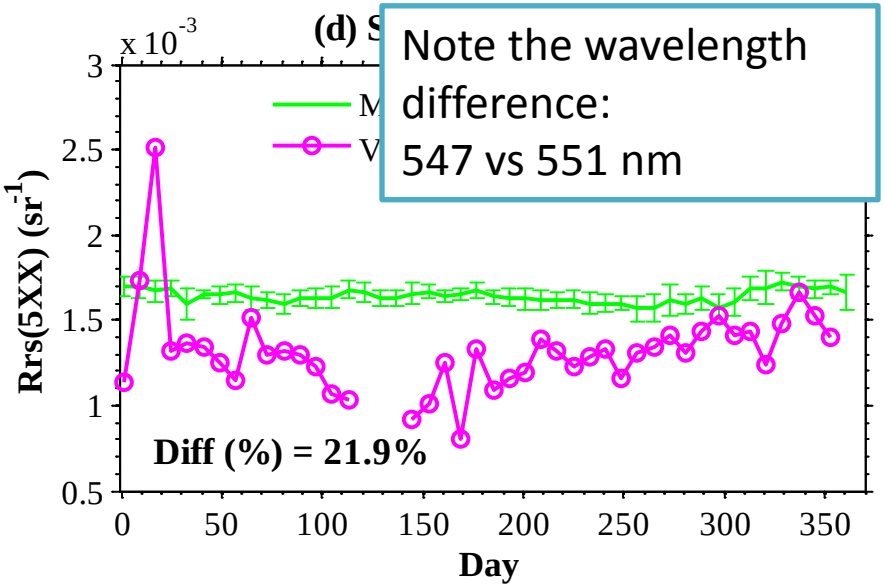
**all are area average**

# 2015 South Pacific Gyre



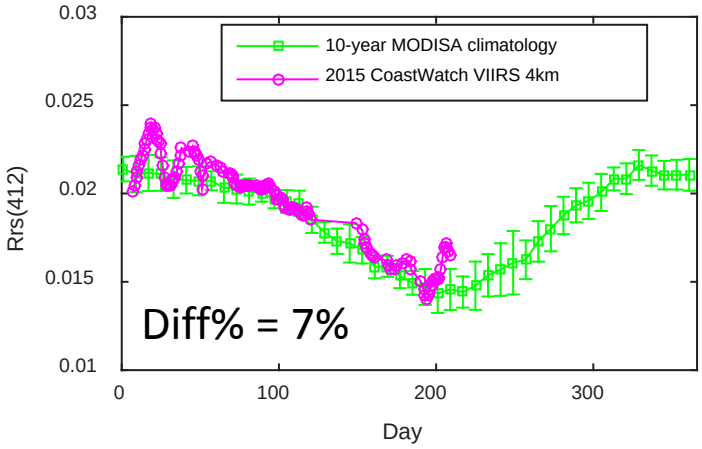



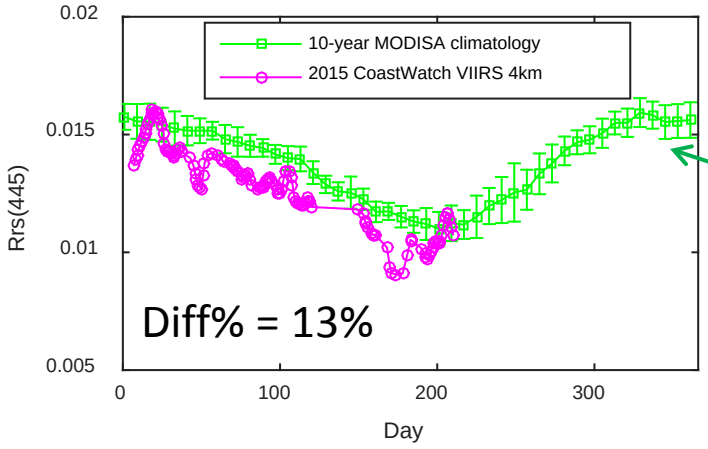



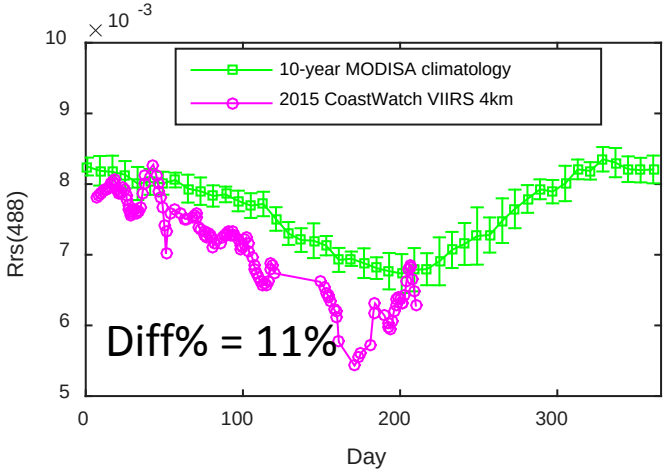

Note the wavelength difference:
547 vs 551 nm

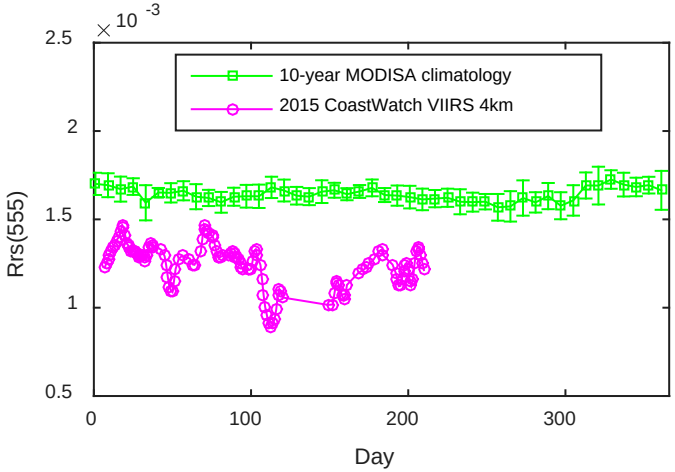
# "Previous" VIIRS Rrs vs MODIS climatology



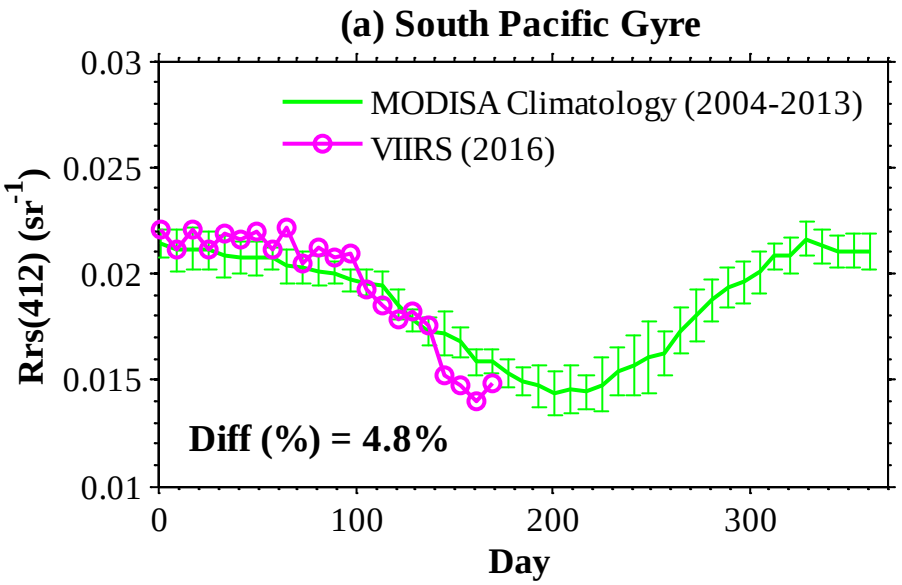



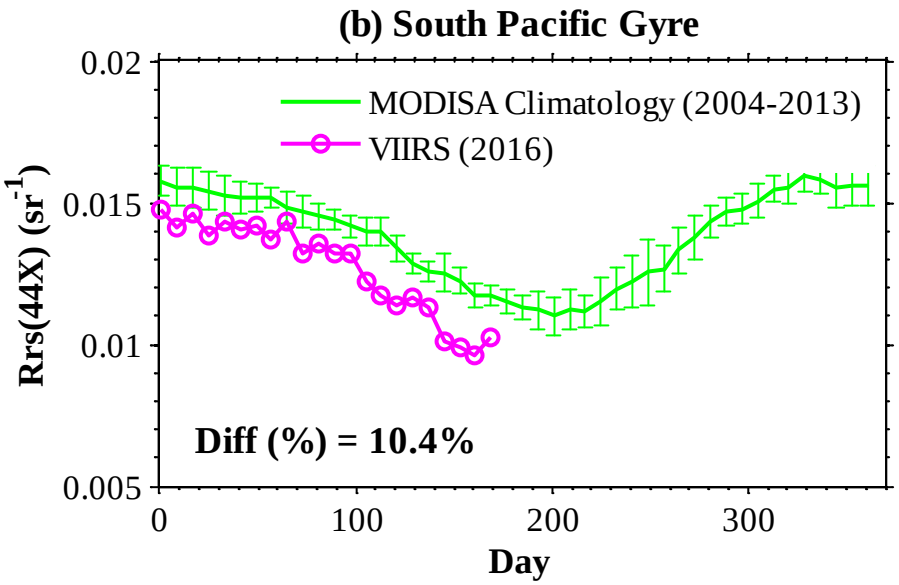

8-day climatology

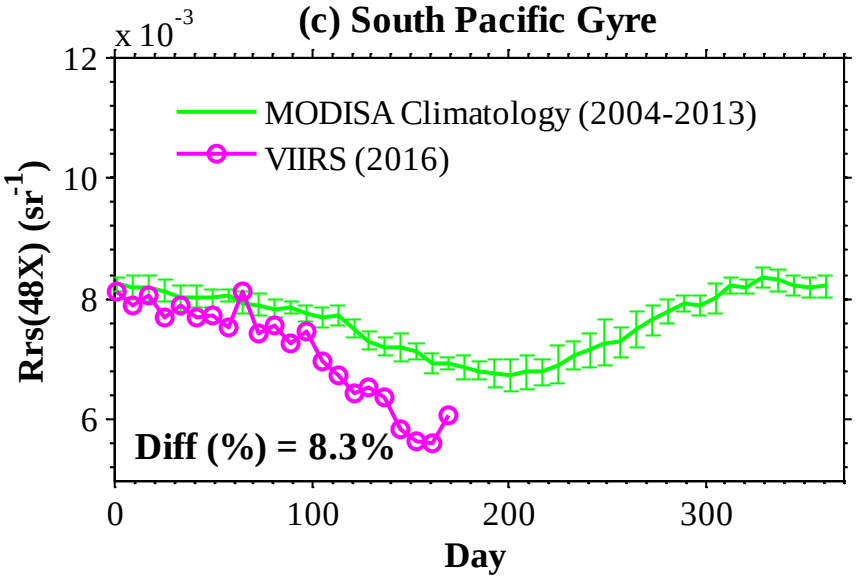


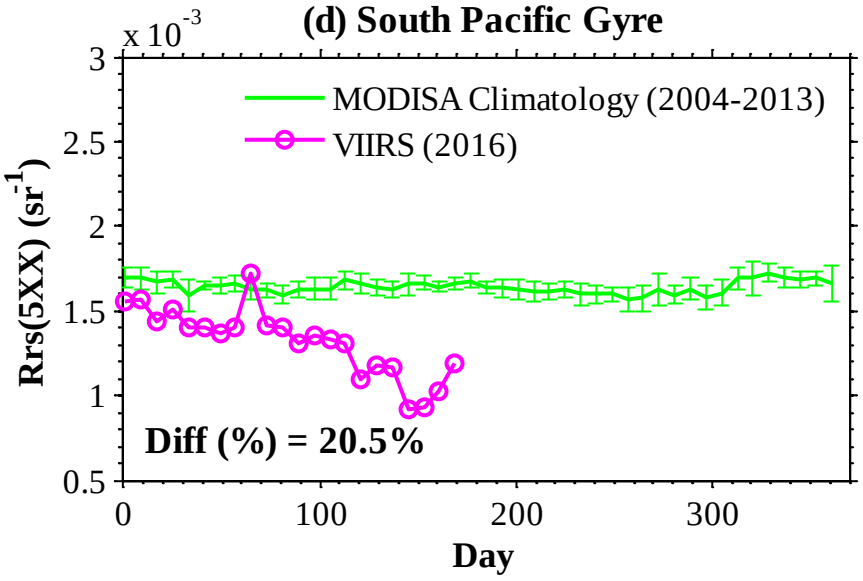



# 2016 South Pacific Gyre

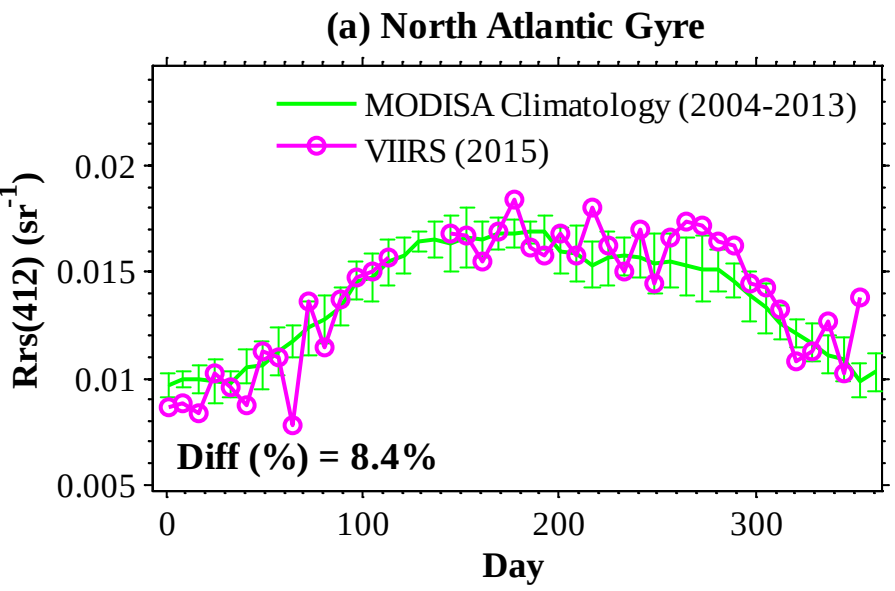


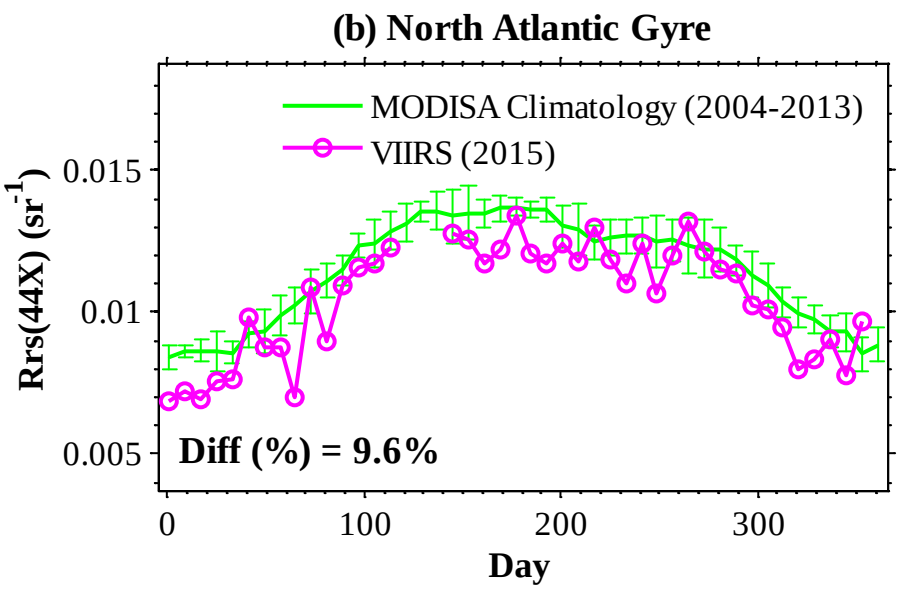



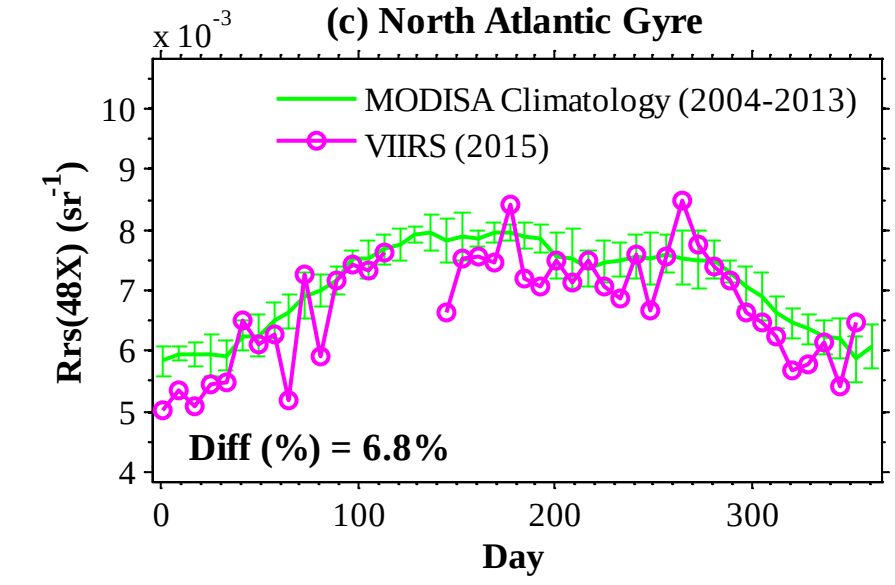



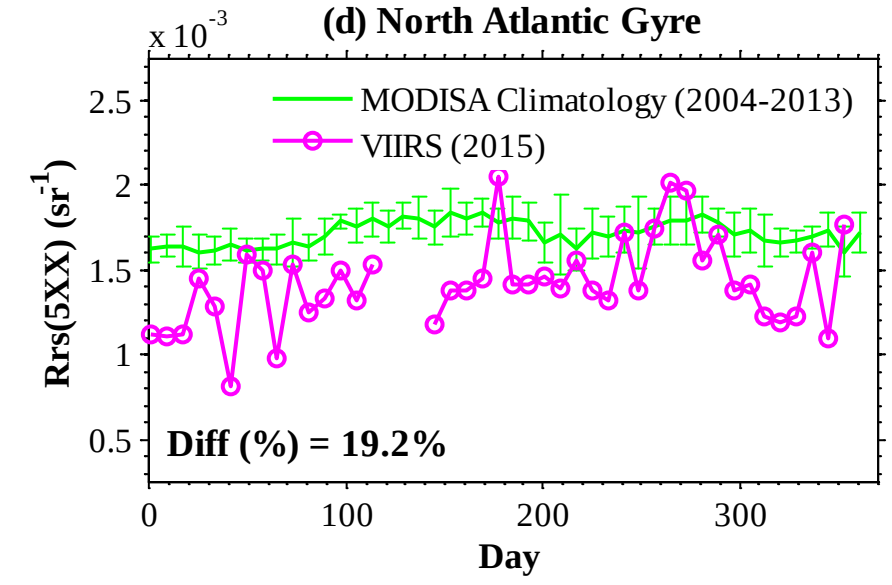



# 2015 North Atlantic Gyre

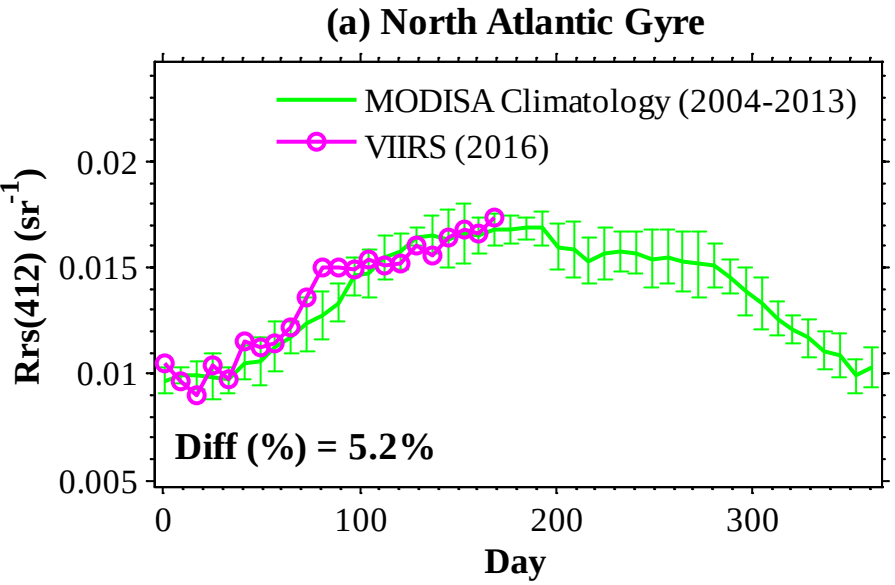


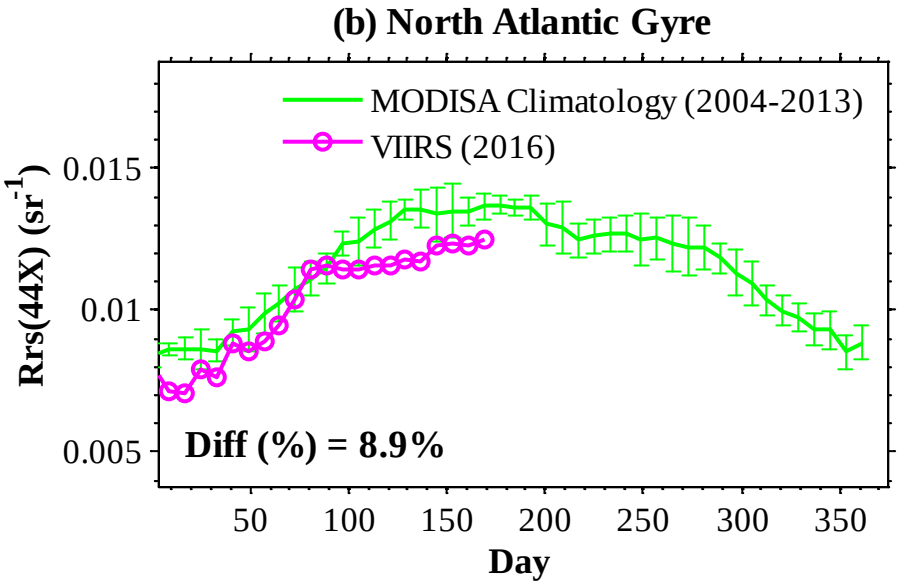



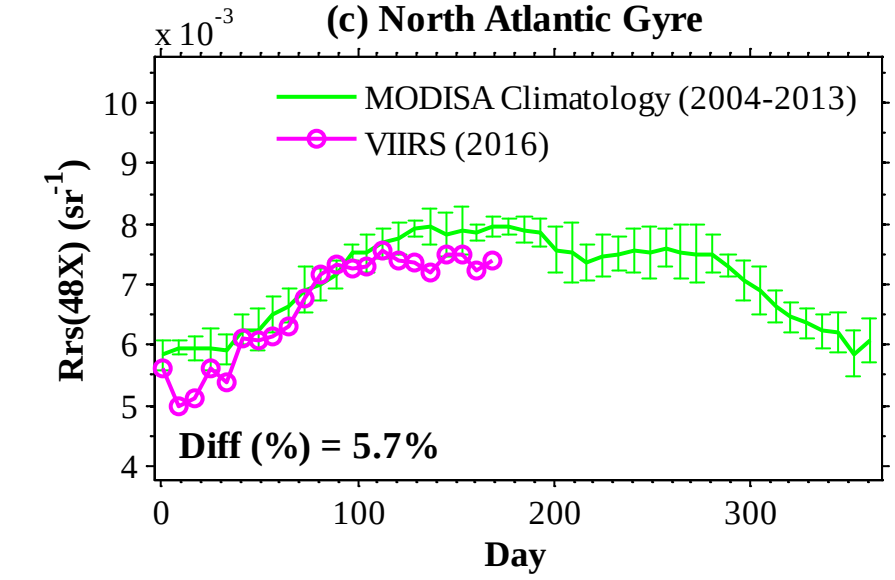



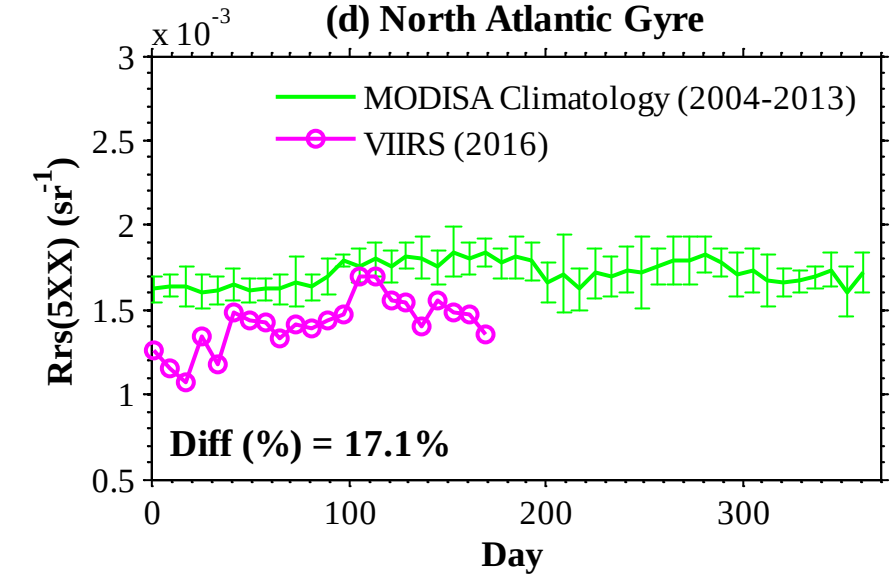



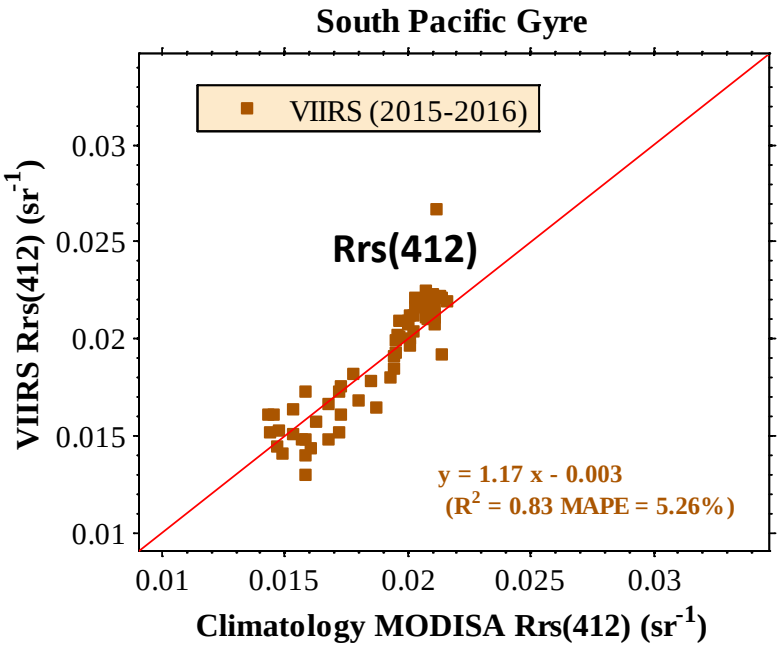
# 2016 North Atlantic Gyre

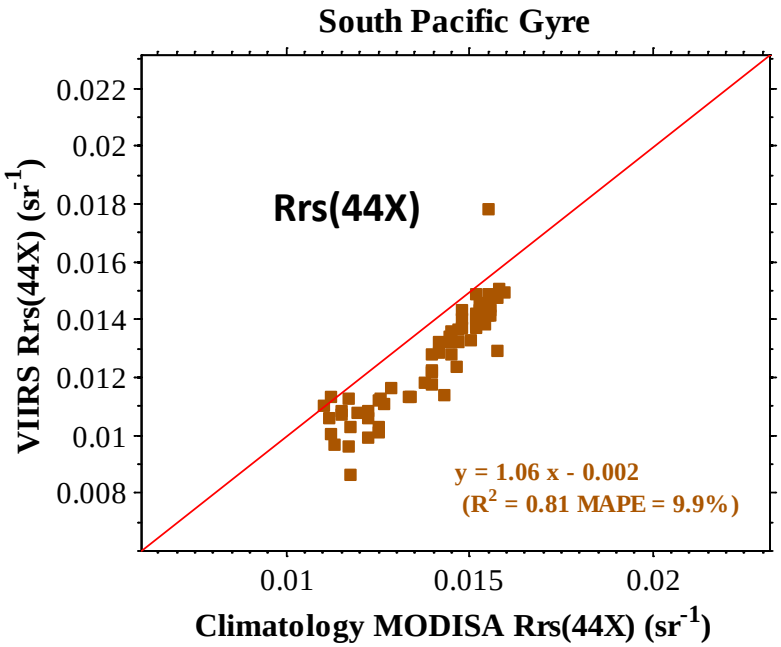


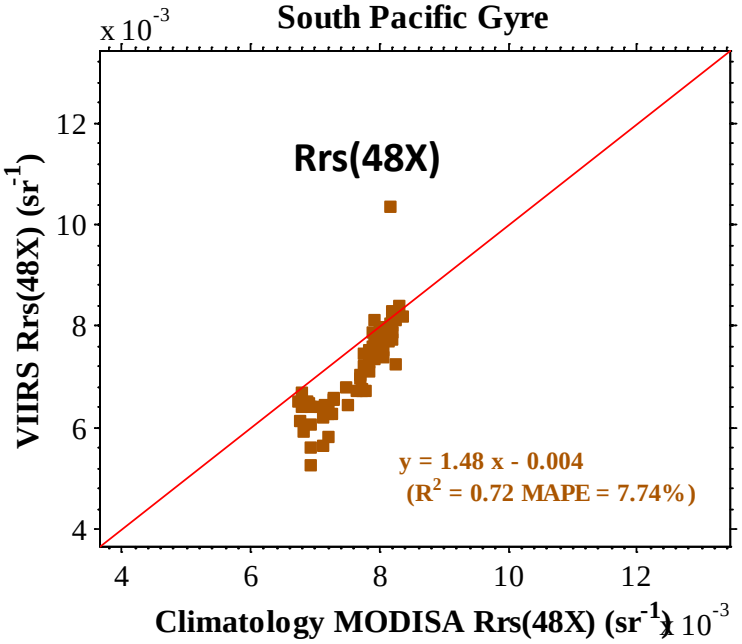



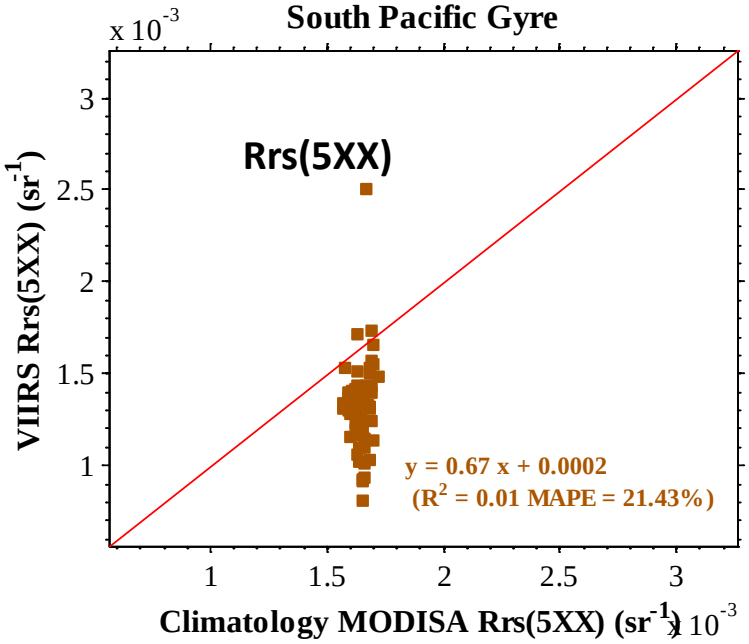



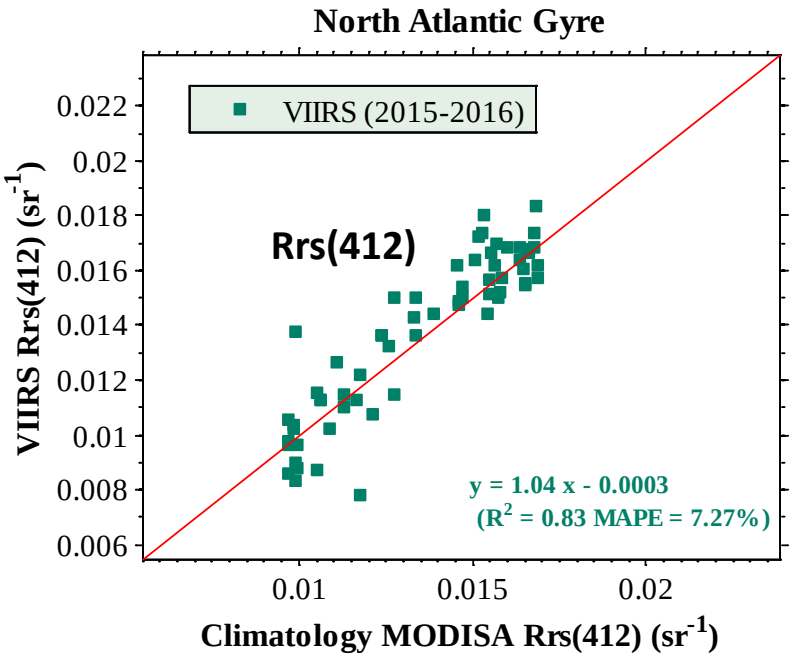



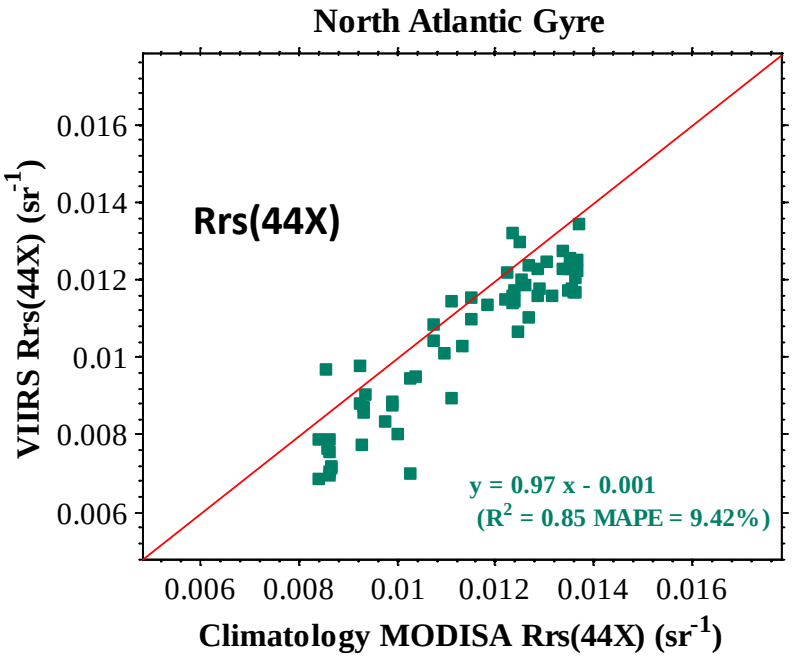

South Pacific Gyre
VIIRS (2015-2016)
Rrs(412)
y = 1.17 x - 0.003
(R2 = 0.83 MAPE = 5.26%)
VIIRS Rrs(412) (sr-1)
Climatology MODISA Rrs(412) (sr-1)
0.01
0.015
0.02
0.025
0.03

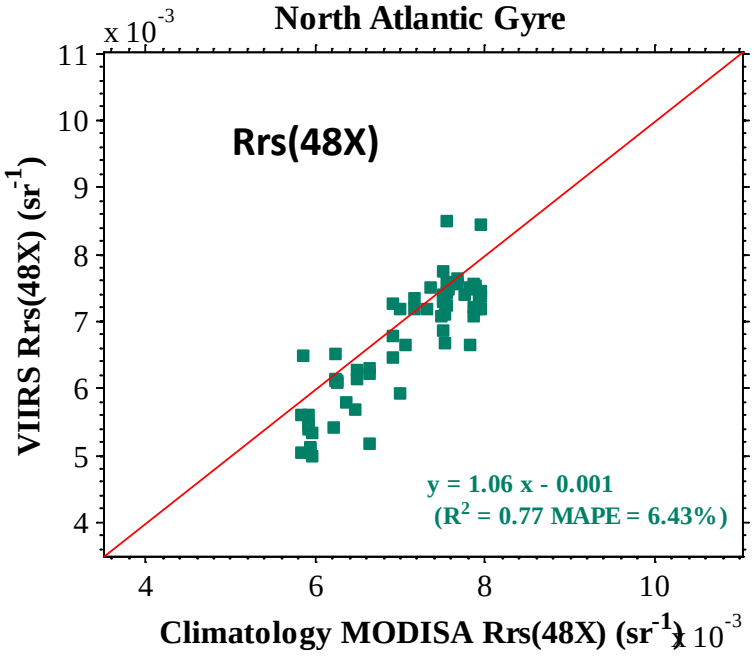

South Pacific Gyre
Rrs(44X)
y = 1.06 x - 0.002
(R2 = 0.81 MAPE = 9.9%)
VIIRS Rrs(44X) (sr-1)
Climatology MODISA Rrs(44X) (sr-1)
0.008
0.01
0.012
0.014
0.016
0.018
0.02
0.022

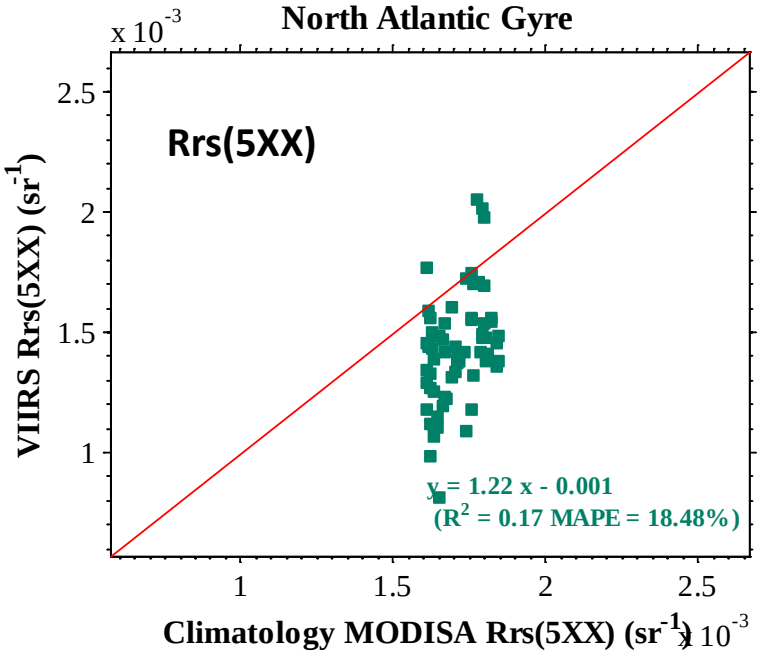

South Pacific Gyre
x 10-3
Rrs(48X)
y = 1.48 x - 0.004
(R2 = 0.72 MAPE = 7.74%)
VIIRS Rrs(48X) (sr-1)
Climatology MODISA Rrs(48X) (sr-1)
x 10-3
4
6
8
10
12


South Pacific Gyre
x 10-3
Rrs(5XX)
y = 0.67 x + 0.0002
(R2 = 0.01 MAPE = 21.43%)
VIIRS Rrs(5XX) (sr-1)
Climatology MODISA Rrs(5XX) (sr-1)
x 10-3
1
1.5
2
2.5
3


North Atlantic Gyre
VIIRS (2015-2016)
Rrs(412)
y = 1.04 x - 0.0003
(R2 = 0.83 MAPE = 7.27%)
VIIRS Rrs(412) (sr-1)
Climatology MODISA Rrs(412) (sr-1)
0.022
0.02
0.018
0.016
0.014
0.012
0.01
0.008
0.006
0.01
0.015
0.02


North Atlantic Gyre
Rrs(44X)
y = 0.97 x - 0.001
(R2 = 0.85 MAPE = 9.42%)
VIIRS Rrs(44X) (sr-1)
Climatology MODISA Rrs(44X) (sr-1)
0.016
0.014
0.012
0.01
0.008
0.006
0.006
0.008
0.01
0.012
0.014
0.016


North Atlantic Gyre
x 10-3
Rrs(48X)
y = 1.06 x - 0.001
(R2 = 0.77 MAPE = 6.43%)
VIIRS Rrs(48X) (sr-1)
Climatology MODISA Rrs(48X) (sr-1) x 10-3
11
10
9
8
7
6
5
4
4
6
8
10


North Atlantic Gyre
x 10-3
Rrs(5XX)
y = 1.22 x - 0.001
(R2 = 0.17 MAPE = 18.48%)
VIIRS Rrs(5XX) (sr-1)
Climatology MODISA Rrs(5XX) (sr-1) x 10-3
2.5
2
1.5
1
1
1.5
2
2.5

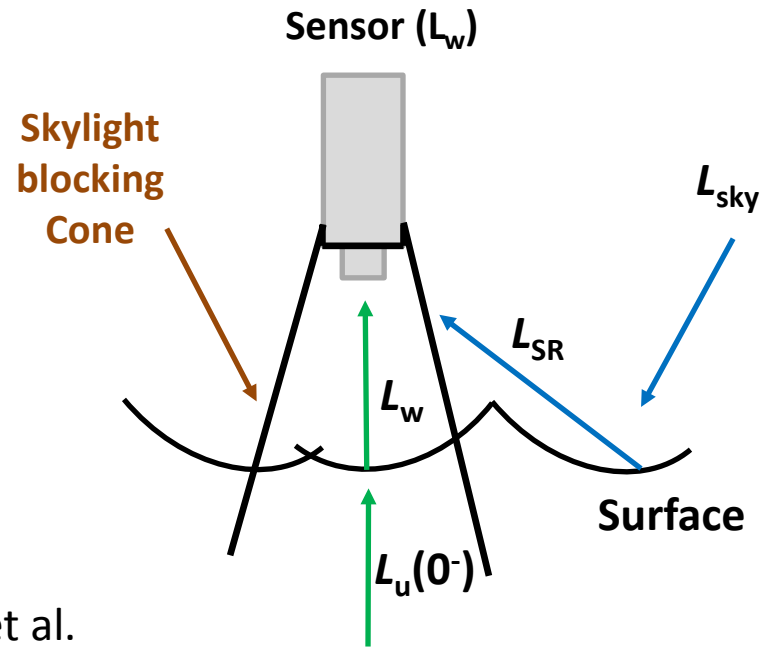
# 1. Evaluation of VIIRS Rrs products

## 1b. Compare VIIRS Rrs with in situ measurements in MassBay

## Satellite - insitu Matchup

**(1). VIIRS CoastWatch Level-2 750 m daily data**
**(2). Mean Rrs in 3x3 box**
**(3). Flags Applied: Atmospheric correction failure, Sun glint (high glint and moderate glint), Cloud**

# Direct Measurement of Water-leaving Radiance ($L_w$)

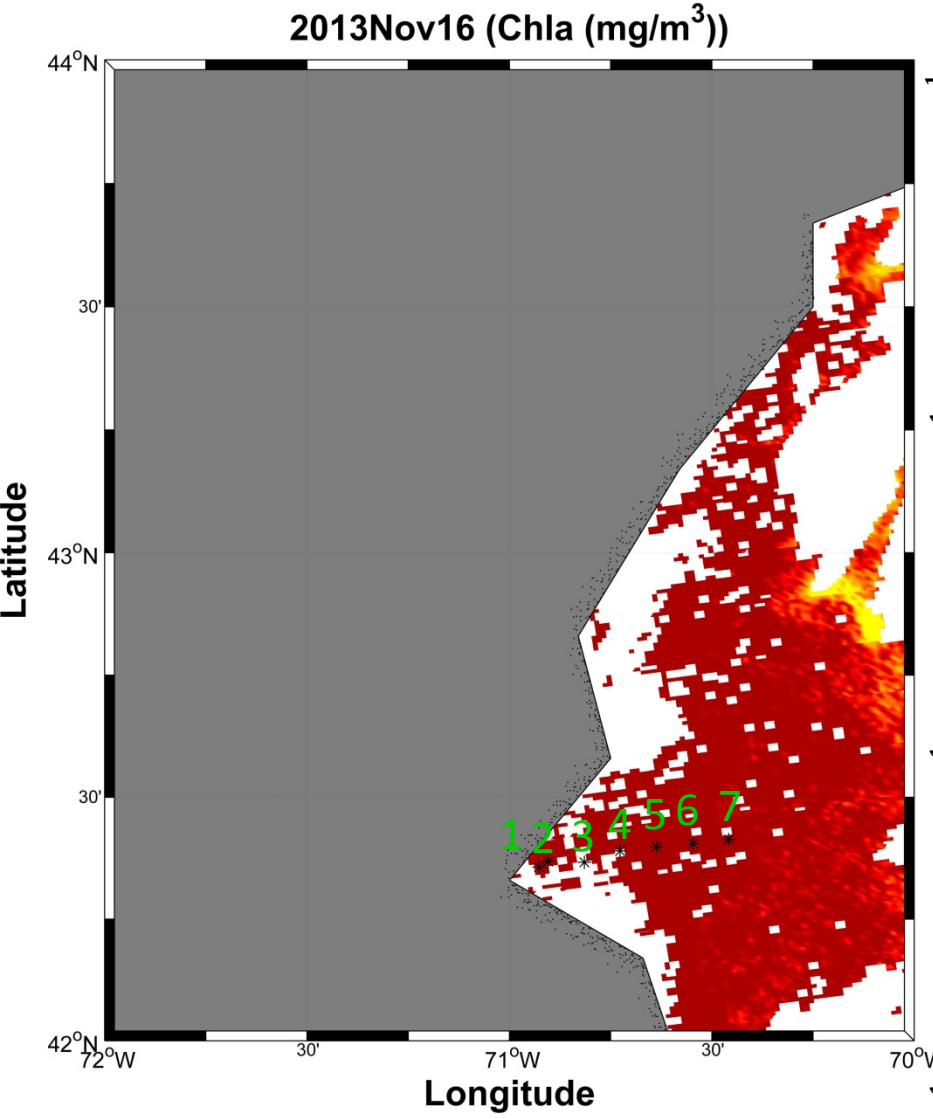


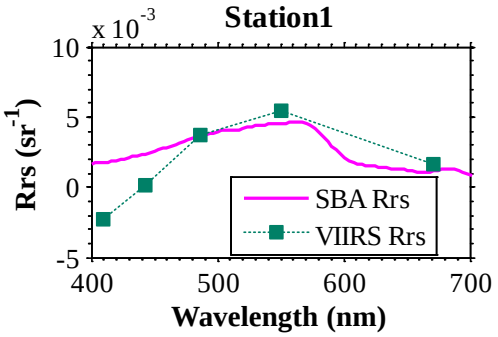

Lee et al. (2013)

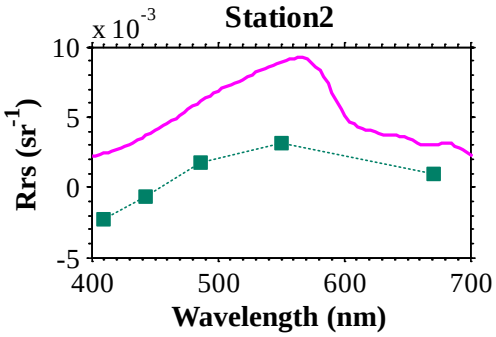


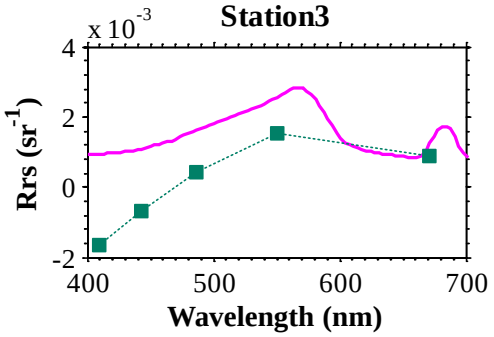


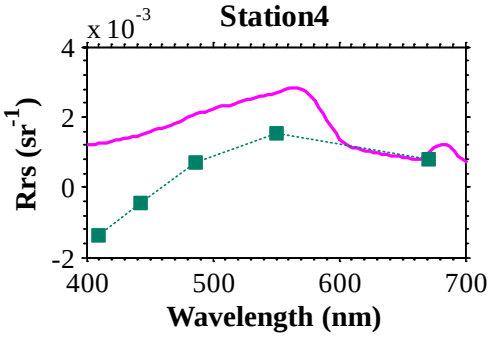
# MassBay, November 16, 2013

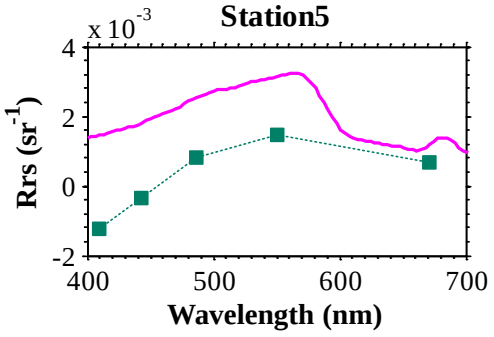


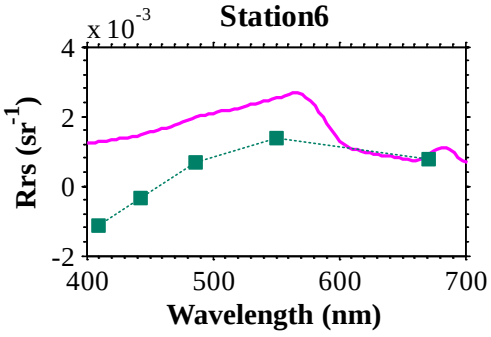



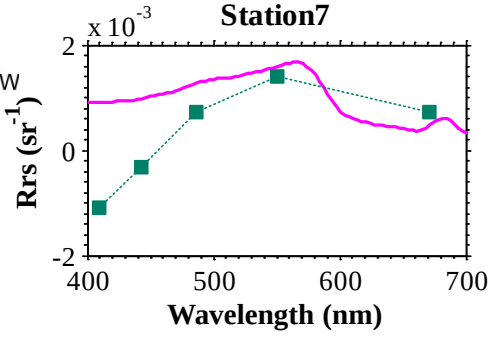



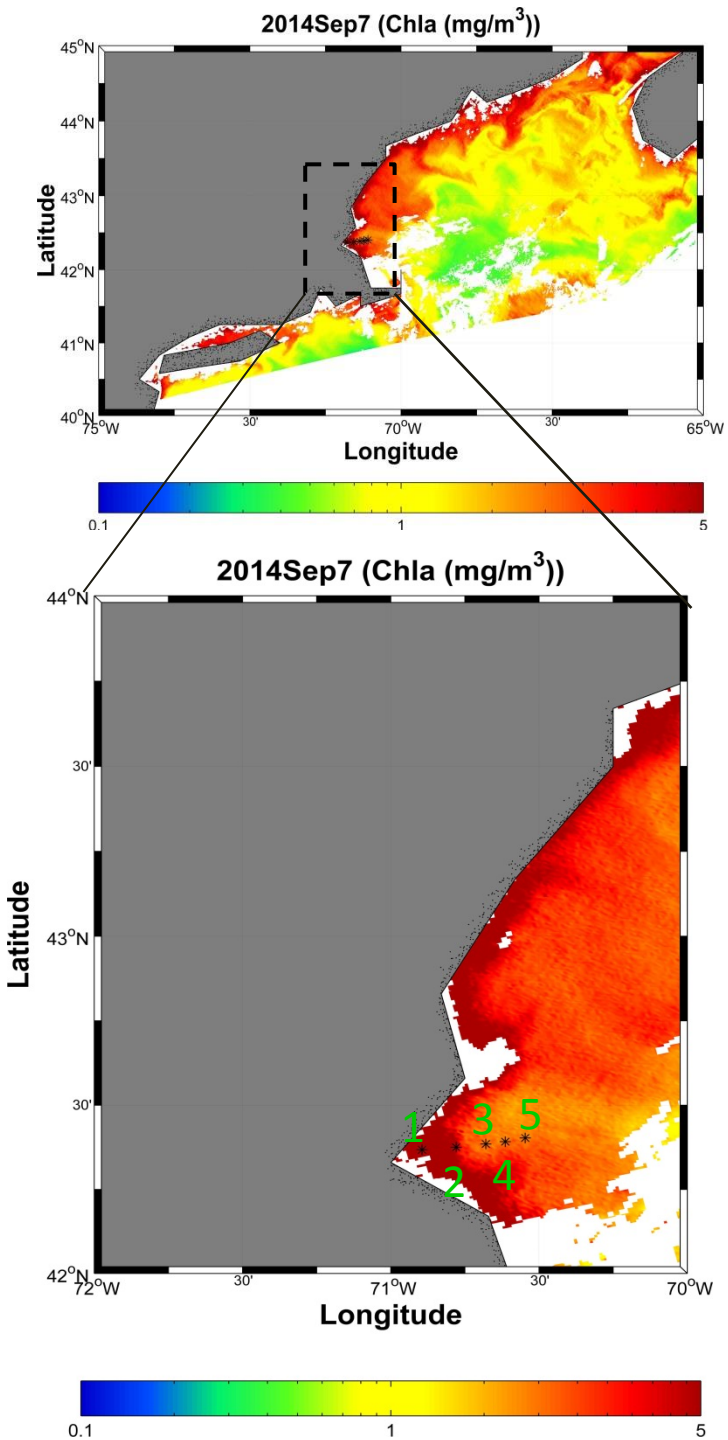



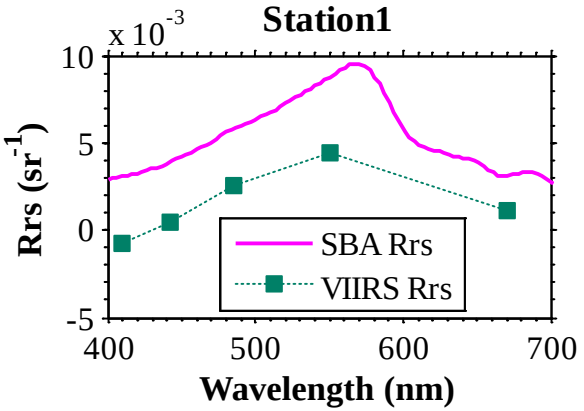



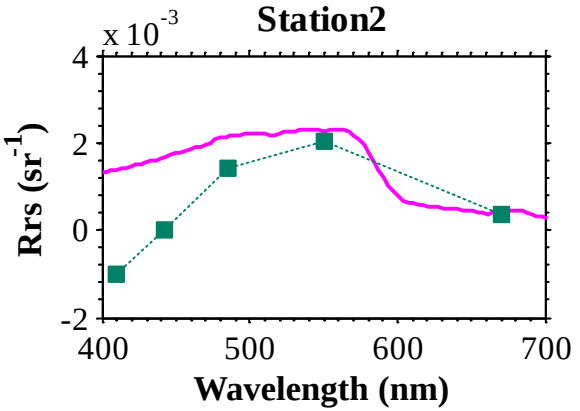



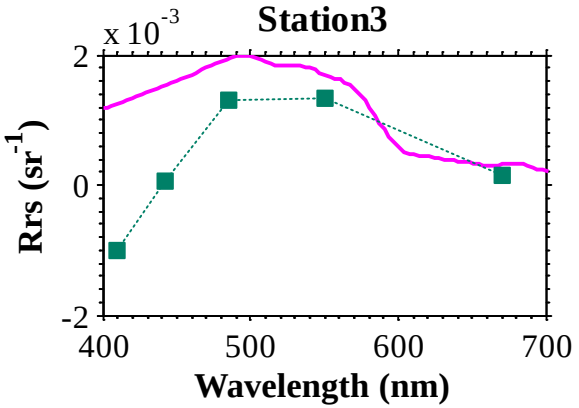



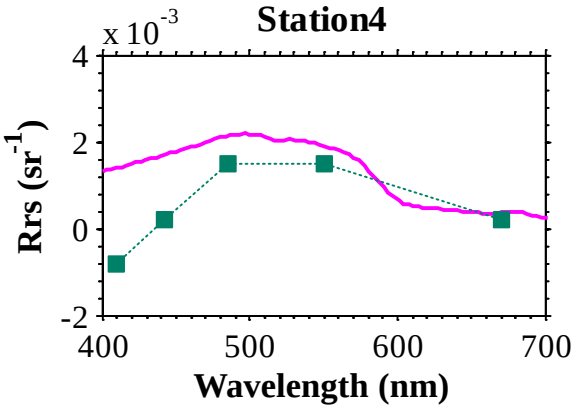
# MassBay, September 7, 2014

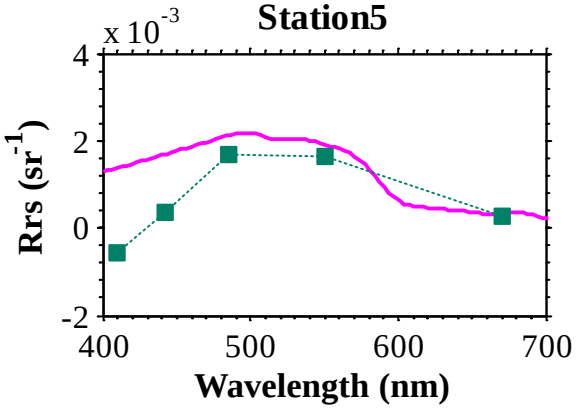


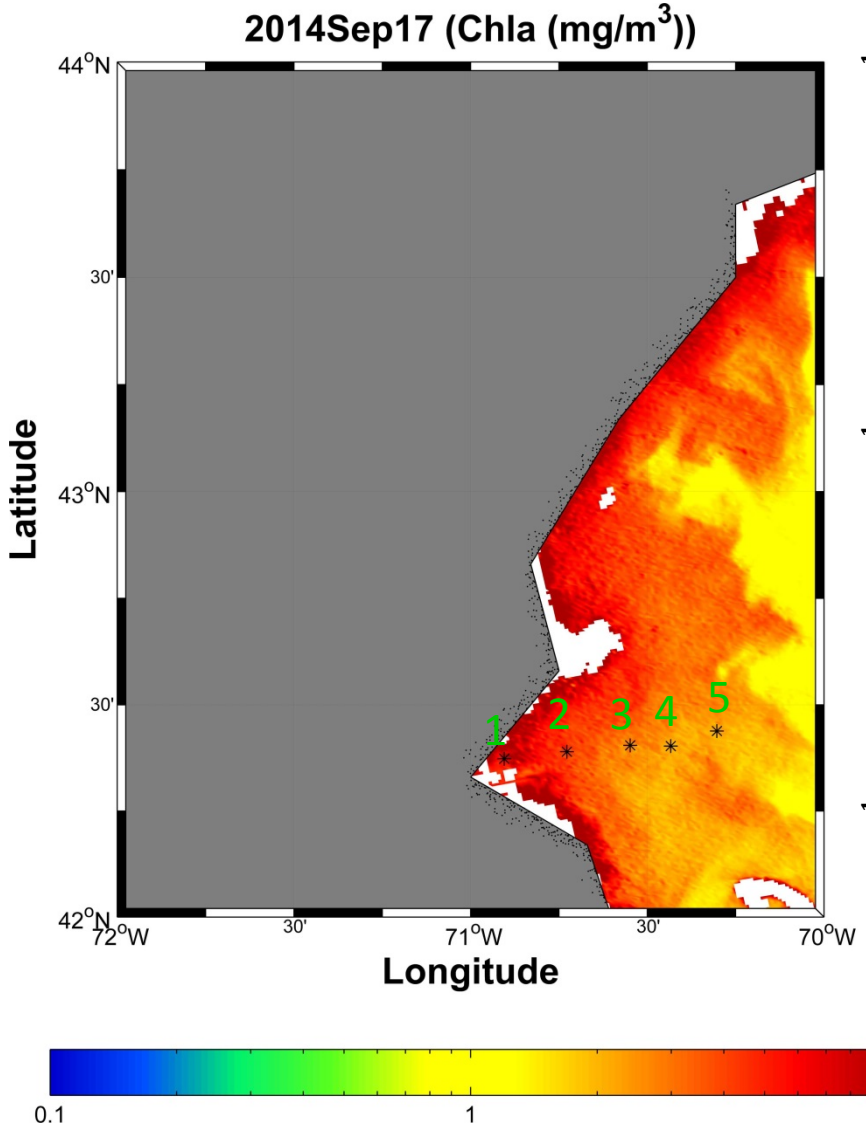



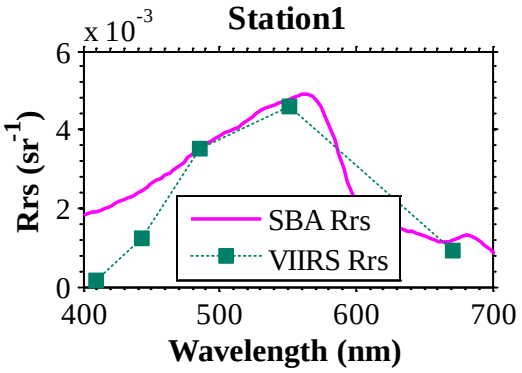



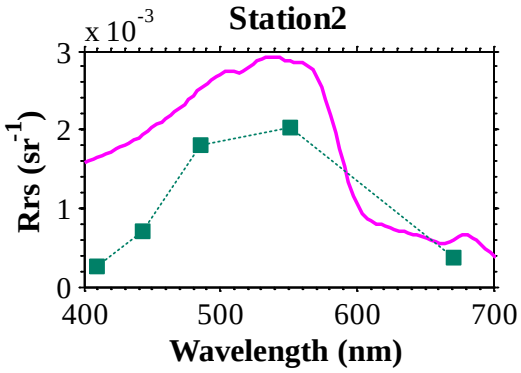



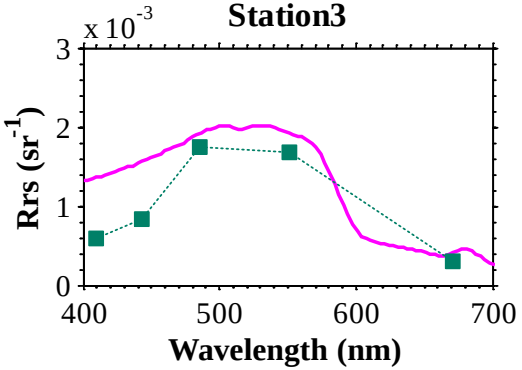



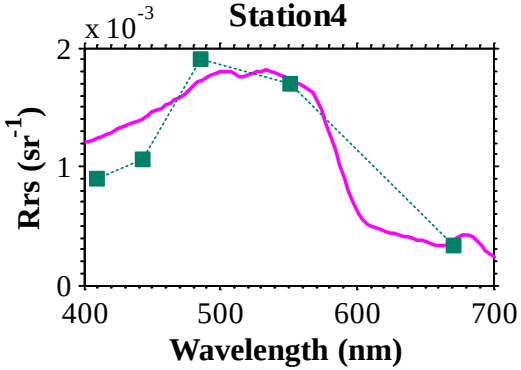
# MassBay, September 17, 2014

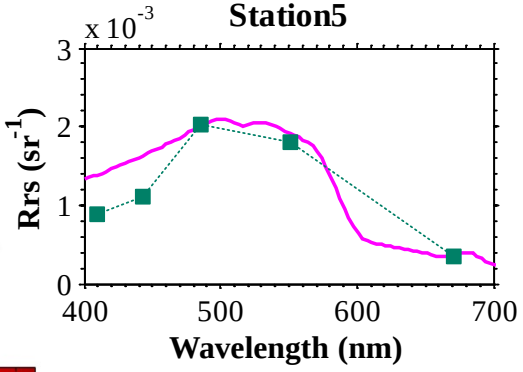


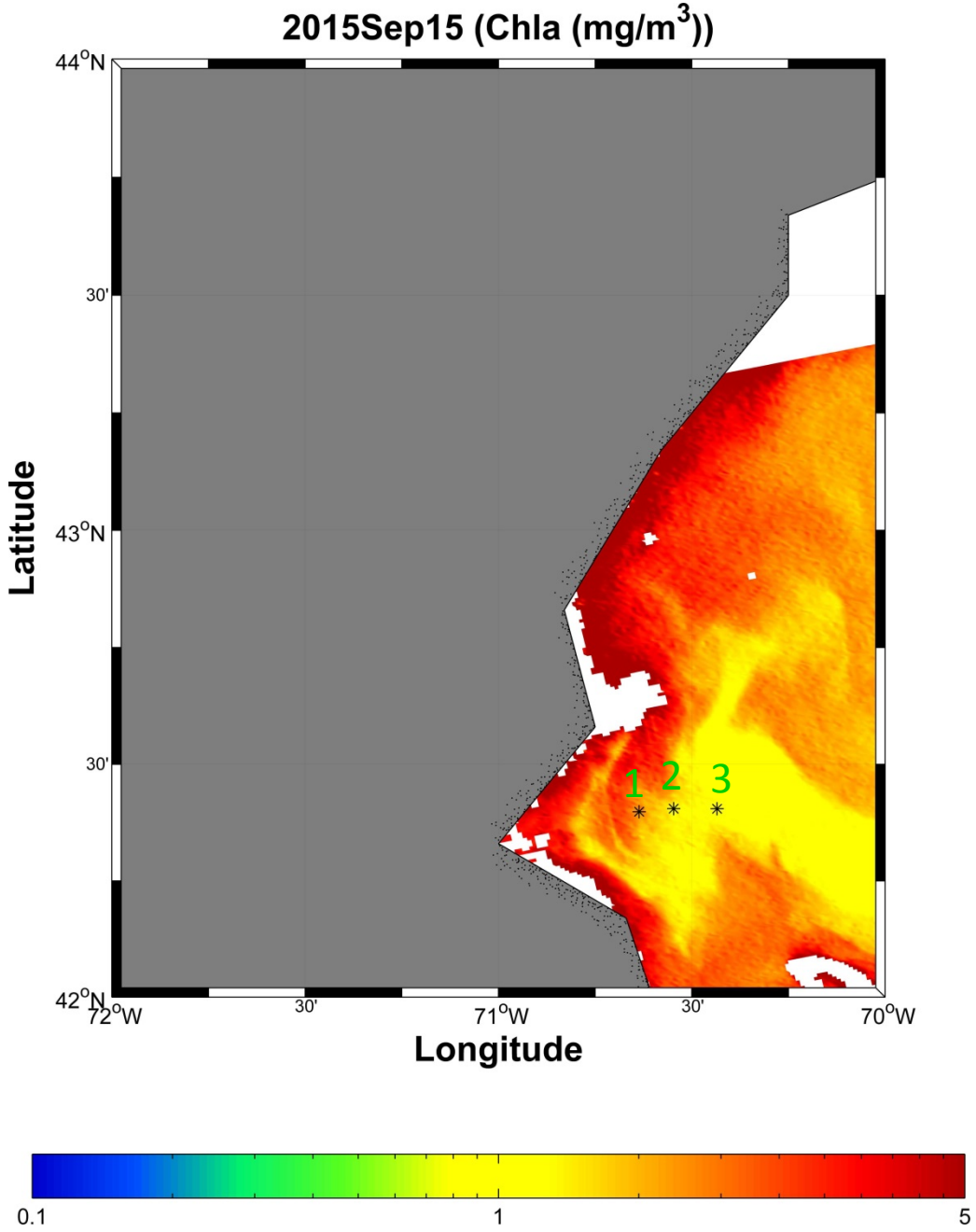



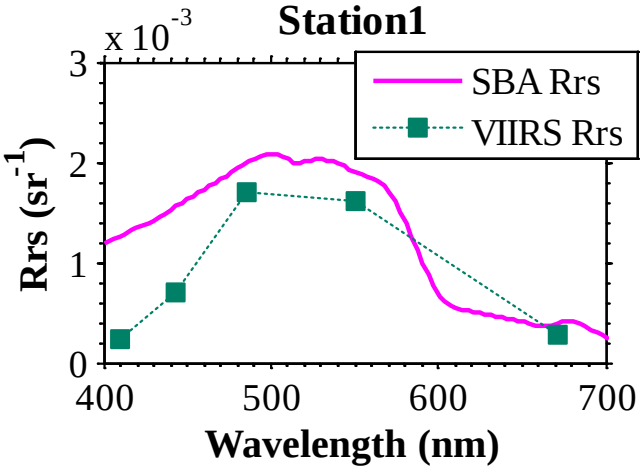



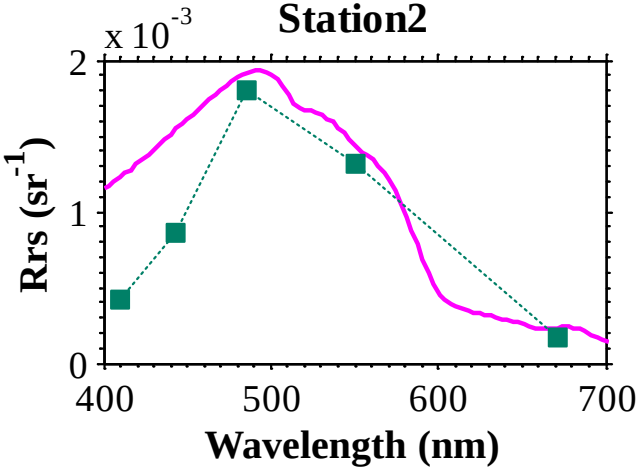



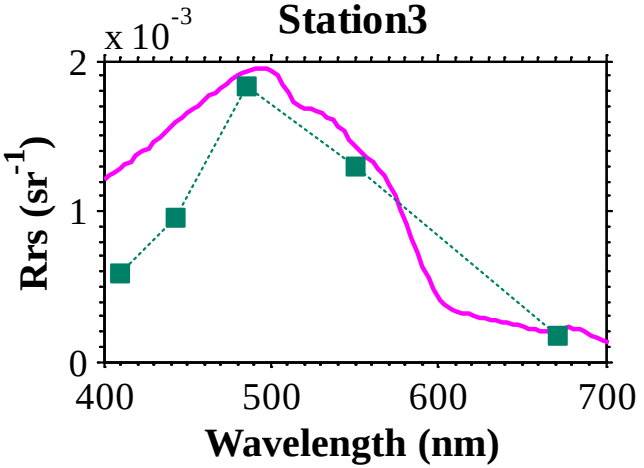



# MassBay, September 15, 2015

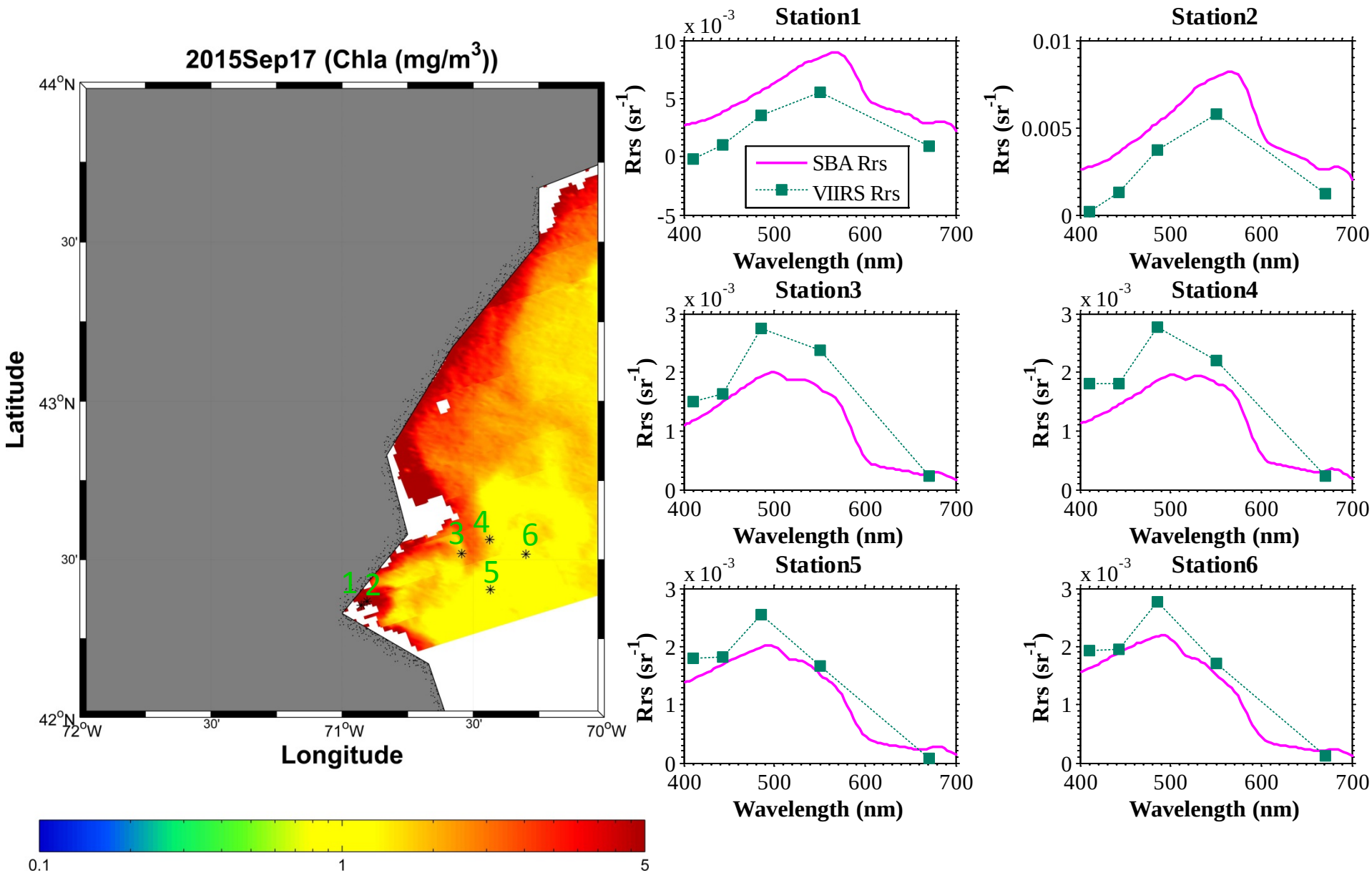


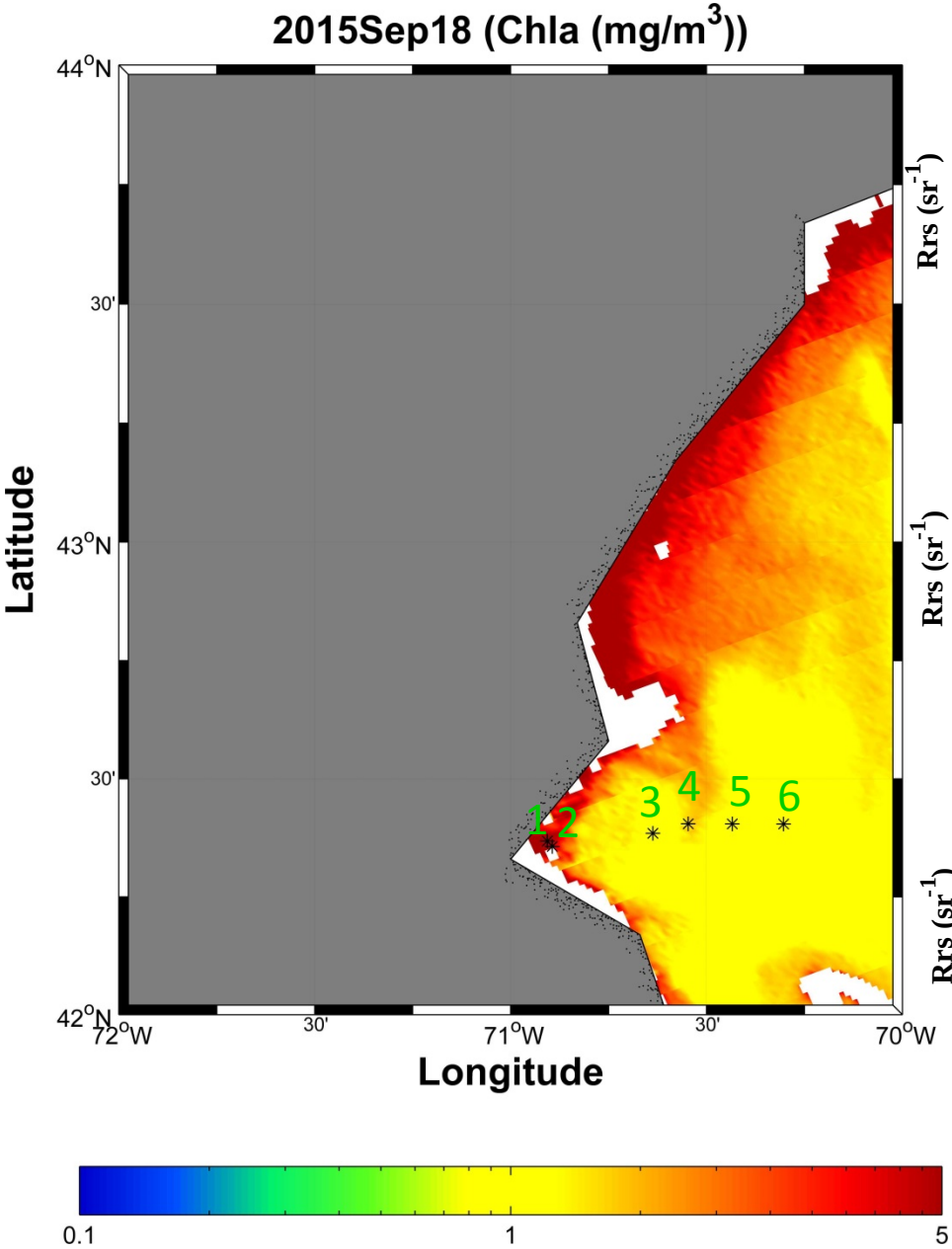



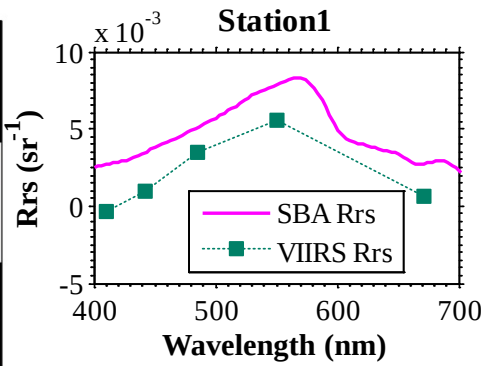



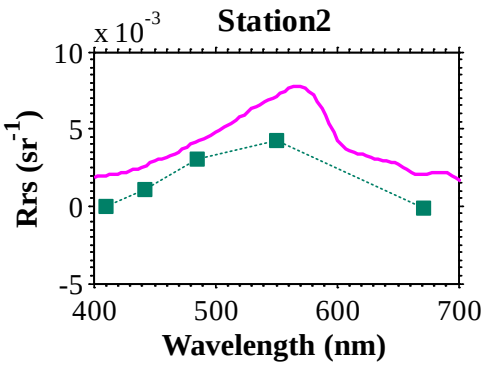
# MassBay, September 17, 2015

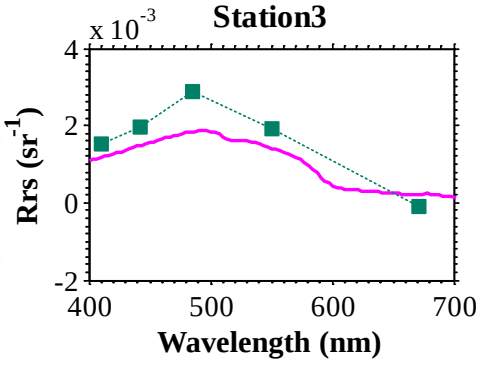


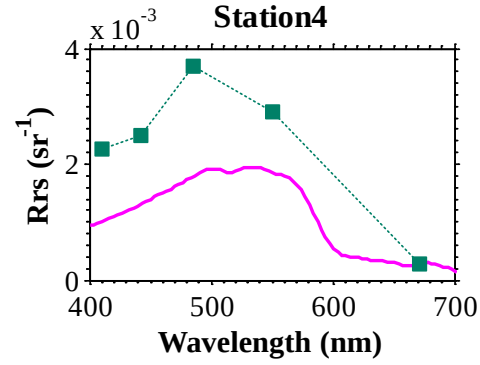
# MassBay, September 18, 2015

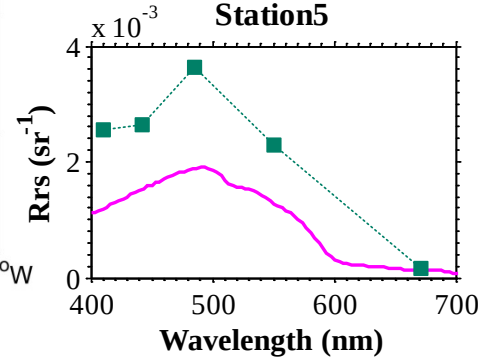


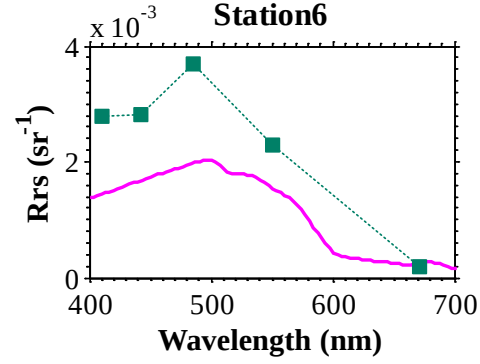



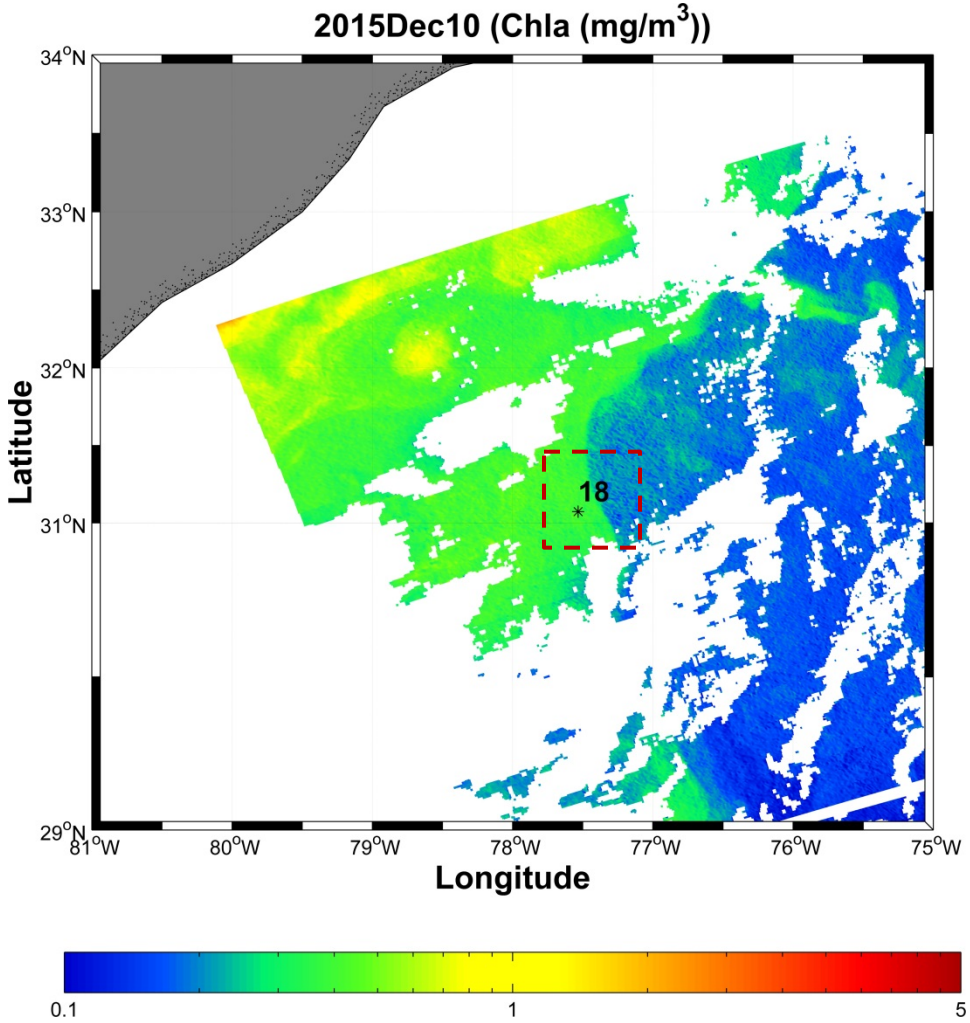



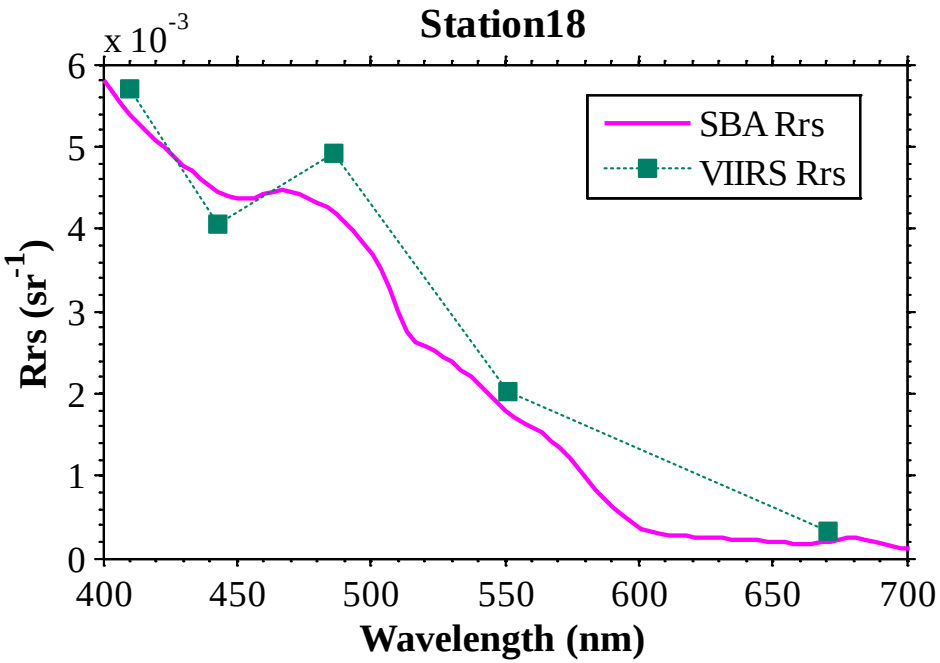



# 1. Evaluation of VIIRS Rrs products

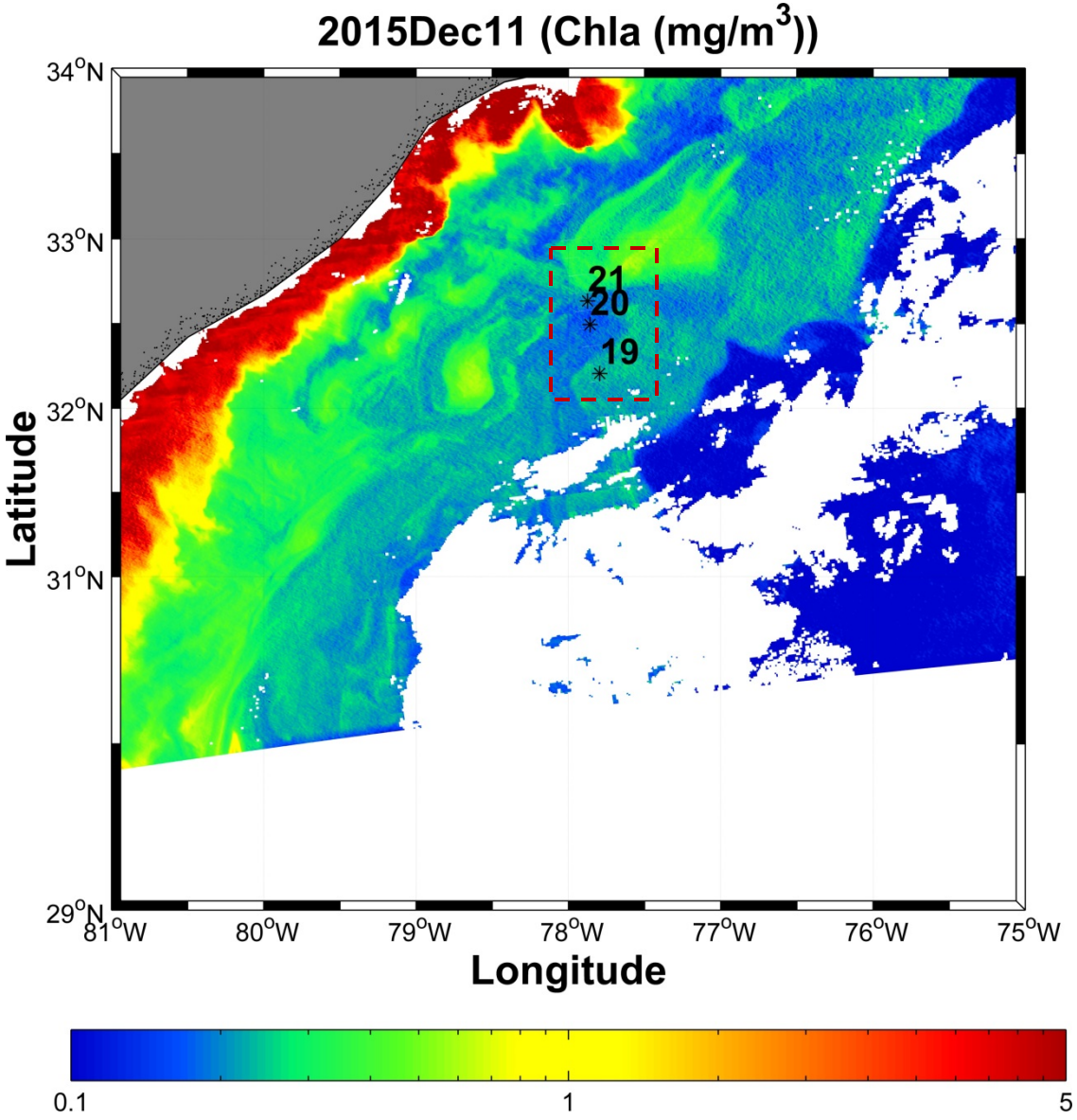
## 1c. Participate NOAA Cal/Val cruise and other cruises

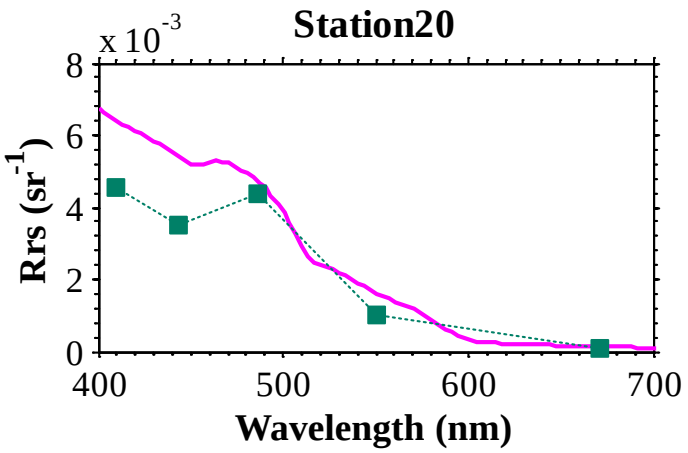
## NOAA/VIIRS Cruise, December 10, 2015

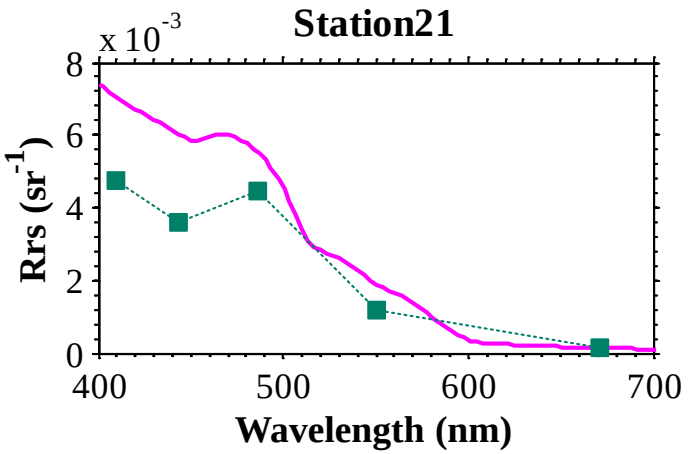


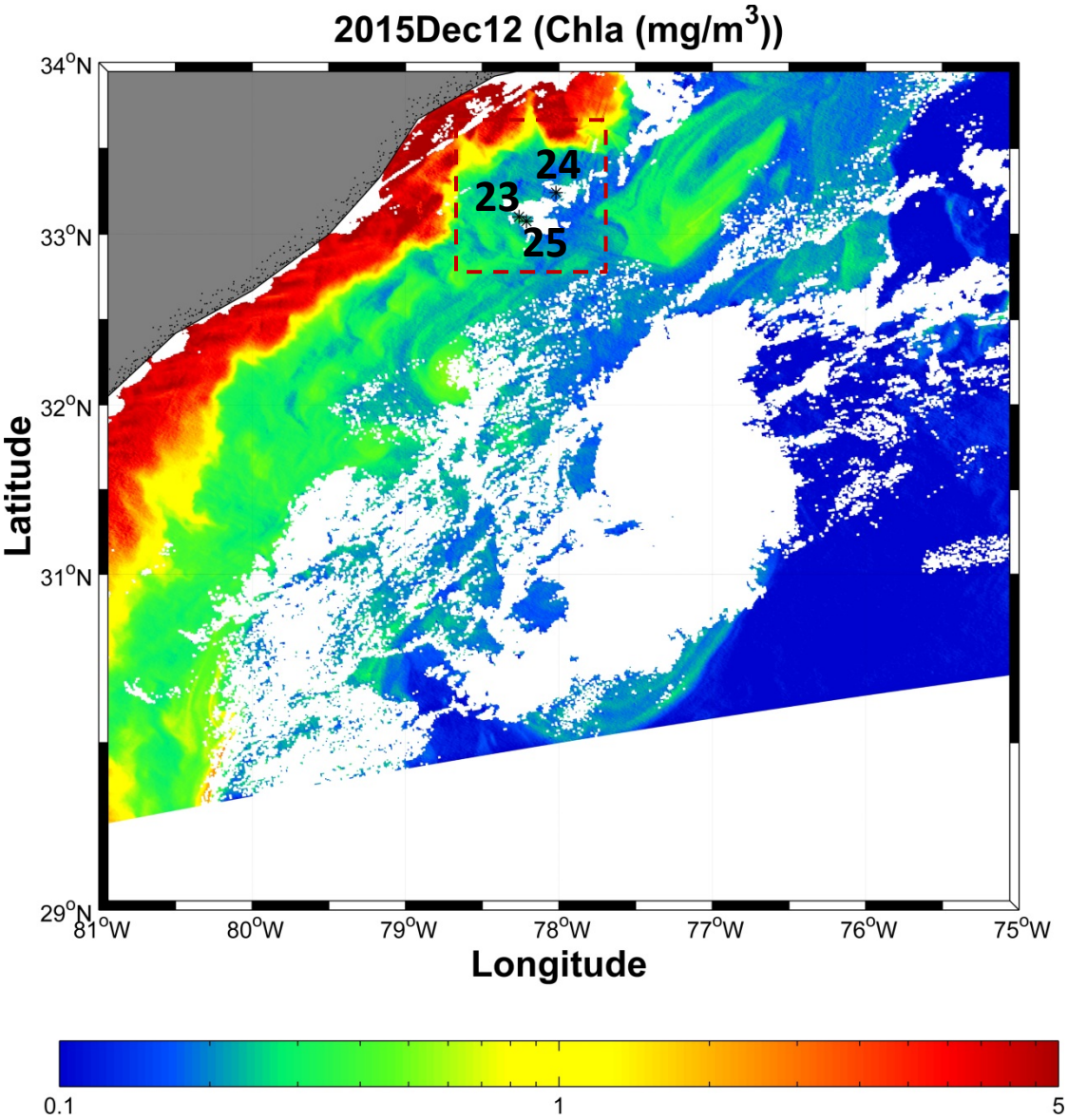
# VIIRS Cruise, December 11, 2015

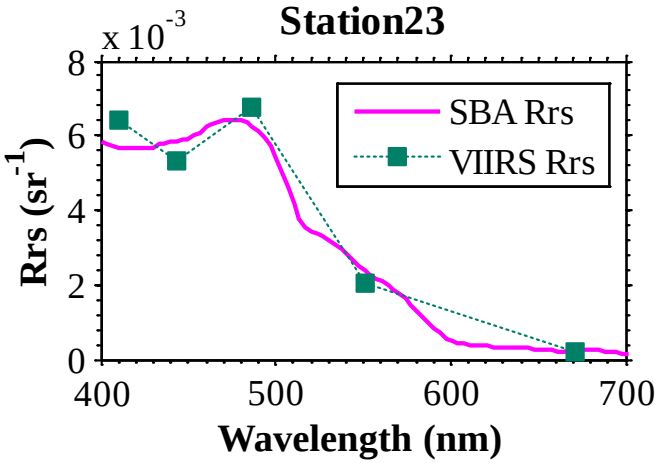


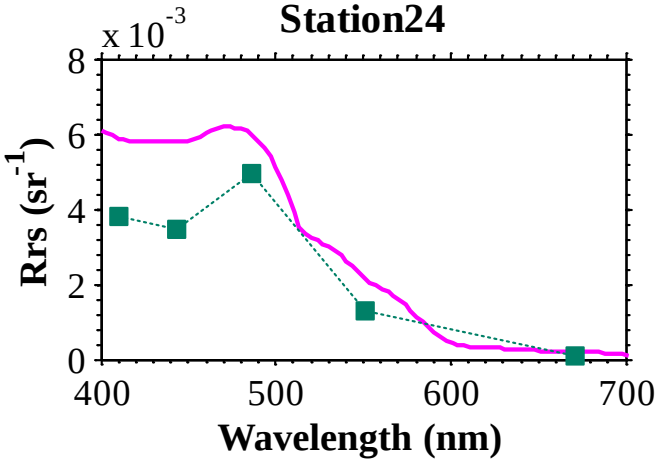



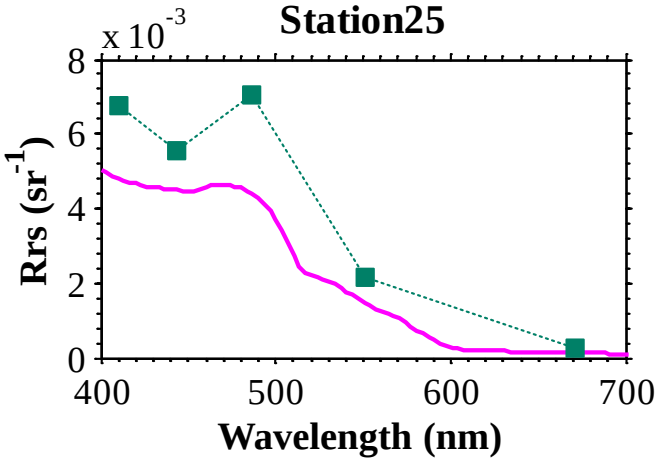



# VIIRS Cruise, December 12, 2015



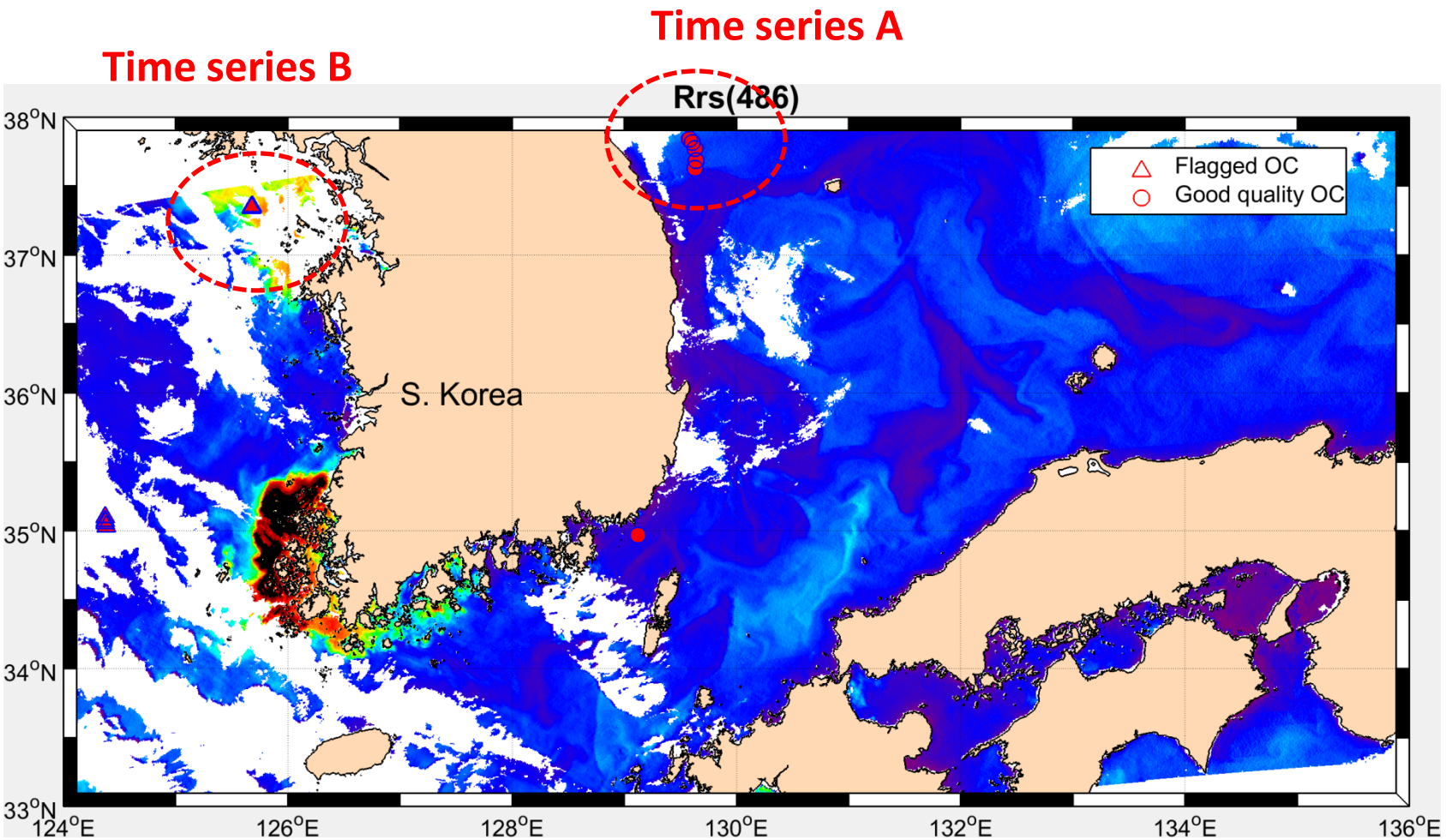



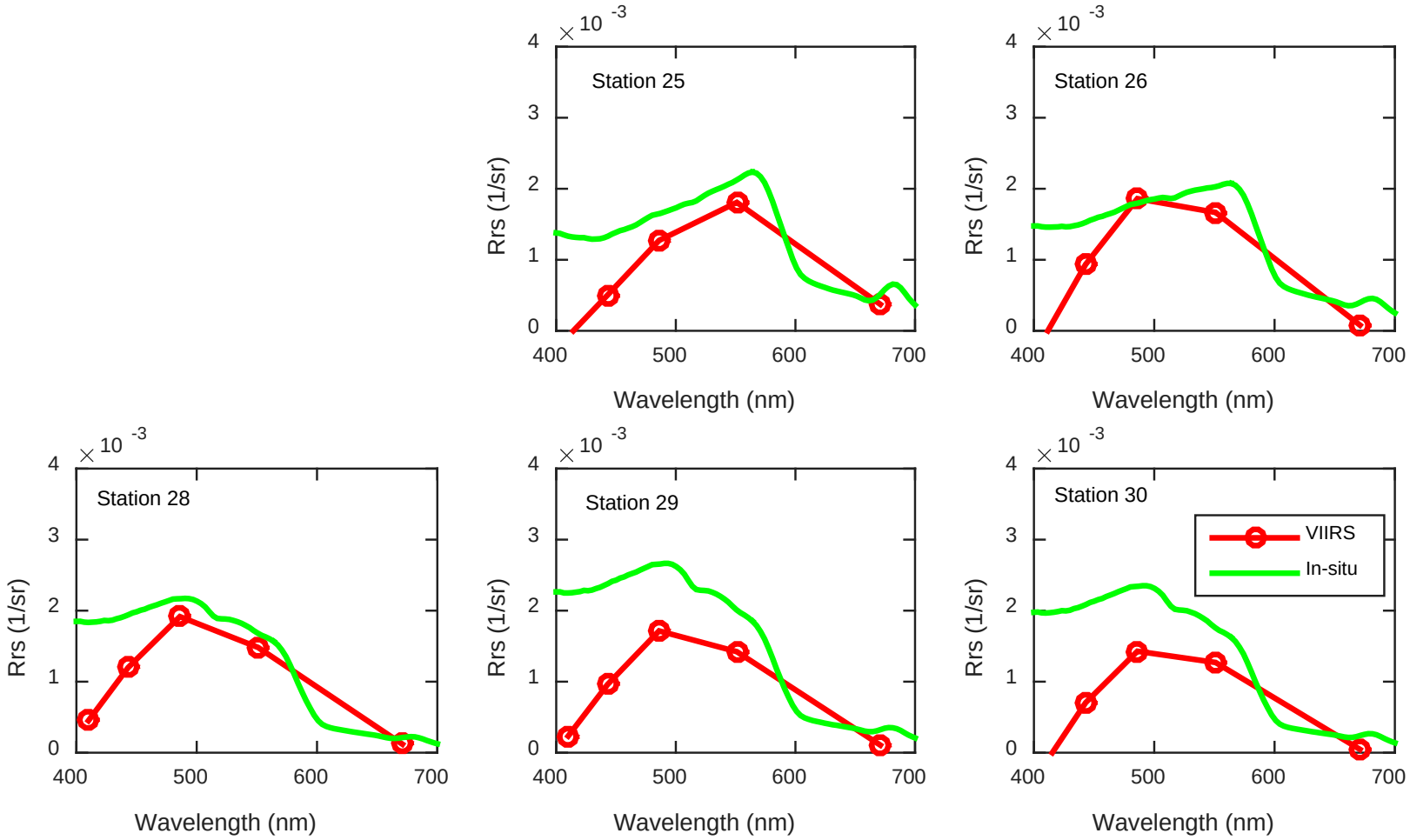
# Cruise just finished in the Yellow Sea and East Sea (June 2016):

## Preliminary results



## Time Series A: offshore waters in the northeast of S. Korea

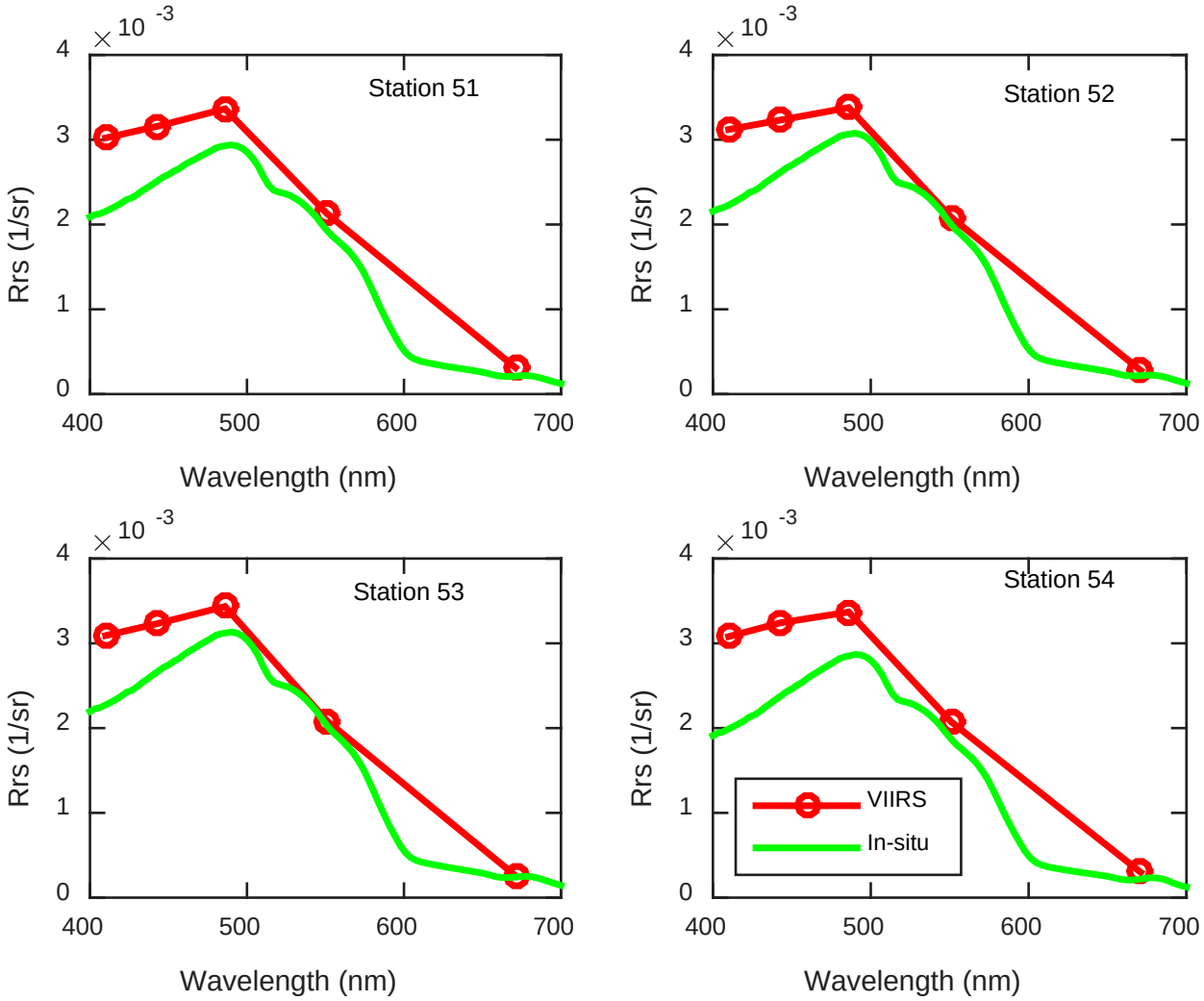
## OC data were "good", with no flags invoked; Time difference < 3 hours




**The location was slightly changing; so different pixels are used for VIIRS data.**

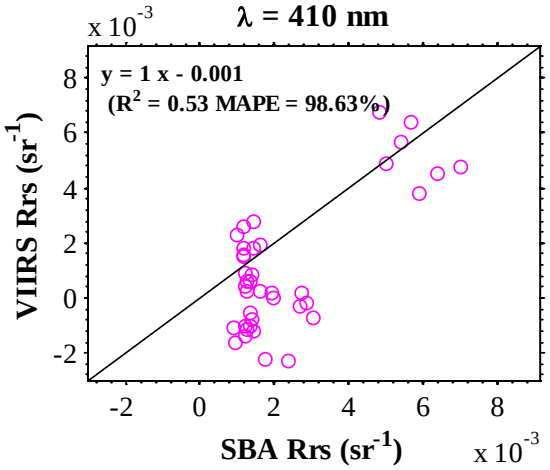
## Time Series B: offshore waters in west of Seoul, S. Korea

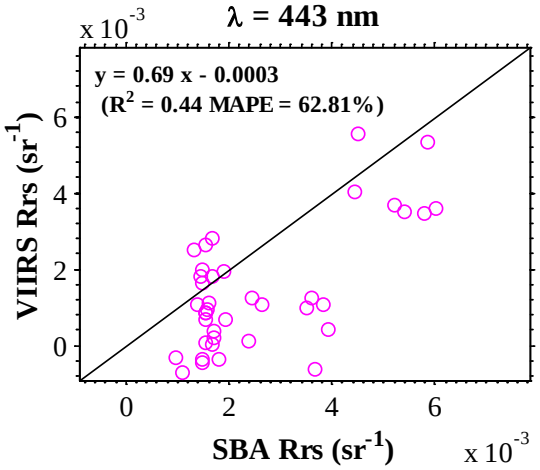
## OC data were "questionable", with flags invoked; Time difference < 3 hours

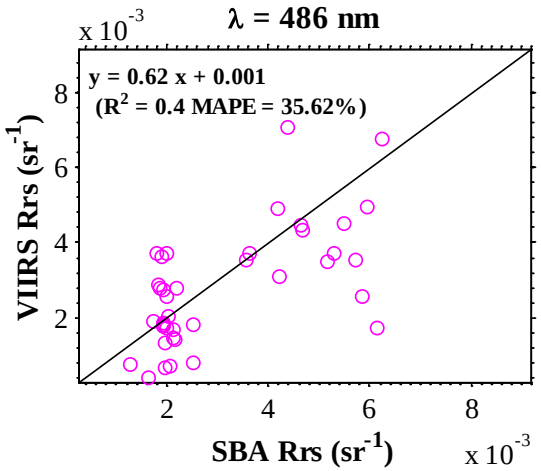


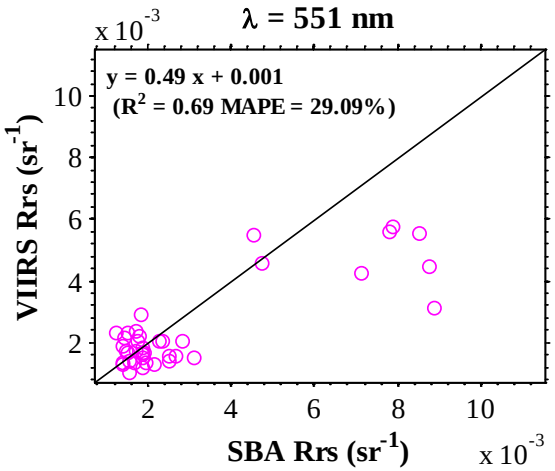

**Same location; so the same VIIRS data are used.**

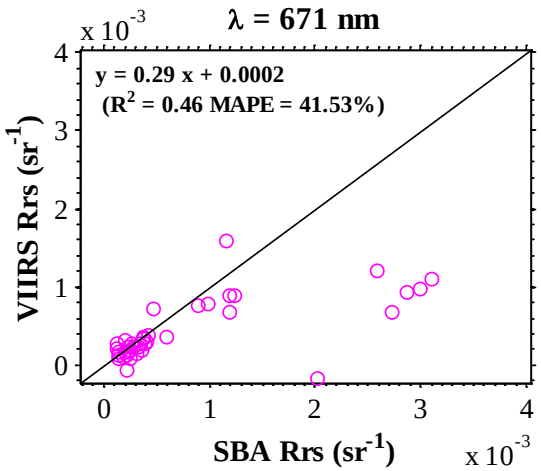
# SBA Rrs vs VIIRS Rrs



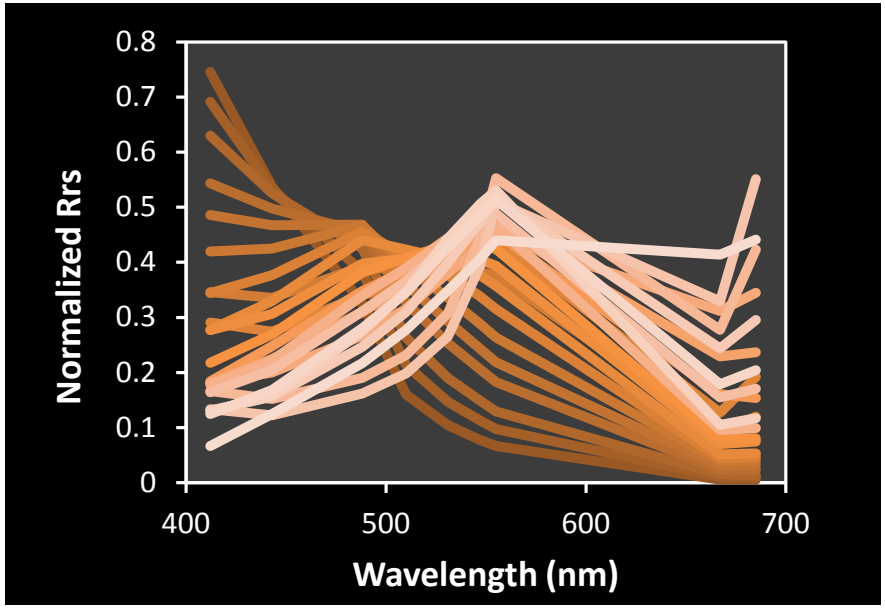



# 2. Development of new products

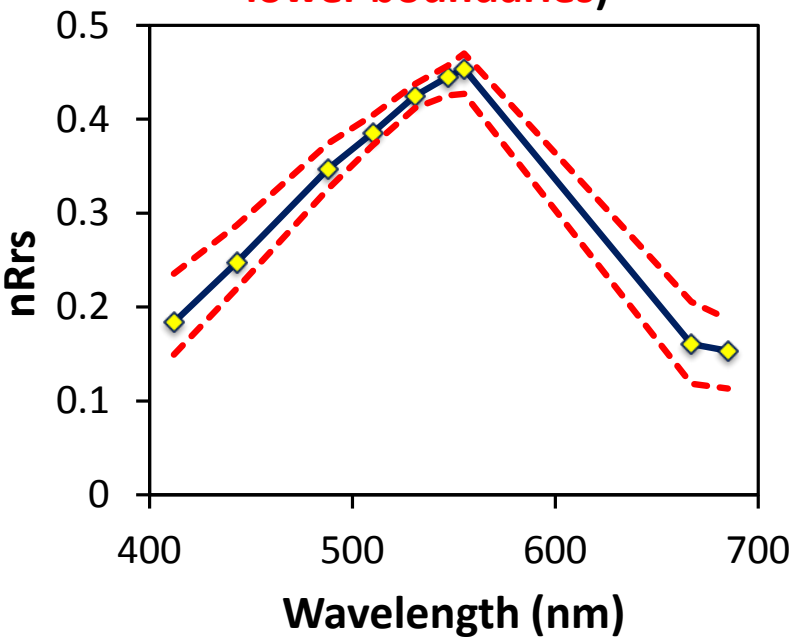
## 2a. Quality Assurance System

**23 spectral Rrs reference system**




**23 water types are developed from a large Rrs data base, according to the Rrs spectral shapes (cosine distance).**

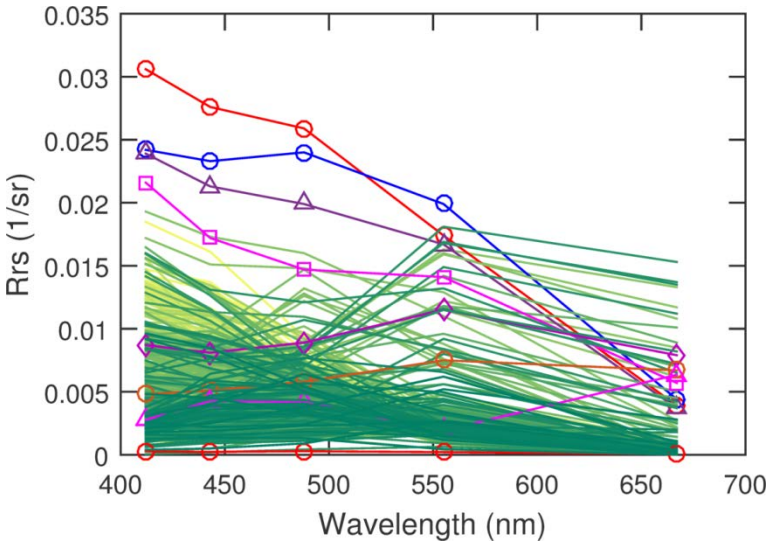
**Scoring system (reference, upper and lower boundaries)**



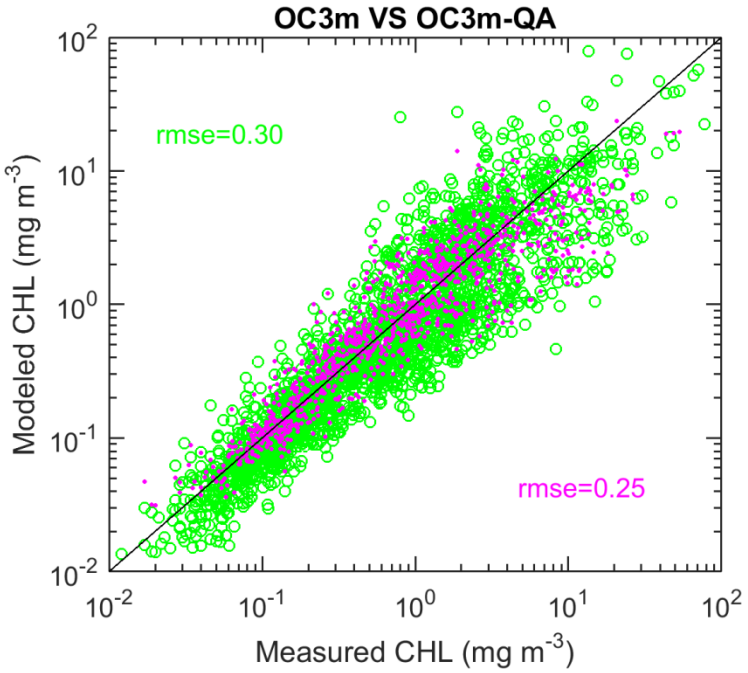

**The score system is to compare target Rrs spectrum with the reference (and its upper and lower boundary)…**

# 2a. Quality Assurance System

## Examples of applications




NOMAD Rrs spectra: A few spectra highlighted as "questionable" data




**"pink" points refer to measurements with the highest scores (=1)**

**The quality assurance system can be readily applied to satellite and in situ ocean color measurements.**

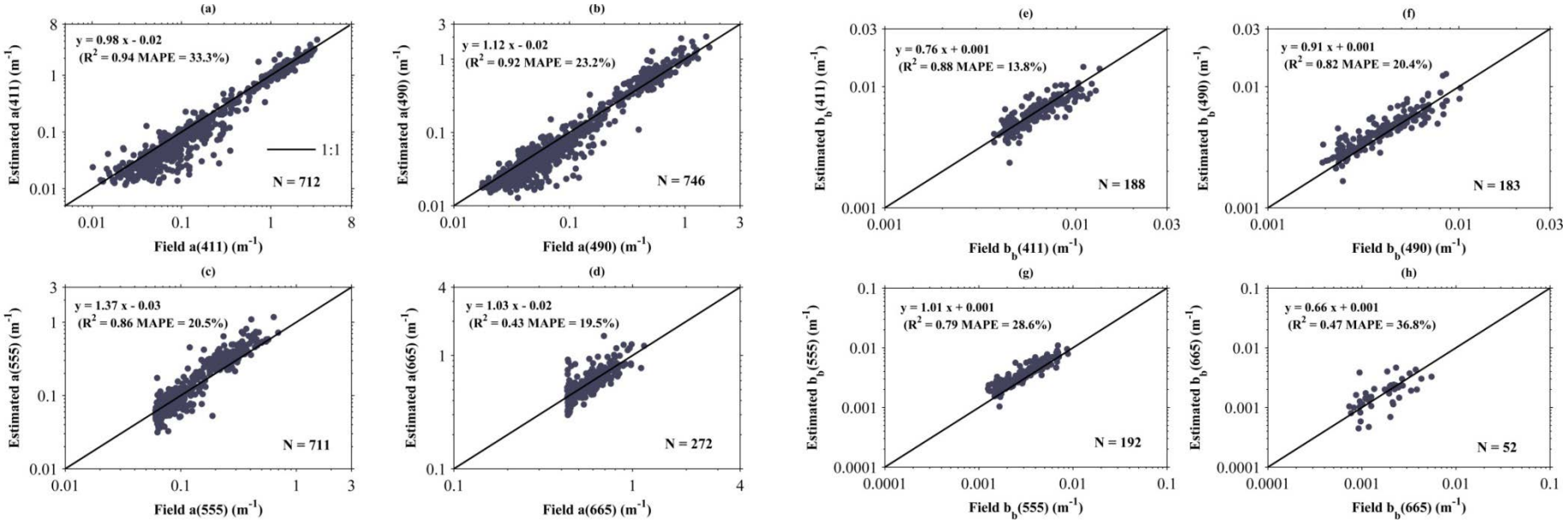
# 2. Development of new products

## 2b. IOPs from in situ AOPs

$$R_{rs} = f_1(a, b_b) \qquad nK_d = f_2(a, b_b)$$

$$\{a, b_b\}$$

**(NOMAD)**



# 2. Development of new products

## 2c. Secchi disk depth ($Z_{SD}$) for VIIRS

$$Z_{SD} \approx \frac{1}{2.5K_d^{tr}} \ln\left(\frac{\left|r_T - r_w^{tr}\right|}{0.013}\right)$$

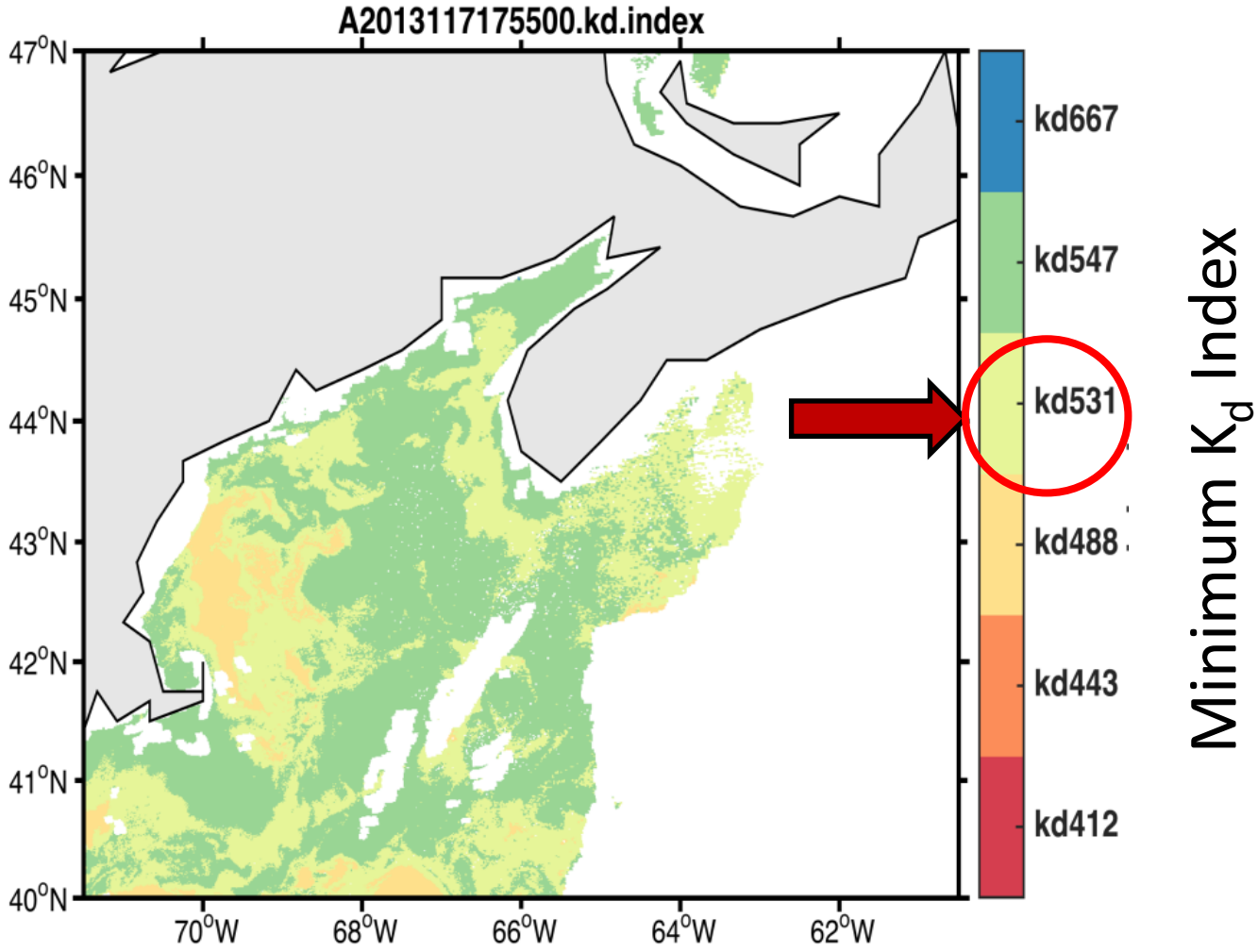
$K_d^{tr}$ : attenuation coefficient in the transparent window

(Lee et al 2015)

**For MODIS:**

$$K_d^{tr} = \min(K_d(412,443,490,531,547,667))$$

# Wavelength of MODIS for Minimum $K_d$




$$K_d^{tr} = \min(K_d(412,443,490,531,547,667))$$

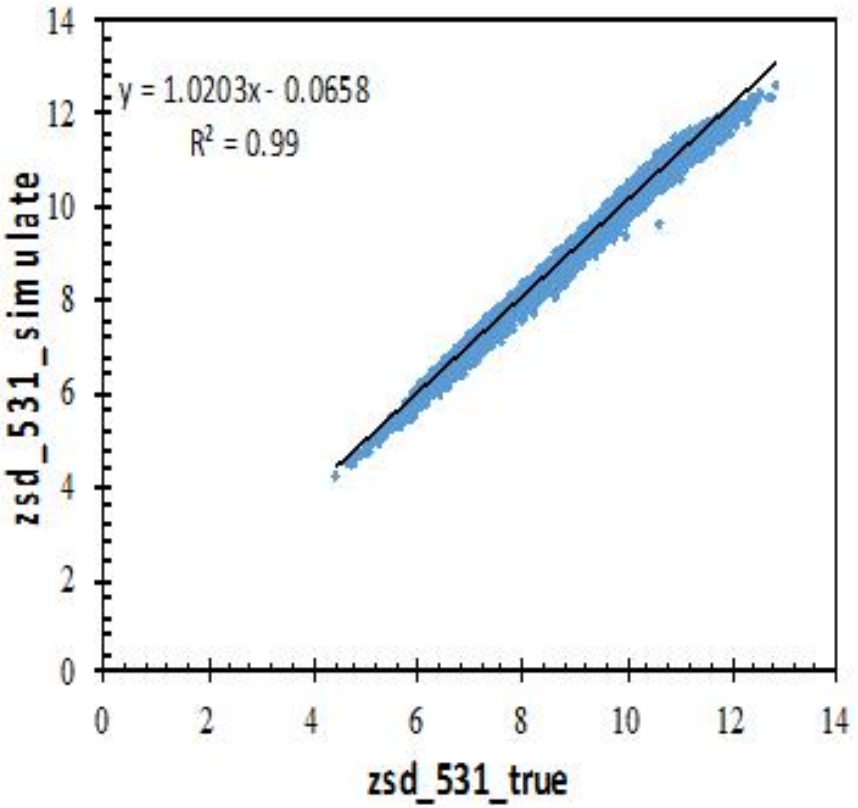
# No 531 nm …?

## Simulate $K_d(531)$

$$K_d531_simulate = 0.2*K_d488 + 0.75*K_d547$$

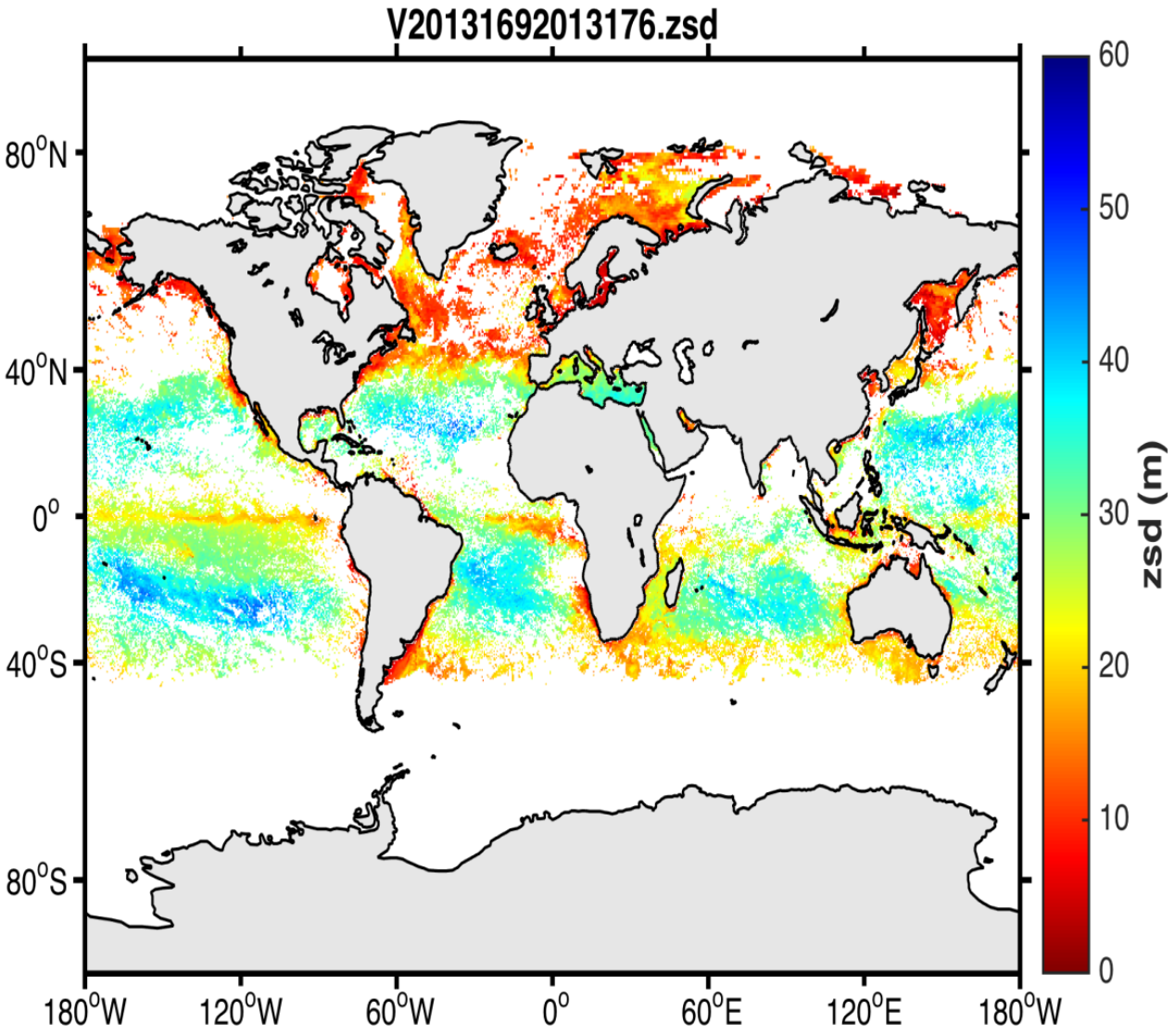
QAA （2002,2013） Lee et al (2005,2013)

$$R_{rs} \rightarrow a\&b_b \rightarrow K_d$$



# VIIRS global $Z_{SD}$

VIIRS weekly $Z_{SD}$, Jun 2013



# Plan of FY17

## Continue monitoring VIIRS Rrs and IOPs …

1a. Compare VIIRS Rrs with climatological Rrs of gyre waters

1b. Compare VIIRS Rrs with in situ measurements
(Puerto Rico, Mass Bay, other opportunities)

1c. Evaluate VIIRS IOPs with improved in situ IOPs

1d. Evaluate VIIRS other products (e.g., $Z_{SD}$)

2a. Participate NOAA Cal/Val cruise to collect AOP/IOP

# Thank you!

JPSS Cal/Val VIIRS Meeting
(Ocean Color Session Wednesday 10)

# West Coast Ocean Color Products & NOAA VIIRS Cruise Comparisons

**Nick Tufillaro**, Jasmine Nahorniak, Curt Davis
Oregon State University
Matthew Ragan & Burt Jones
USC

10-11 August 2016
**NOAA** Center Greenbelt, Maryland

E: nbt@coas.oregonstate.edu

Outline

1.) **Southern California Aeronet SeaPRISM (Platform Eureka)**

Comparison of Side-by-Side SeaPRISMS

Correlations on individual Bands

Time Series Comparisons: March 2016 - 4 August 2016

2). **2015 October Cal/Val Cruise**

Satlantic Optical Profiler ('HyperPro')

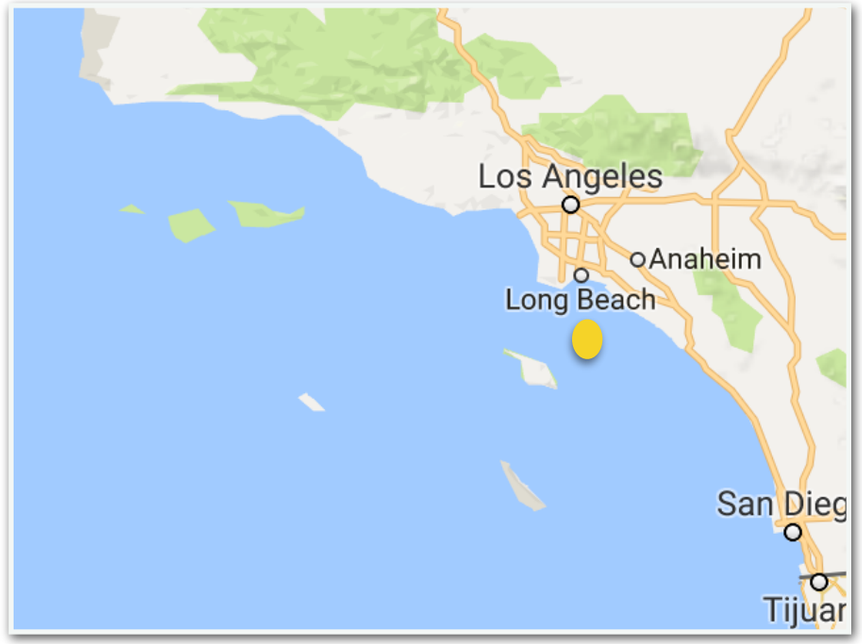
**SP**ectral **EV**olution Above Water Spectrometer (SPEV)
SPEV Measurement Protocols
SPEV Procoessing Protocols
Automated processing codes
Assumptions, Settings, Usage

Comparison of HyperPro and Spectral Evolution at
2, 6, 13, 14, 15, 16, 17, 18, 19, 20, 21, 23, 24, 25, 26, 27

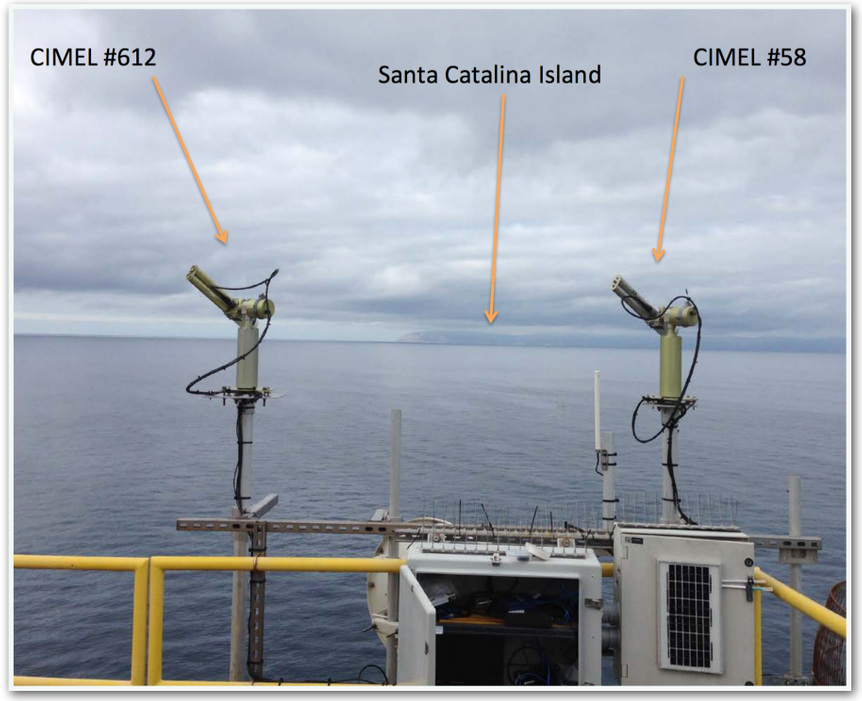
# Comparison of side-to-side SeaPrisms in Southern California




## Map




## Two SeaPRISM’s



# Timeline of recent events at Southern California Aeronet ‘Platform Eureka’ SeaPRISM

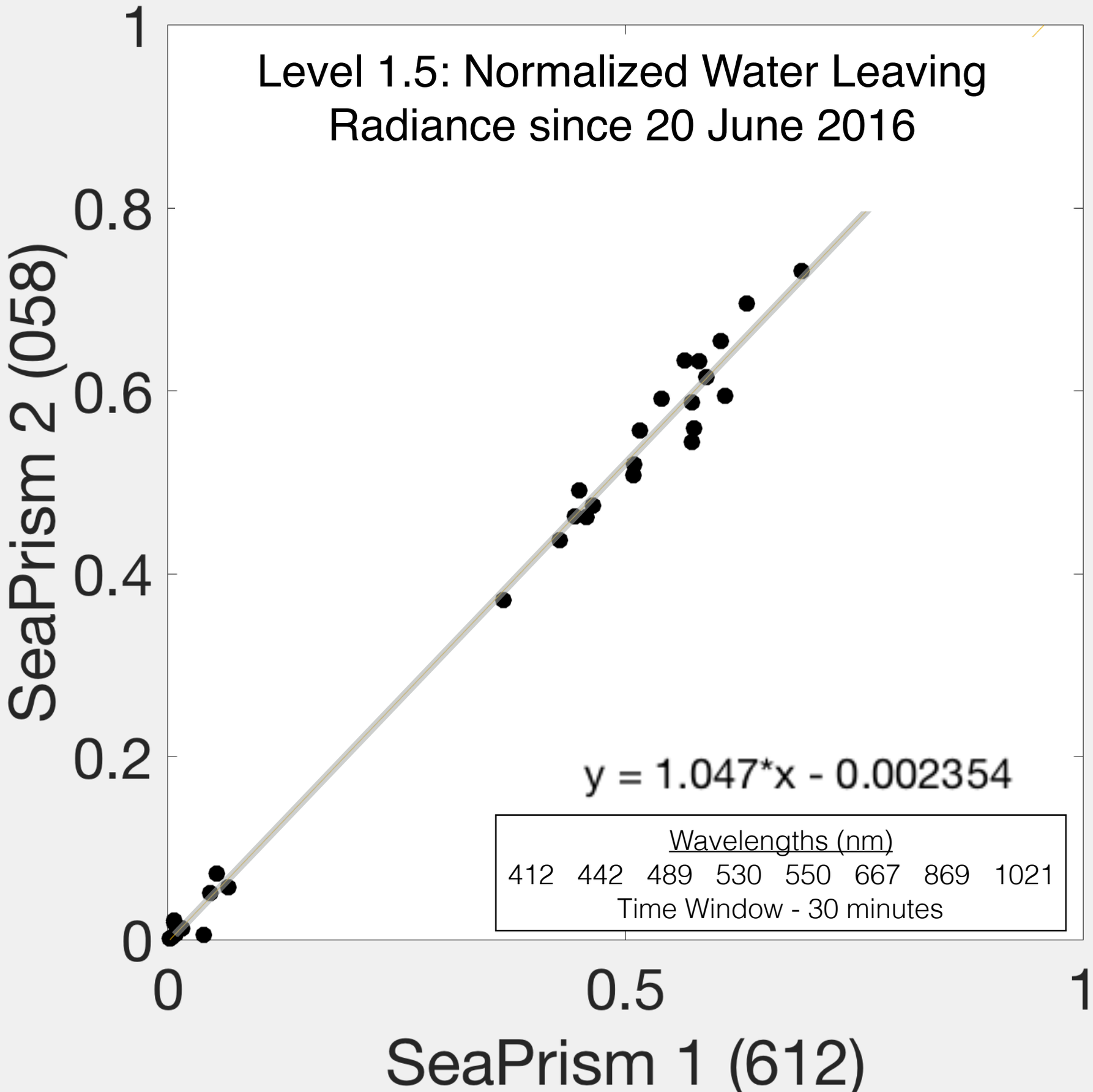
02/11/2016:  CIMEL #612 was removed from Platform Eureka and sent to GSFC for calibration

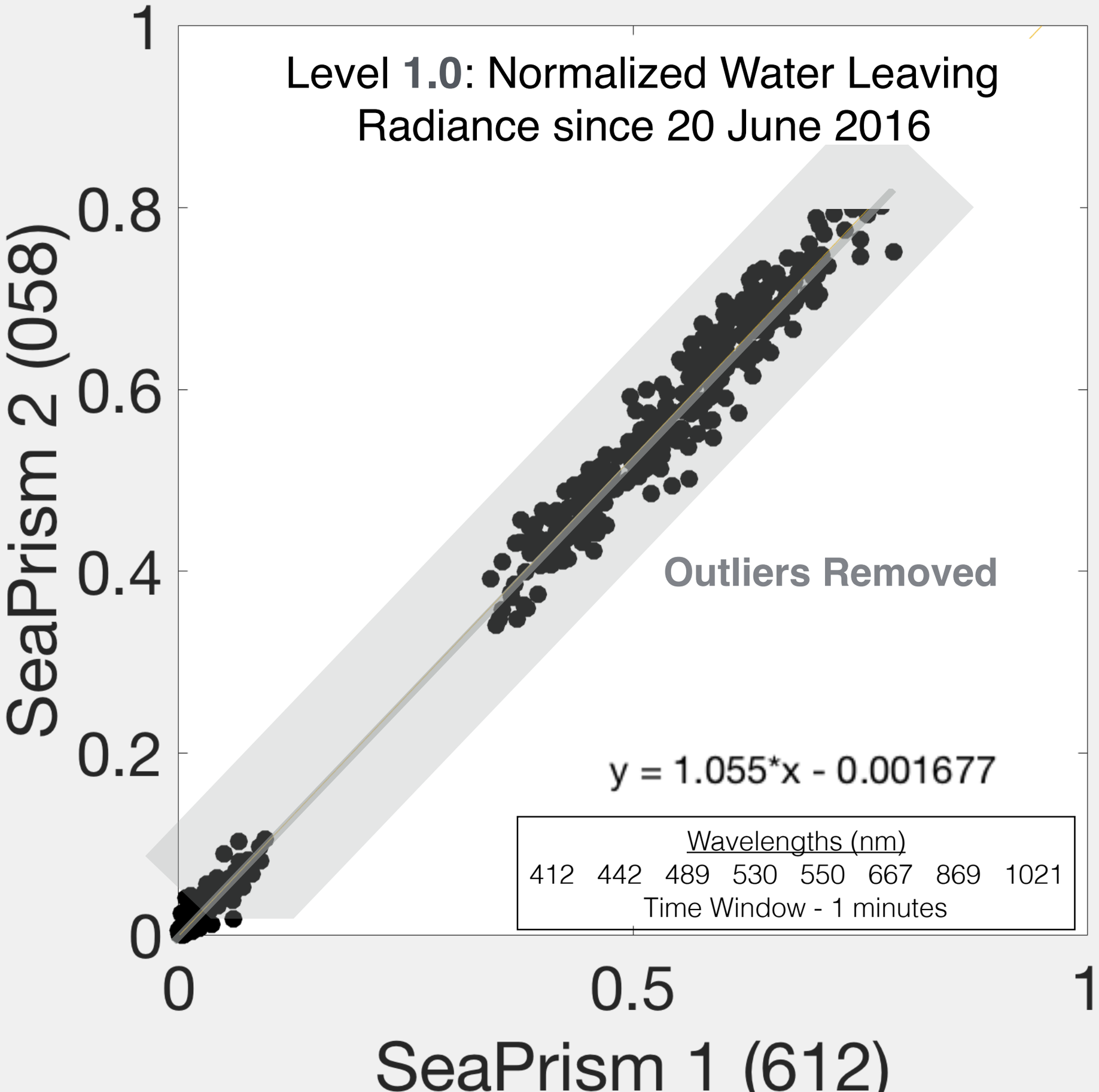
03/08/2016:  Asea value on CIMEL #58 changed from -50 to -90 (per Giuseppe and Mikhail)

04/27/2016: Requested site access to reinstall #612.  Site access rules were changed and new Access Agreement was required

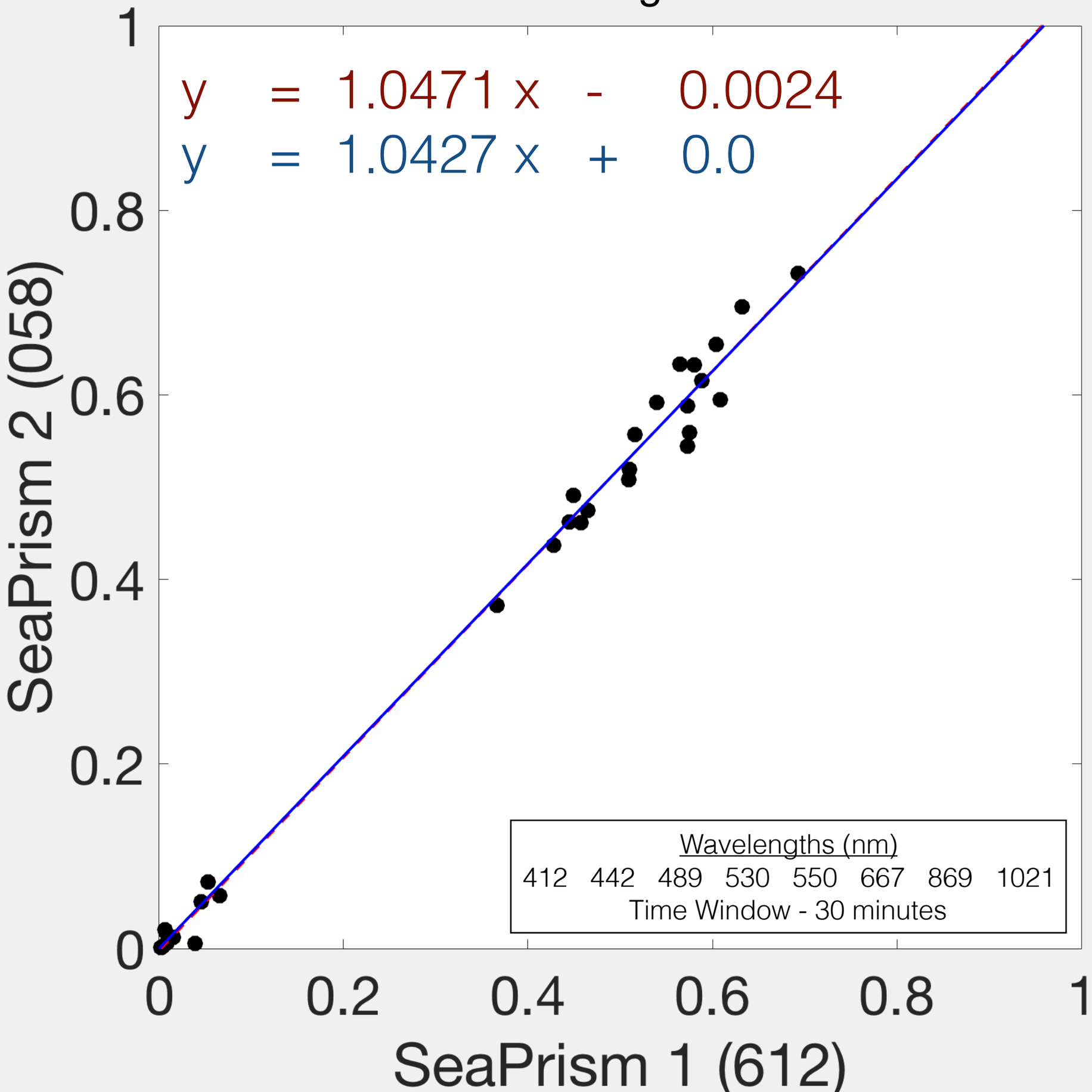
06/20/2016: CIMEL #612 reinstalled after calibration.

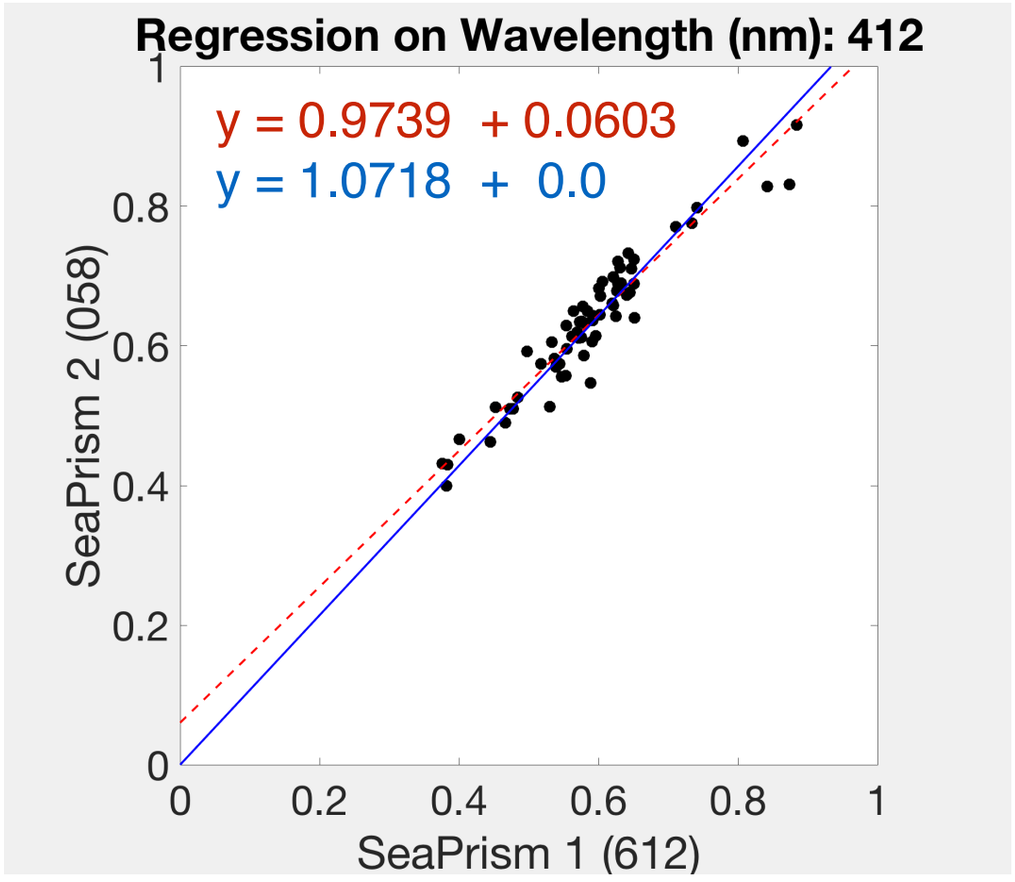
Based on this information, the best dates for side by side comparison are from 06/20/2016.  That is when #612 has updated calibrations and #58 has correct Asea values.

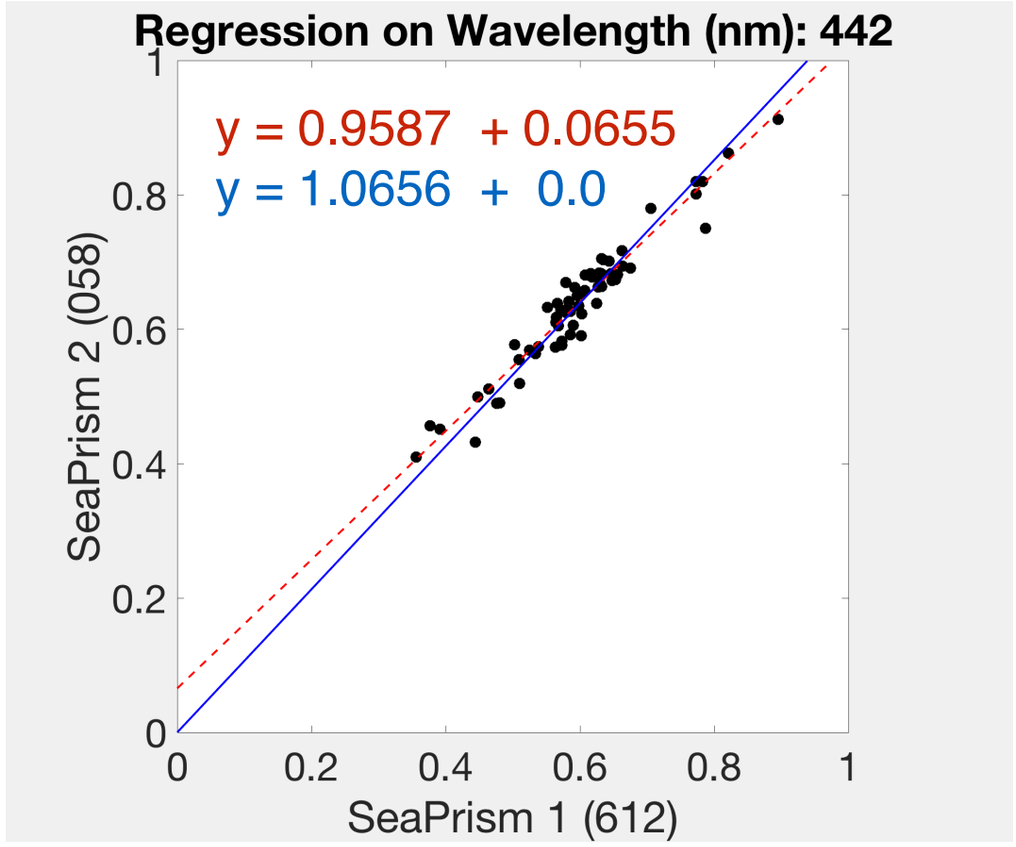

Level 1.5: Normalized Water Leaving Radiance since 20 June 2016
SeaPrism 2 (058)
SeaPrism 1 (612)
0
0.2
0.4
0.6
0.8
1
0
0.5
1
y = 1.047*x - 0.002354
Wavelengths (nm)
412 442 489 530 550 667 869 1021
Time Window - 30 minutes

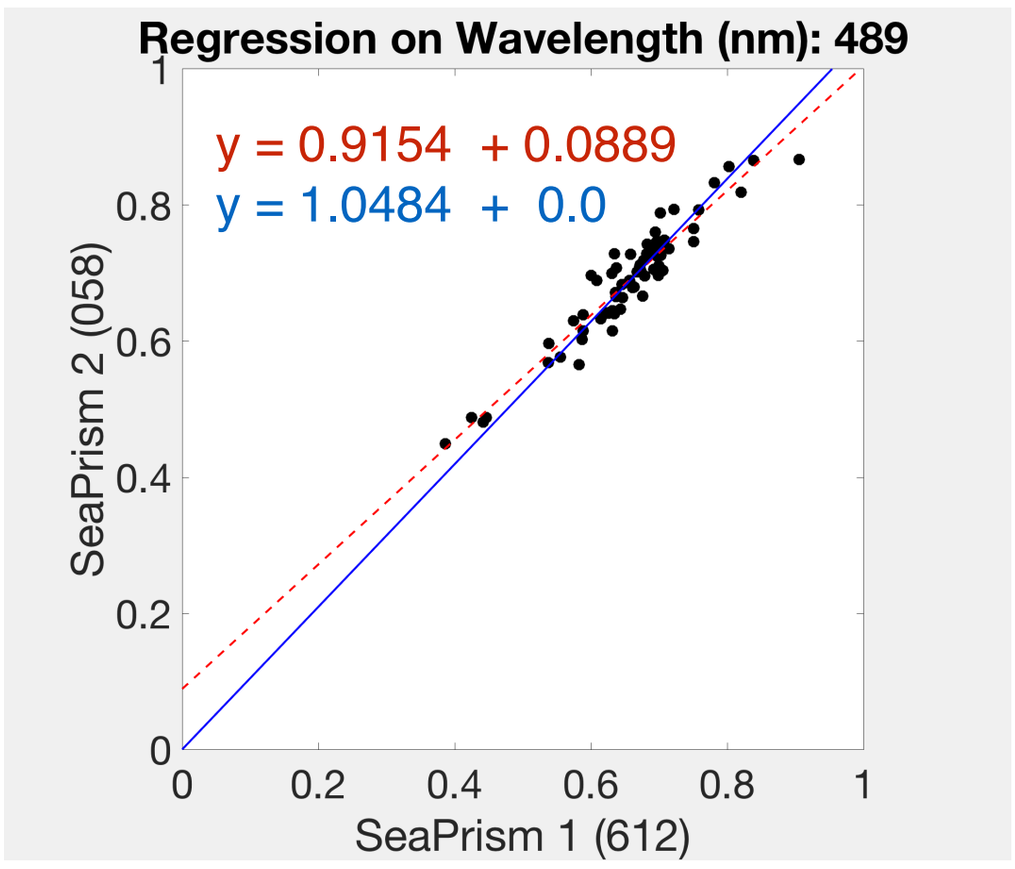

Level 1.0: Normalized Water Leaving Radiance since 20 June 2016
Outliers Removed
y = 1.055*x - 0.001677
Wavelengths (nm)
412 442 489 530 550 667 869 1021
Time Window - 1 minutes
SeaPrism 2 (058)
SeaPrism 1 (612)
0
0.2
0.4
0.6
0.8
1
0
0.5
1

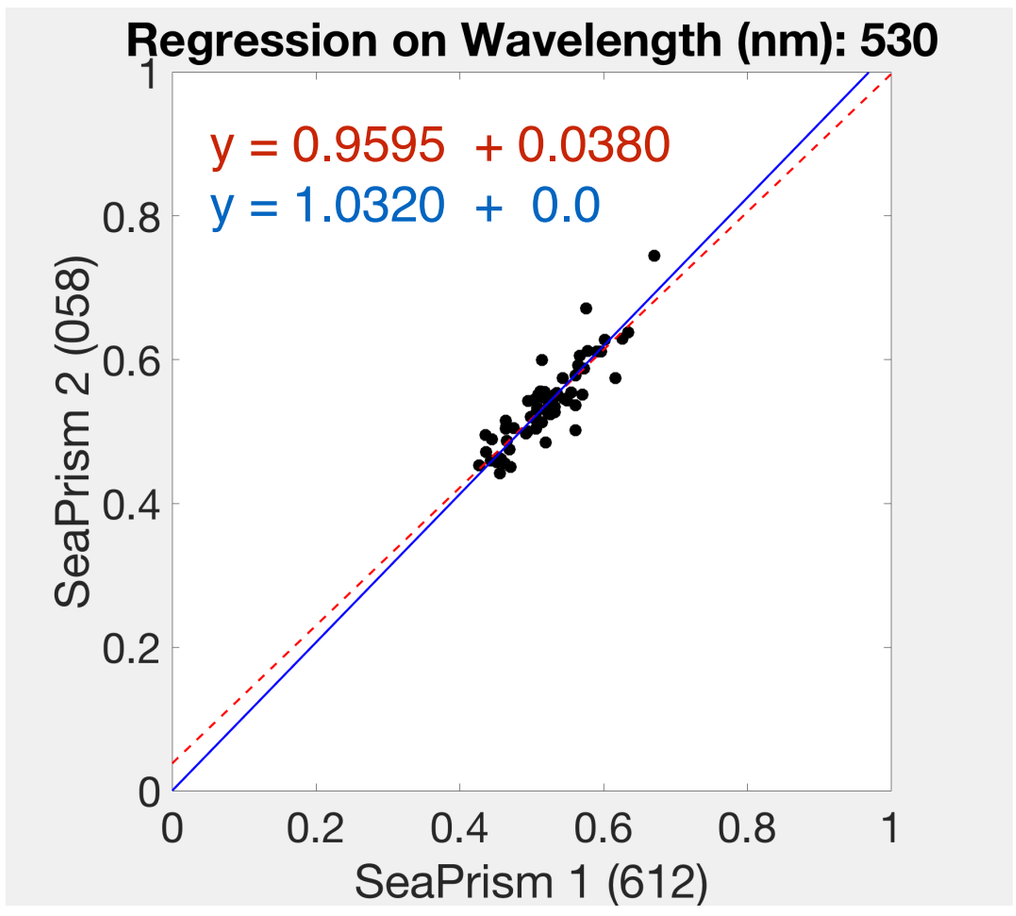
Level 1.5: Normalized Water Leaving Radiance since 20 June 2016

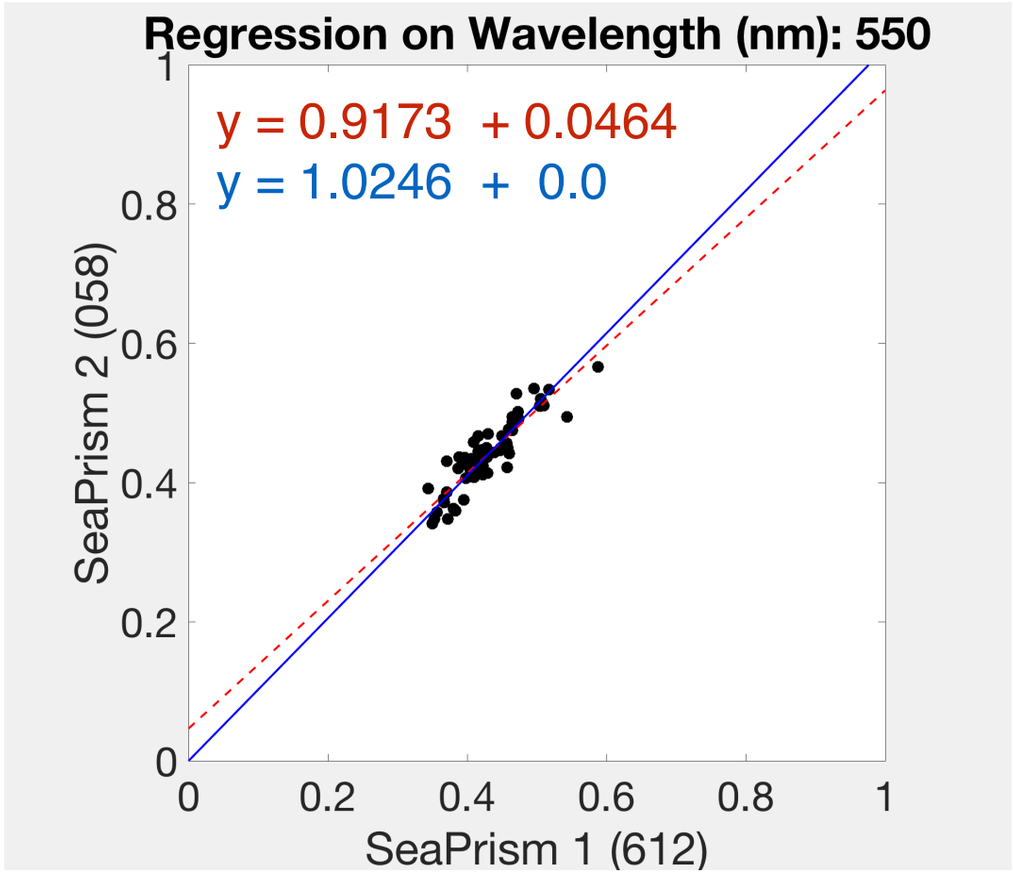


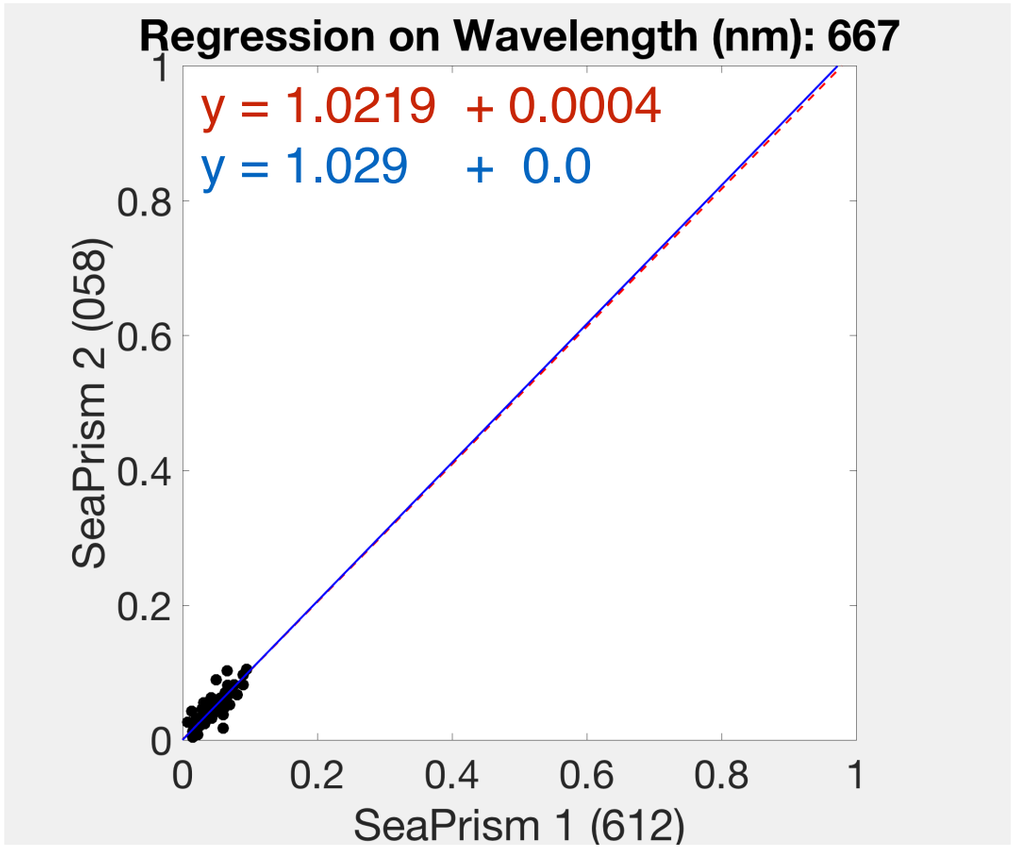

Regression on Wavelength (nm): 412
y = 0.9739 + 0.0603
y = 1.0718 + 0.0
SeaPrism 2 (058)
SeaPrism 1 (612)
0
0.2
0.4
0.6
0.8
1

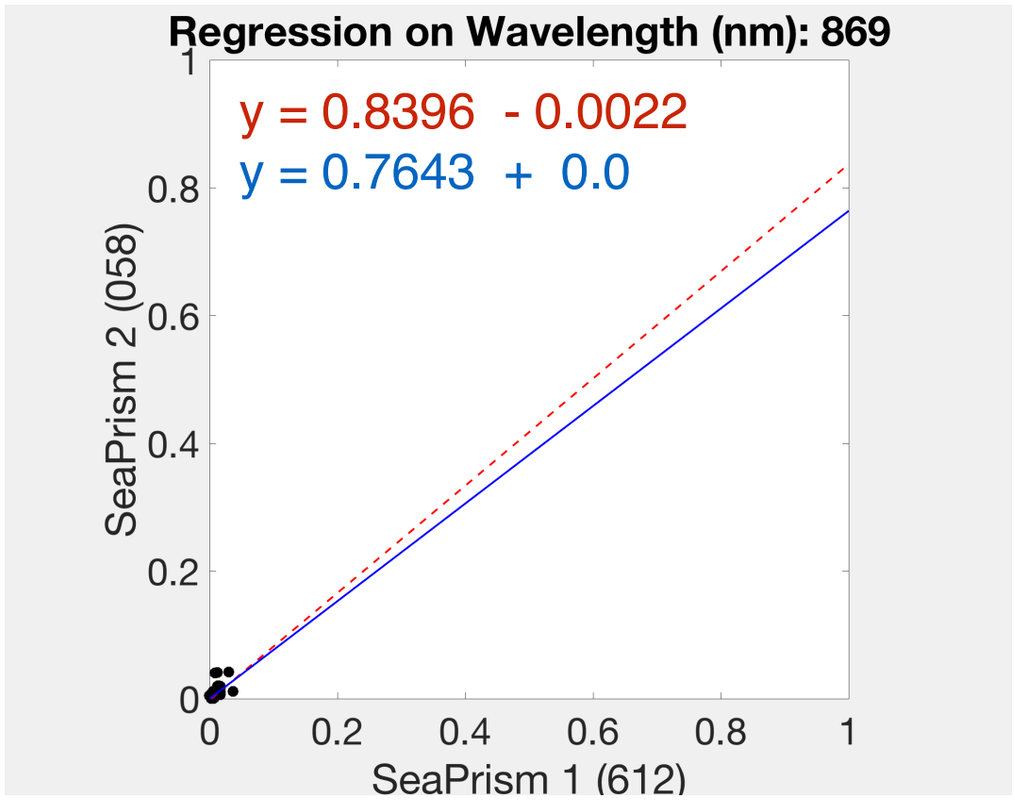

Regression on Wavelength (nm): 442
y = 0.9587 + 0.0655
y = 1.0656 + 0.0
SeaPrism 2 (058)
SeaPrism 1 (612)
0
0.2
0.4
0.6
0.8
1

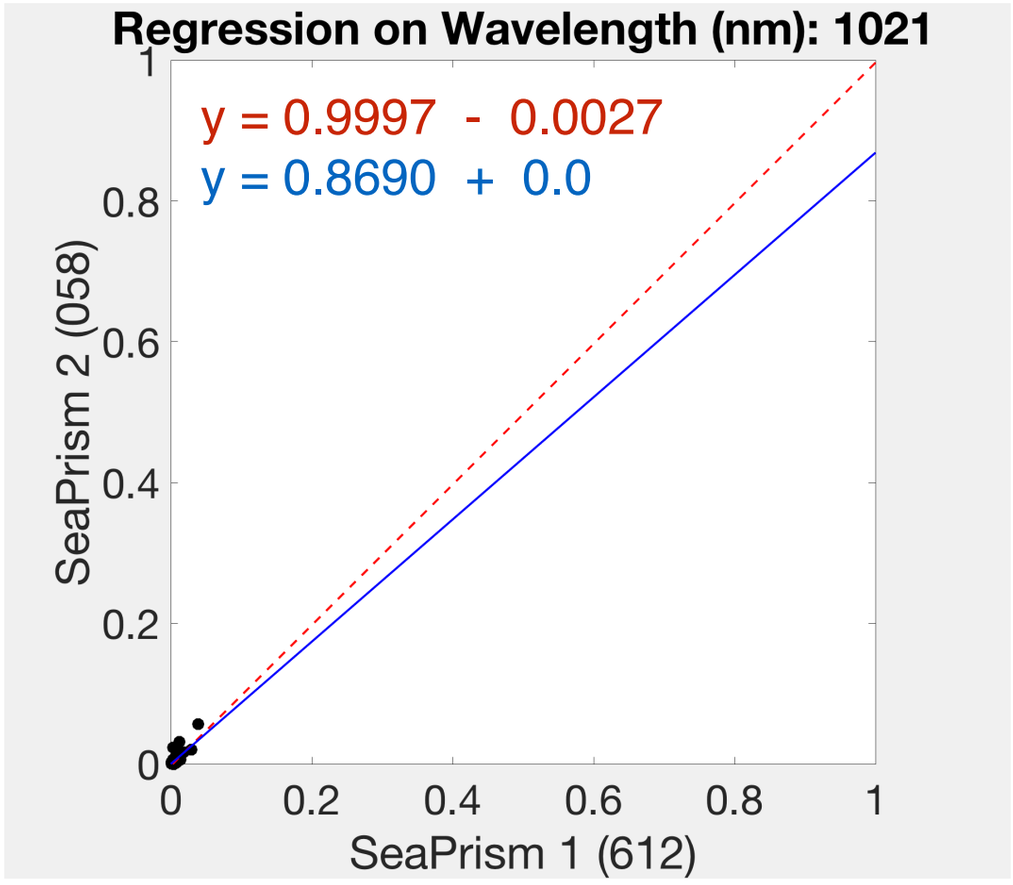

Regression on Wavelength (nm): 489
y = 0.9154 + 0.0889
y = 1.0484 + 0.0
SeaPrism 2 (058)
SeaPrism 1 (612)
0
0.2
0.4
0.6
0.8
1


Regression on Wavelength (nm): 530
y = 0.9595 + 0.0380
y = 1.0320 + 0.0
SeaPrism 2 (058)
SeaPrism 1 (612)
0
0.2
0.4
0.6
0.8
1

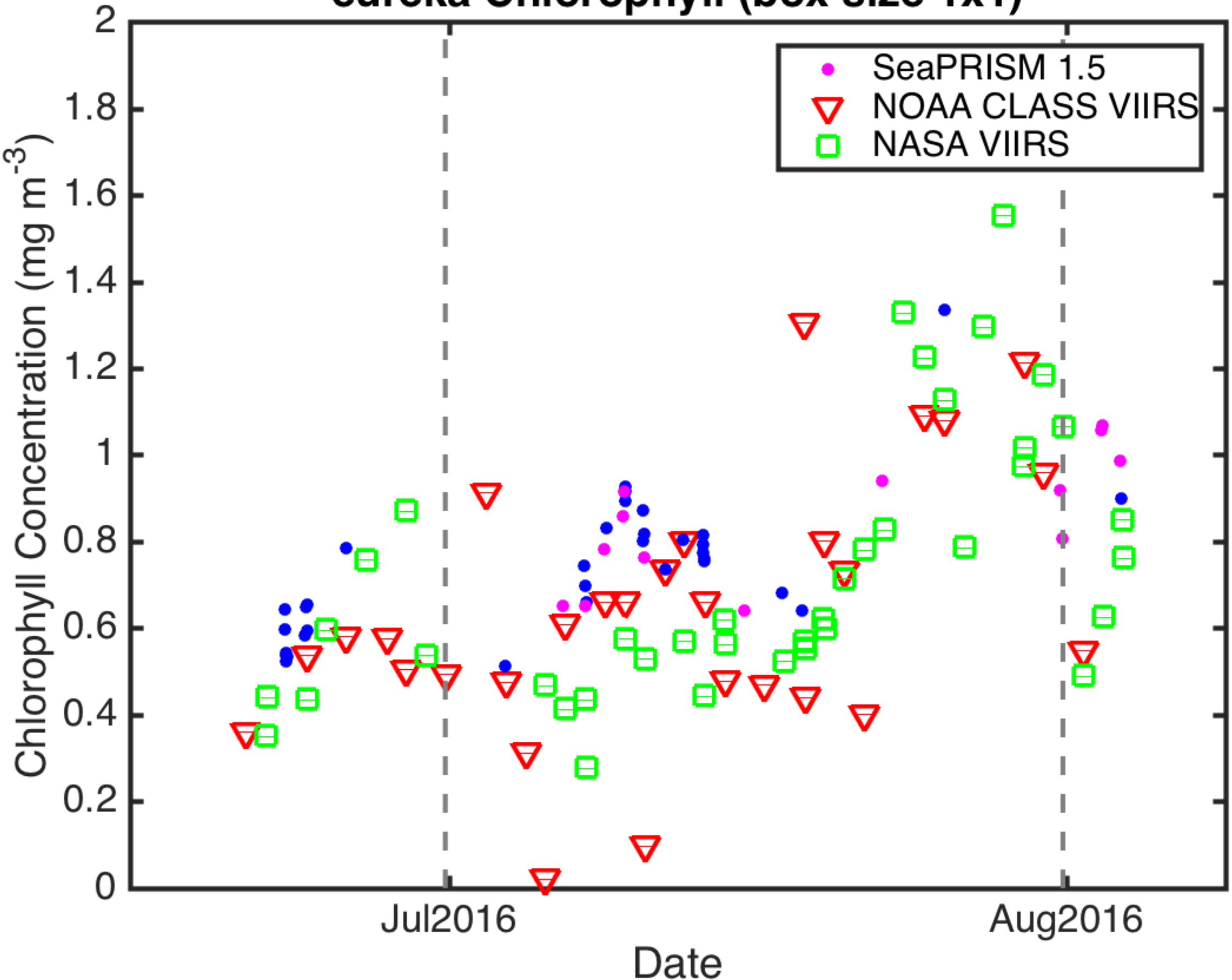

Regression on Wavelength (nm): 550
y = 0.9173 + 0.0464
y = 1.0246 + 0.0
SeaPrism 2 (058)
SeaPrism 1 (612)
0
0.2
0.4
0.6
0.8
1


Regression on Wavelength (nm): 667
y = 1.0219 + 0.0004
y = 1.029 + 0.0
SeaPrism 2 (058)
SeaPrism 1 (612)
0
0.2
0.4
0.6
0.8
1


Regression on Wavelength (nm): 869
y = 0.8396 - 0.0022
y = 0.7643 + 0.0
SeaPrism 2 (058)
SeaPrism 1 (612)
0
0.2
0.4
0.6
0.8
1


Regression on Wavelength (nm): 1021
y = 0.9997 - 0.0027
y = 0.8690 + 0.0
SeaPrism 2 (058)
SeaPrism 1 (612)
0
0.2
0.4
0.6
0.8
1

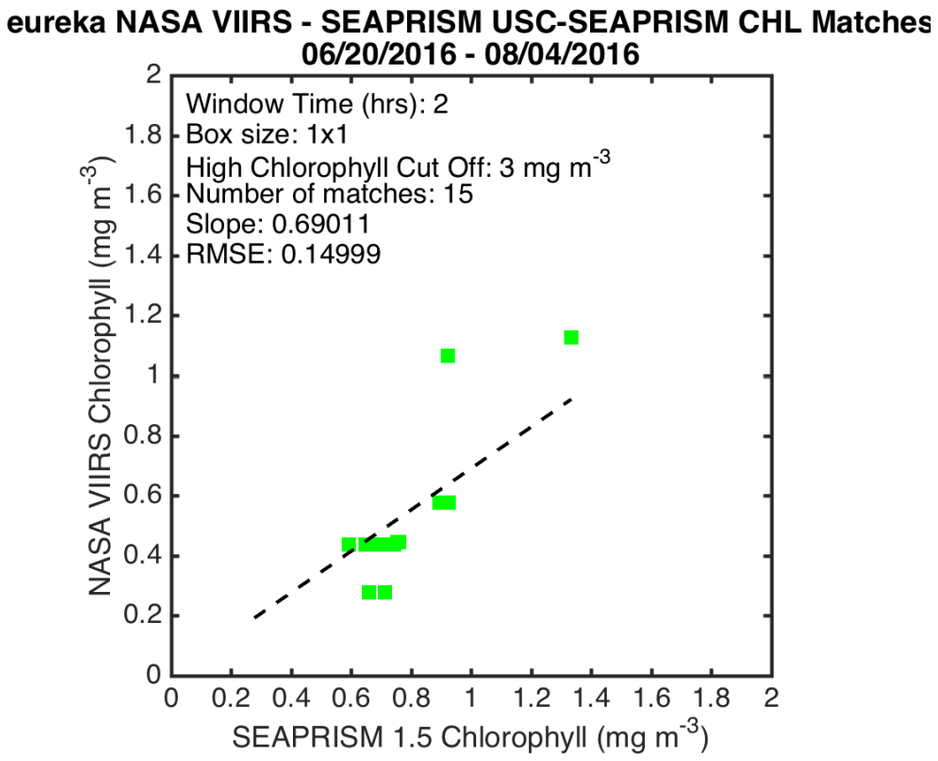
# eureka Chlorophyll (box size 1x1)

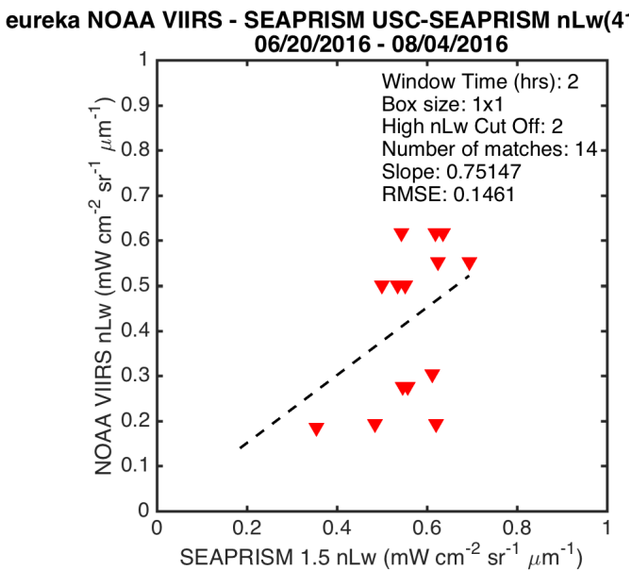


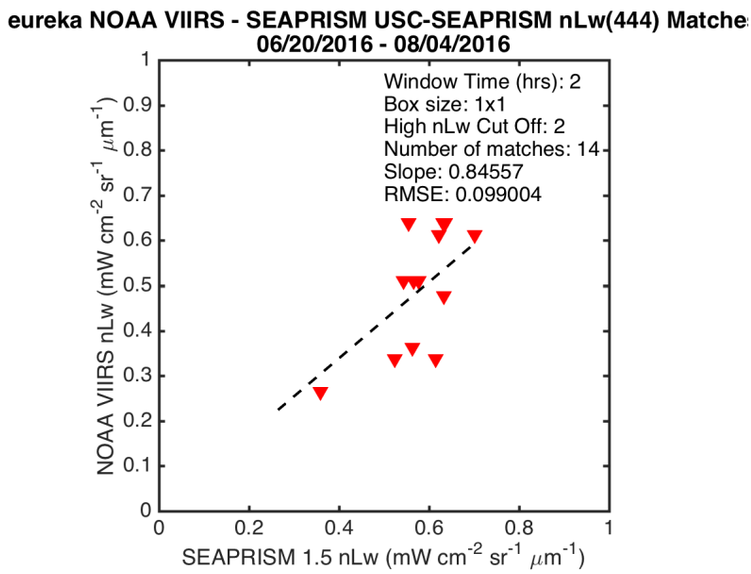
# NOAA VIIRS nLw < SEAPRISM nLw

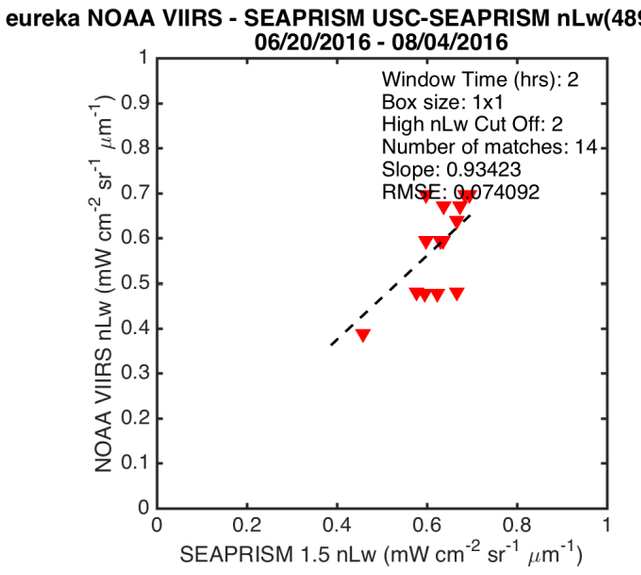
| nLw | CHL-a | 412 | 444 | 489 | 550 |
|---|---|---|---|---|---|
| Slope | 0.69 | 0.75 | 0.85 | 0.93 | 0.83 |

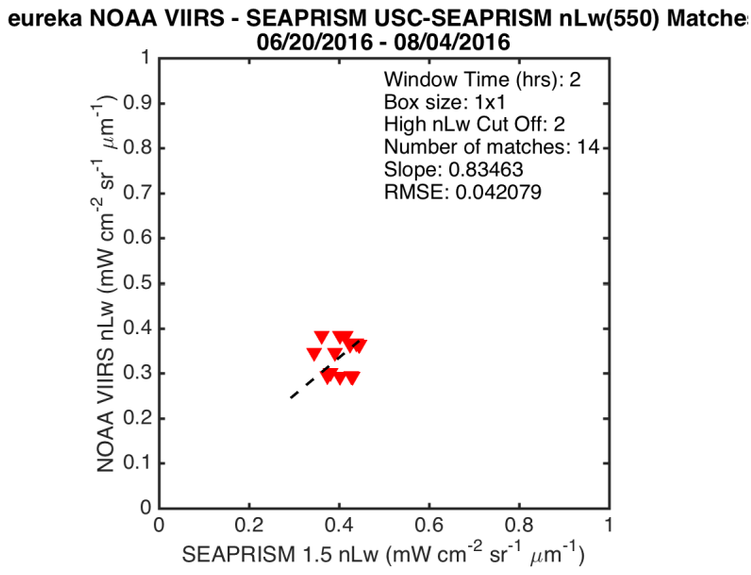
20 June - 4 August 2016, 1x1, approx 14 matches



Comments:

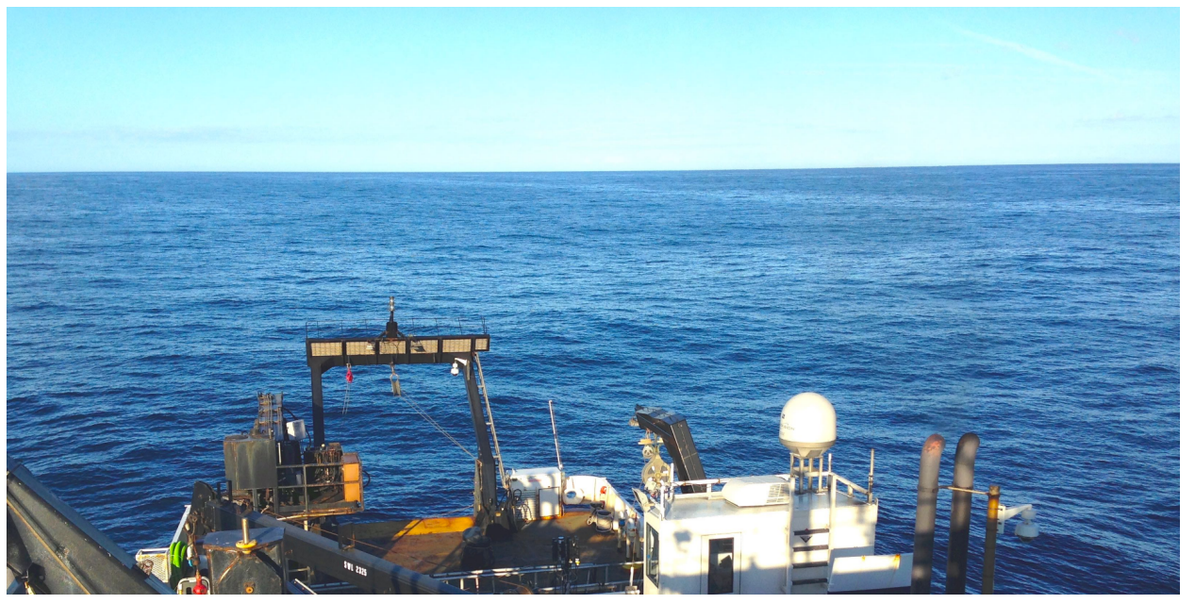
SeaPRISM discripencies at Platform Eureka are resolved since 20 June 2016.

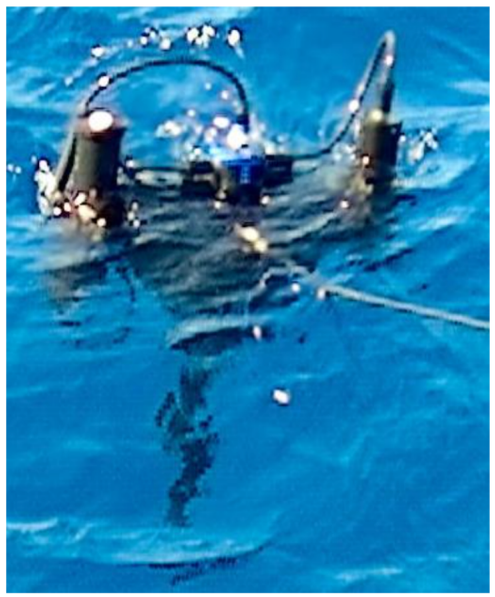
With a bit more L1.5 SeaPRISM data, will track/analyze any systemtic discripencies with NOAA STAR MSL12 and NASA Ocean Color Products.

State of reprocessing old SeaPrism pre June 2016 Platform Eureka SeaPRISM data (both NOAA STAR & NASA)?

# December 2015 NOAA Nancy Foster Cruise Measurements

## HyperPro Measurements







## Spectral Evolution Measurements

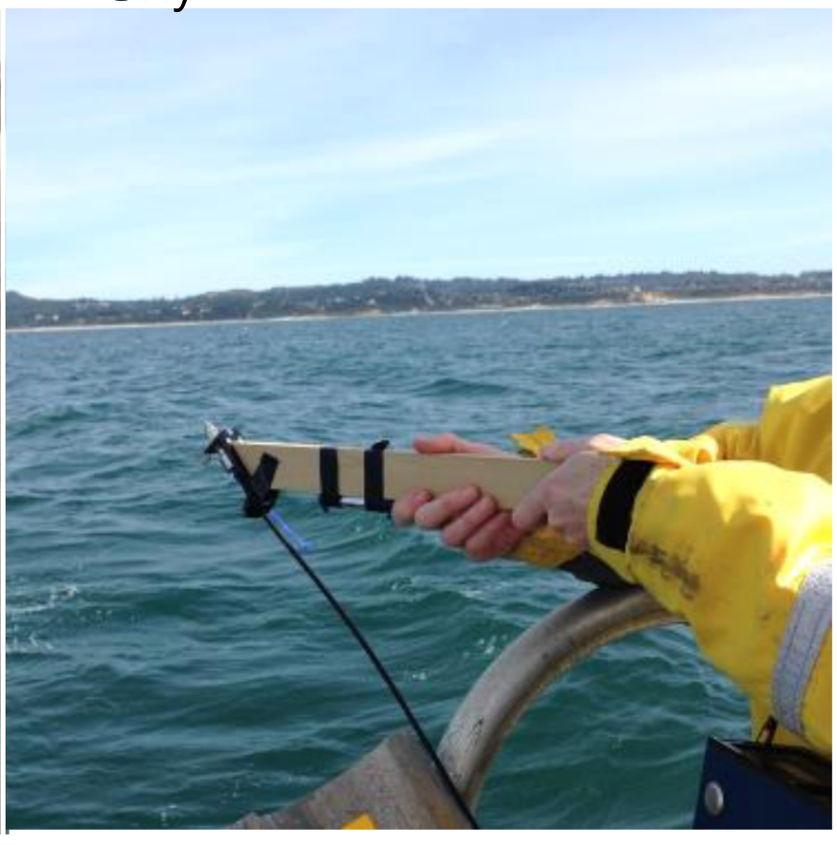
Reference



Water



Sky



Spectral Evolution and HyperPRO matches shadded.

| Day | Sta | Time | Lat | Lon | ~Time_Diff | Match |
|---|---|---|---|---|---|---|
| 339 | V | 1848 | | | | |
| | **6** | **1800** | **24.42319** | **-77.32309** | **-50** | **x** |
| | 7 | 2100 | 24.38379 | -77.28607 | 130 | |
| 340 | V | 1829 | | | | |
| | **8** | **1830** | **23.66923** | **-76.58686** | **1** | **x** |
| | 9 | 2030 | 23.67043 | -76.59076 | 120 | |
| 341 | | | | | | |
| 342 | V | 1754 | | | | |
| | **12** | **1930** | **28.72759** | **-80.43781** | **95** | **x** |
| 343 | V | 1916 | | | | |
| | 13 | 1440 | 30.72109 | -80.53379 | -275 | |
| | 14 | 1800 | 30.92241 | -80.60434 | -75 | |
| | **15** | **1930** | **30.98747** | **-80.53848** | **15** | **x** |
| 344 | V | 1857 | | | | |
| | 16 | 1440 | 31.15840 | -77.675208 | -260 | |
| | 17 | 1745 | 31.16818 | -77.734846 | -95 | |
| | **18** | **1920** | **31.07281** | **-77.53271** | **20** | **x** |
| 345 | V | 1838 | | | | |
| | 19 | 1345 | 32.22296 | | -260 | |
| | 20 | 1630 | 32.49639 | -77.854955 | -125 | |
| | **21** | **1900** | **32.63534** | **-77.424925** | **20** | **x** |
| | 22 | 2100 | | | 200 | |
| 346 | V | 1819 | | | | |
| | 23 | 1420 | 33.10018 | -78.247406 | -220 | |
| | **24** | **1730** | **33.24041** | **-78.006083** | **-45** | **x** |
| | 25 | 1945 | 33.07888 | -78.211748 | 85 | |
| 347 | V | 1800 | | | | |
| | 26 | 1516 | 32.16127 | -79.316675 | -165 | |
| | **27** | **1820** | **32.19267** | **-79.093385** | **20** | **x** |

VIIRS and HyperPRO matches marked by ‘x’

VIIRS NOAA STAR MSL12
ftp://ftp.star.nesdis.noaa.gov/pub/socd/mecb/color/VIIRS_for_Mike/req_20160107/

Spectral Evolution Automate Processing from Radiance to Rrs

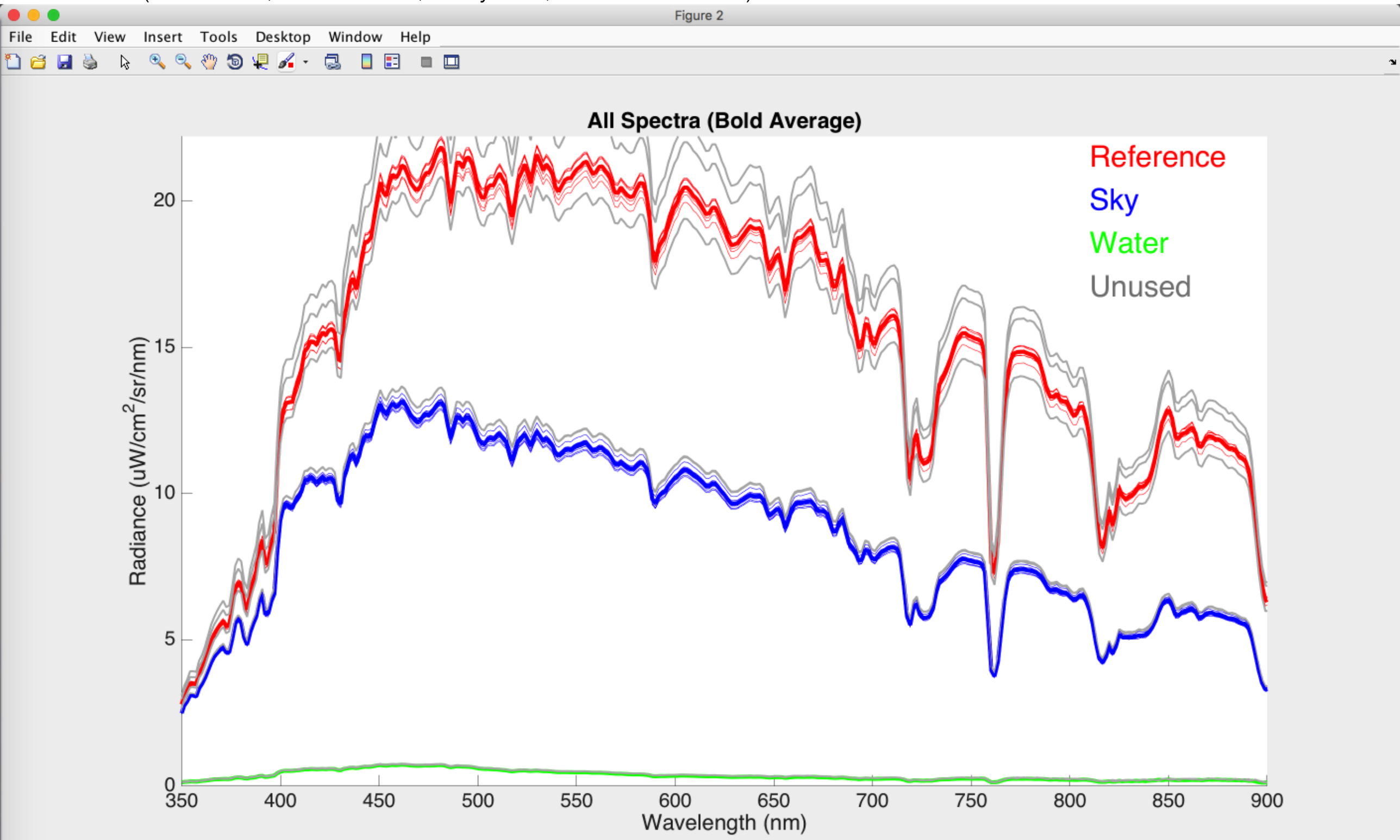
**Settings:** NOAA Cruise Station 6

Year = 2015 Month = 12 Day = 05 Hour = 17 Minute = 35 Seconds = 0

Lat = 24.4867 Lon = -77.3204 Alt = 0 Wind_Speed = 3

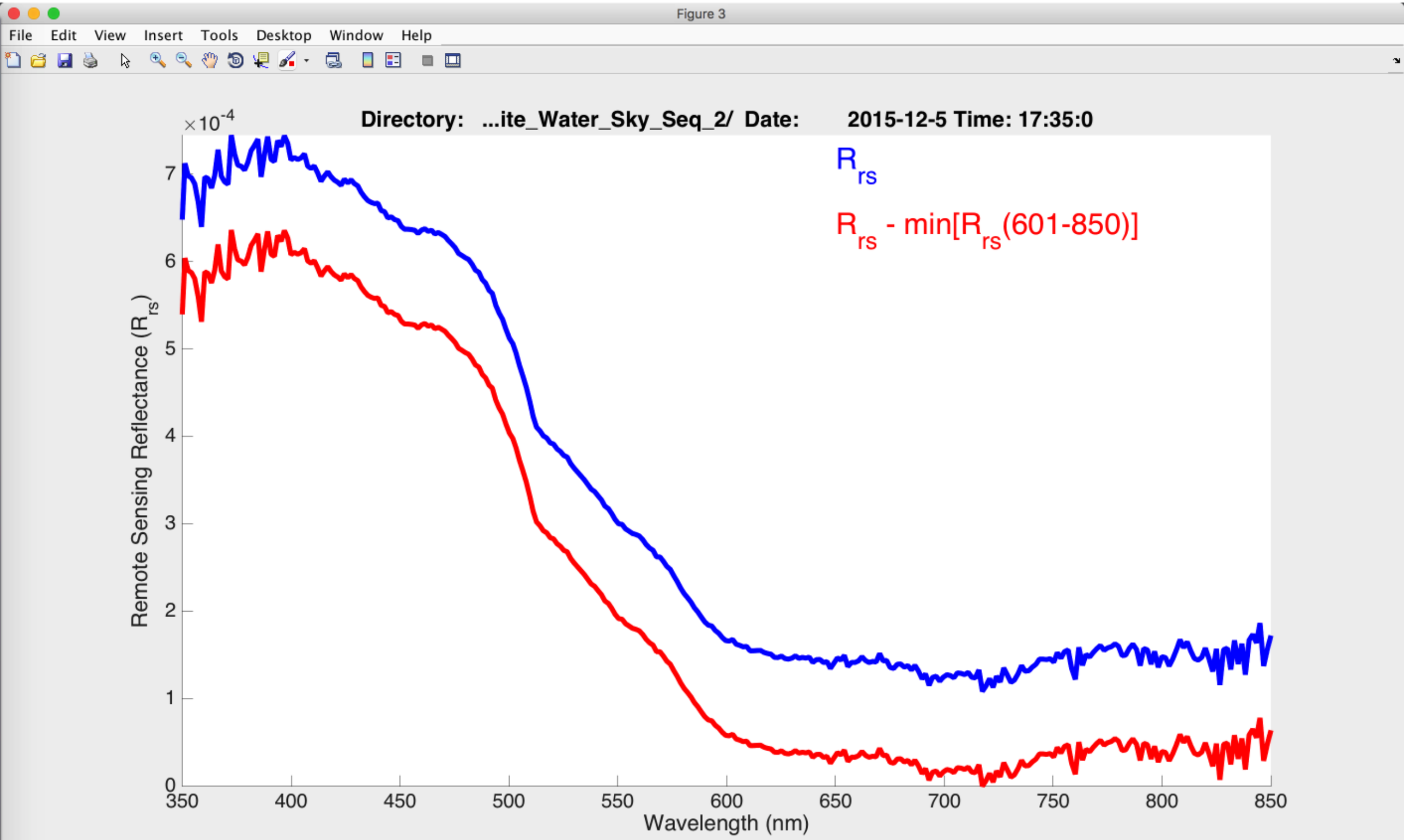
Sigma_Water = 2 Sigma Sky = 1.5 Sigma_Reference = 1

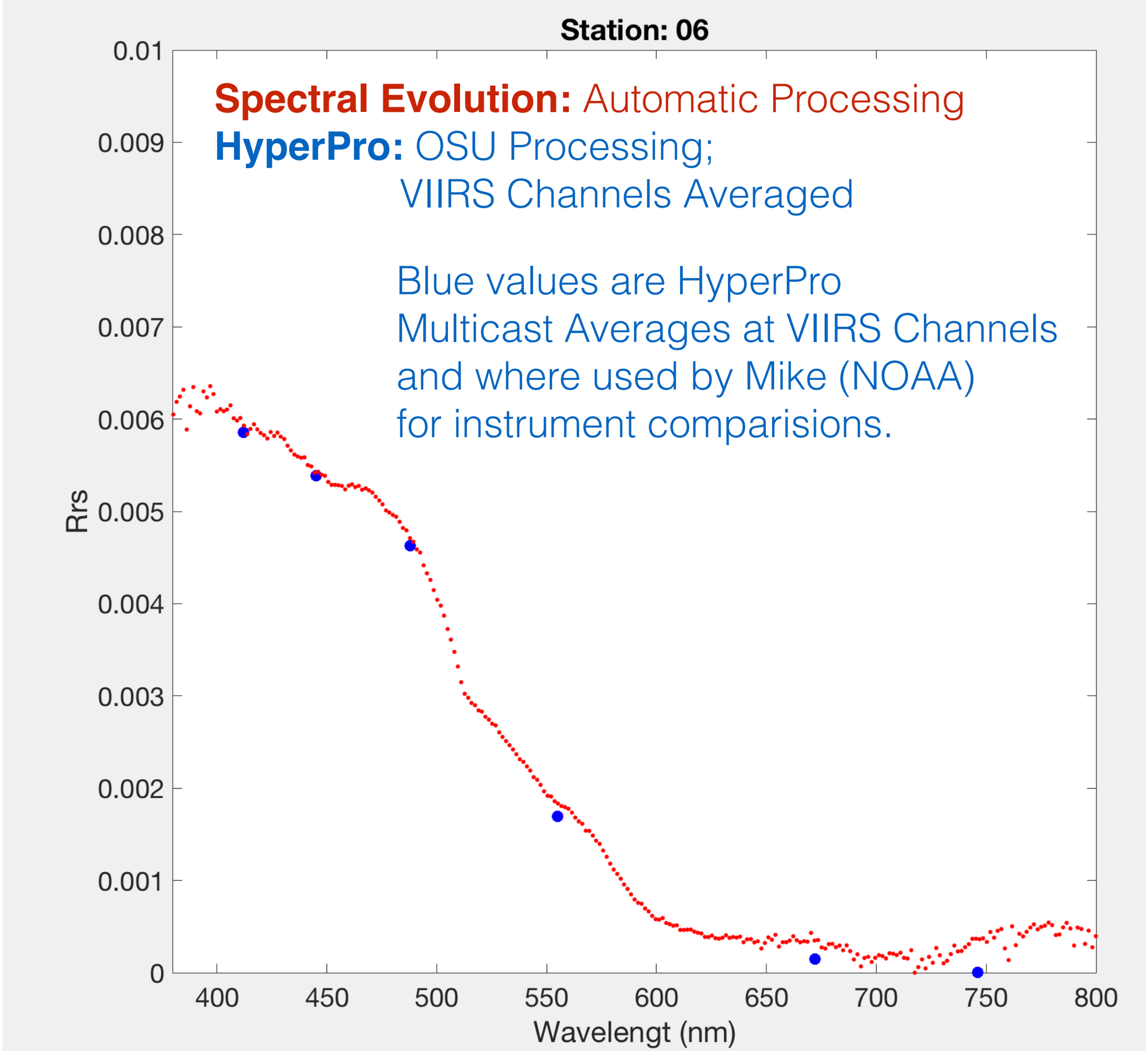
Scale = 3 (0 Fixed-30; 1 Water Max; 2 Sky Max; 3 Reference Max)

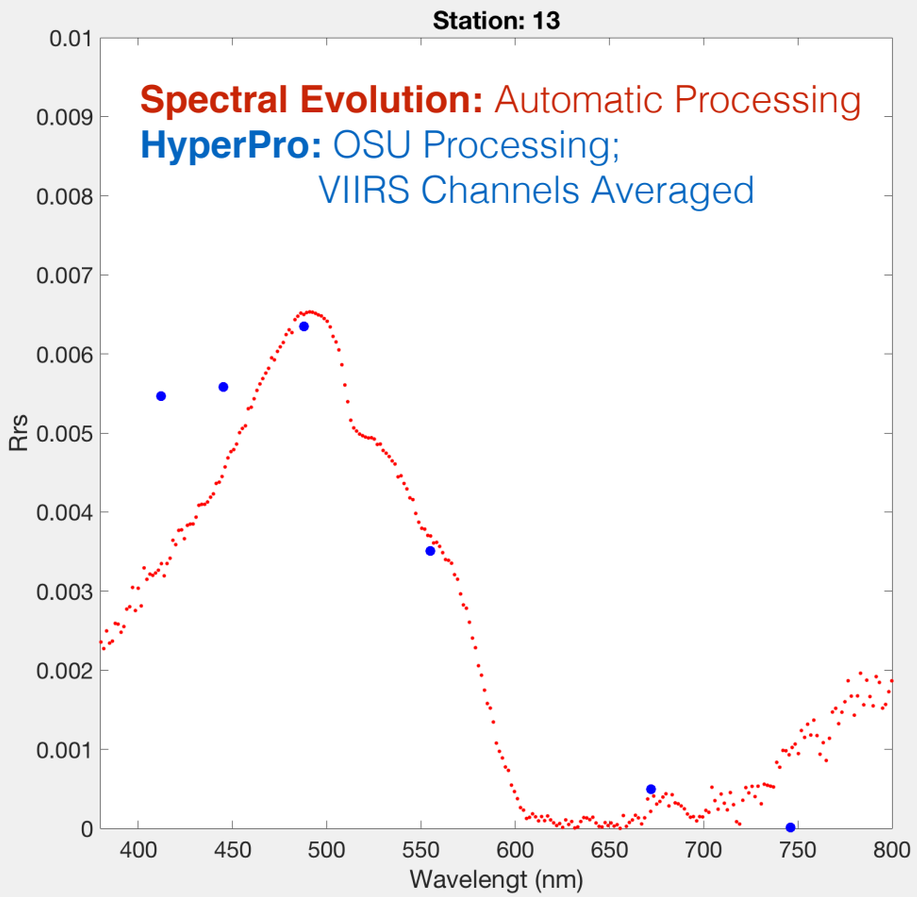


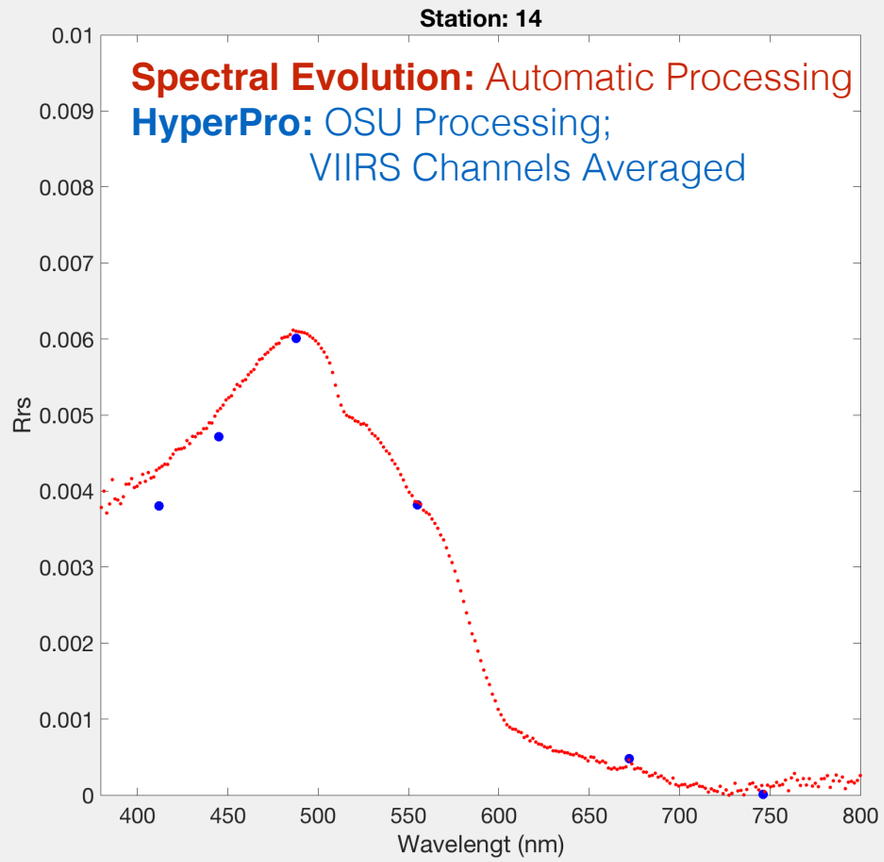
# Red Adjustment  for Rrs

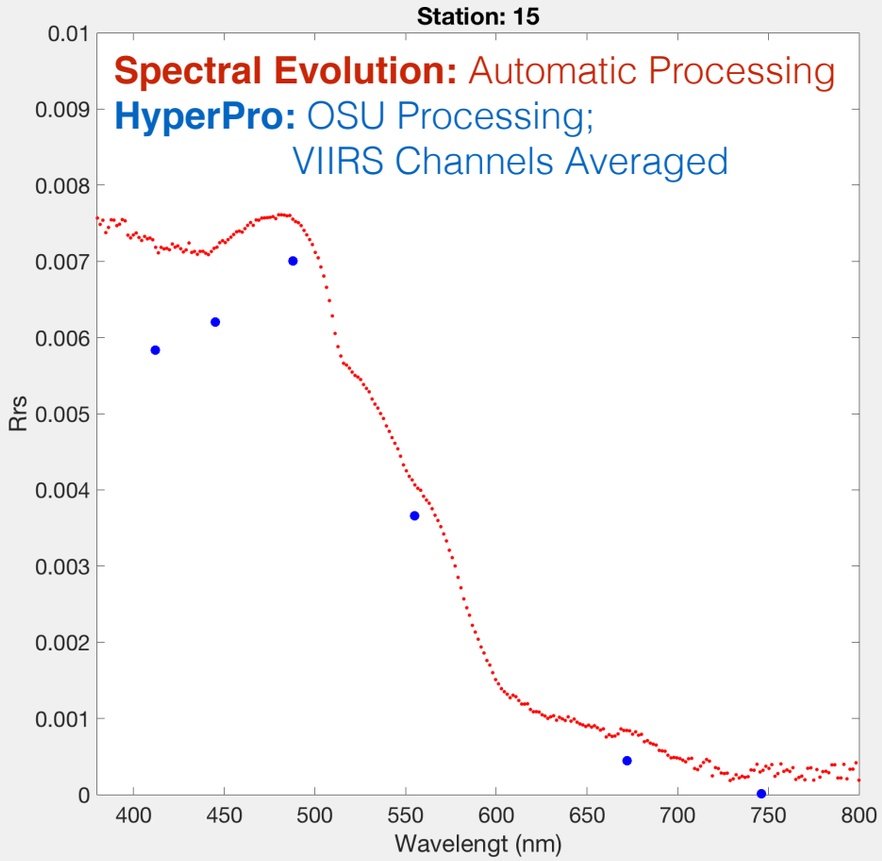
## NOAA Cruise Station 6

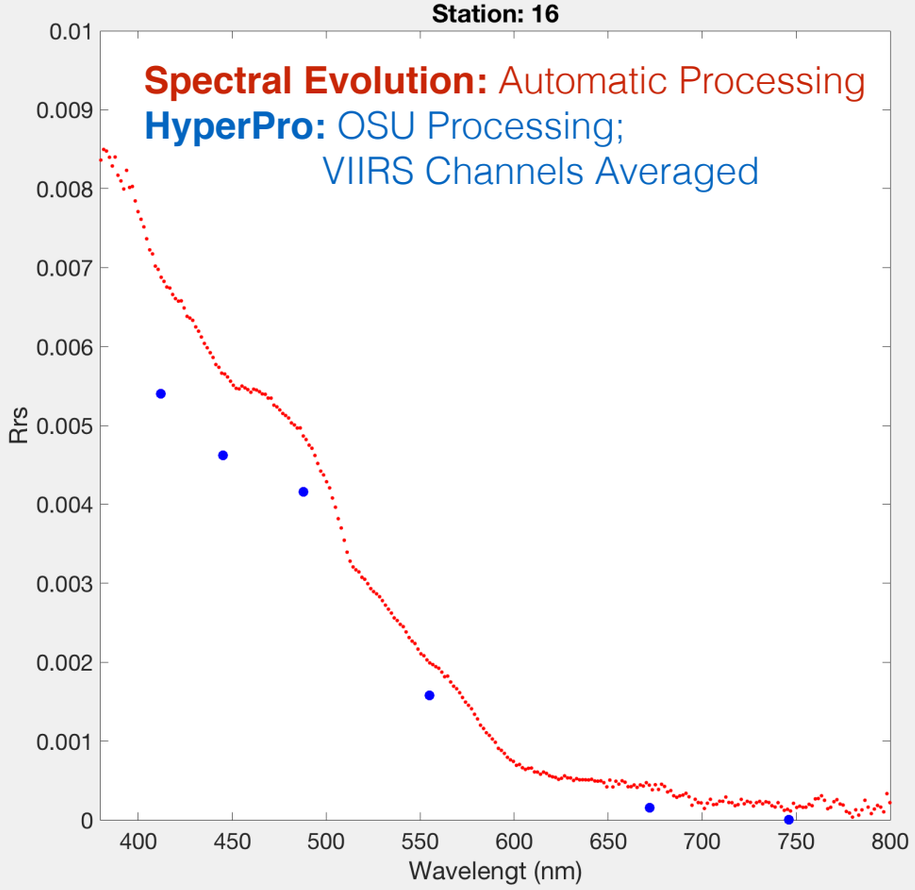


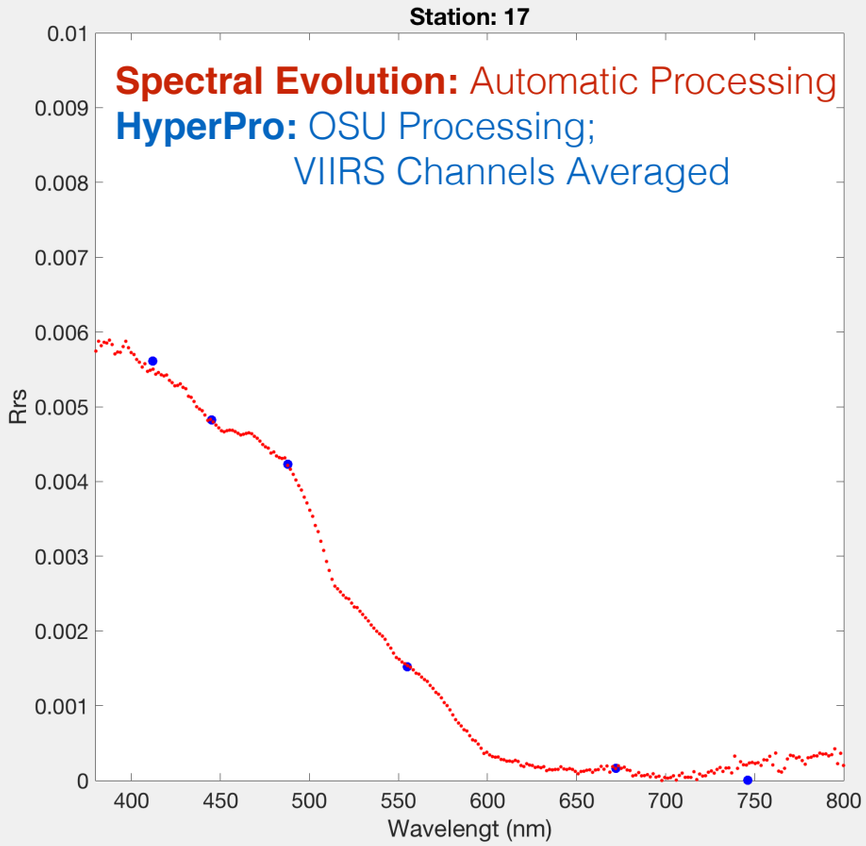

Station: 06
Spectral Evolution: Automatic Processing
HyperPro: OSU Processing;
VIIRS Channels Averaged
Blue values are HyperPro
Multicast Averages at VIIRS Channels
and where used by Mike (NOAA)
for instrument comparisions.
Rrs
0.01
0.009
0.008
0.007
0.006
0.005
0.004
0.003
0.002
0.001
0
400
450
500
550
600
650
700
750
800
Wavelengt (nm)

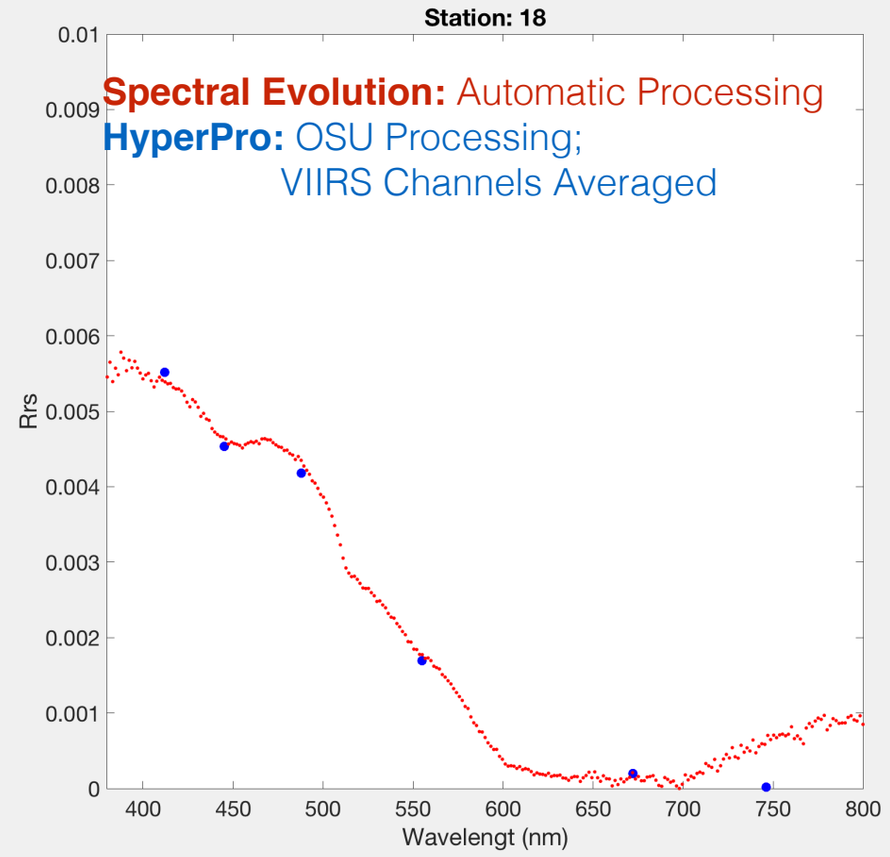

Station: 13
Spectral Evolution: Automatic Processing
HyperPro: OSU Processing;
VIIRS Channels Averaged
Rrs
Wavelengt (nm)
0.01
0.009
0.008
0.007
0.006
0.005
0.004
0.003
0.002
0.001
0
400
450
500
550
600
650
700
750
800

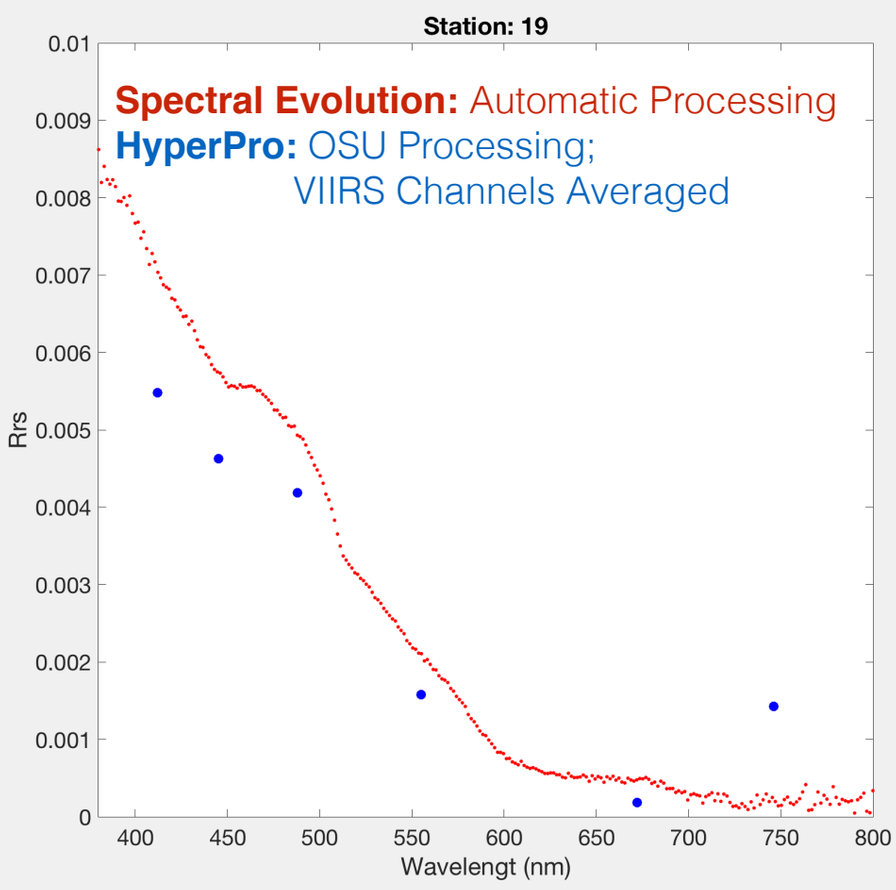

Station: 14
Spectral Evolution: Automatic Processing
HyperPro: OSU Processing;
VIIRS Channels Averaged
Rrs
Wavelengt (nm)
0.01
0.009
0.008
0.007
0.006
0.005
0.004
0.003
0.002
0.001
0
400
450
500
550
600
650
700
750
800

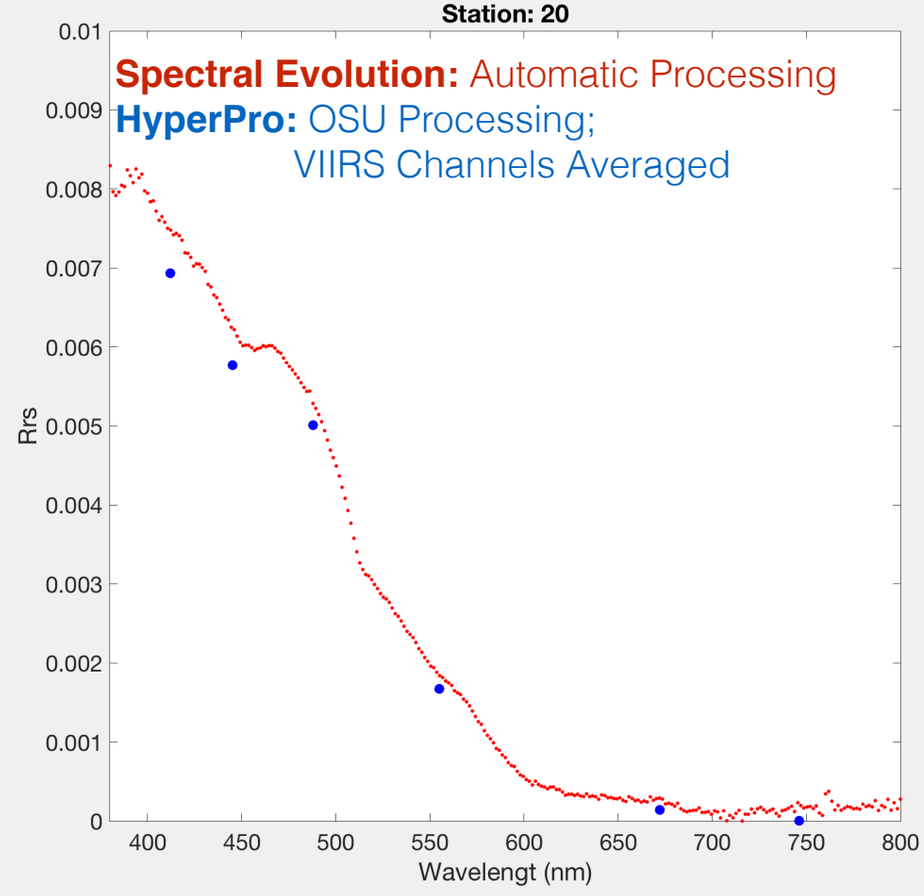

Station: 15
Spectral Evolution: Automatic Processing
HyperPro: OSU Processing;
VIIRS Channels Averaged
Rrs
Wavelengt (nm)
0.01
0.009
0.008
0.007
0.006
0.005
0.004
0.003
0.002
0.001
0
400
450
500
550
600
650
700
750
800

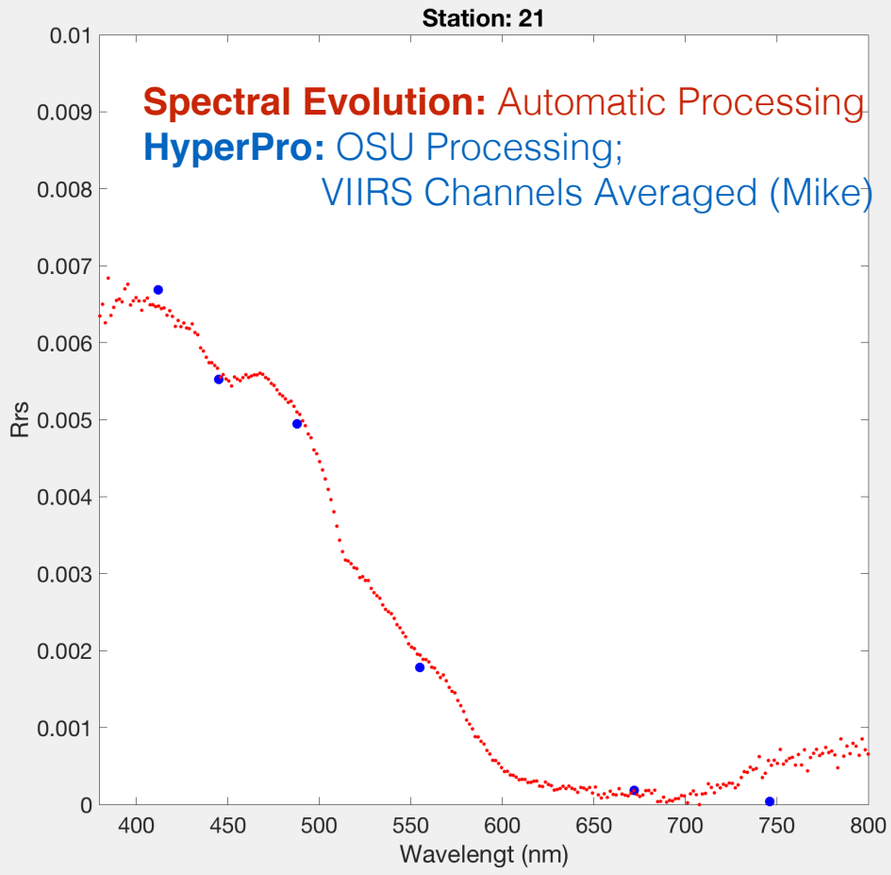

Station: 16
Spectral Evolution: Automatic Processing
HyperPro: OSU Processing;
VIIRS Channels Averaged
Rrs
Wavelengt (nm)
0.01
0.009
0.008
0.007
0.006
0.005
0.004
0.003
0.002
0.001
0
400
450
500
550
600
650
700
750
800

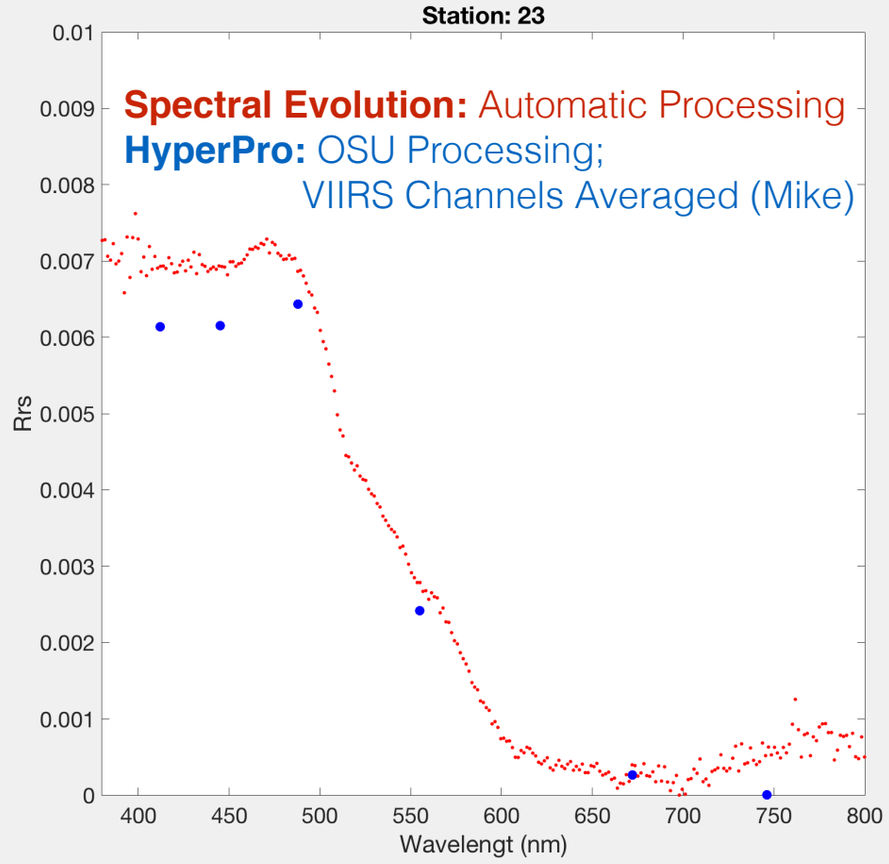

Station: 17
Spectral Evolution: Automatic Processing
HyperPro: OSU Processing;
VIIRS Channels Averaged
Rrs
Wavelengt (nm)
0.01
0.009
0.008
0.007
0.006
0.005
0.004
0.003
0.002
0.001
0
400
450
500
550
600
650
700
750
800

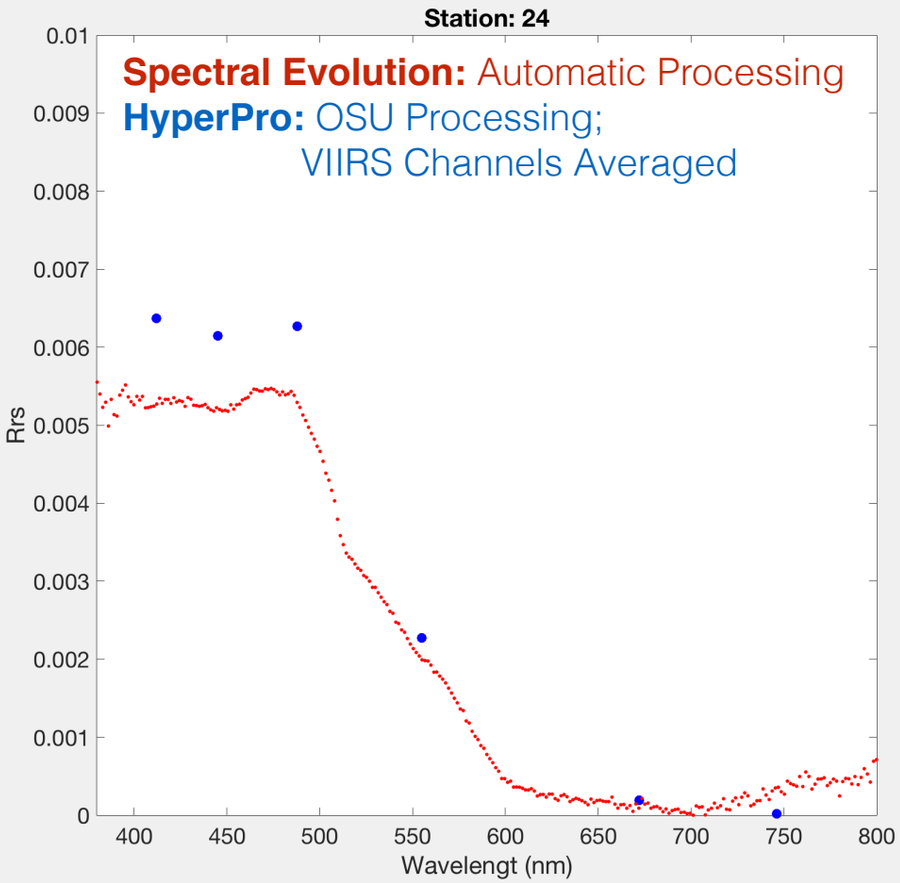

Station: 18
Spectral Evolution: Automatic Processing
HyperPro: OSU Processing;
VIIRS Channels Averaged
Rrs
Wavelengt (nm)
0.01
0.009
0.008
0.007
0.006
0.005
0.004
0.003
0.002
0.001
0
400
450
500
550
600
650
700
750
800

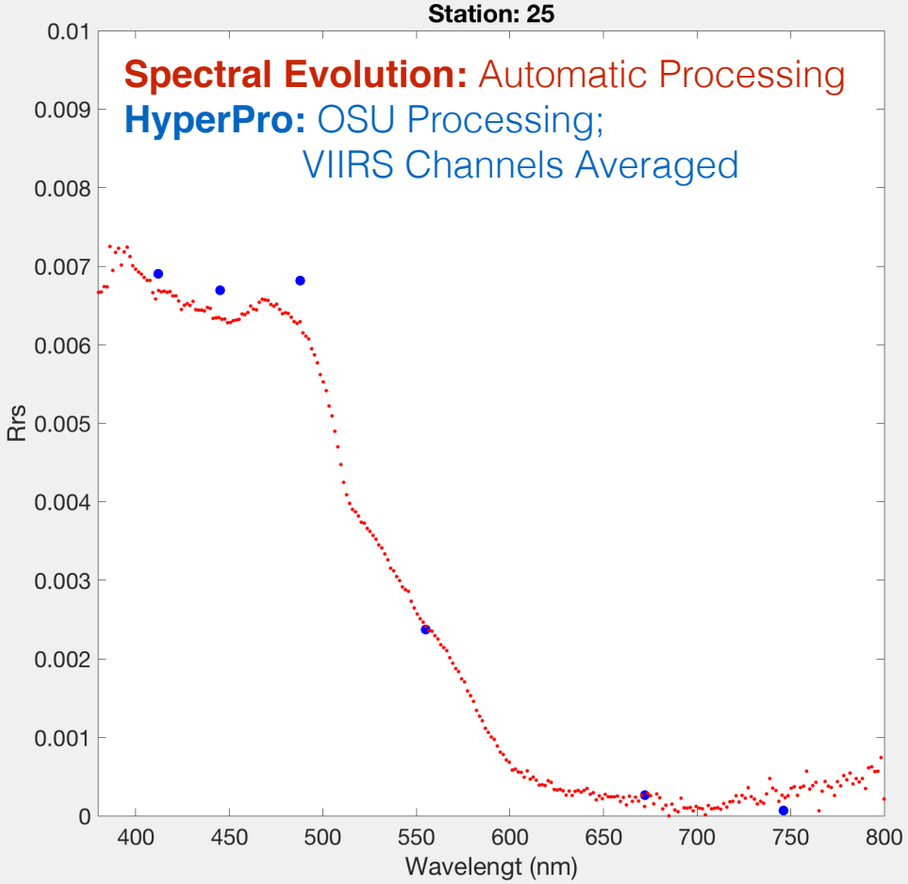

Station: 19
Spectral Evolution: Automatic Processing
HyperPro: OSU Processing;
VIIRS Channels Averaged
Rrs
Wavelengt (nm)
0.01
0.009
0.008
0.007
0.006
0.005
0.004
0.003
0.002
0.001
0
400
450
500
550
600
650
700
750
800


Station: 20
Spectral Evolution: Automatic Processing
HyperPro: OSU Processing;
VIIRS Channels Averaged
Rrs
Wavelengt (nm)
0.01
0.009
0.008
0.007
0.006
0.005
0.004
0.003
0.002
0.001
0
400
450
500
550
600
650
700
750
800


Station: 21
Spectral Evolution: Automatic Processing
HyperPro: OSU Processing;
VIIRS Channels Averaged (Mike)
Rrs
Wavelengt (nm)
0.01
0.009
0.008
0.007
0.006
0.005
0.004
0.003
0.002
0.001
0
400
450
500
550
600
650
700
750
800


Station: 23
Spectral Evolution: Automatic Processing
HyperPro: OSU Processing;
VIIRS Channels Averaged (Mike)
Rrs
Wavelengt (nm)
0.01
0.009
0.008
0.007
0.006
0.005
0.004
0.003
0.002
0.001
0
400
450
500
550
600
650
700
750
800


Station: 24
Spectral Evolution: Automatic Processing
HyperPro: OSU Processing;
VIIRS Channels Averaged
Rrs
Wavelengt (nm)
0.01
0.009
0.008
0.007
0.006
0.005
0.004
0.003
0.002
0.001
0
400
450
500
550
600
650
700
750
800


Station: 25
Spectral Evolution: Automatic Processing
HyperPro: OSU Processing;
VIIRS Channels Averaged
Rrs
Wavelengt (nm)
0.01
0.009
0.008
0.007
0.006
0.005
0.004
0.003
0.002
0.001
0
400
450
500
550
600
650
700
750
800

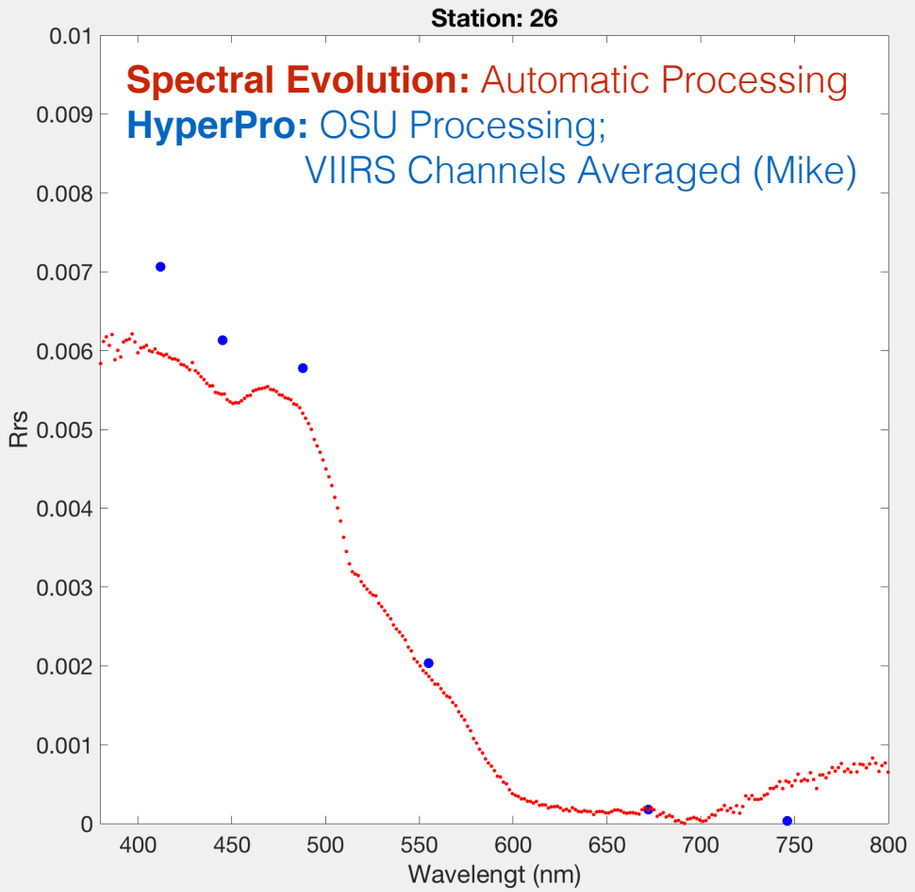
Spectral Evolution
90/40 Protocol & Automated Processing Reliable

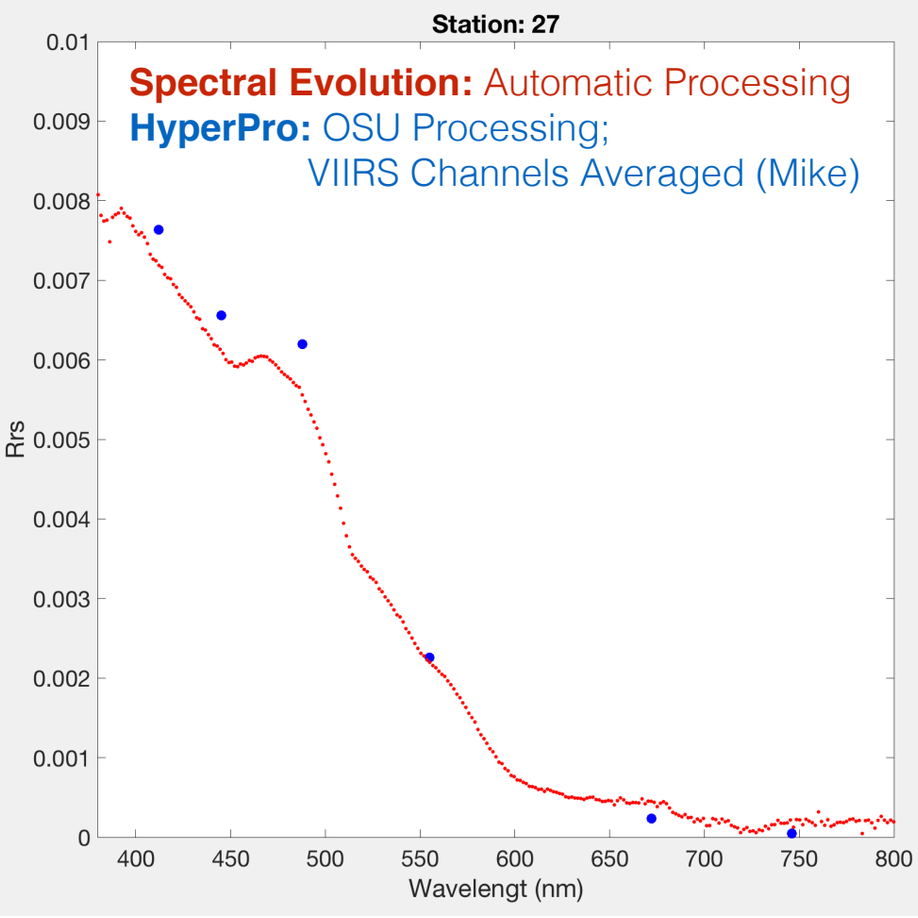
Often anomalously high values above 700 nm (measurement artifacts or instrument?)

Sometimes low values below 400 nm.

Automated processing could be extended to other instruments (ASD).

<u>Questions:</u> Tracking down systematic differences to measurement artifacts; height (boat reflections), ship state (rocking), sea state (white caps),



# Oregon State and USC Summary for 2015-2016 West Coast Products: Summary

Resolved USC ('Platform Eureka') NASA Aeronet SeaPRISM issues.
(Finally) Getting consisten data from Southern California
Platform Eureka SeaPRISM (as of 20 June 2016)!

With reprocessing (Pre June 2016), will redo Platform Eureka
comparisions to VIIRS and continue to check consistency.

Developed protocols for above water spectrometry with new instrument:
Spectral Evolution Field Spectrometer, and validated against
Satlantic Optical Profiler (HyperPRO).
Automated protocols can be extended to other instruments like ASD.

Supplied 'SeaBASS' type data to NOAA (Veronica) for all cruises
between 2014-2016 (HyperPro, Spectral Evolution, HPLC, IOP's)
San Francisco Bay
Newport
Southern California
Hawaii

OSU December 2016 'Nancy Foster' Cruise Report at:
http://meris.coas.oregonstate.edu/tmp/
OSU_NOAA_CRUISE_REPORT_2015_12/

# Filling the Gap of Missing Pixels in the Satellite Images Using the DINEOF Method

Xiaoming Liu and Menghua Wang

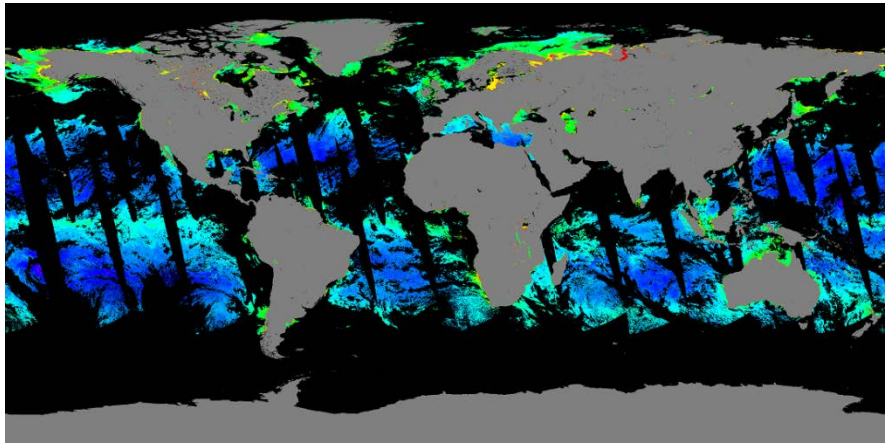
NOAA Center for Satellite Applications and Research (STAR)

STAR JPSS 2016 Annual Science Team Meeting

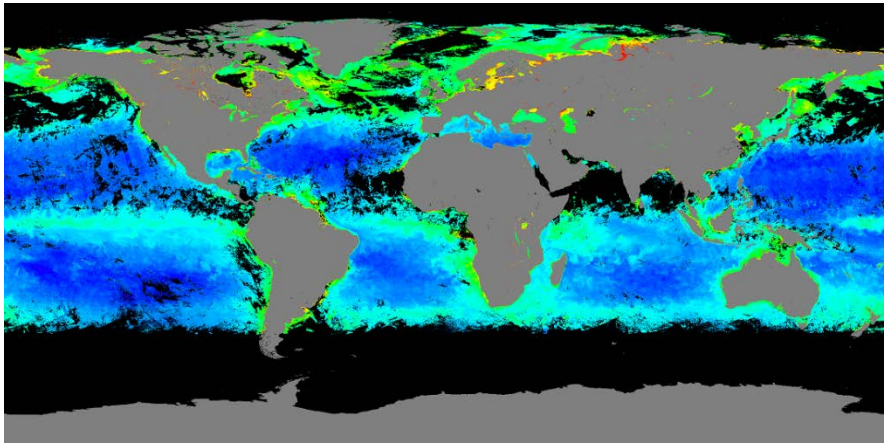
August 8-12, 2016

# Why Using DINEOF?

- Satellite ocean color images provide a variety of ocean optical, biological, and biogeochemical property products, and can be used for various applications such as the short- and long-term ocean environment monitoring, disaster and ocean hazard monitoring and prevention, ocean ecosystem and water quality evaluation and analysis.
- However, there are generally many missing pixels in the satellite images due to various reasons, mainly from cloud cover.



VIIRS Chl-a, 7/1, 2016

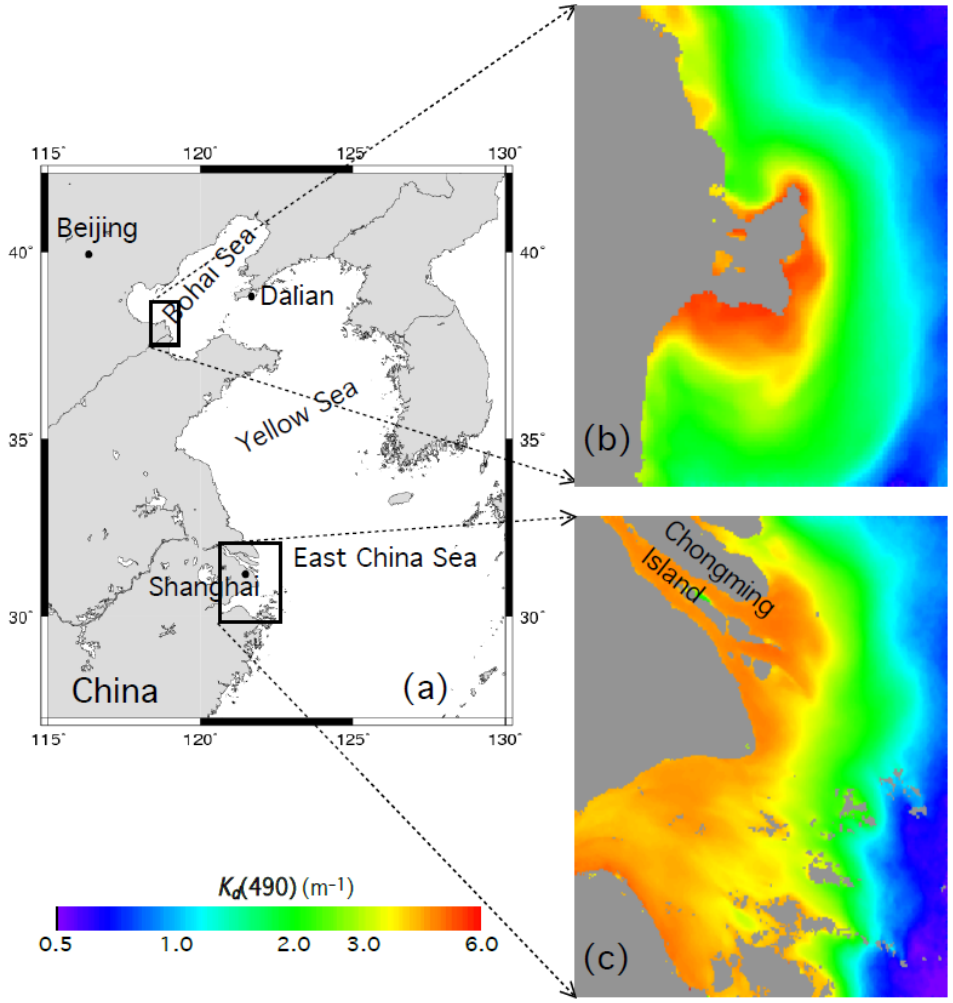


VIIRS Chl-a, 6/25–7/2, 2016

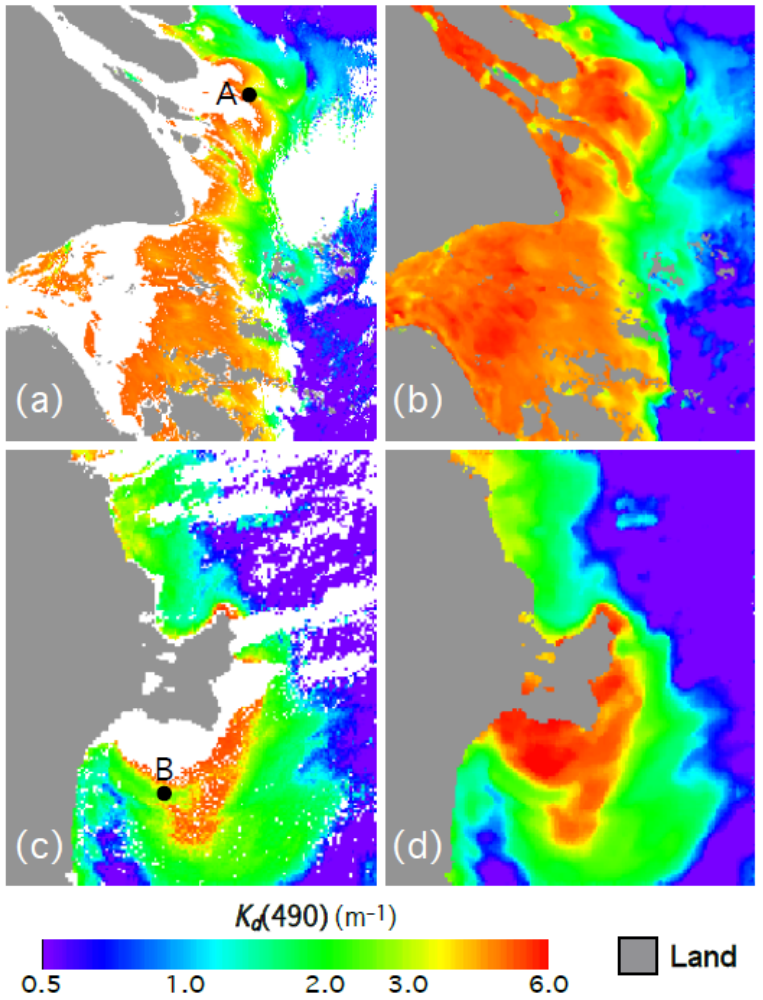
# What is DINEOF?

- The Data Interpolating Empirical Orthogonal Functions (DINEOF) (*Alvera-Azcarate et al.*, 2005; *Beckers and Rixen*, 2003) is an EOF-based technique developed to reconstruct missing data in geophysical datasets. It exploits the spatio-temporal coherency of the data to infer a value at the missing location.
- The Empirical Orthogonal Function (EOF) analysis is a method to determine a set of orthogonal functions that characterizes the co-variability of time series for a set of grid points. It is often used to study possible spatial modes (patterns) of variability and how they change with time.
- The DINEOF method is based on the fact that an EOF analysis aims to extract a small number of significant modes, present in the physical system, from a large data set. These reduced variables should represent a large fraction of the original variability of the data set. The combination of the dominant EOF modes and their amplitudes can therefore help recover missing data values.

# A Case Study on GOCI $K_d$(490) Images



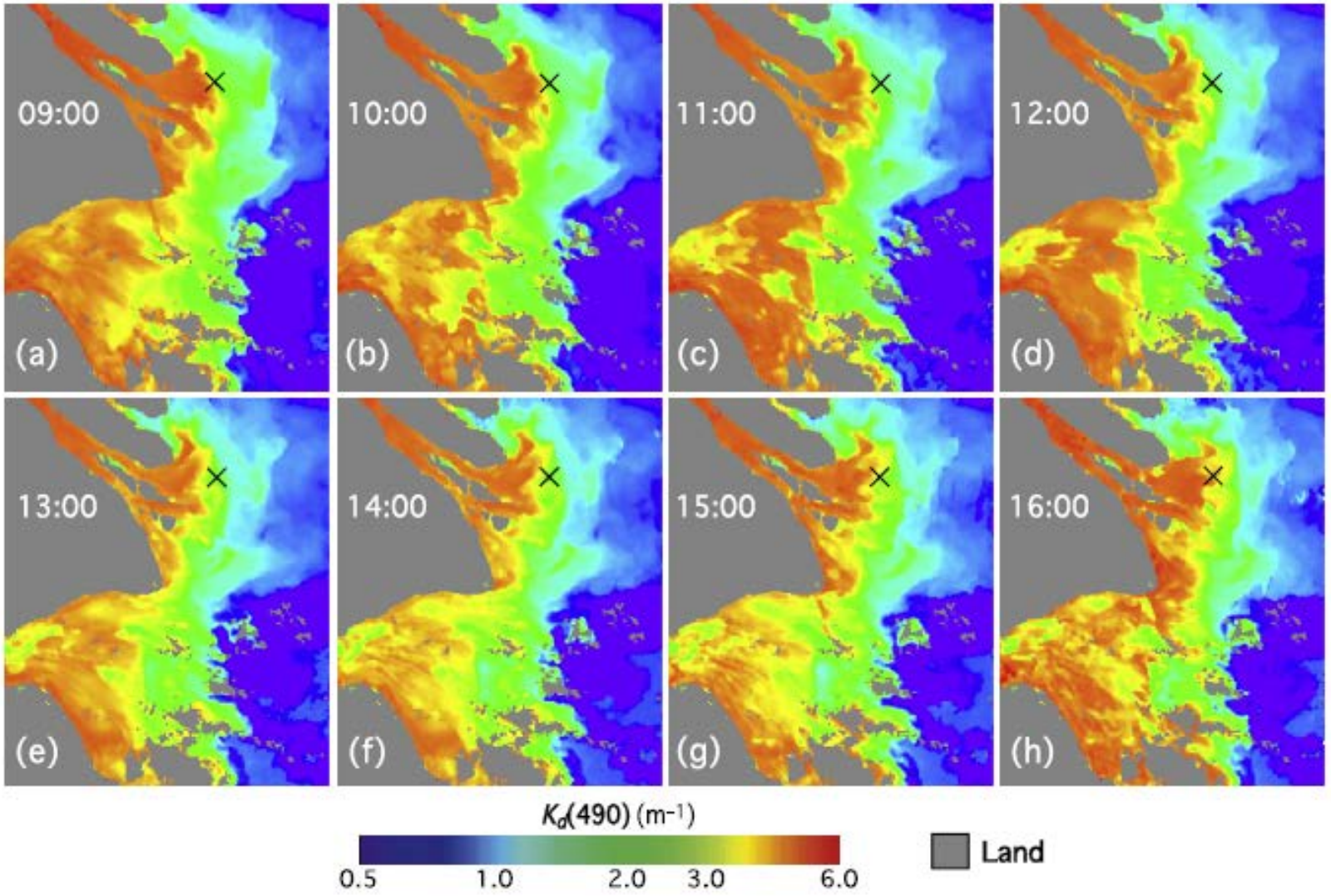

Areas of study (8/1 – 9/30, 2013)




Examples of reconstructed images


Liu, X. and M. Wang, "Analysis of diurnal variations from the Korean Geostationary Ocean Color Imager measurements using the DINEOF method," *Estuar. Coast. Shelf Sci.*, **180**, 230–241, 2016. http://dx.doi.org/10.1016/ecss.2016.07.006

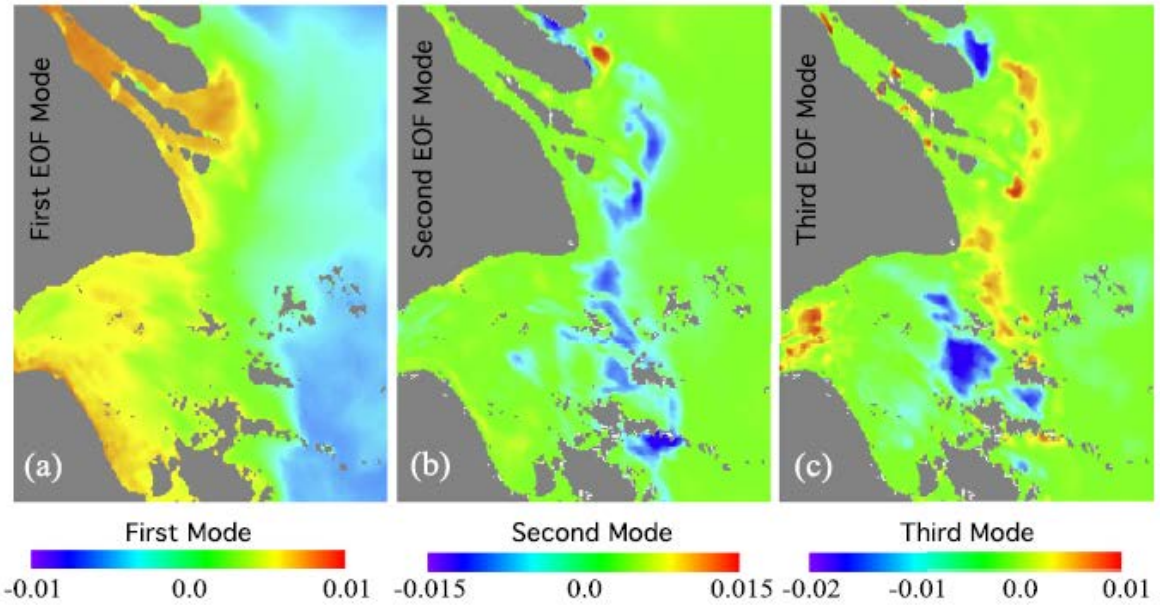
# Analysis of Tidal Variations



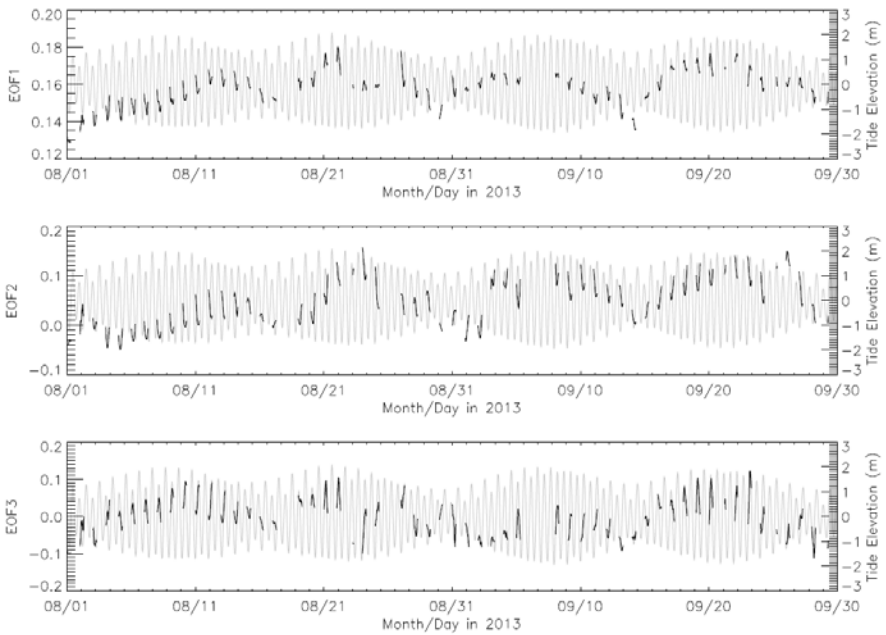

Example of eight filled consecutive $K_d$(490) images at about 09:00 to 16:00 local time hourly (a-h) for the Yangtze River mouth region on August 6, 2013.

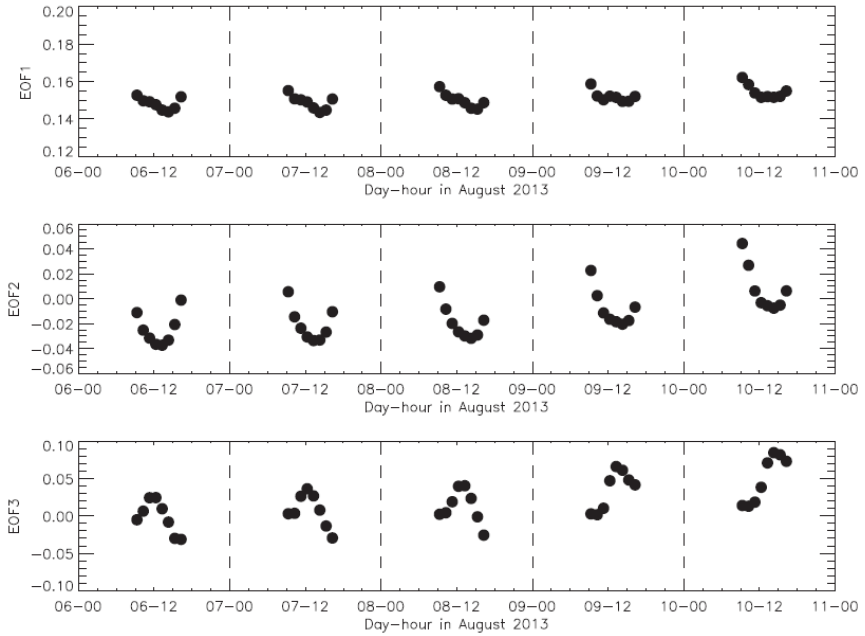
# Analysis of Tidal Variations

Spatial EOF Patterns

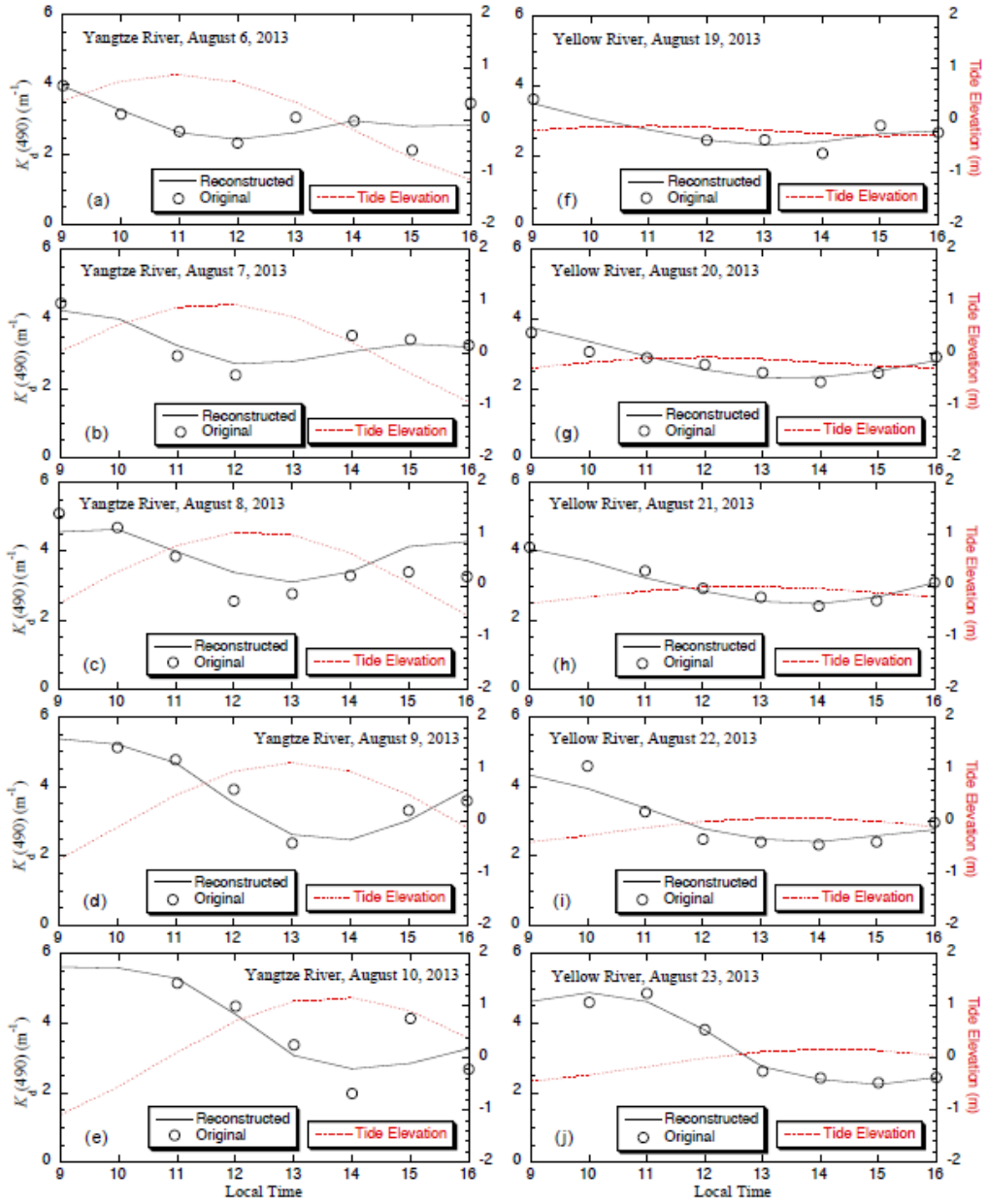



Temporal EOF Functions



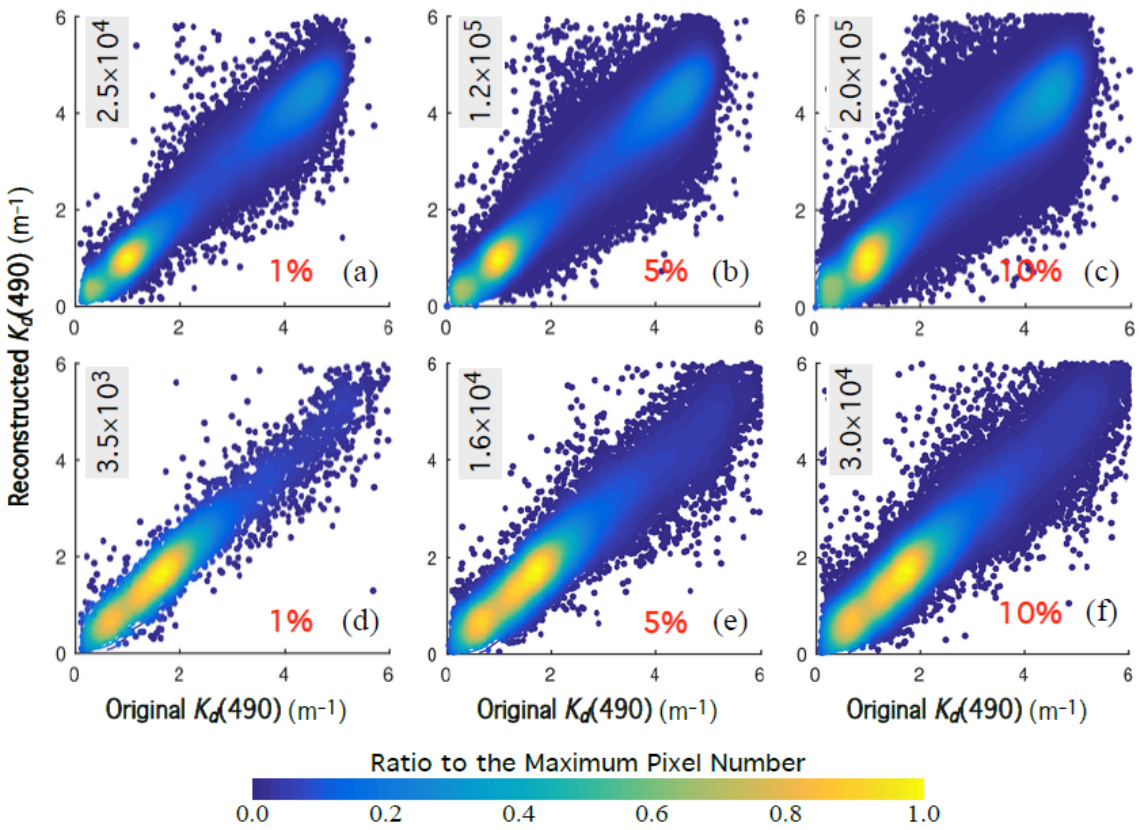



# Validation of DINEOF on GOCI




Time series (diurnal variation) of $K_d(490)$ for the original and reconstructed pixels, as well as the tide elevation (scale noted in right), for the locations A and B, respectively, for the Yangtze River mouth for August 6-10, 2013 (a-e) and the Yellow River mouth for August 19-23, 2013 (f-j).

# Validation of DINEOF on GOCI




Yangtze River Mouth

| | 1% | 5% | 10% |
|---|---|---|---|
| Mean | 1.024 | 1.024 | 1.025 |
| STD | 0.255 | 0.262 | 0.285 |

Yellow River Mouth

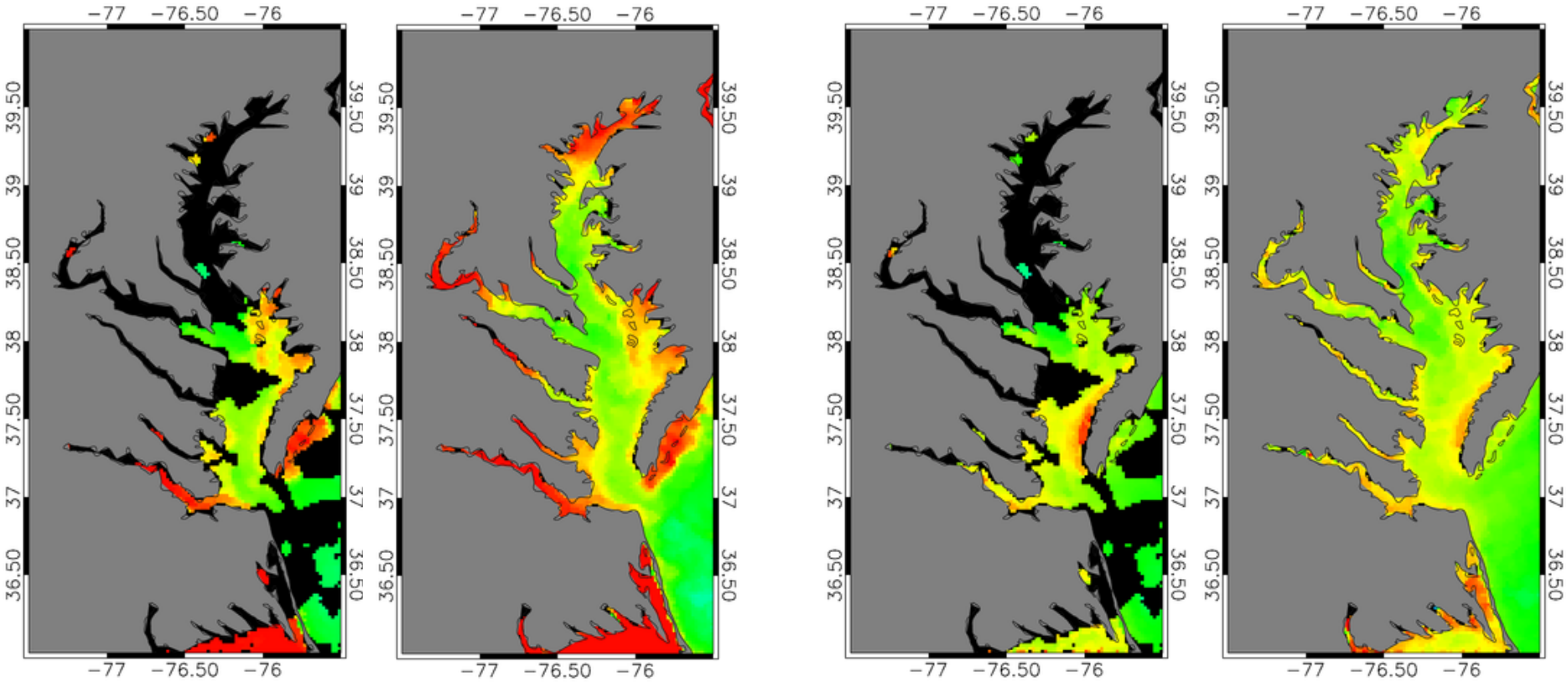
| | 1% | 5% | 10% |
|---|---|---|---|
| Mean | 1.030 | 1.031 | 1.041 |
| STD | 0.302 | 0.303 | 0.527 |

Scatter and density plots of the reconstructed versus original $K_d$(490) values for the Yangtze River mouth (panels a, b, and c), and the Yellow River mouth (panels d, e, and f). Panels a and d have 1% validation pixels, panels b and e have 5% validation pixels, and panels c and f have 10% validation pixels.

# Application of DINEOF on VIIRS

$K_d(490)$

Chl-a

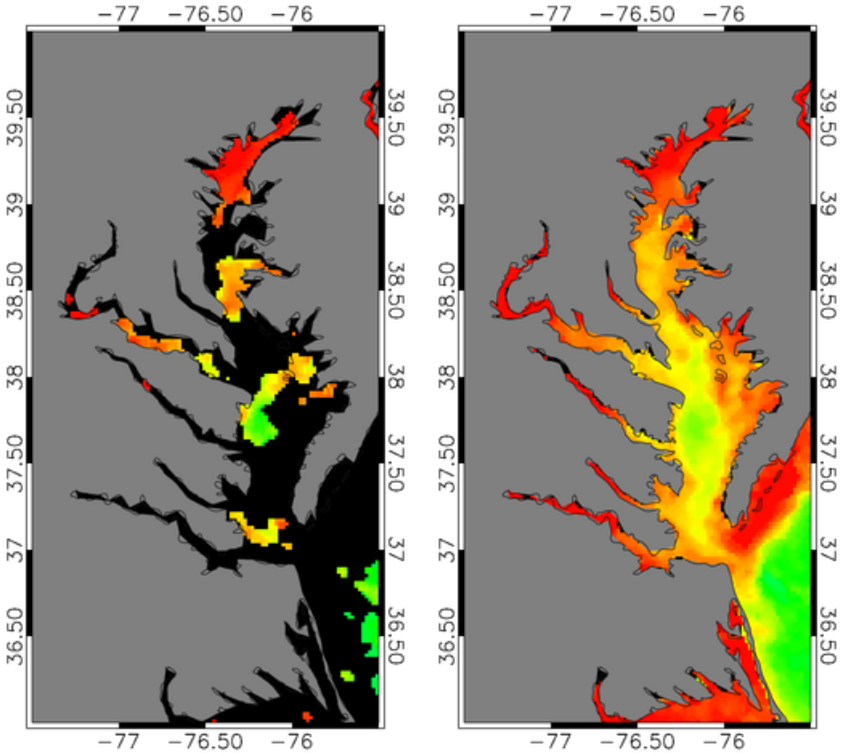



Original Reconstructed Original Reconstructed

**Chesapeake Bay**, April 30 – May 7, 2016

# Application of DINEOF on VIIRS

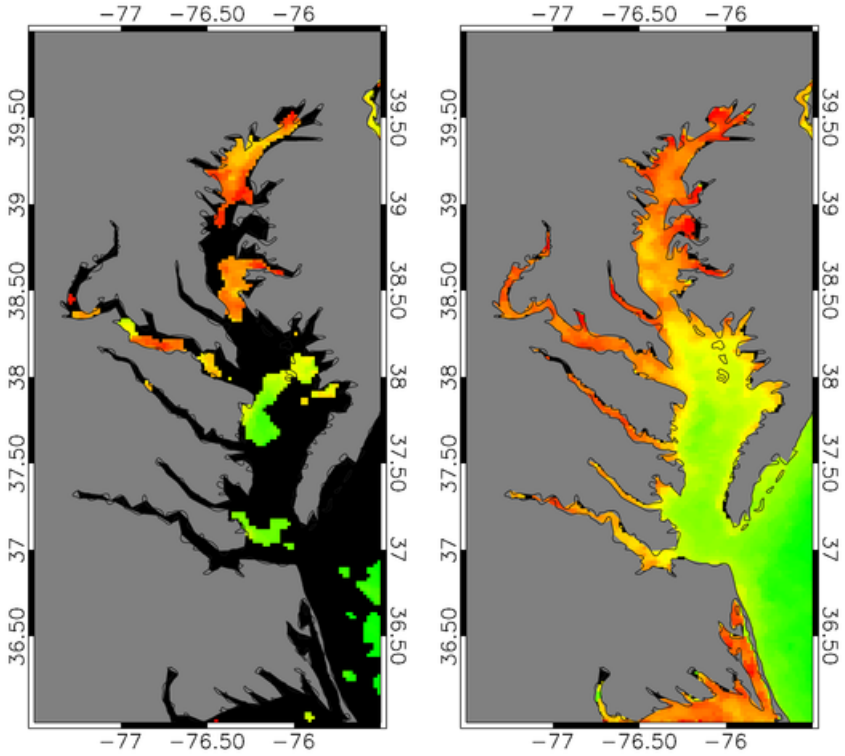
**$K_d$(490)**




Original

Reconstructed

**Chl-a**




Original

Reconstructed

**Chesapeake Bay**, Sep. 22–29, 2015

# Summary and Future Work

- DINEOF method has been applied to GOCI and VIIRS ocean color images for filling the gaps of missing pixels. Validation results from GOCI images show the differences between DINEOF reconstructed pixels and the original pixels are small. The missing spatial features in the ocean color images can be reconstructed.
- DINEOF will be used for filling the gaps in VIIRS high resolution (1 km) ocean color images for selected regions, such as, the US east and west coasts, Gulf of Mexico, Great Lakes, etc. It will also be used to test and evaluate non-gap global ocean color images at 9-km resolution.

# “Improving MOBY vicarious calibration products at longer wavelengths”

UNIVERSITY OF MIAMI

Kenneth Voss, Physics Dept., Univ of Miami

Co-Authors: Howard Gordon (UM), Stephanie Flora (MLML), Carol Johnson (NIST), Mark Yarbrough(MLML), Mike Feinholz (MLML), and Terry Houlihan (MLML)

8/16, STAR JPSS 2016 annual meeting, College Park, Md.

1) Brief statement on current status of MOBY Operation and Refresh

2) Statement of problem for measurement at wavelengths >575nm

3) Description of new data products which add a correction, and wavelength dependent uncertainties.

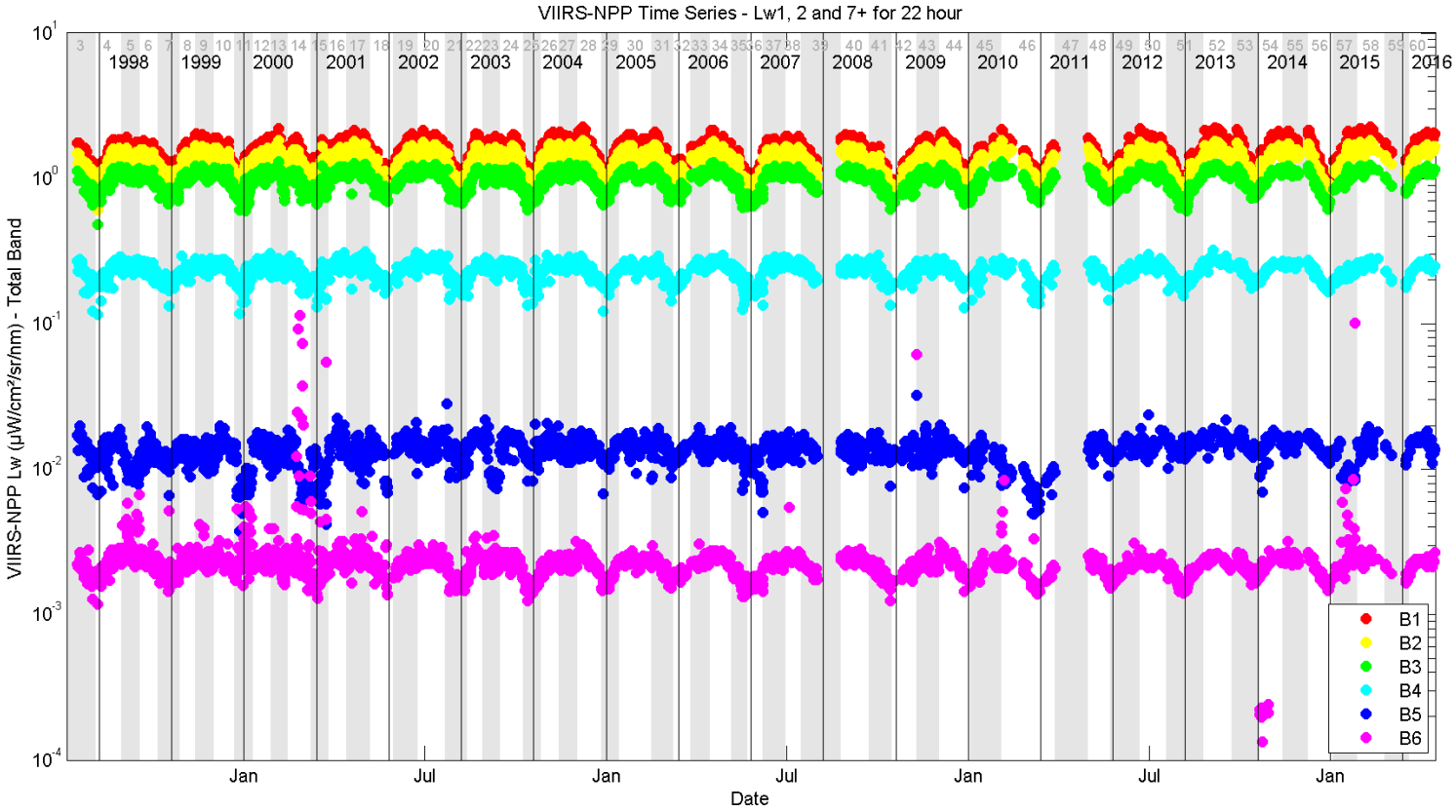
4) Impact on MOBY data

2 thru 4 based on paper to be submitted to JAOT very soon.





Currently have a 19 yr + time series of vicarious calibration data at the MOBY site thanks to NASA, NOAA, Dennis Clark, and the rest of the MOBY team (many of whom have been in the project since the beginning.



# Current status

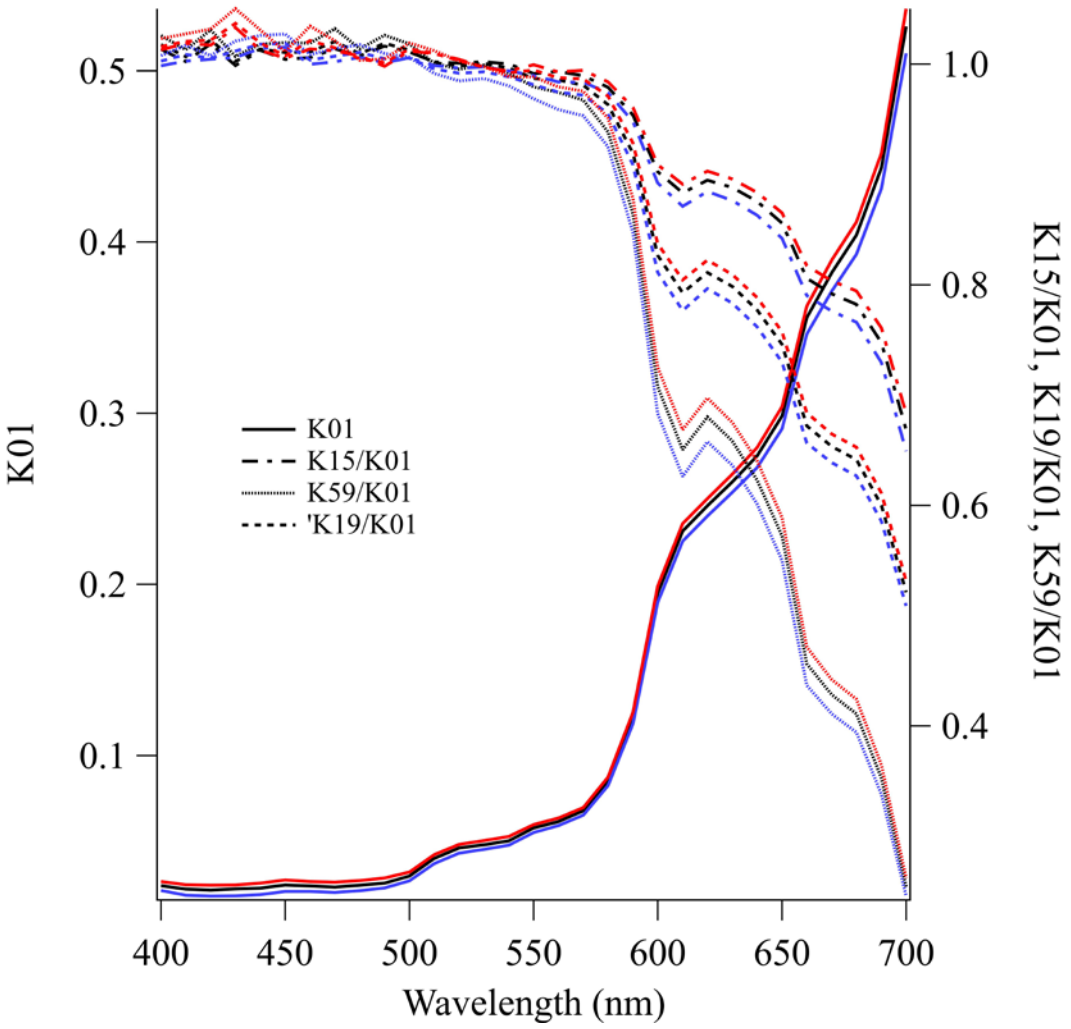
- Next deployment will be next week.
- Will have first, test, deployment of the blue refresh spectrometer.





As we showed at Ocean Optics 2010, even in well mixed water, the upwelling radiance K (KL) varies in the upper part of the water column at wavelengths greater than 575 nm. This is due to both Raman scattering and Chl fluorescence. Since our best KL is from 1-5m, and we need KL from 0-1m we need to correct for this effect.

This graph shows modeling results from Howard Gordon.



Currently we produce:

Lw1 (and Lwn1) which uses KL(1-5m) and Lu(1m).

Lw2 (and Lwn2) which uses KL(1-9m) and Lu(1m).

and Lw7 (and Lwn7) which uses KL(5-9m) and Lu(5m)

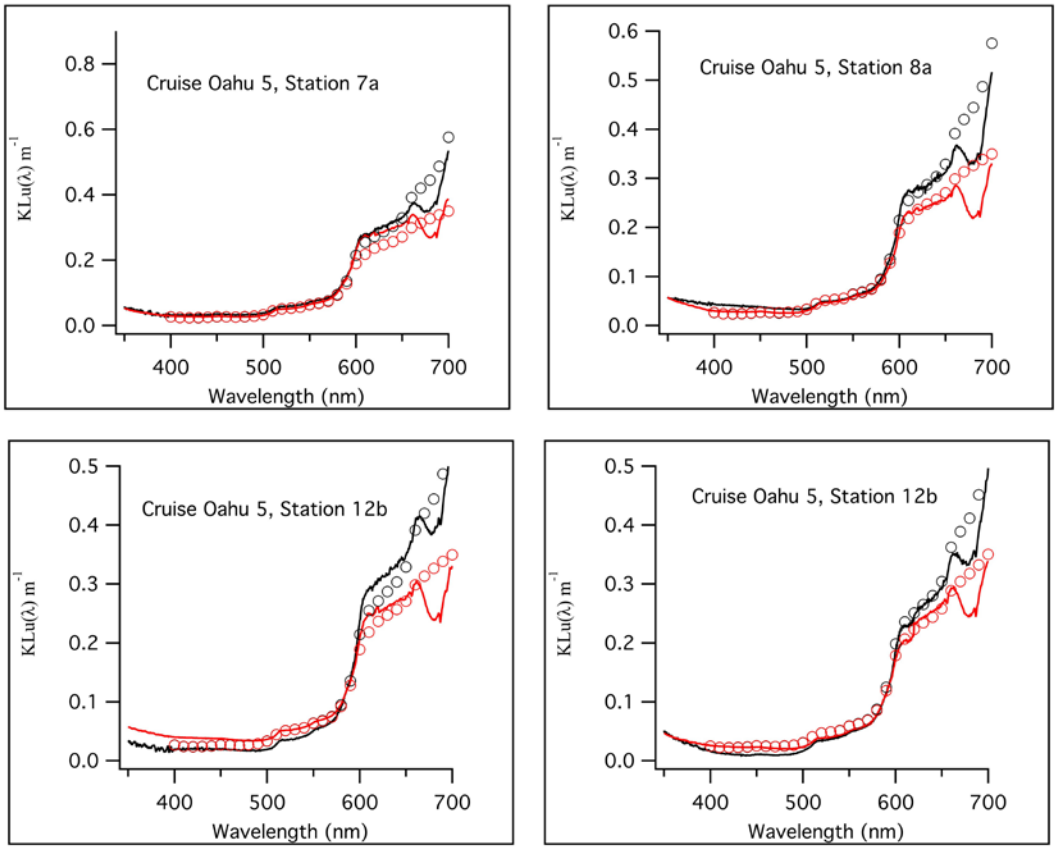
Lw1 is the preferred product.

We have modeled KL(0-1m), KL(1-5m), KL(1-9m), and KL(5-9m) for Chl's 0, 0.05, 0.10, and 0.15 mg/m3 (basically the range at MOBY), and solar zenith angles of 10, 20, 30, 40, 50, 60 degrees.

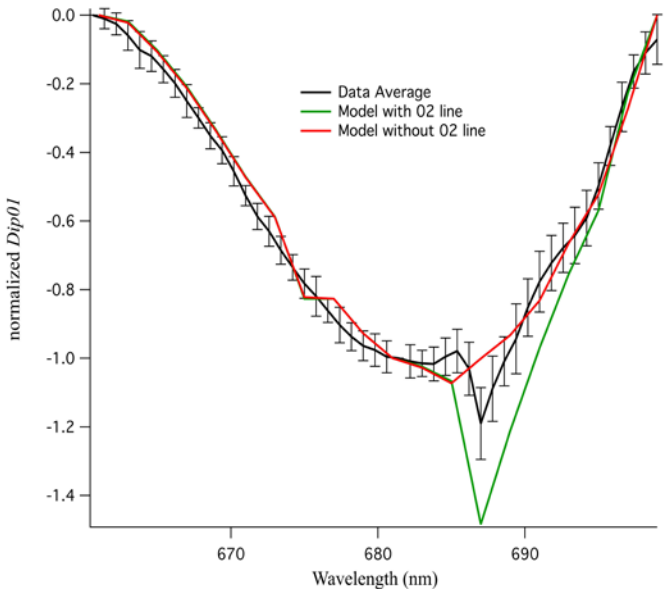


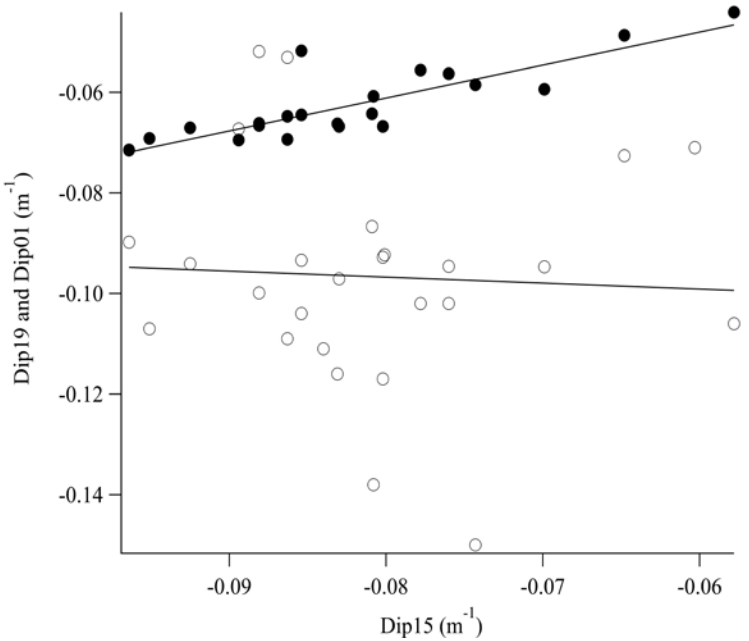


To check our model, we had a data set of special MOS/ROV data from a cruise off of Oahu with measurements at 0.1,1, 5, and 9 m. The data are the solid lines, the model the circles. This has no Chl correction in the model (660-700 nm “dip”). As can be seen the model and data agree very well.



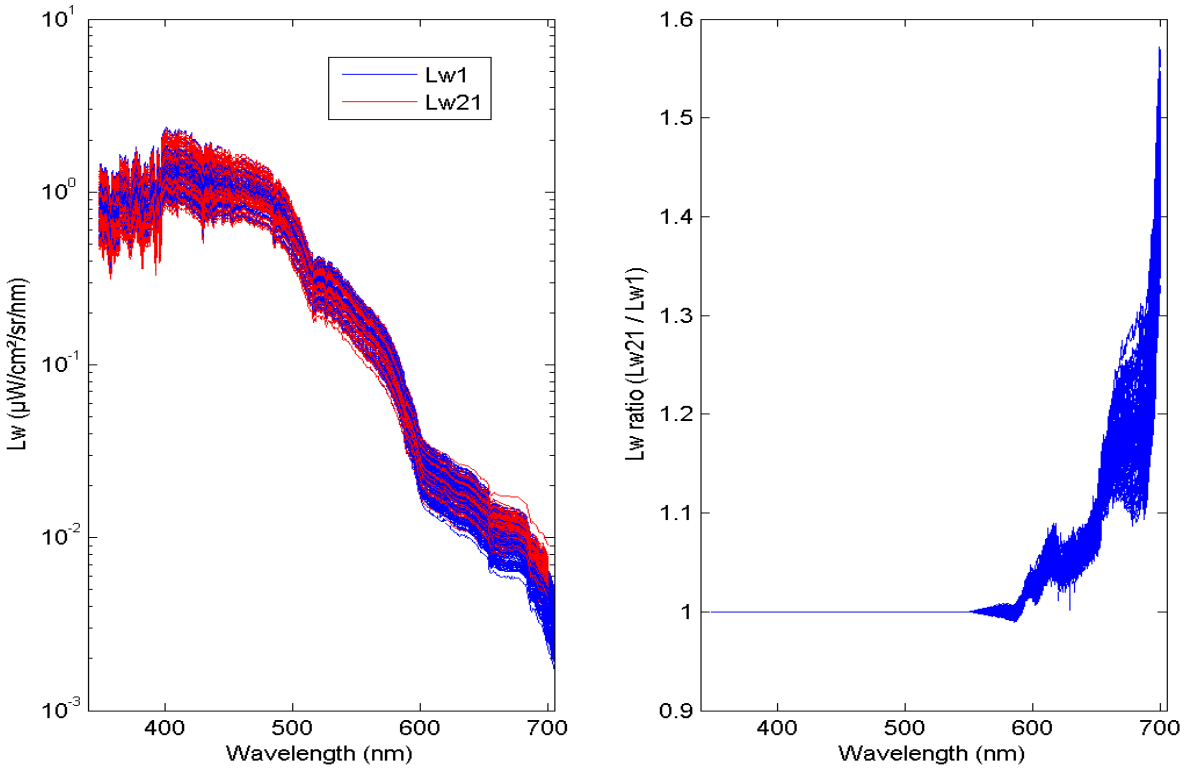

Yarbrough, M.A., M.E. Feinholz, S. Flora, T. Houlihan, B.C. Johnson, Y.S. Kim, M.Y. Murphy, M. Ondrusek, and D.K. Clark, 2007a: Results in coastal waters with high-resolution *in-situ* spectral radiometry: The Marine Optical System ROV. *Proc. SPIE 6680, Coastal Ocean Remote Sensing*. 66800I, doi:10.1117/12.735064.



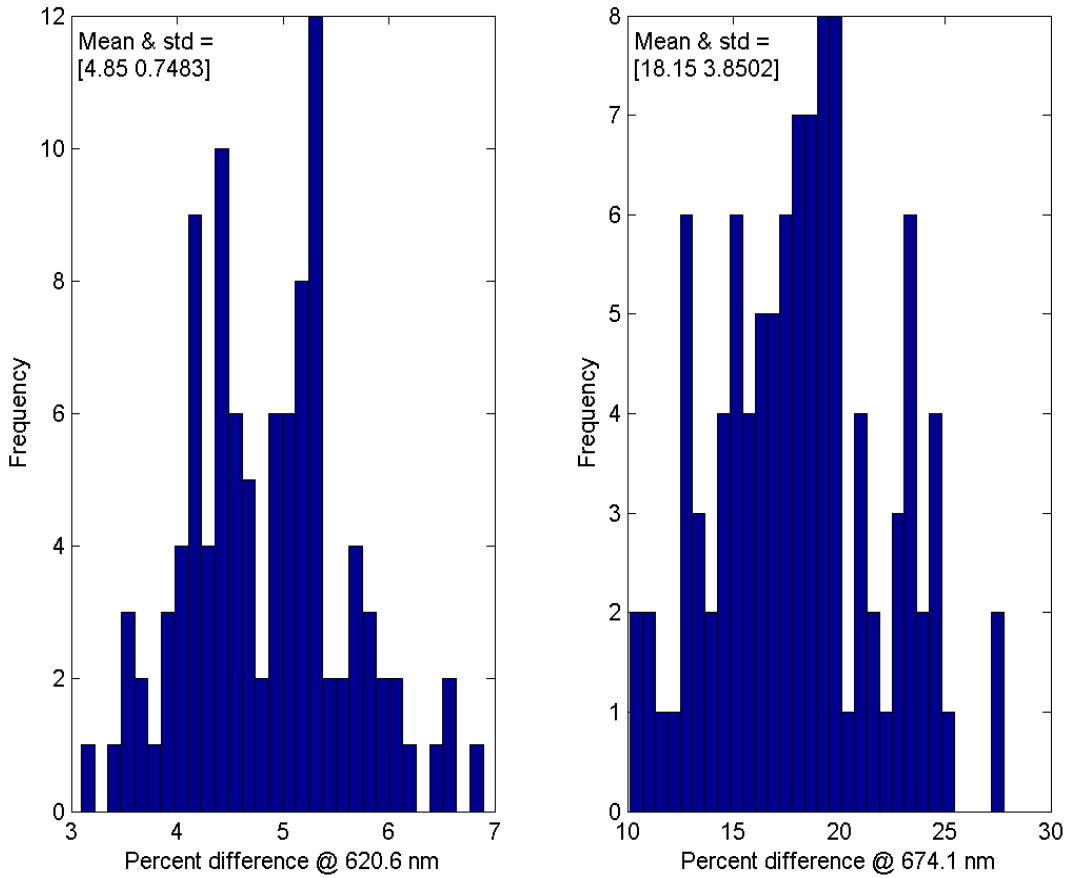




For Chl dip, a baseline from 660-700nm is determined and the deviation from this baseline was obtained for each measurement in our validation data set…resulted in a very good average shape. We use this average in our correction.

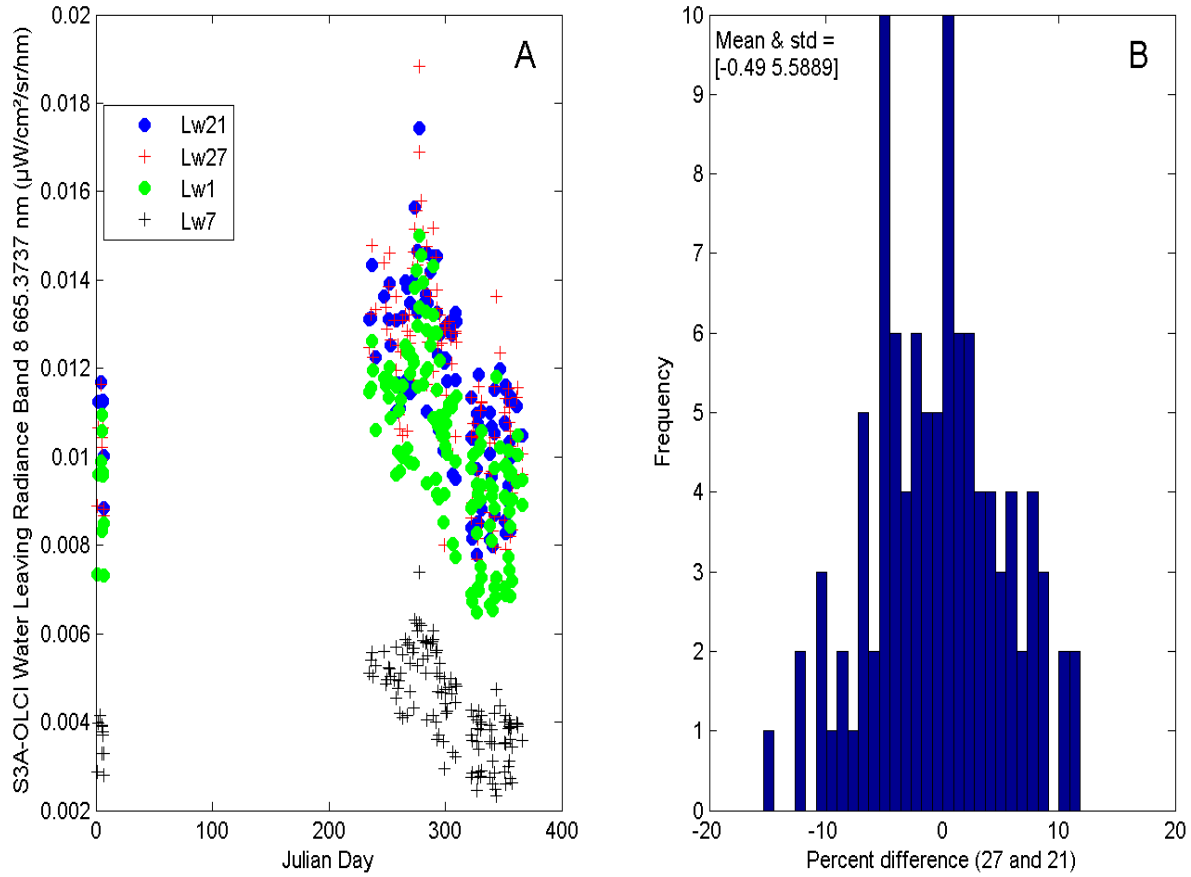
Interestingly, while the dip in 1-5m data was correlated with the dip in the 1-9m data, it was not correlated at all with the 0-1m data. Thus we use an average magnitude of 0.10$m^{-1}$ to do the correction.




Left panel without correction (Lw1) and with correction (Lw21), right panel, ratio. First, very little light at these wavelengths at MOBY site. However, correction is a large value there. This is for one full deployment.




For the blue wavelengths, not much difference, in the red, however, a large difference, here I show two red bands in the OLCI instrument (which has many red bands)




We can do a similar correction for Lw7 (and Lw2), the hardest is Lw7, but as shown here, the data after our correction (Lw21 and Lw27) agree very well.

We will continue to make the normal products…Lw1, Lw2, and Lw7.

However we are going to also produce Lw21, Lw22, and Lw27.

Along with this product we will be introducing and developing a spectrally dependent uncertainty product for each data set and Lw product.

We are going to be continuing development of this uncertainty product going forward. This uncertainty product will include measurement specific uncertainties due to instrument tilt (and variation during measurement period), compass, etc.

Expect this product to roll out in early fall...messages will be coming out about this when we are ready to put it online.





# NIST Calibration Support for VIIRS Ocean Earth Data Records Products

PI: Carol Johnson

Presenter: David Allen

Sensor Science Division, NIST

August 10, 2016

cjohnson@nist.gov

NIST
National Institute of Standards and Technology
U.S. Department of Commerce

# Topics

- SeaPRISM filter measurements
- NOAA's Spectral Radiance Standard
- Blue Tile

# SeaPRISM Filters

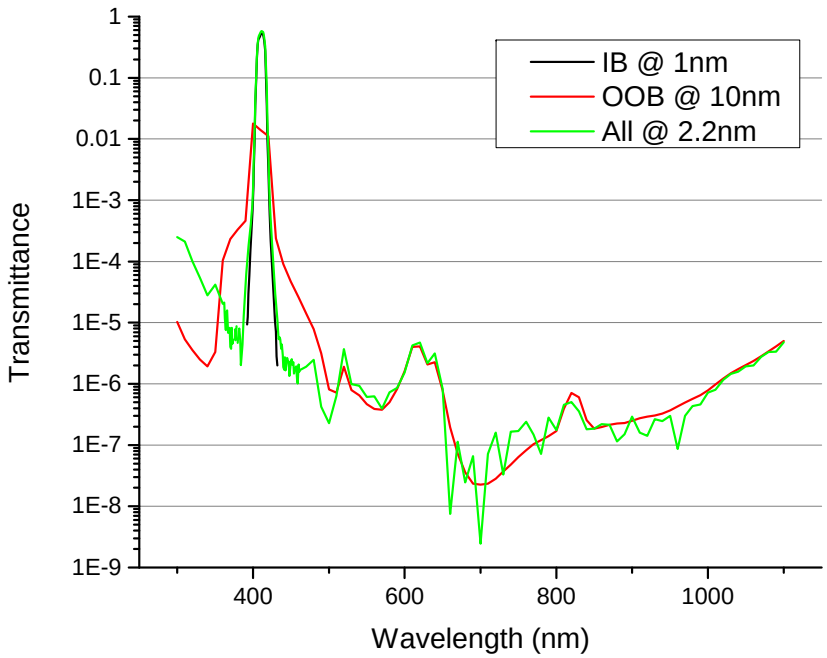
- The spectral out-of-band could not be measured for the SeaPRISM080 NIST that was characterized and calibrated on SIRCUS
- This is important because differences between the spectral distributions of the calibration and measured sources cause bias if there is spectral out of band in the filters
- A spare set of AERONET-OC SeaPRISM filters was measured twice for transmittance at NIST by Howard Yoon
- We present the final data and results of a sensitivity study

# Specifications

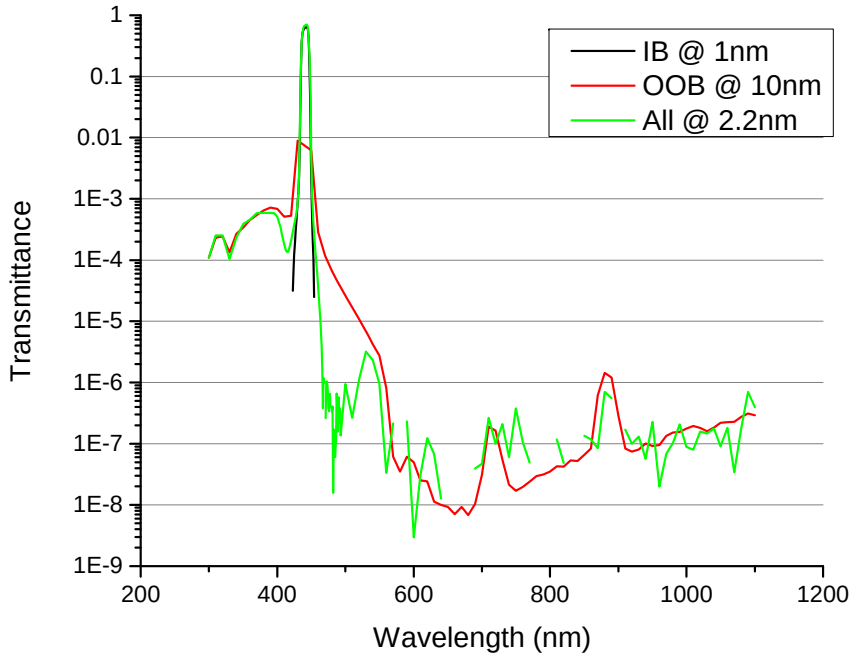
| Nominal Wavelength (nm) | Nominal Bandpass (nm) | Designations |
|---|---|---|
| 412 | 10 | from #610 412/10nm #03 Lot 11087 Interferenzoptic GmbH |
| 443 | | POC Part No.: 8746-801, Filter Ass'y 443nm, S/N 45, Test Lot# 3805, Made in USA |
| 490 | 10 | POC Part No.: 8746-805, Filter Ass'y 490/10nm, S/N 27, Test Lot# 4305, Made in USA |
| 531 | 10 | POC Part No.: 8746-807, Filter Ass'y 531/10nm, S/N 12, Test Lot# 3905, Made in USA |
| 551 | 10 | POC Part No.: 8746-809, Filter Ass'y 551/10nm, S/N 12, Test Lot# 1006, Made in USA |
| 667 | 10 | POC Part No.: 8746-803, Filter Ass'y 667/10nm, S/N 33, Test Lot# 4505, Made in USA |

The first measurements were 1nm bandpass (in band) and 10nm bandpass (out of band). These data were presented on a TelCon. It was then recognized the measurements at 10nm bandpass gave incorrect results on the shoulders because of the stray light in the Cary 14 spectrophotometer. So, a second set of measurements was performed, and the results were re-analyzed.

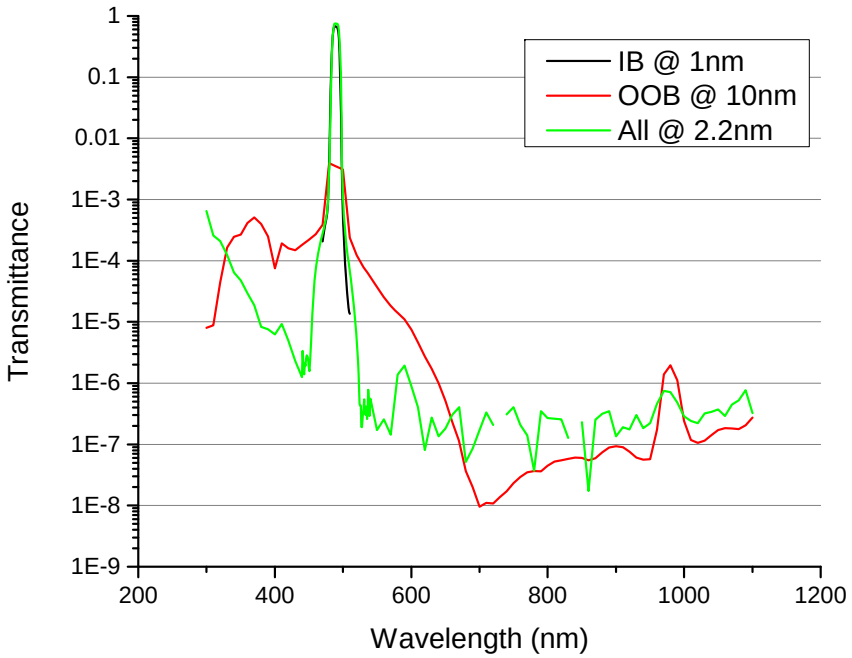
## 412 nm


IB @ 1nm
OOB @ 10nm
All @ 2.2nm
Transmittance
1
0.1
0.01
1E-3
1E-4
1E-5
1E-6
1E-7
1E-8
1E-9
400
600
800
1000
Wavelength (nm)

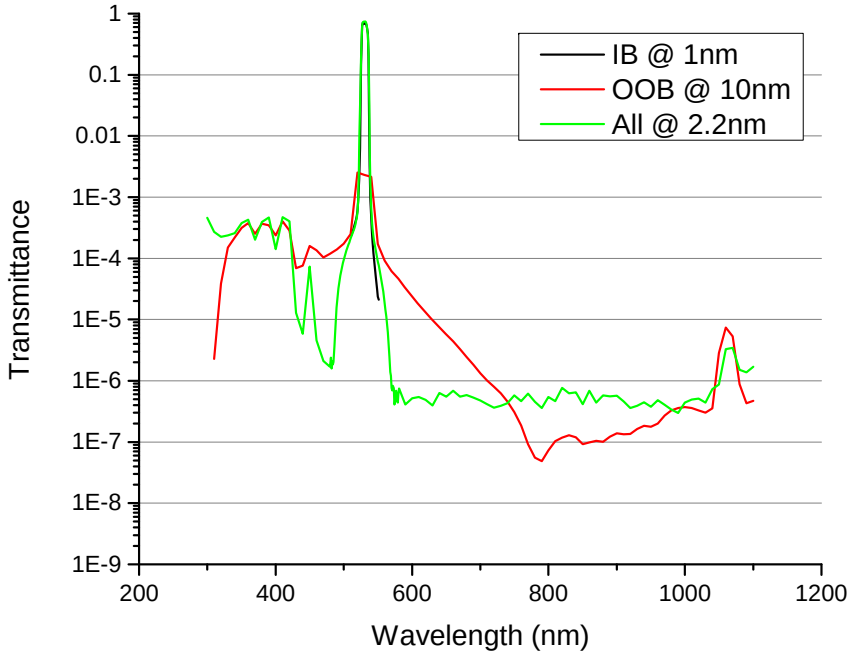
## 443 nm


IB @ 1nm
OOB @ 10nm
All @ 2.2nm
Transmittance
1
0.1
0.01
1E-3
1E-4
1E-5
1E-6
1E-7
1E-8
1E-9
200
400
600
800
1000
1200
Wavelength (nm)

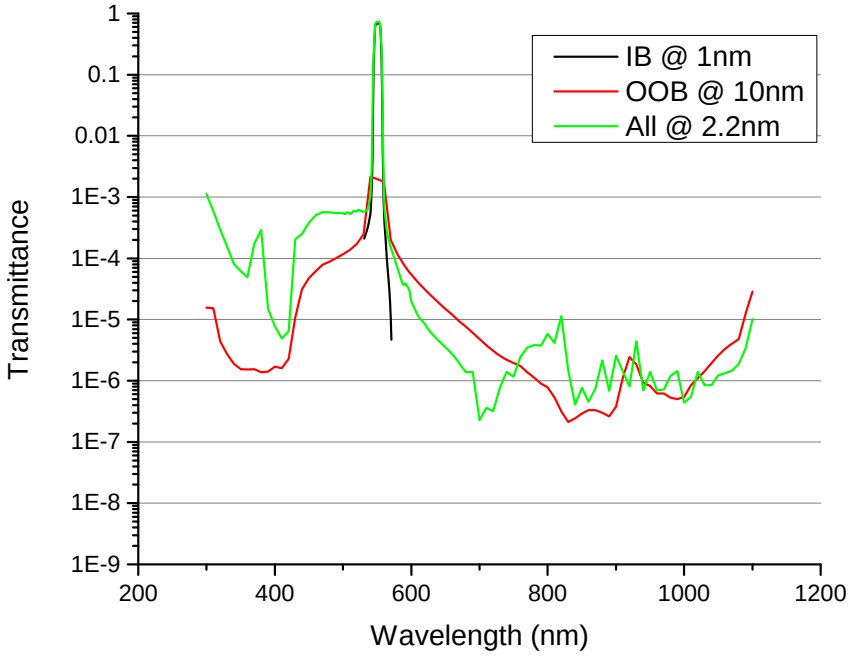
## 490 nm


IB @ 1nm
OOB @ 10nm
All @ 2.2nm
Transmittance
1
0.1
0.01
1E-3
1E-4
1E-5
1E-6
1E-7
1E-8
1E-9
200
400
600
800
1000
1200
Wavelength (nm)

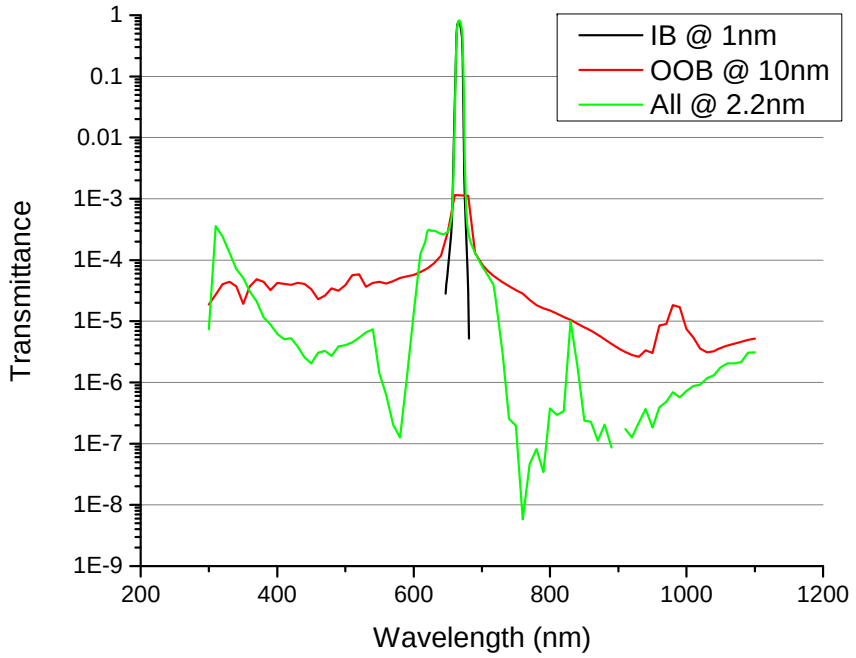
## 531 nm


IB @ 1nm
OOB @ 10nm
All @ 2.2nm
Transmittance
1
0.1
0.01
1E-3
1E-4
1E-5
1E-6
1E-7
1E-8
1E-9
200
400
600
800
1000
1200
Wavelength (nm)

## 551 nm


IB @ 1nm
OOB @ 10nm
All @ 2.2nm
Transmittance
1
0.1
0.01
1E-3
1E-4
1E-5
1E-6
1E-7
1E-8
1E-9
200
400
600
800
1000
1200
Wavelength (nm)

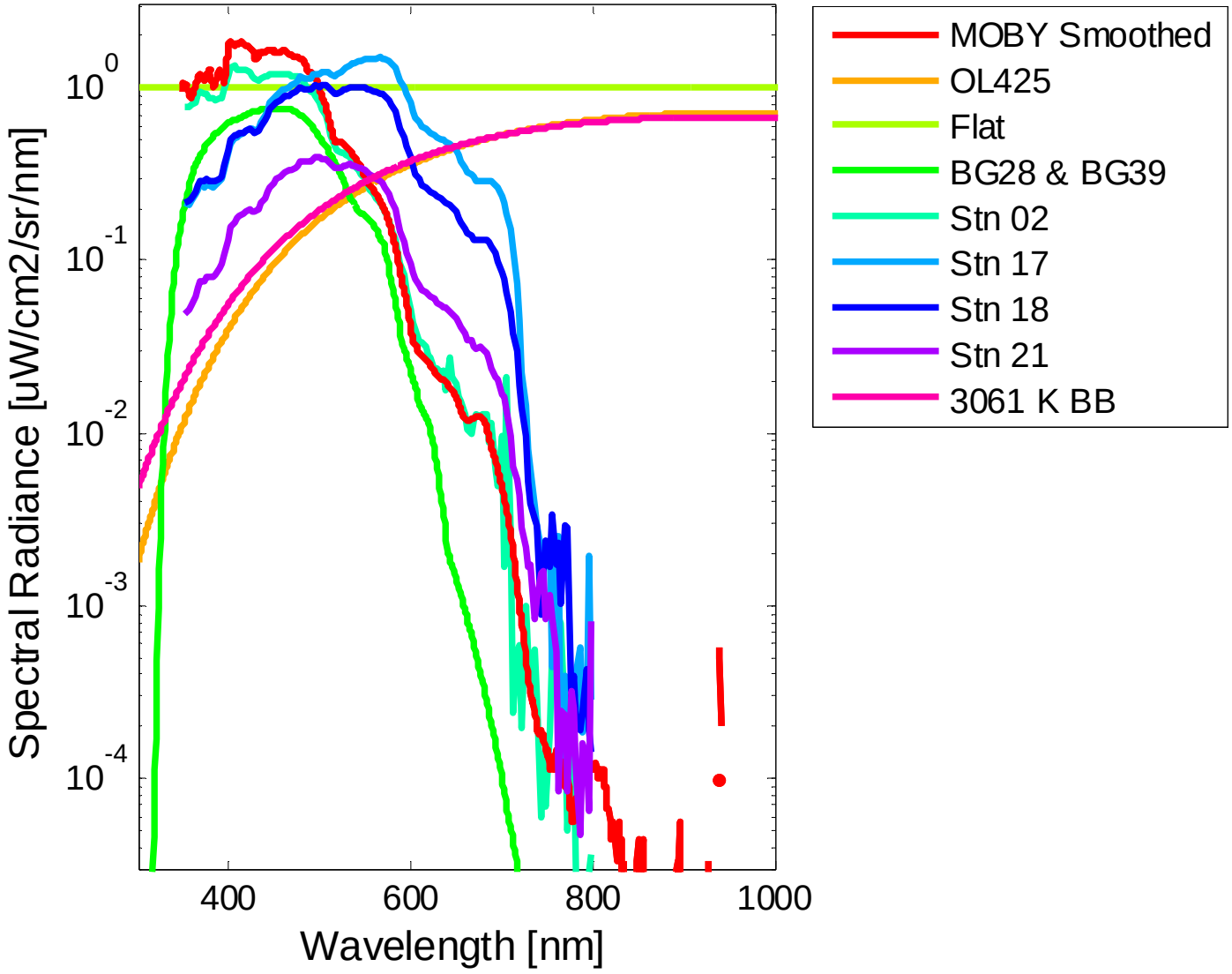
## 667 nm


IB @ 1nm
OOB @ 10nm
All @ 2.2nm
Transmittance
1
0.1
0.01
1E-3
1E-4
1E-5
1E-6
1E-7
1E-8
1E-9
200
400
600
800
1000
1200
Wavelength (nm)

# Sensitivity Analysis

- Approach
  - Multiply all transmittance values by the flux responsivity of a silicon photodiode
  - Set the transmittance to zero in the out-of-band regions for the comparison case (“In-Band”)
  - Select spectral distributions to represent Lw
  - Use measurement equations to find the sensitivity to In-band vs Total-Band

# Input Distributions



# Measurement Equations

$$\lambda_{c,w} = \frac{\int \lambda L_{c,w}(\lambda)\tau(\lambda)r(\lambda)d\lambda}{\int L_{c,w}(\lambda)\tau(\lambda)r(\lambda)d\lambda}$$

Channel wavelength depends on the spectral distribution of the source measured: c = calibration; w = water

$$D_{c,w} = \frac{S_{c,w}}{L_{c,w}(\lambda_{c,w})}$$

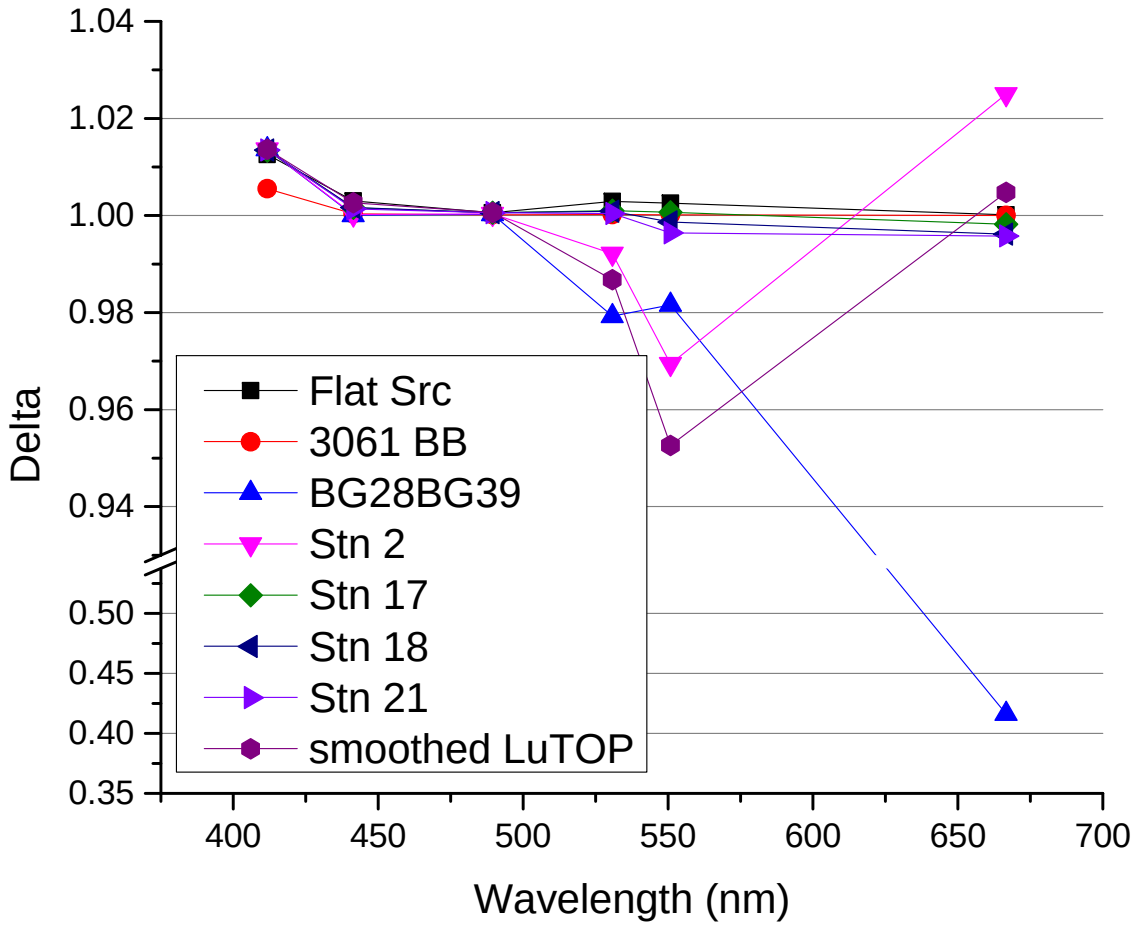
Using the calculated signals, a calibration coefficient is defined given the calibration and water spectral distributions. They will differ because of spectral out of band.

$$\delta = \frac{\left(\frac{D_c}{D_w}\right)_{IB}}{\left(\frac{D_c}{D_w}\right)_{Total}} = \frac{L_w(\lambda_{w,IB})}{L_c(\lambda_{c,IB})}\frac{L_c(\lambda_{c,TOT})}{L_w(\lambda_{w,TOT})}$$

The bias is found by comparing the calibration coefficient ratios calculated with only the in band data or with full, total band data.

Parr and Johnson, J Res NIST, 116(5), p751-760 (2011)

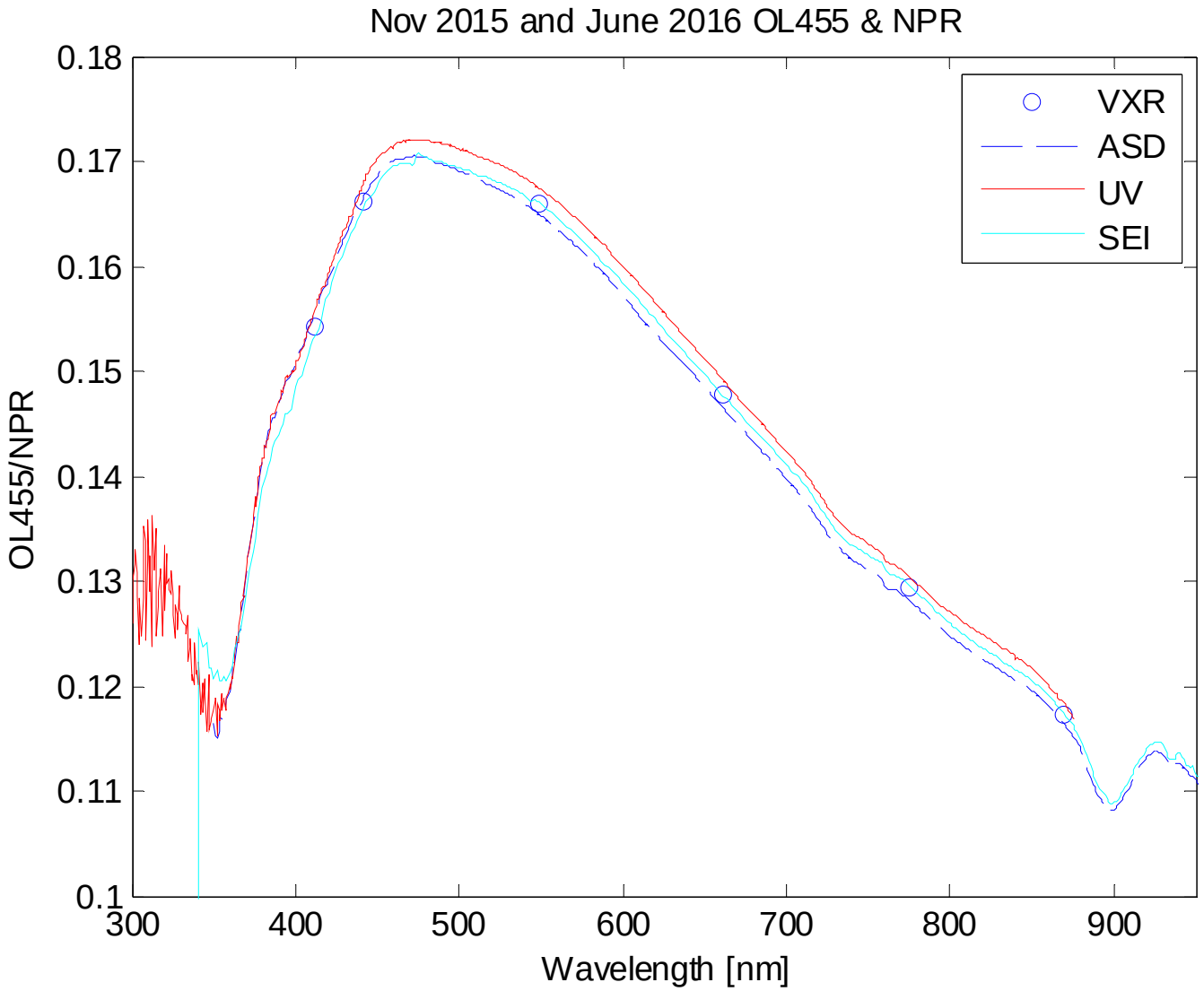
# Results



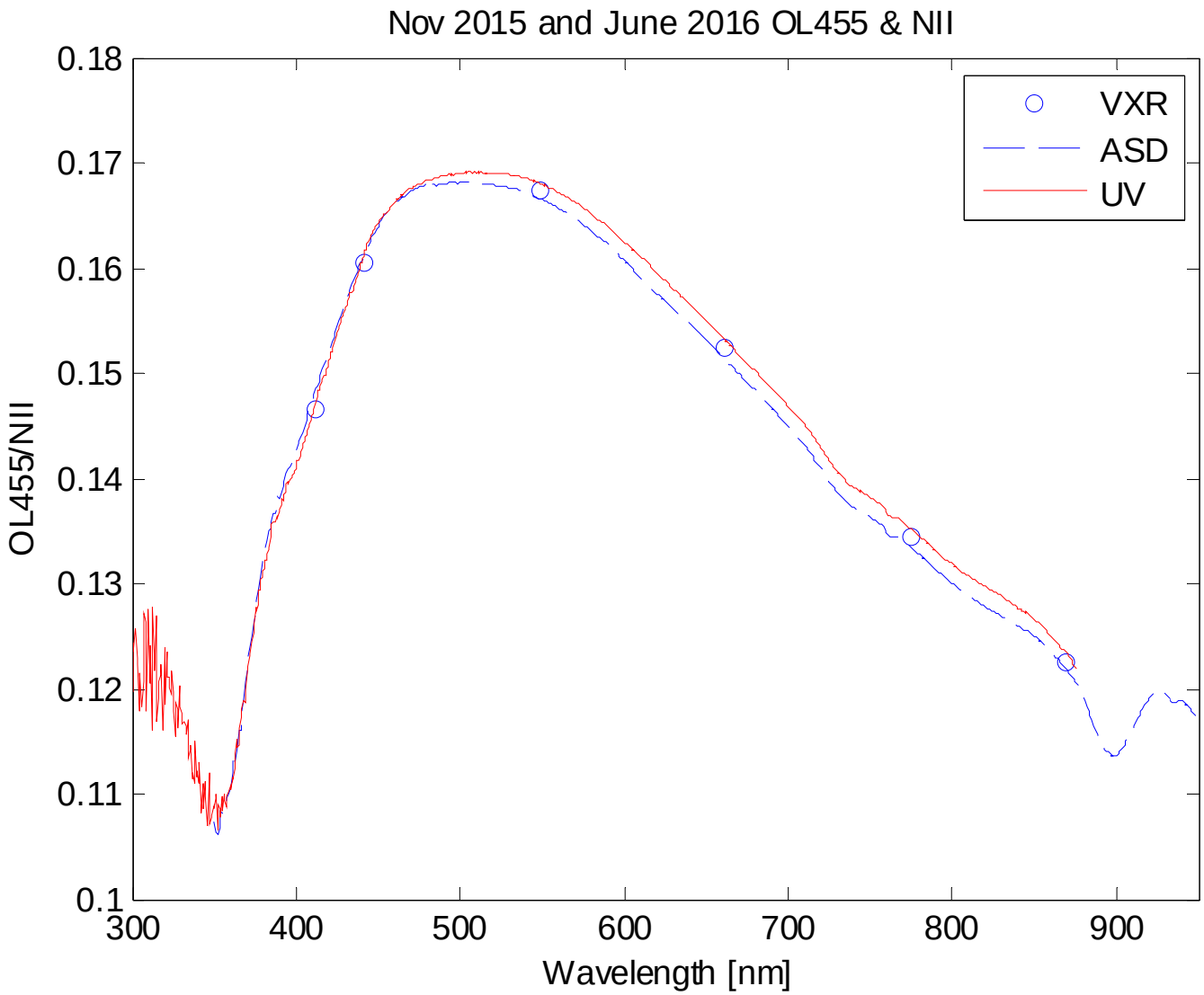

Delta is referenced to the spectral radiance standard, the OL425 spectrum in this case.

# NOAA Spectral Radiance Validation

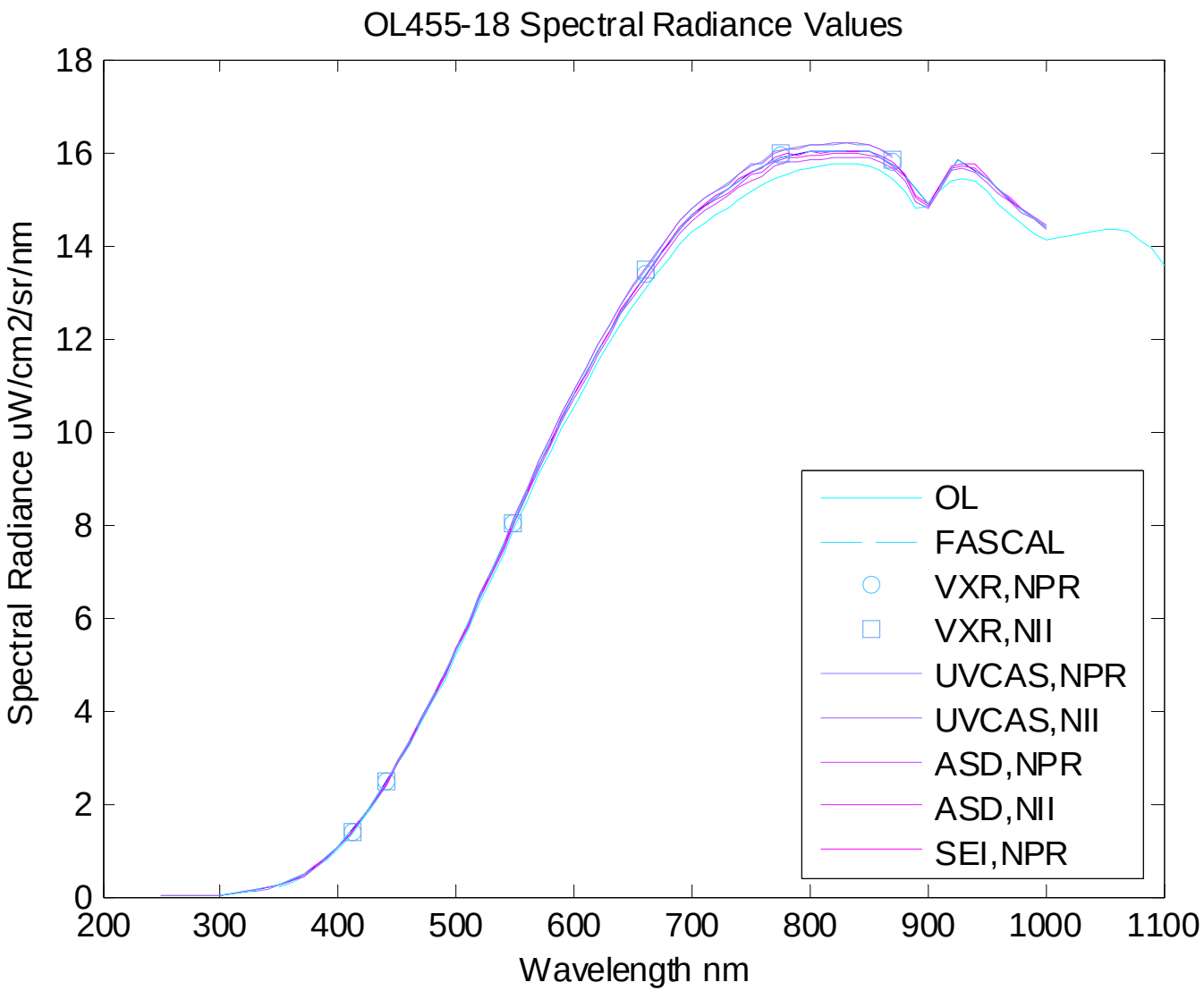
- OL455-18 is the spectral radiance standard in the NOAA/STAR calibration laboratory
- Externally-illuminated 18” sphere with monitor photodiode
  - Aug 2013 calibration by Optronic Labs
  - Nov 2015 & Jun 2016 validation in Remote Sensing Lab (RSL) at NIST
  - Apr 2016 NIST FASCAL calibration
- User adjusts an iris between the lamp and sphere to maintain calibration value of the monitor photodiode



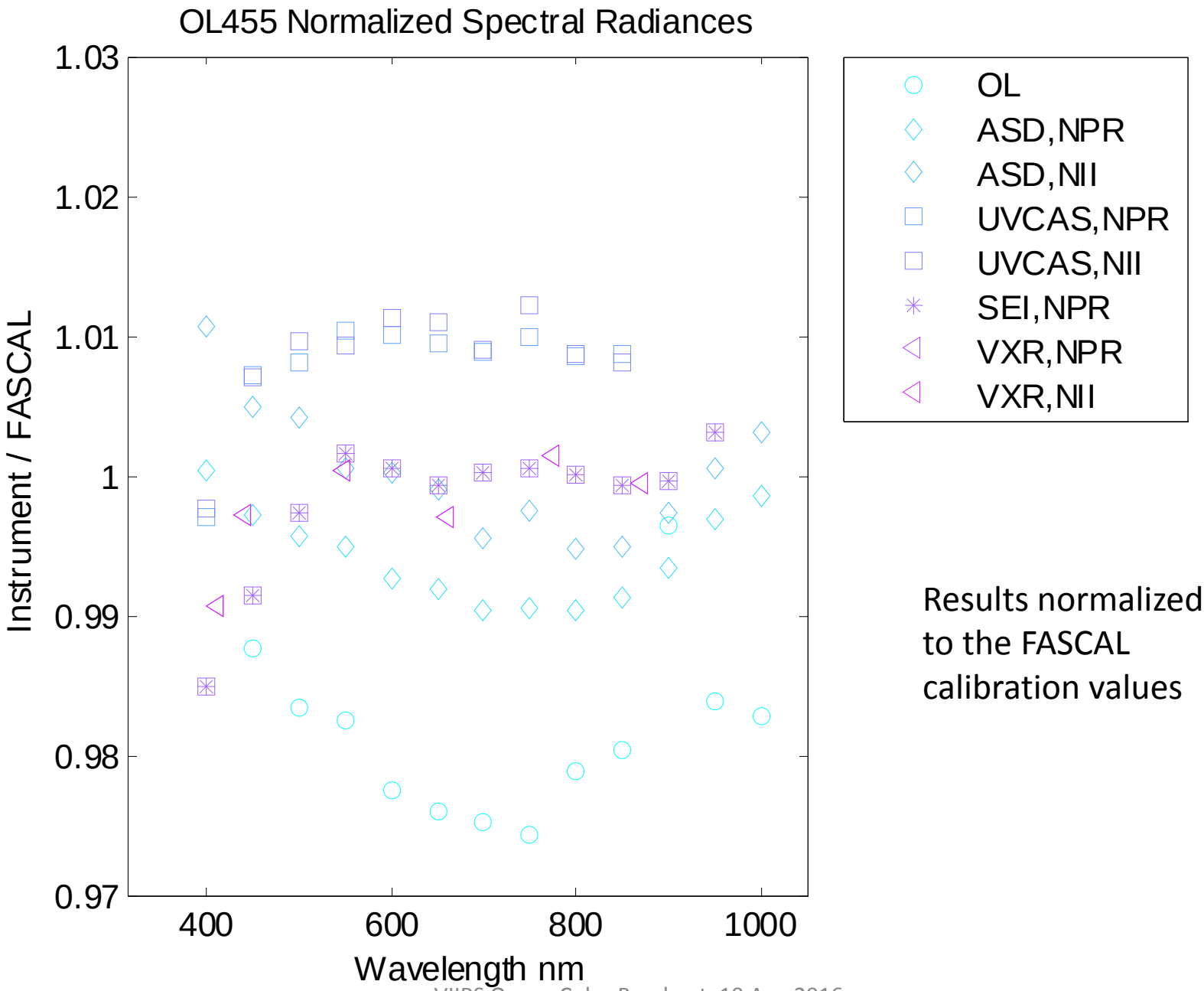

Signal ratios of the OL455 to the RSL NIST Portable Radiance (NPR) sphere source for four transfer radiometers (one filter, three spectrographs).




Signal ratios of the OL455 to the RSL NIST Portable Radiance II (NII) sphere source for three transfer radiometers (one filter, two spectrographs).




Spectral radiances from OL, FASCAL, and the validation in RSL.

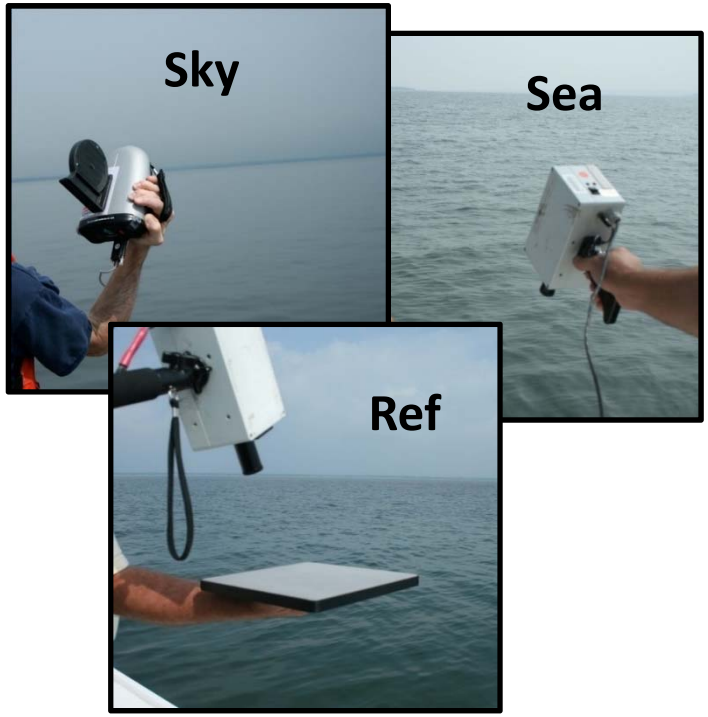



Results normalized to the FASCAL calibration values

# Blue Tile

- Validation of hand-held radiance radiometers and the in-air technique during cruises to determine remote sensing reflectance
- Tasks
  - Measure a reflectance target that differs in BRDF and spectral parameters from the white or gray Spectralon reflectance standard targets
  - Measure the BRDF of this blue tile in NIST and GSFC facilities
  - Independently reduce the Nancy Foster blue tile date

# $R_{rs}$ using Reflectance Standards



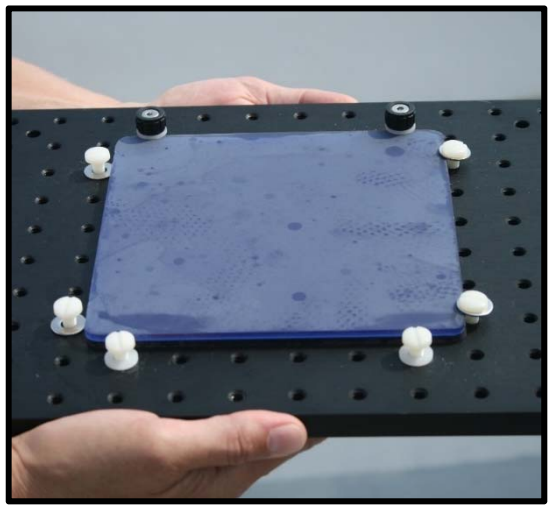

Hand-held, in-air method

Blue Tile measurement equation

$$\rho_{\text{tile}} = \frac{S_{\text{tile}}}{S_{\text{std}}} \frac{E_i(t_{\text{std}})}{E_i(t_{\text{tile}})} \rho_{\text{std}}$$

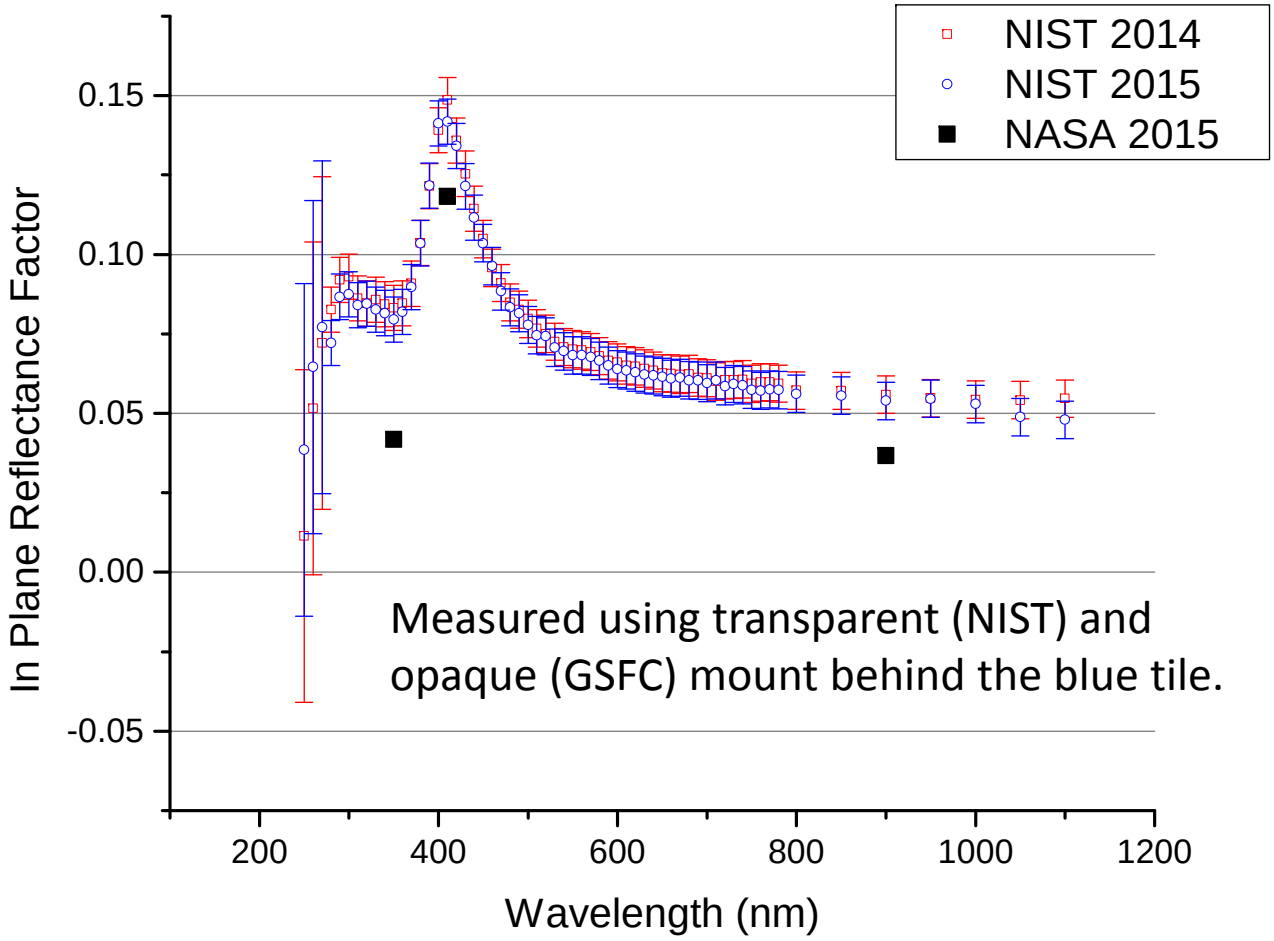
If reference standard is Lambertian, then

$$\rho_{\text{std}} = \rho_{\text{d,std}}(8°, \phi_{\text{i}}; 2\pi)$$



Blue Tile Target: ground blue glass, shown here at the Long Island Workshop

# Blue Tile 0/45 Reflectance Factor



# Independent Analysis

- Status
  - Tested reader for binary files from ASD
  - Automated programs being written to ingest all the raw files and produce tables of header data as an aid to organization
- 2014 Cruise had 1 station, 2015 Cruise has 4 stations
- Poster submitted to OOXXIII

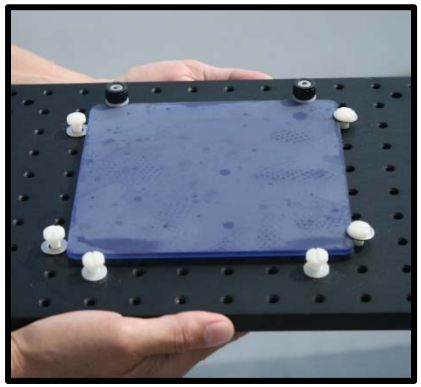
# Upcoming Work

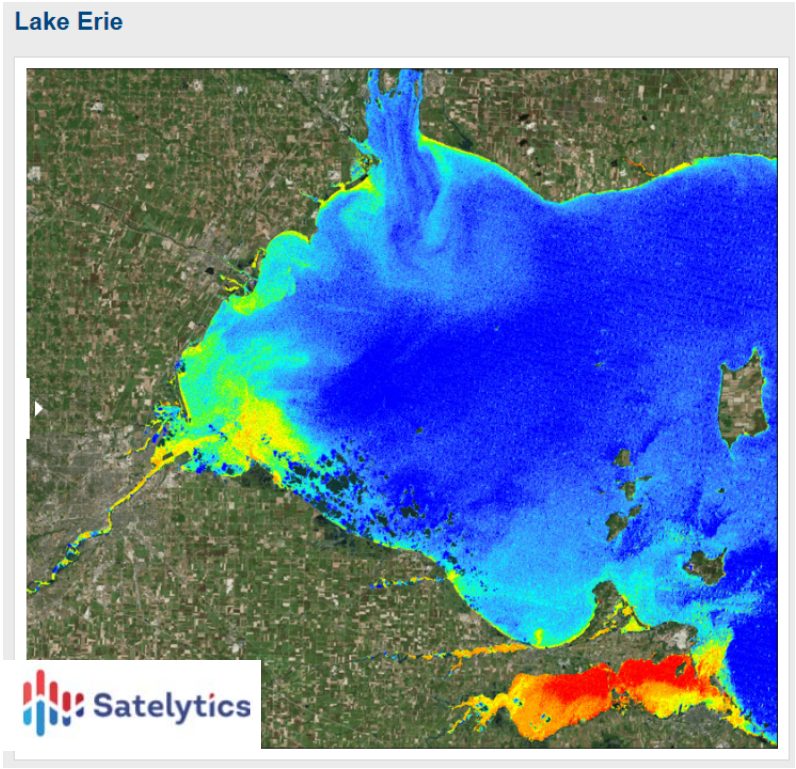
- Archival paper on SeaPRISM080
- Analysis of blue tile for 2014, 2015 cruises
- Validation of NOAA's irradiance bench
- BRDF measurements of blue tile
- Controlled field experiments with the blue tile

# Other Activities

# Emerging Applications of Spectral Remote Sensing

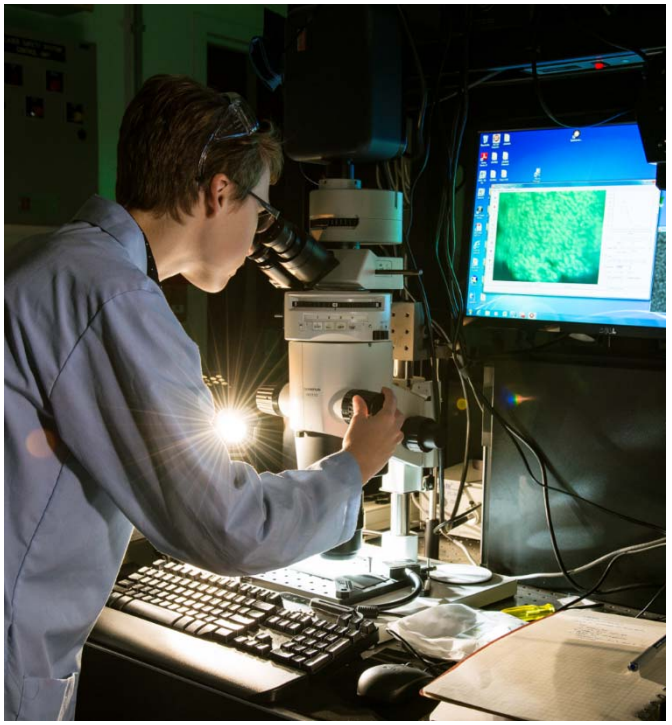
- Custom Data Products (inland bodies of water)
- Need for validation
- End-to-end analysis

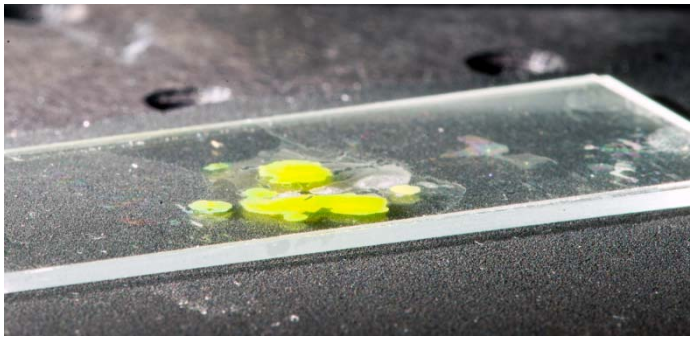




# Remote Sensing of Harmful Algal Blooms (HABs)

- Cyanobacterial blooms have the potential to release harmful toxins into the water
  - Not all species release toxins, and some toxic species do not always produce toxins.
- **Objective**: to determine if there is a way to use hyperspectral remote sensing to identify toxic blooms without physical sampling
- This will be done in part through analysis of algal samples with a hyperspectral microscope.





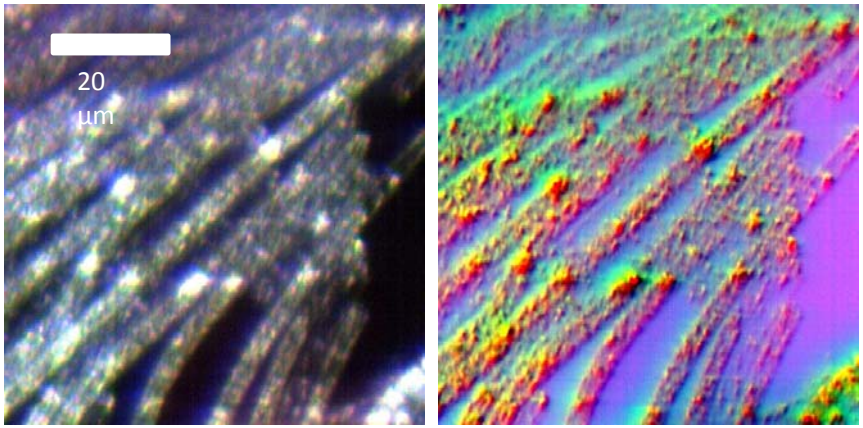
Emily Paine
USGS/NAGT Intern, NIST Guest Researcher

USGS
science for a changing world

# Remote Sensing of HABs

- The resolution of a HS microscope can be used to identify small-scale variations within cells.
- Ideally, this could be used to identify more informative spectral features that could be used to locate blooms that are producing toxins.

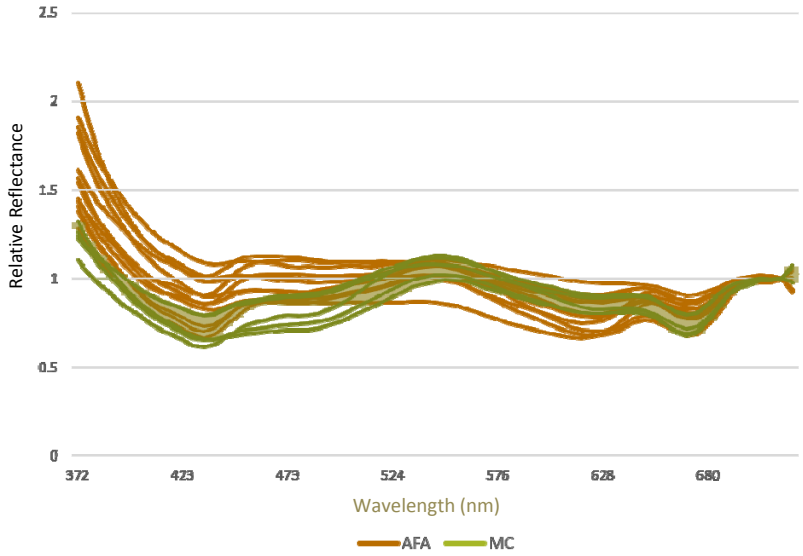
*Aphanizomenon flos-aquae*




True color



PCA Bands 1,2, and 3

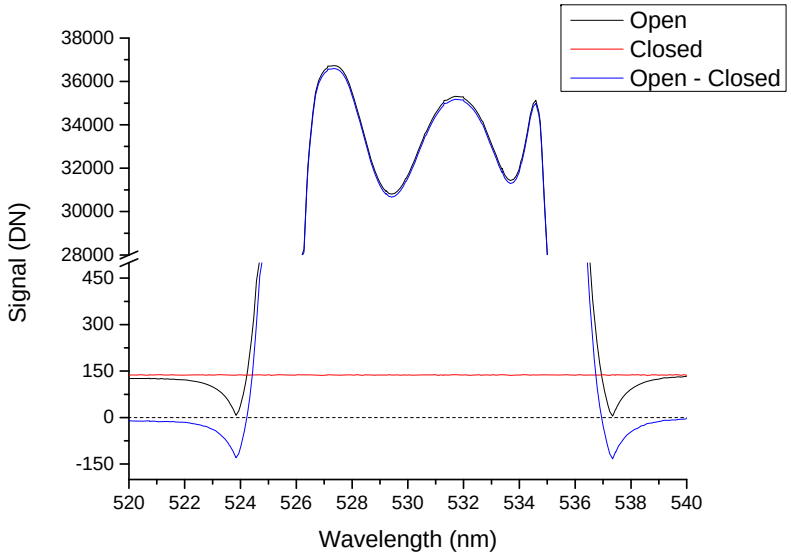



Emily Paine
USGS/NAGT Intern, NIST Guest Researcher

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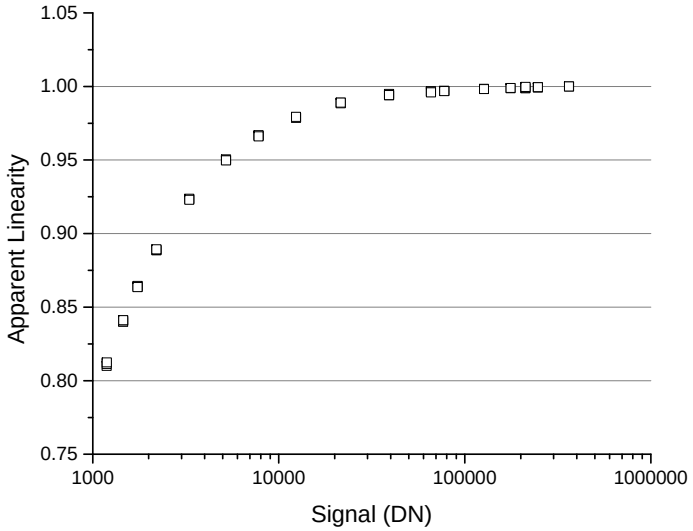
# Back Up Slides

# SeaPRISM Program vs RS232 Commands




Normalized by the SIRCUS sphere monitor photodiode, SeaPRISM signals from 364k DN to 1.2k DN demonstrated a 20% nonlinearity – something never observed during GSFC or JRC characterizations.

SIRCUS laser blocked gave an offset; laser open gave signals that decreased to zero and then increased; hence nets were negative – not physical behavior. The PRS mode on a broadband source gave 0 DN with the source blocked.

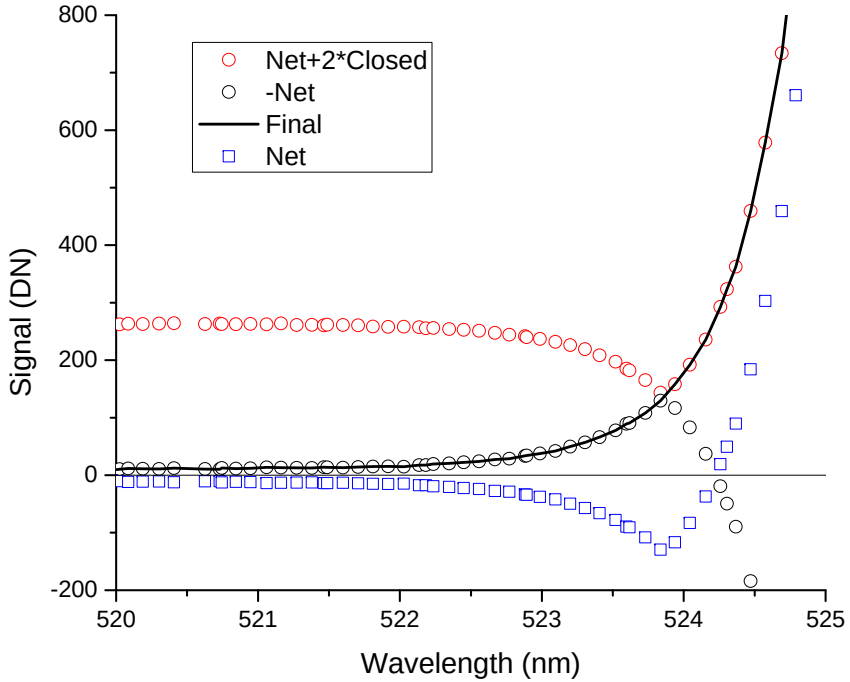



Measurement sequence: @, G, *i* then [Open, C, Close, C, step laser] x *N* times/band

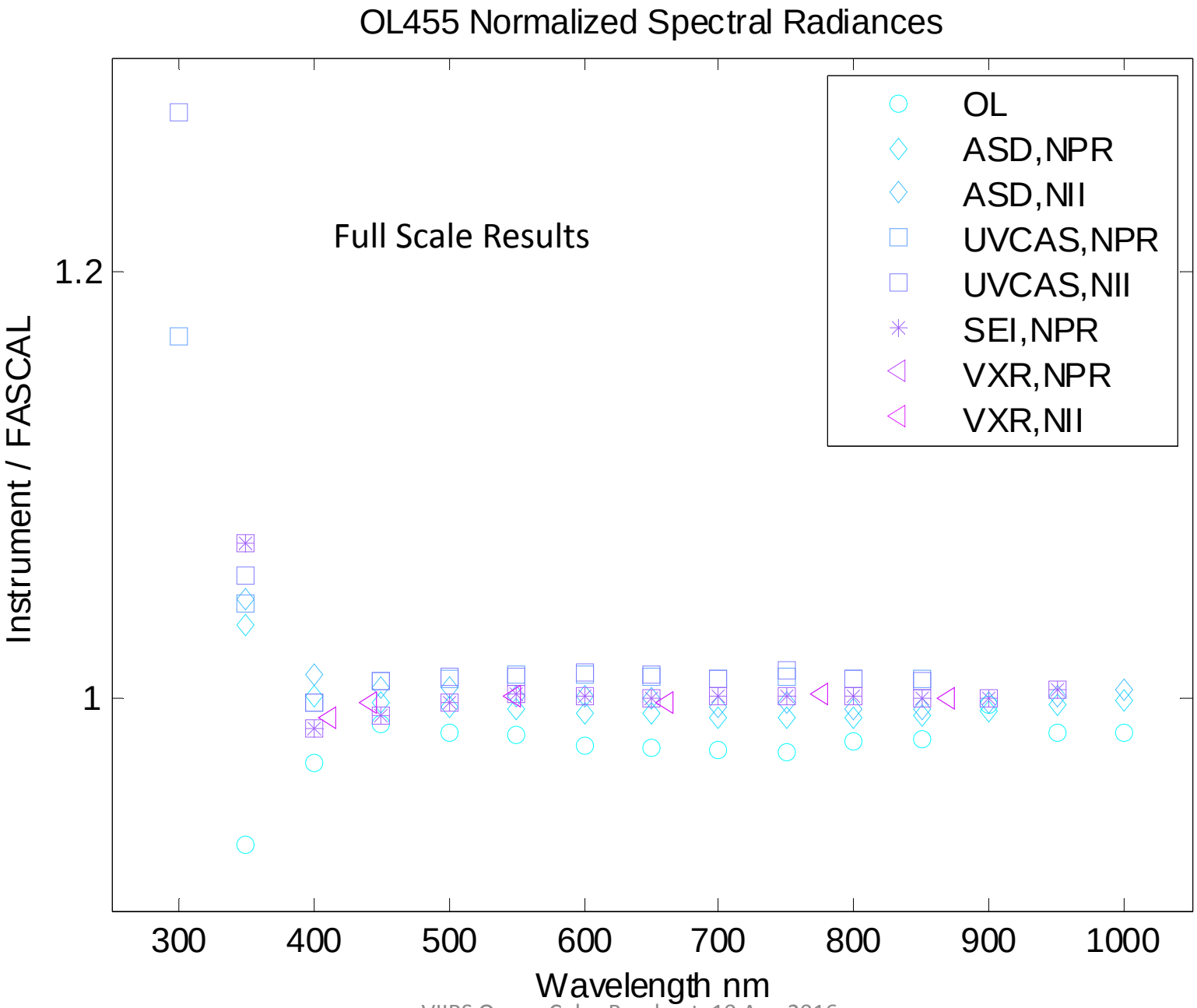
# Correction Model

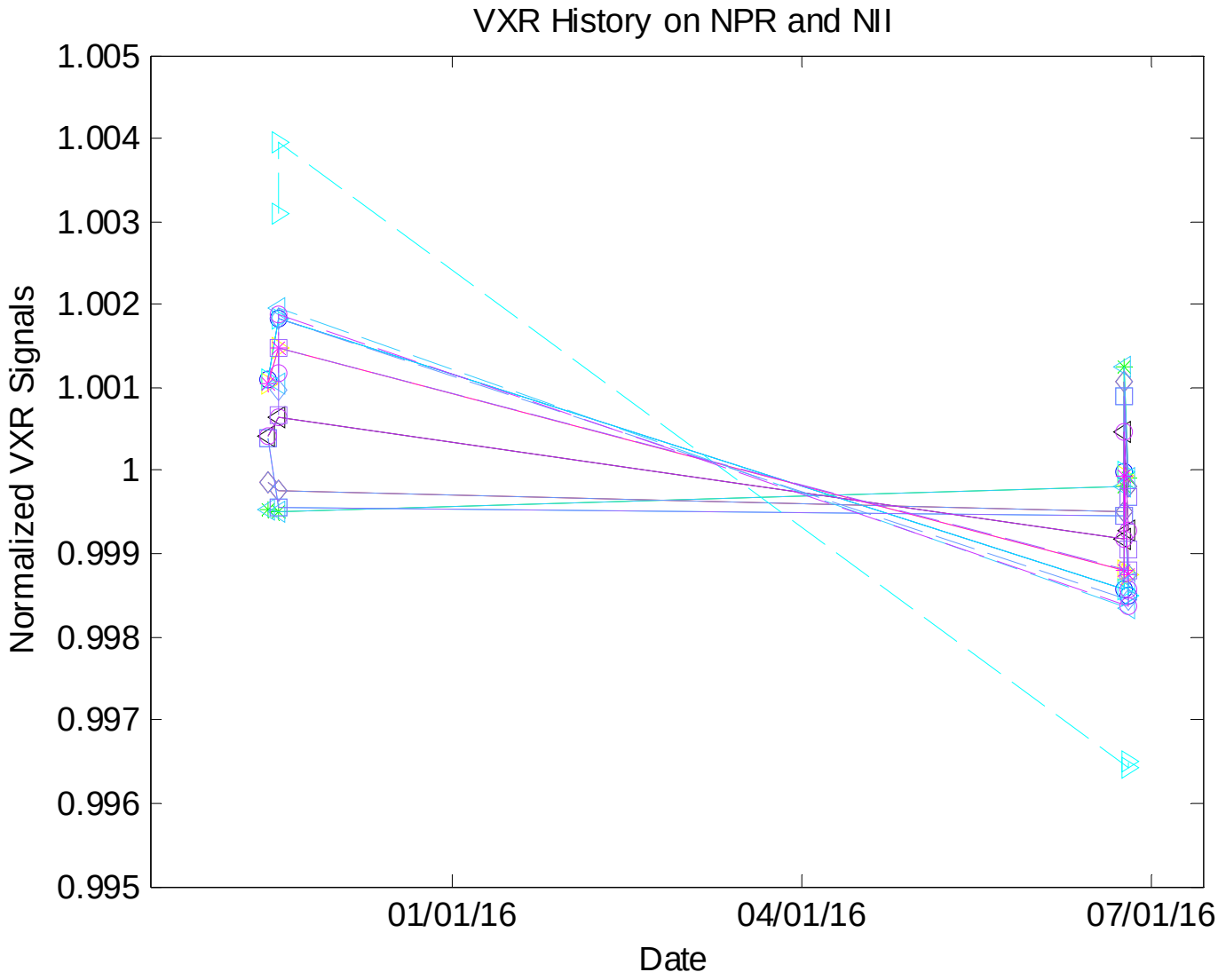
- What if
  - *There is an internal offset $B_{int}$, a positive value in units of DN, that is always subtracted prior to outputting the measurement result; and*
  - *if the result of this internal subtraction is negative, the sign is reversed so that only positive values are output.*
- Identifying $S_{closed}$ with $B_{int}$ allowed us to correct the SIRCUS data

# Ambiguity Exists for Low DN Output




The ambiguity affects the spectral characterization: example: $B_{int}$ = 138 DN, then an output of 2 DN means the signal was either 140 DN or 136 DN due to the internal subtraction and sign reversal. The relative error depends on the signal level – worse case is for zero or $2*B_{int}$. This limits the dynamic range, and measurements of the out-of-band at the system level are not possible.

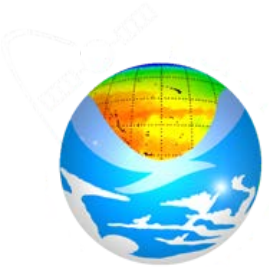

OL455 Normalized Spectral Radiances
Full Scale Results
OL
ASD,NPR
ASD,NII
UVCAS,NPR
UVCAS,NII
SEI,NPR
VXR,NPR
VXR,NII
Instrument / FASCAL
1.2
1
300
400
500
600
700
800
900
1000
Wavelength nm




Normalized ratios of the VXR net signals indicate the stability of the VXR/NPR and VXR/NII systems before and after the FASCAL calibration of the OL455-18.

# Update:
# Monitoring Land-Based Sources of Pollution for US Coral Reef Task Force Priority Watersheds with VIIRS

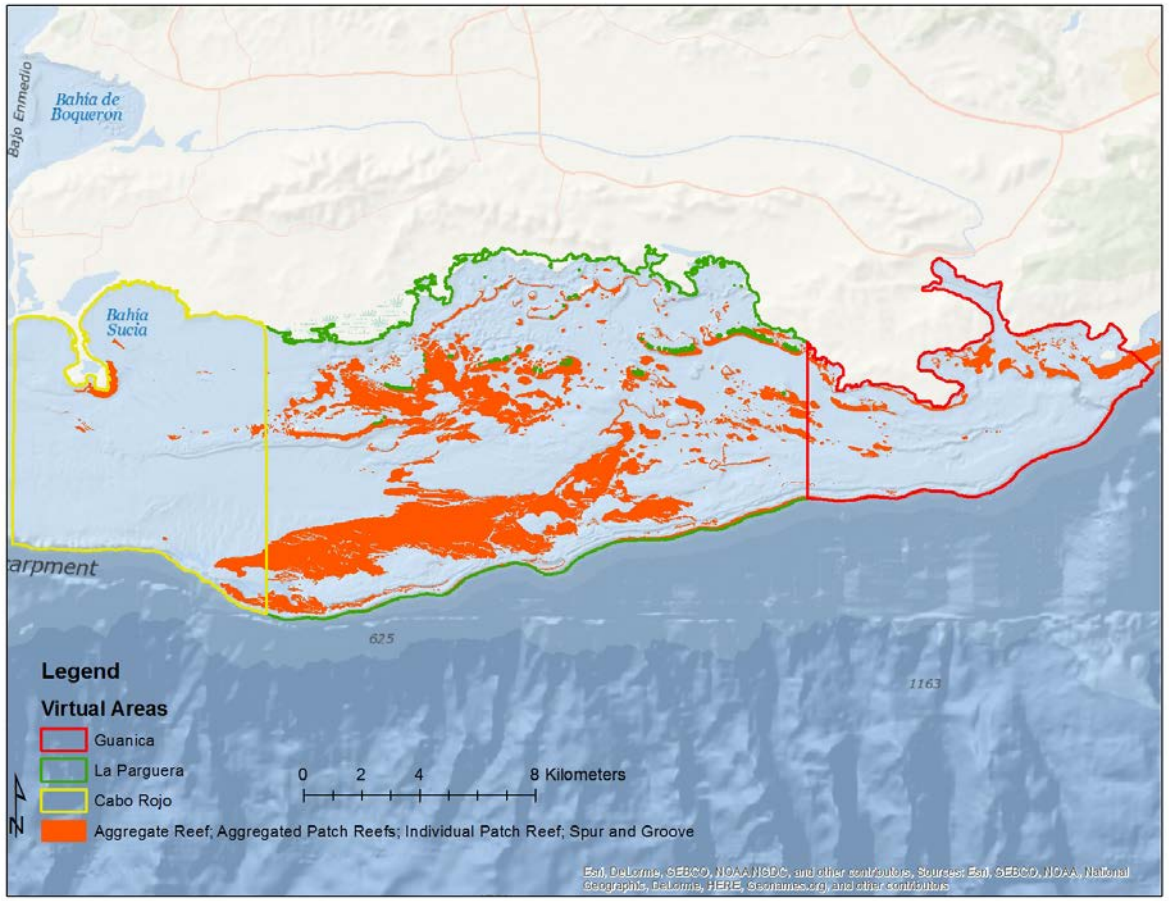
2nd Year: West Maui Expansion Efforts, University of Hawaii Maui College




Alan E. Strong & Rob Warner
with NOAA's Coral Reef Watch
and STAR's Ocean Color Team and NOS/NCCOS
and NOAA's Educational Partnership Program

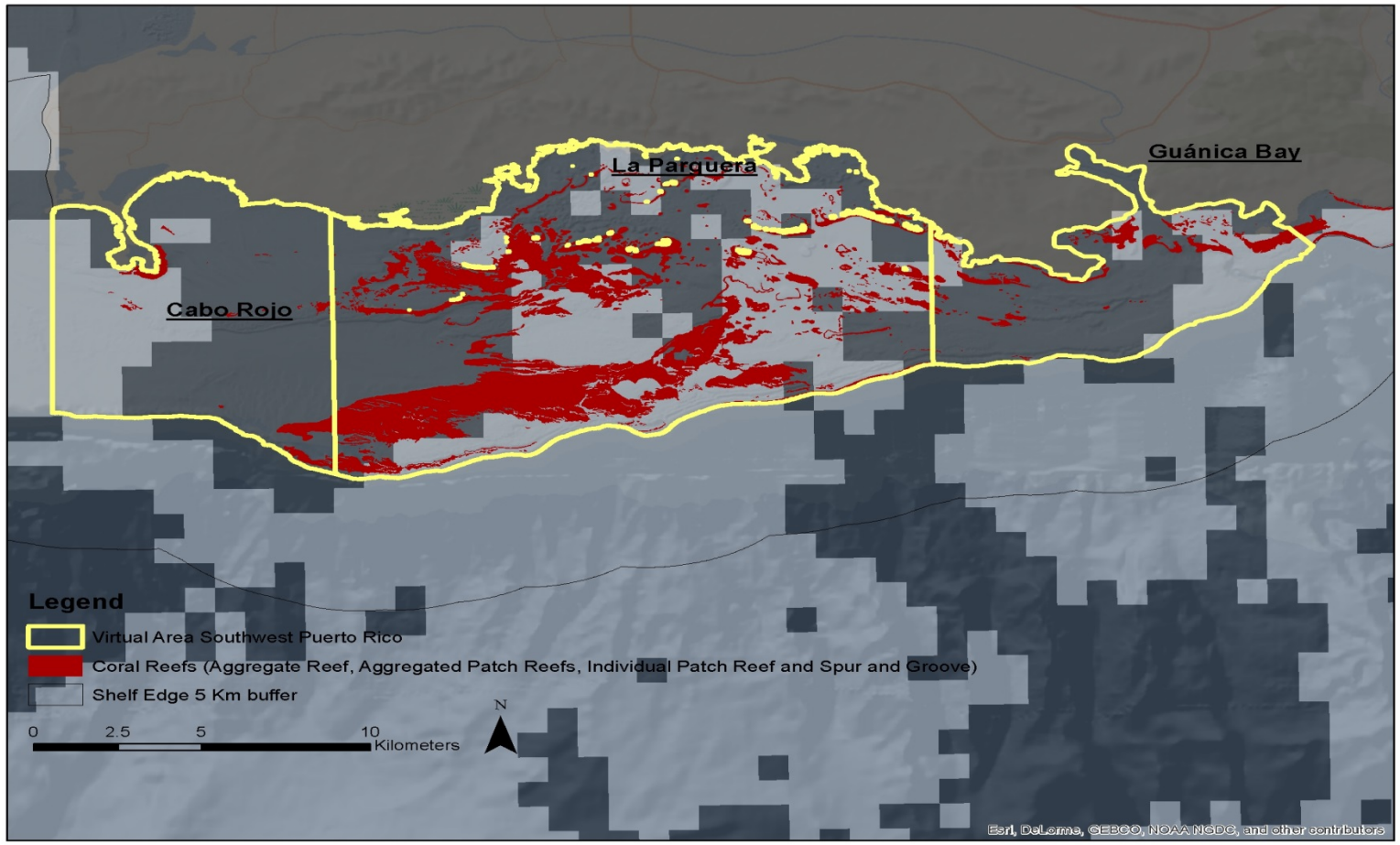

with funding from NOAA's Coral Program and STAR

# Guánica Effluent Virtual Areas



# Guánica Watershed's 3 Virtual Areas

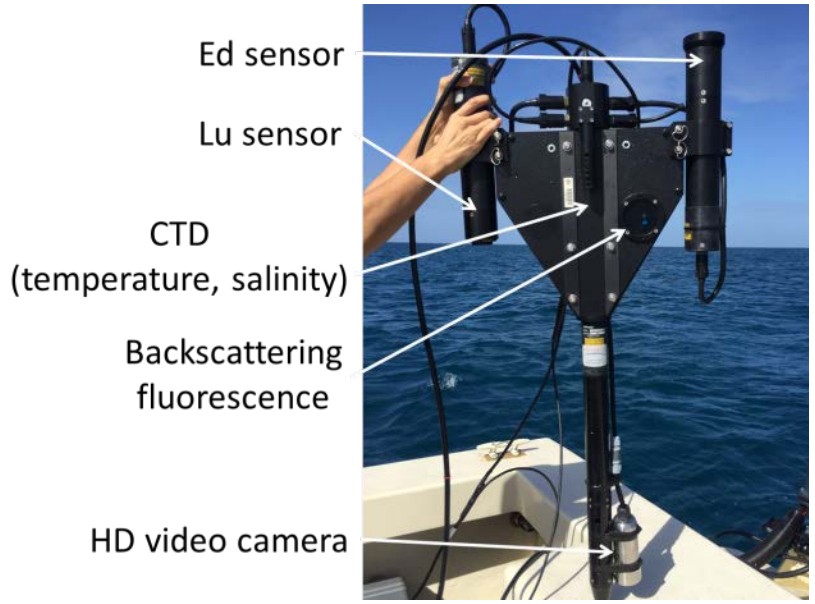
## - with 750m VIIRS pixel overlay



# Bio-Optical Oceanography Laboratory

## Roy Armstrong's BOOL Support

- Simultaneous with Landsat 8 OLI image capture
- Instruments
  - **Satlantic Hyperpro Profiling radiometer (Lu, Ed, Rrs, Lw, Kd)**
  - GER 1500 Spectro-radiometer (Lw, Ed, Rrs)
  - SolarLight Datalogging Radiometer (PAR)
  - Hydroscat-6 (backscattering, fluorescence)
  - SCUFA (fluorescence, turbidity)
  - Water samples
    - CHL, TSS, CDOM






Hydroscat-6

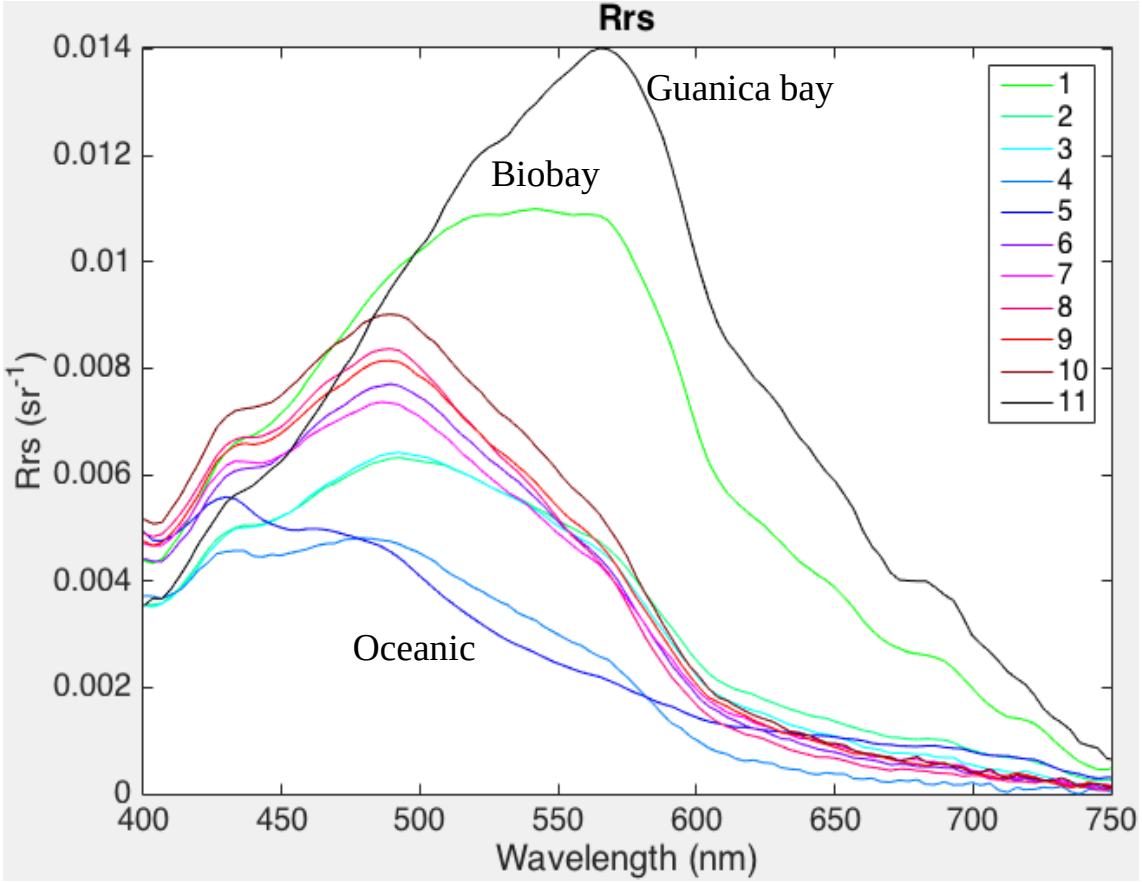


GER1500



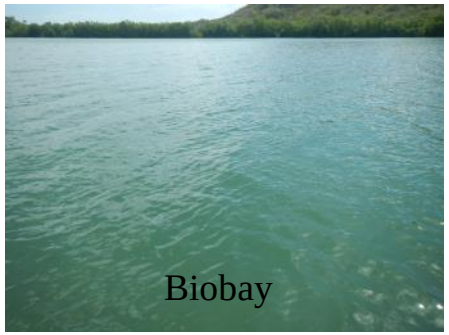

SCUFA

# Satlantic surface remote sensing reflectance












# Virtual Areas for West Maui Watershed (Hawaii)










**Three proposed VIIRS study areas**

- **Point source – Hono Lua (salmon)**
- **Ka'anapali – Kahekili (yellow)**
- **West Maui coast (green)**

# University of Hawaii – Maui College

## Professor Brown's Student Exploratory Team



# West Maui - May 2016

## Local UCSD Local Color Enthusiast & Crew



# Off Ka’anapali Coast – West Maui
# May 2016



# Hotel Complex – West Maui (south)



# Airport Watershed – West Maui (central)



# Study Site:
# West Maui (north)

Wahikuli and Honokowai watersheds

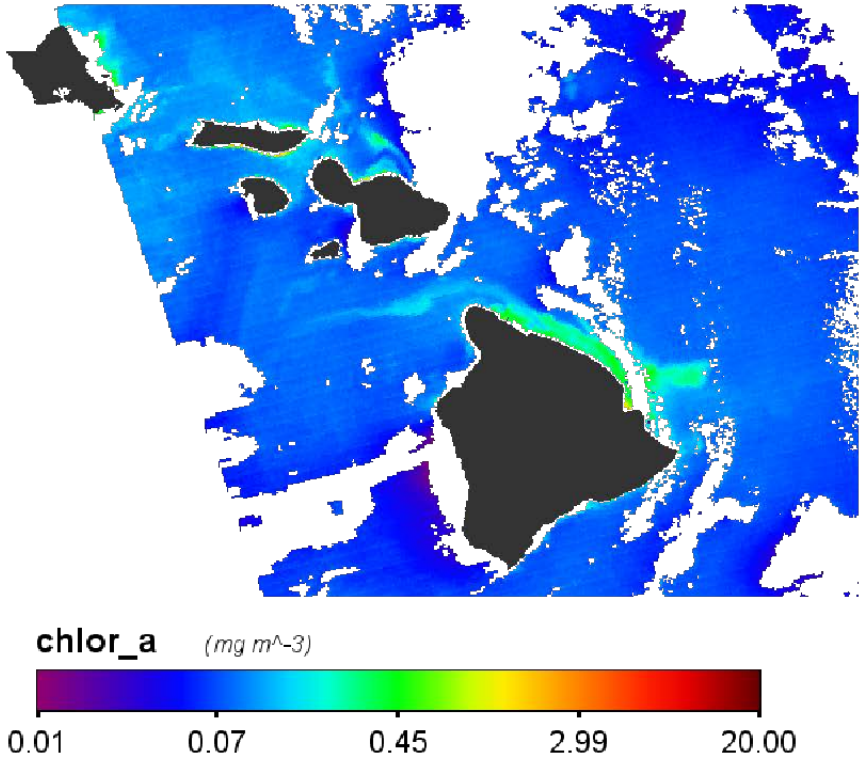


Falinski_IEA_2014

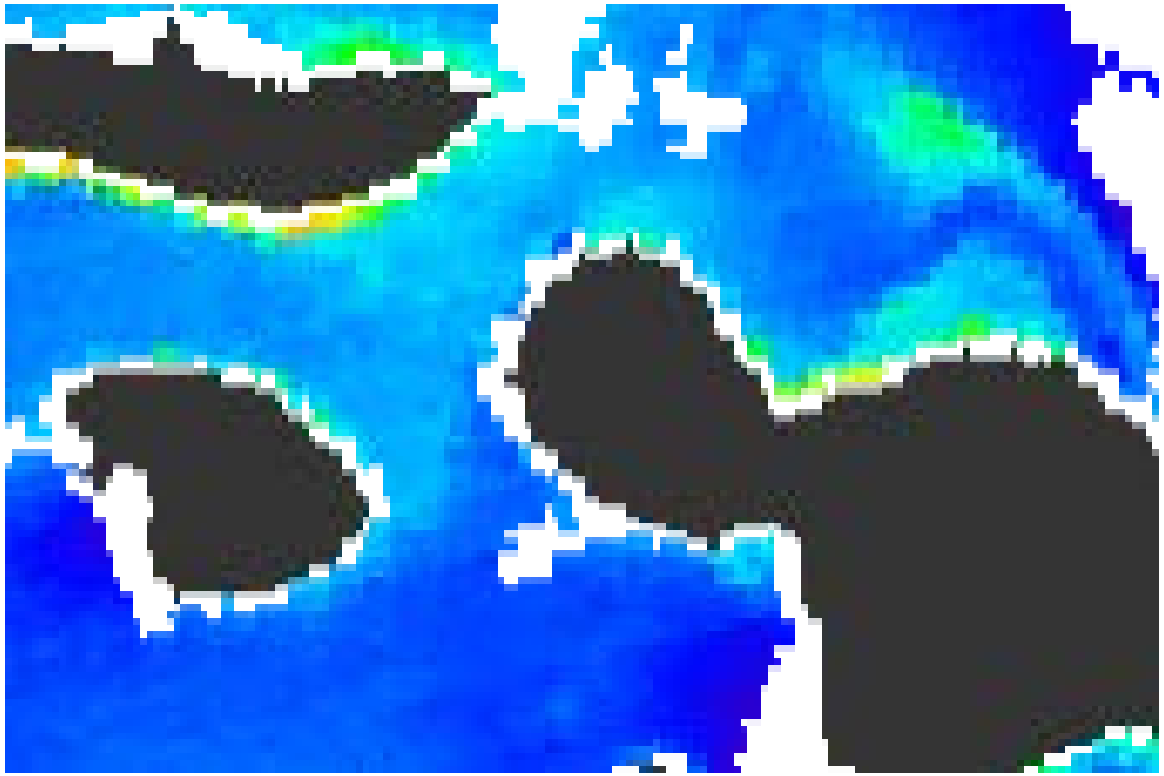
# West Maui (north) Runoff Example



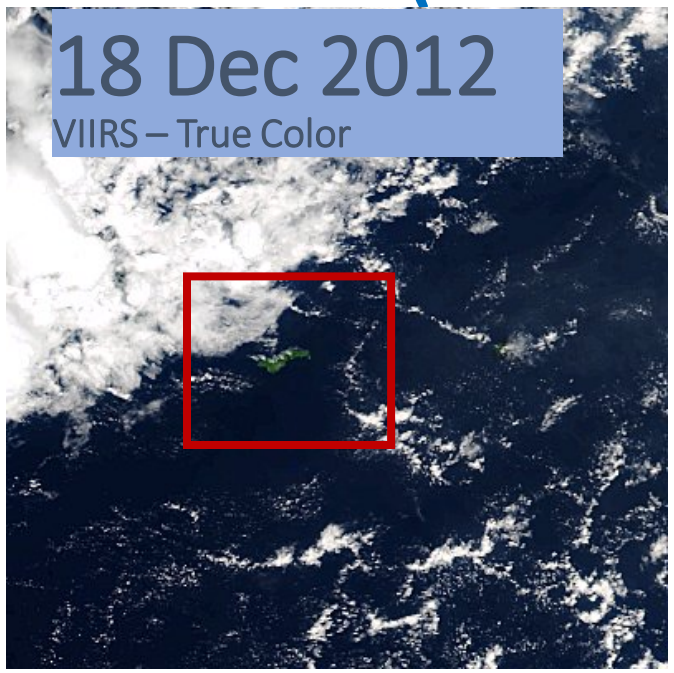
# Following TS Darby – 25 July 2016
# VIIRS Chl-a



# West Maui Watershed – 25 July 2016
# VIIRS Chl-a



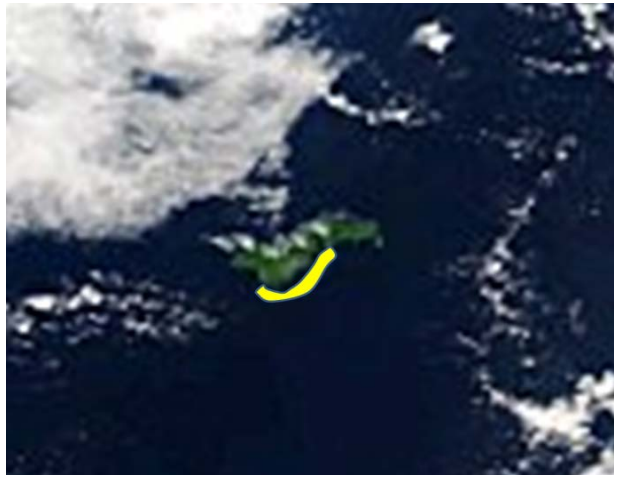
# Virtual Areas for Faga'alu Watershed (American Samoa)




**Three proposed VIIRS study areas for LBSP American Samoa Watershed[s]**

- **Point source – Fa'agalu (salmon)**
- **SW plume:**
  - **Fa'agalu to Fagatele Bay (yellow)**
- **North Coast – Vatia (green)**







# Ocean color, biological heating and upper ocean thermal structure: A sensitivity analysis

Lead PI: Dr. Avichal Mehra[1]

Co-PI's: Drs. Hae-Cheol Kim[2], Eric Bayler[3], David Behringer[2]

Collaborators: Drs. Jim Cummings[4], Zulema Garraffo[2], Sudhir Nadiga[2], Vladimir Krasnopolsky[1], Carlos Lozano[1], Victoria Coales[5], Seunghyun Son[6]

1: NOAA/NWS/NCEP/EMC; 2: IMSG at NOAA/NWS/NCEP/EMC; 3: NOAA/NESDIS/STAR; 4: SAIC at NOAA/NWS/NCEP/EMC; 5: UMD/HPL; 6: CIRA at NOAA/NESDIS/STAR

# Project Descriptions

(Background)

- The NOAA Ecological Forecasting Roadmap (EFR) for 2015-2019 states that its objective is "to provide dependable, higher quality forecast products, derived from the successful transition of research and development into useful applications…."

- In support of the NOAA-approved roadmap, this project proposes to evaluate approaches and develop a prototype foundational global biogeochemical modeling capability for NOAA's global operational Real-Time Ocean Forecast System (RTOFS-Global) for reliably providing the global modeling fields required to support the ecological forecasts of the EFR technical teams

# Project Descriptions

(Background)

- Specifically,
  - ➢ to establish a component for the national modeling 'backbone' that will generate global predictions of the common physical and biogeochemical variables used by ecological forecasts

  - ➢ to address key linkages and gaps within the EFR infrastructure framework via JPSS VIIRS ocean color data and physical-biogeochemical numerical modeling because ocean color data from VIIRS provides a unique path toward ecological forecasting through biogeochemical (BGC) analyses and forecasts, facilitating both real-time and scenario-based marine ecosystem applications

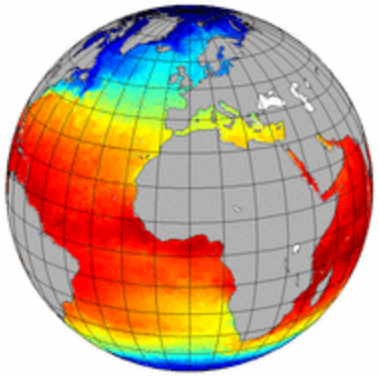
# Scientific Objectives

- Employing coupled BGC-physical modeling to improve NWS forecasting skill at short-term and seasonal scales
  - ➢ by including the effects of biological heating on upper-ocean thermal structure
  - ➢ by exploring the direct assimilation of ocean color products (e.g., VIIRS) in conjunction with radiative transfer (RT) computations using existing validated algorithms (Lee et al., 2005).
- Providing scenario-based forecasting
  - ➢ to predict system responses to potential changes by drivers (natural or through ecosystem management decisions)
- Assessing the effects of carbon dynamics between the atmosphere and the ocean and subsequent changes in the acidity of the global ocean
- Exploring BGC model to support for upper-trophic-level modeling

# Ocean Color and Biological Heating

# Ocean Model

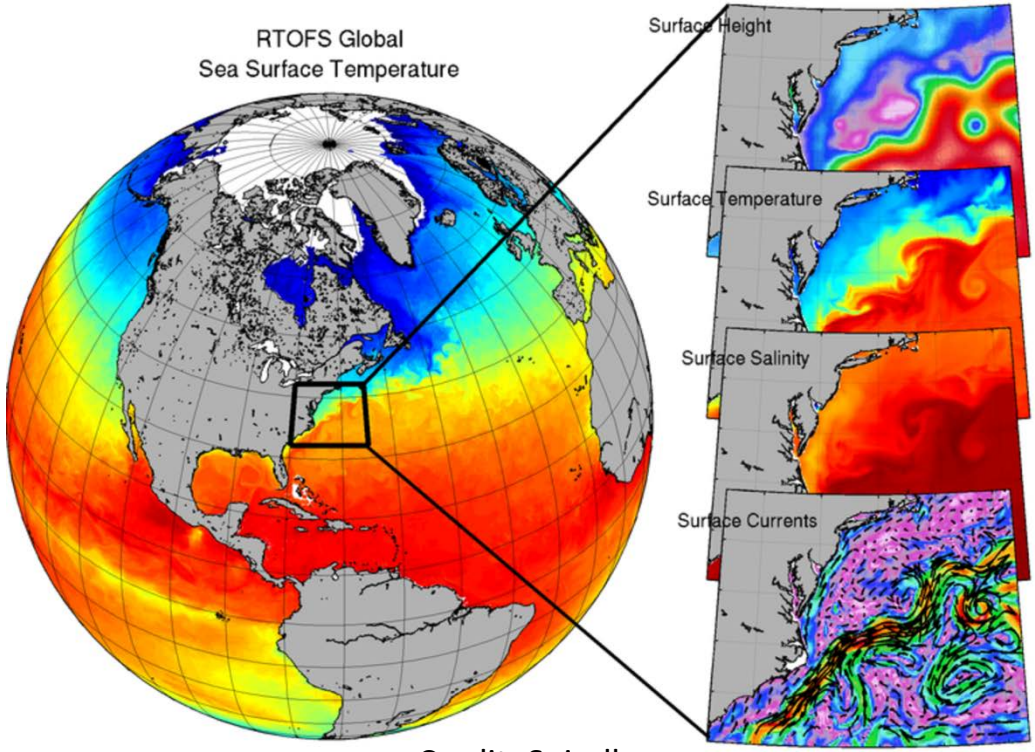
## (HYbrid Coordinate Ocean Model; HYCOM)



Credit: Spindler

- GLBa0.24
  - Hybrid Coordinate Ocean Model (HYCOM) with 1/4° and 32 layers
  - iso-pycnal (deep ocean), z-levels (surface), σ (coasts)
  - Tripole grid (1 at South Pole and 2 from Arctic patches)
  - Recti-linear (<47°N) and curve-linear (>47°N)

- RTOFS-Global (NCEP's operational)
  - HYCOM-base (1/12° and 41 layers)
  - NAVOCEANO daily initialization with MVOI (now 3DVAR) data assimilation from NCODA (Navy Coupled Ocean Data Assimilation)
  - KPP for vertical mixing
  - 2-day nowcast (GDAS) and 6-day forecast (GFS)




Credit: Spindler

# Numerical Experiments

| Experiments | Ocean color product | Sensor | Period | Algorithms |
|---|---|---|---|---|
| **KparCLM** | Long-term climatological $K_{dPAR}$ (Son and Wang, 2015) | SeaWiFS | 1997-2009 | Kara et al. (2004) |
| **ChlaCLM** | Long-term climatological Chl-*a* (O'Reilly et al., 1998) | SeaWiFS | 1997-2009 | Lee et al. (2005) |
| **ChlaID** | Interannual mean Chl-*a* (O'Reilly et al., 1998) | SeaWiFS | Each year (2001 – 2009) | Lee et al. (2005) (diurnal variation of solar zenith angle) |
| **ChlaIND** | Interannual mean Chl-*a* (O'Reilly et al., 1998) | SeaWiFS | Each year (2001 – 2009) | Lee et al. (2005) (no diurnal variation of solar zenith angle) |

- KparCLM vs. ChlaCLM: algorithmic differences
- ChlaCLM vs. ChlaID: mesoscale variabilities
- ChlaID vs. ChlaIND: diurnal variabilities and short-term scale effects

# Configurations

- SeaWiFS ocean color data, combined with hourly CFSR (Saha *et al*., 2010) with additional flux correction, were used to hindcast ocean state 2001-2009

- The optical algorithm (CHL) is a two-band scheme for CASE 1 waters (Lee *et al*., 2005) newly implemented in the latest HYCOM source code version (src2.2.98)

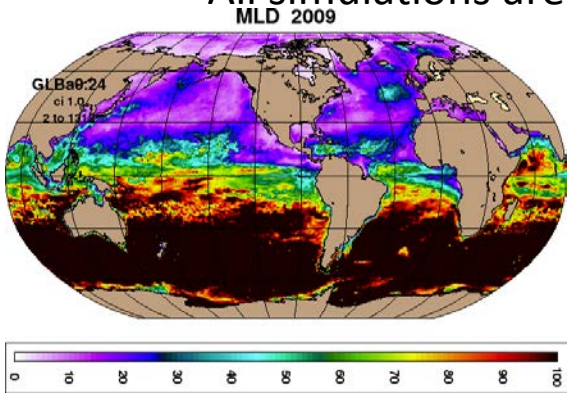
- The two-bands include the visible (VIS; 400-700 nm) and red bands (IR; 700-2000 nm)

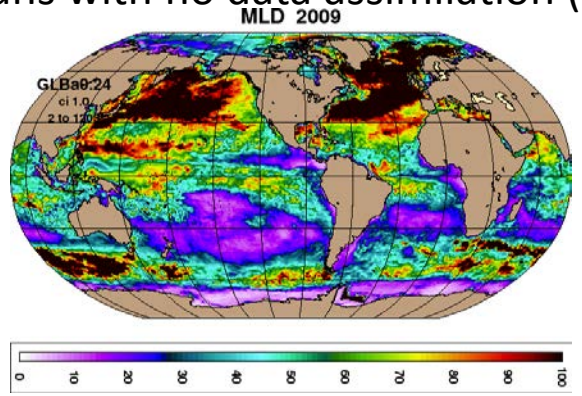
- Required input are:

  - Total absorption coefficient at the surface for 490 nm ($a_{490}$, $m^{-1}$)
  - Total backscattering coefficient at the surface for 490 nm ($b_{b490}$, $m^{-1}$)
  - These inherent optical properties (IOP's) are functions of chlorophyll and pure water
  - $K_{VIS}(IOP,z)=K_1(IOP,\theta_a)+K_2(IOP,\theta_a)/(1+z)^{0.5}$
  - $K_{IR}(z,\theta_a)=[0.56+2.304/(0.001+z)^{0.65}](1+0.002\theta_a)$
  - Considered valid for global, basin-scale oceanography

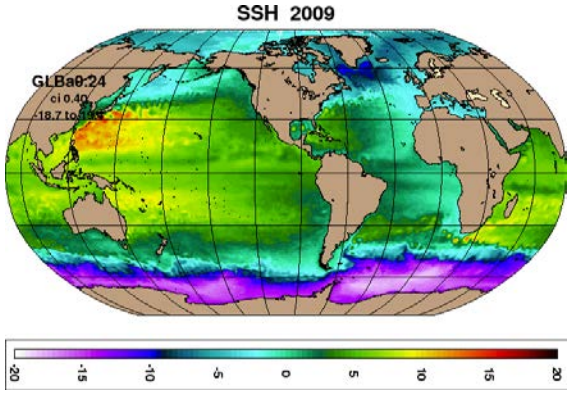
# Simulations (2001-2009)

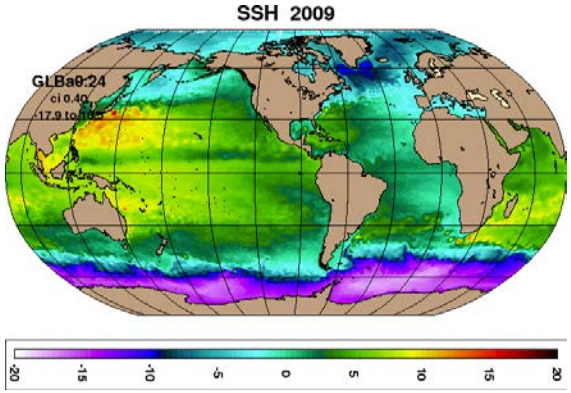
- All runs are initialized at Jan. 1, 2001
- All simulations are free runs with no data assimilation (2001-2009)



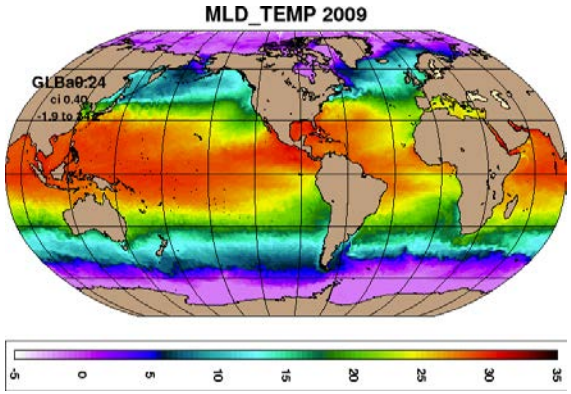



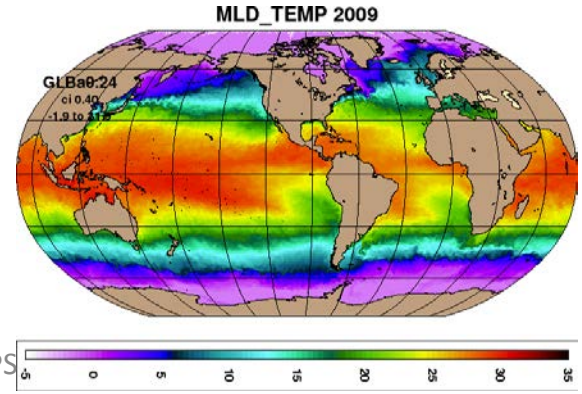

Mixed Layer Depth (MLD)



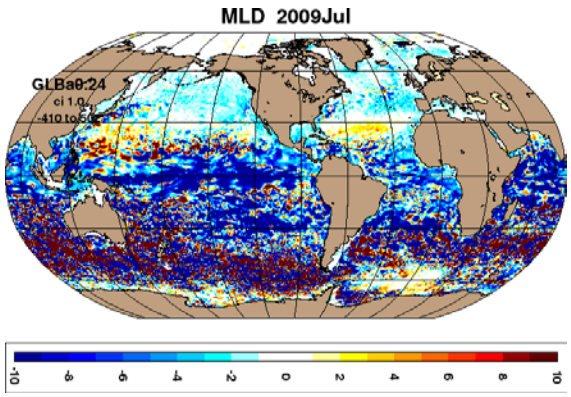

Sea Surface Height

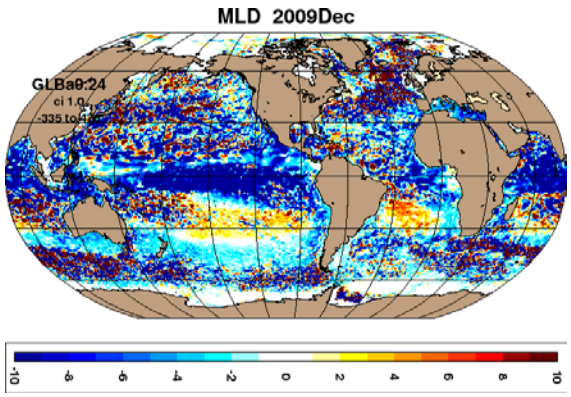


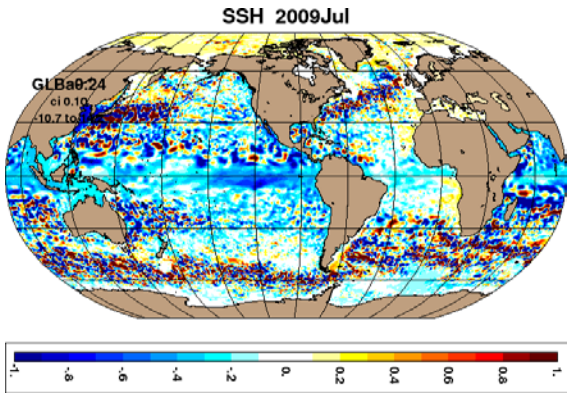

MLD-averaged Tempearture

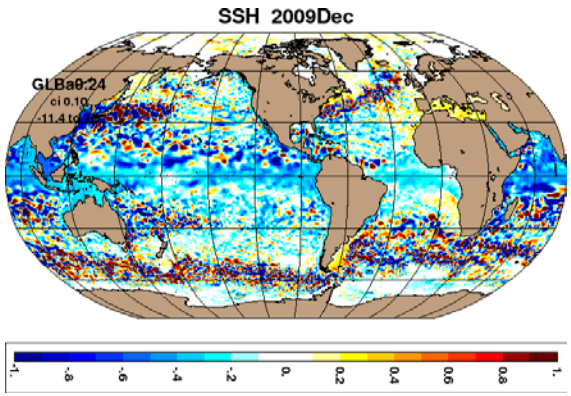
# KparCLM minus ChlaCLM
## (Algorithm Difference)



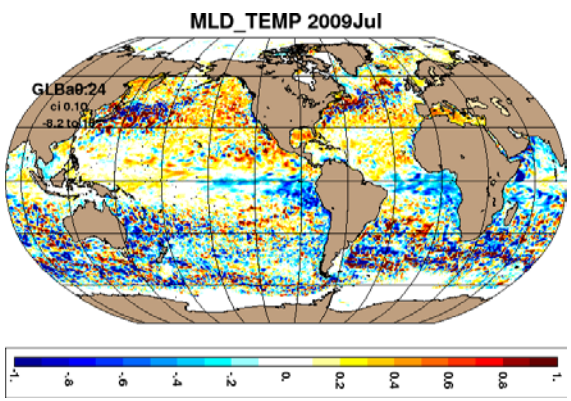



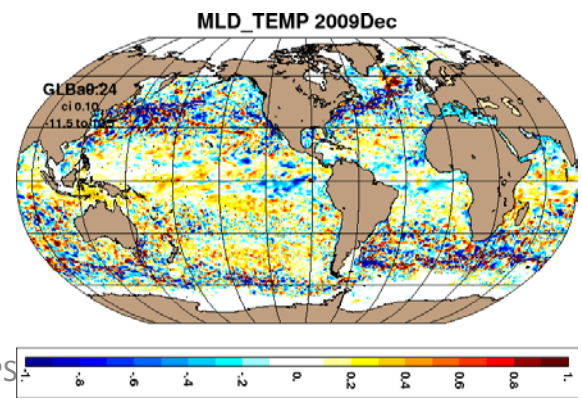

Mixed Layer Depth (MLD)



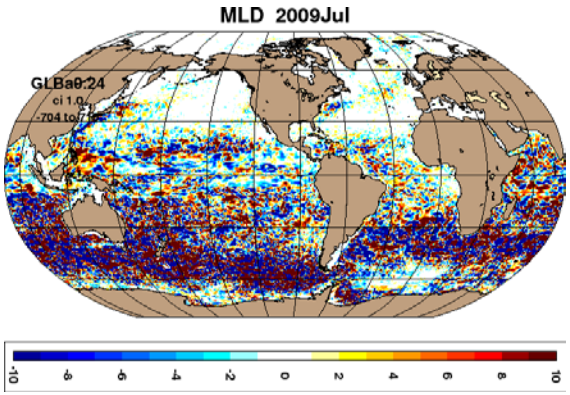

Sea Surface Height

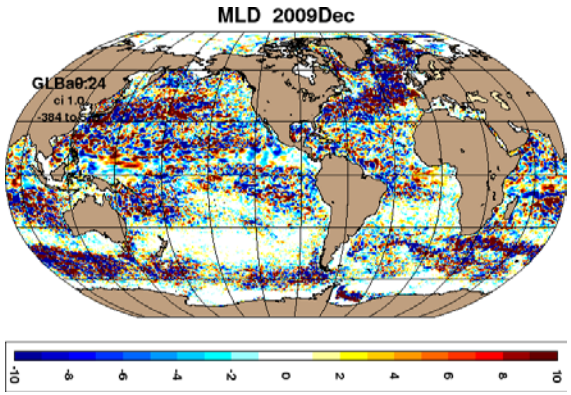


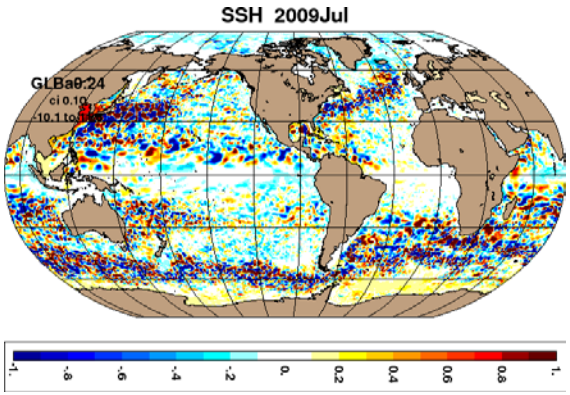

MLD-averaged Tempearture

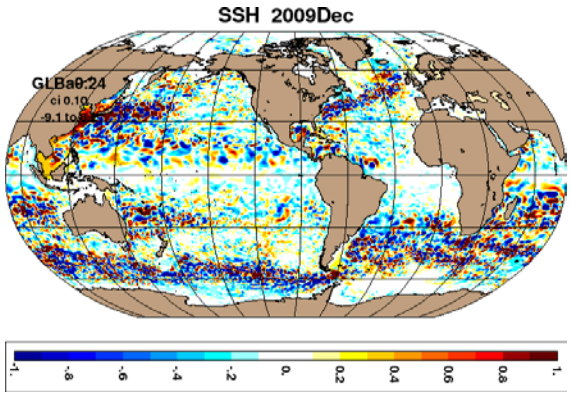
# ChlaCLM minus ChlaID
## (mesoscale variabilities)



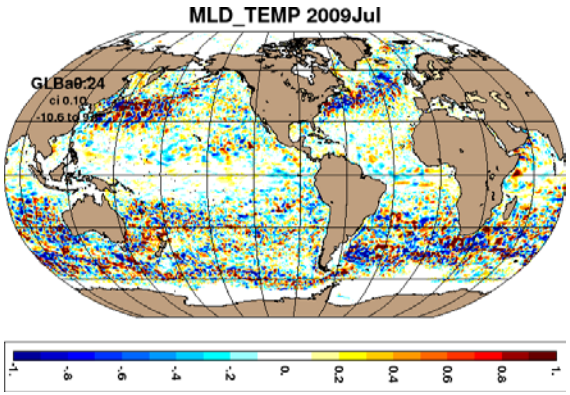



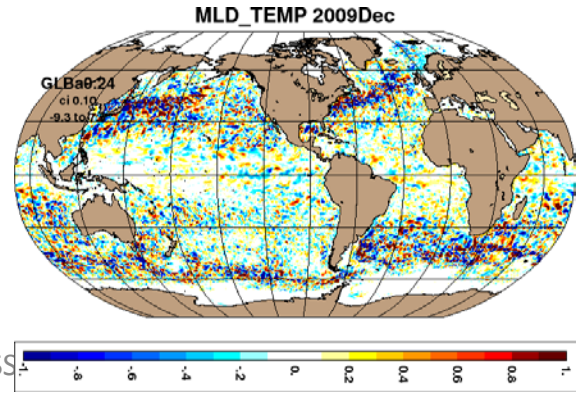

Mixed Layer Depth (MLD)




Sea Surface Height

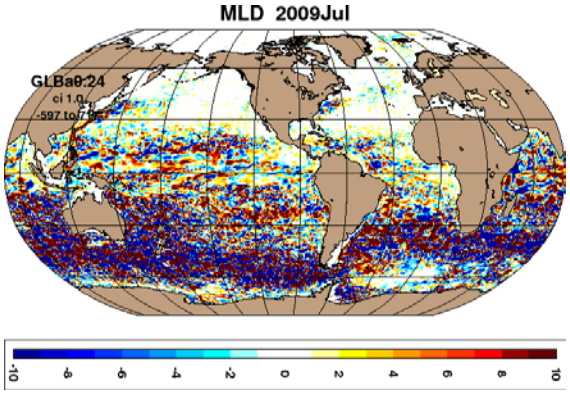


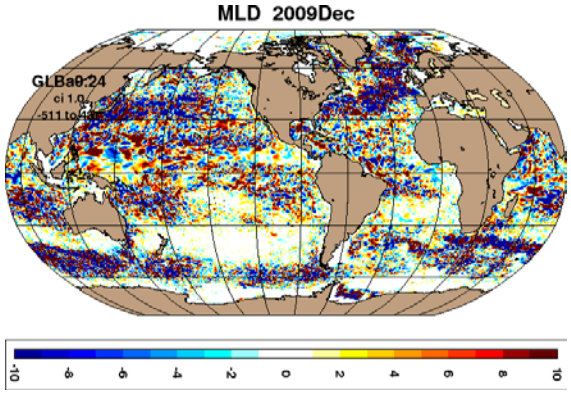




MLD-averaged Tempearture

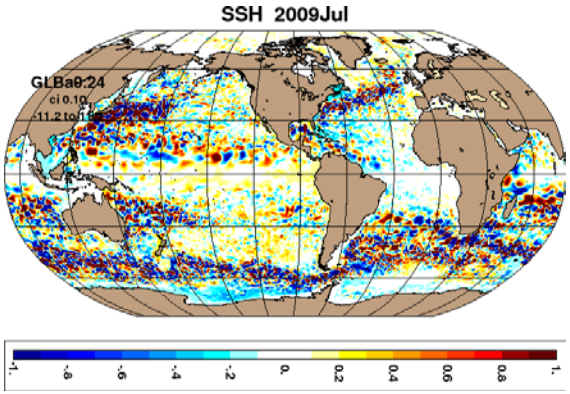
# ChlaID minus ChlaIND

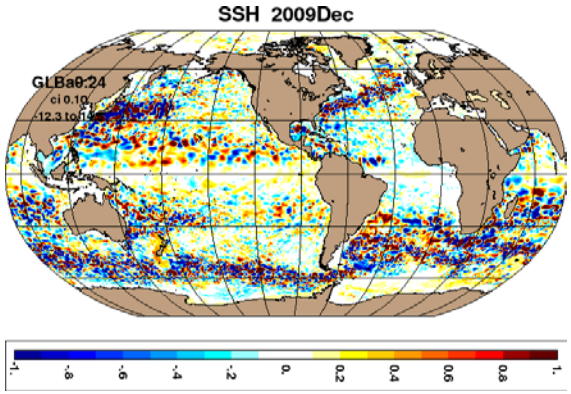
## (diurnal variabilities of solar zenith angle)



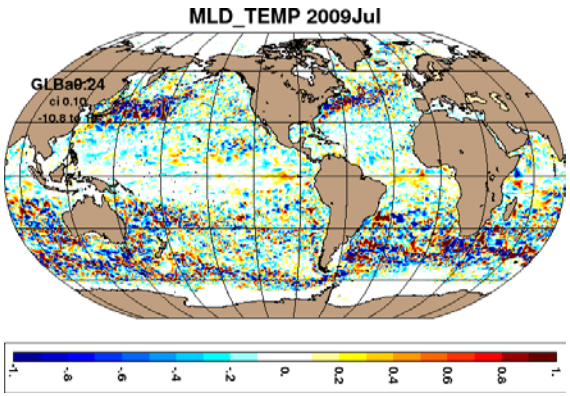



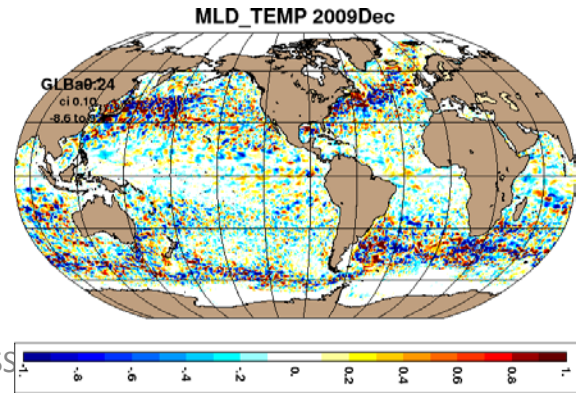

Mixed Layer Depth (MLD)



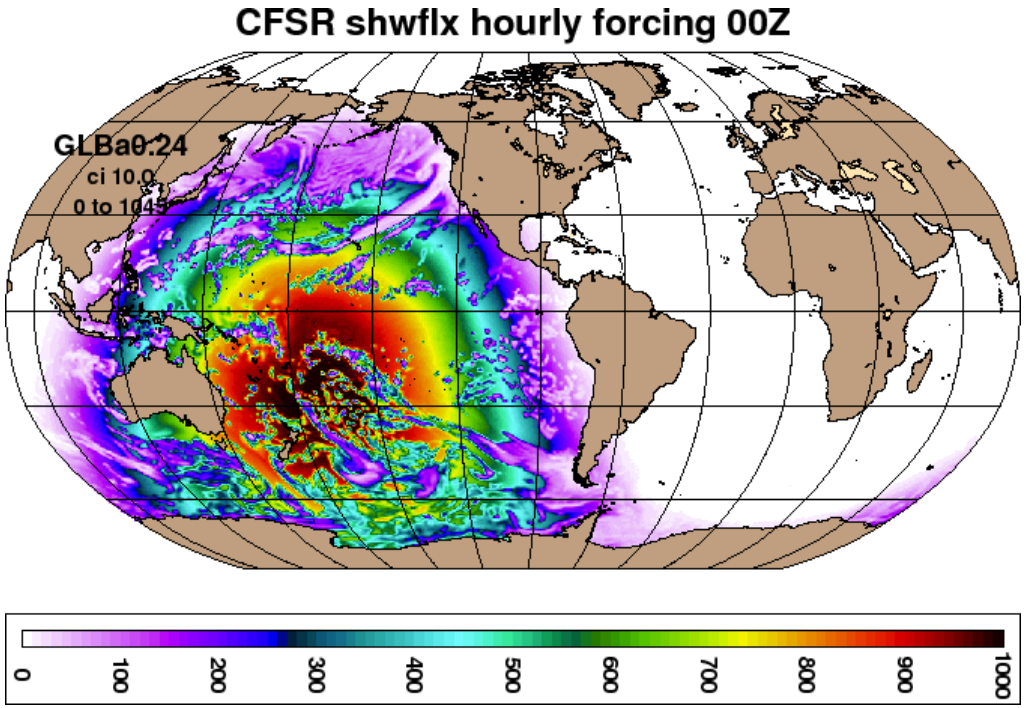

Sea Surface Height

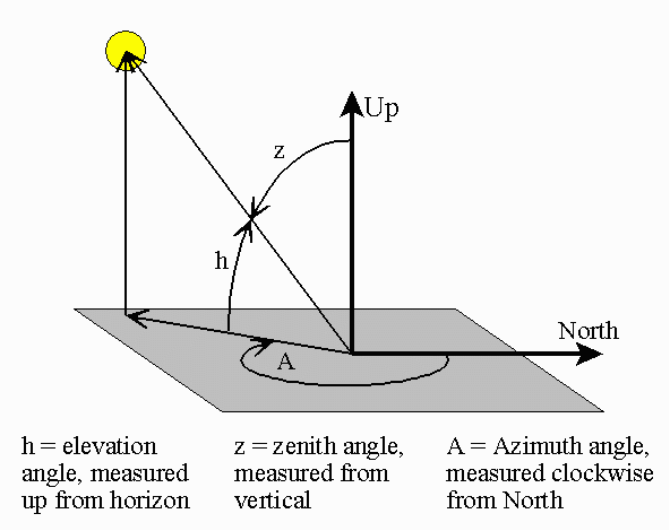



MLD-averaged Tempearture

# Diurnal variation of surface forcings



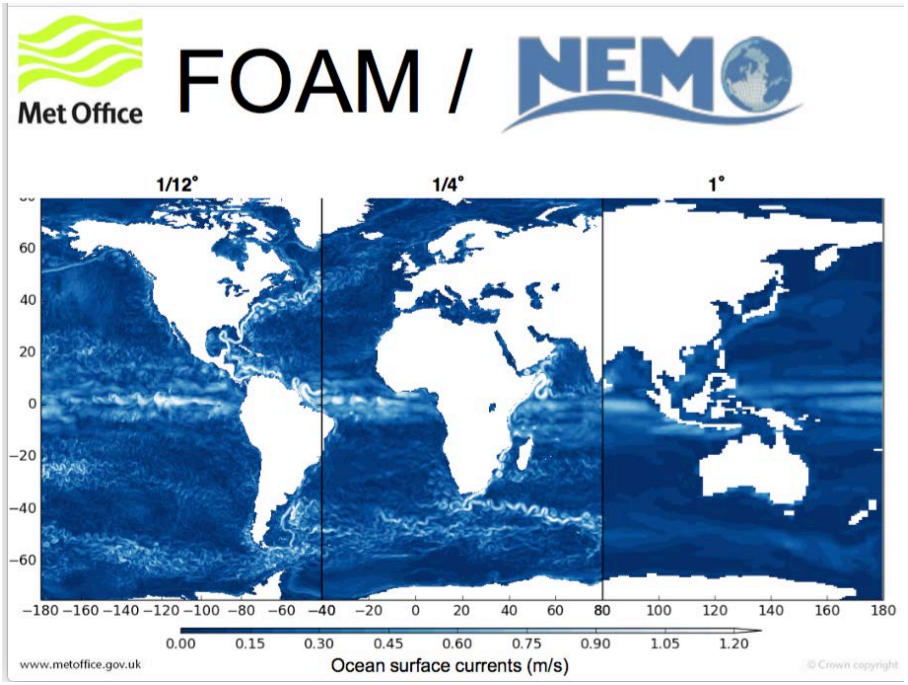

Credit: ESRL (www.esrl.noaa.gov)

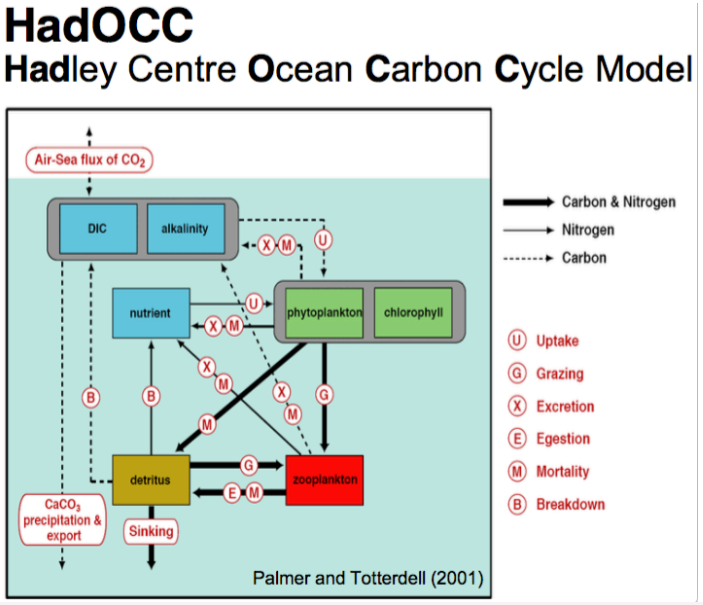
- Diurnal variation effect of in-water solar zenith angle is significant and should be considered (especially, when high frequency forcings are used)

# Ecological Forecasting

# Ecological Forecasting

## (Efforts in Europe: e.g., U.K. Met Office)

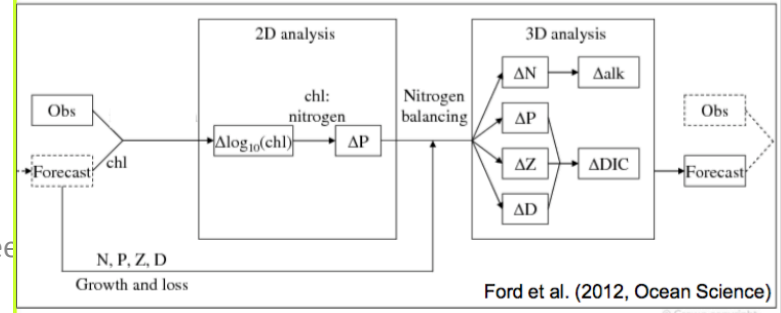



Forecasting Ocean Assimilation Model recently transitioned to Nucleus for European Modeling of the Ocean as a core ocean modeling component

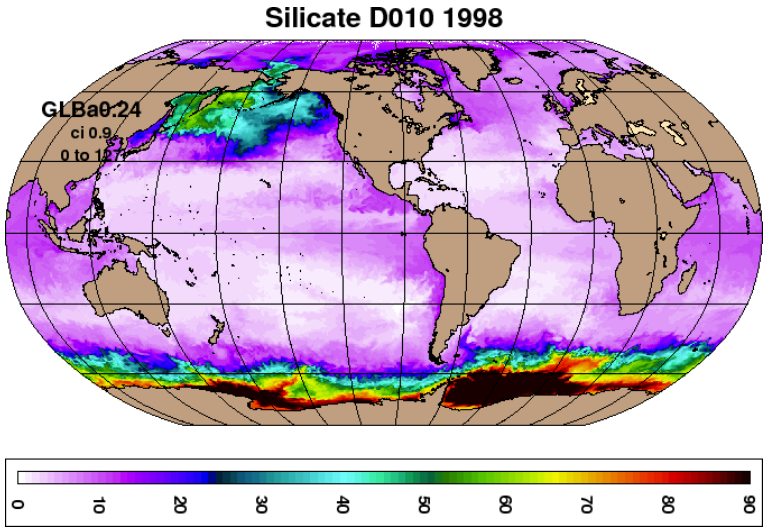
## Ocean colour data assimilation

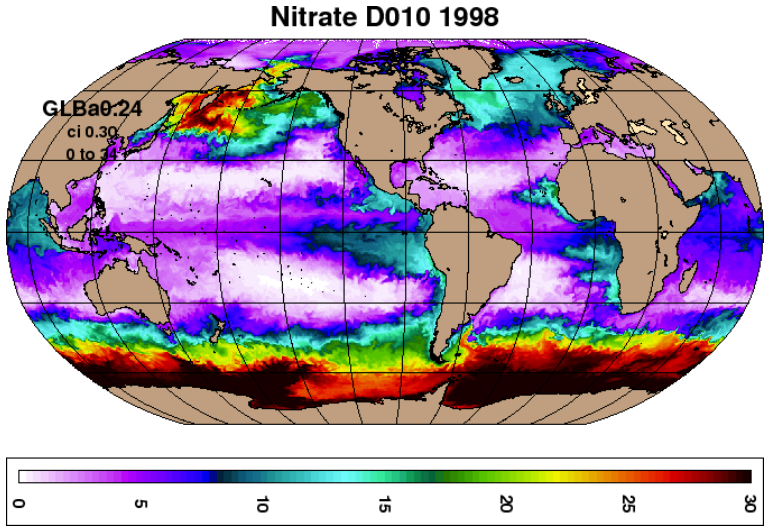
- Surface $\log_{10}$(chlorophyll) increments produced by 3D-Var (NEMOVAR)
- All 3D biogeochemical state variables updated by nitrogen balancing (Hemmings et al., 2008)

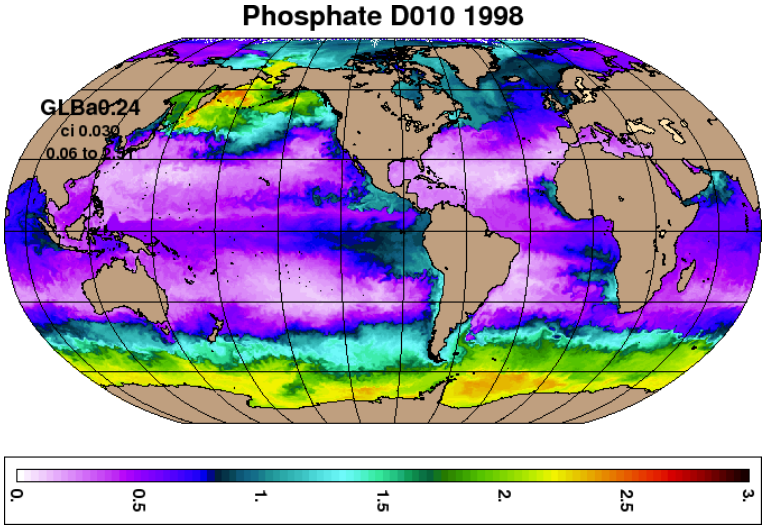


# Ecosystem Model

- A testbed region (GLBa0.24) was made and set up for implementation of on-line coupling of NPZD-type ecosystem models

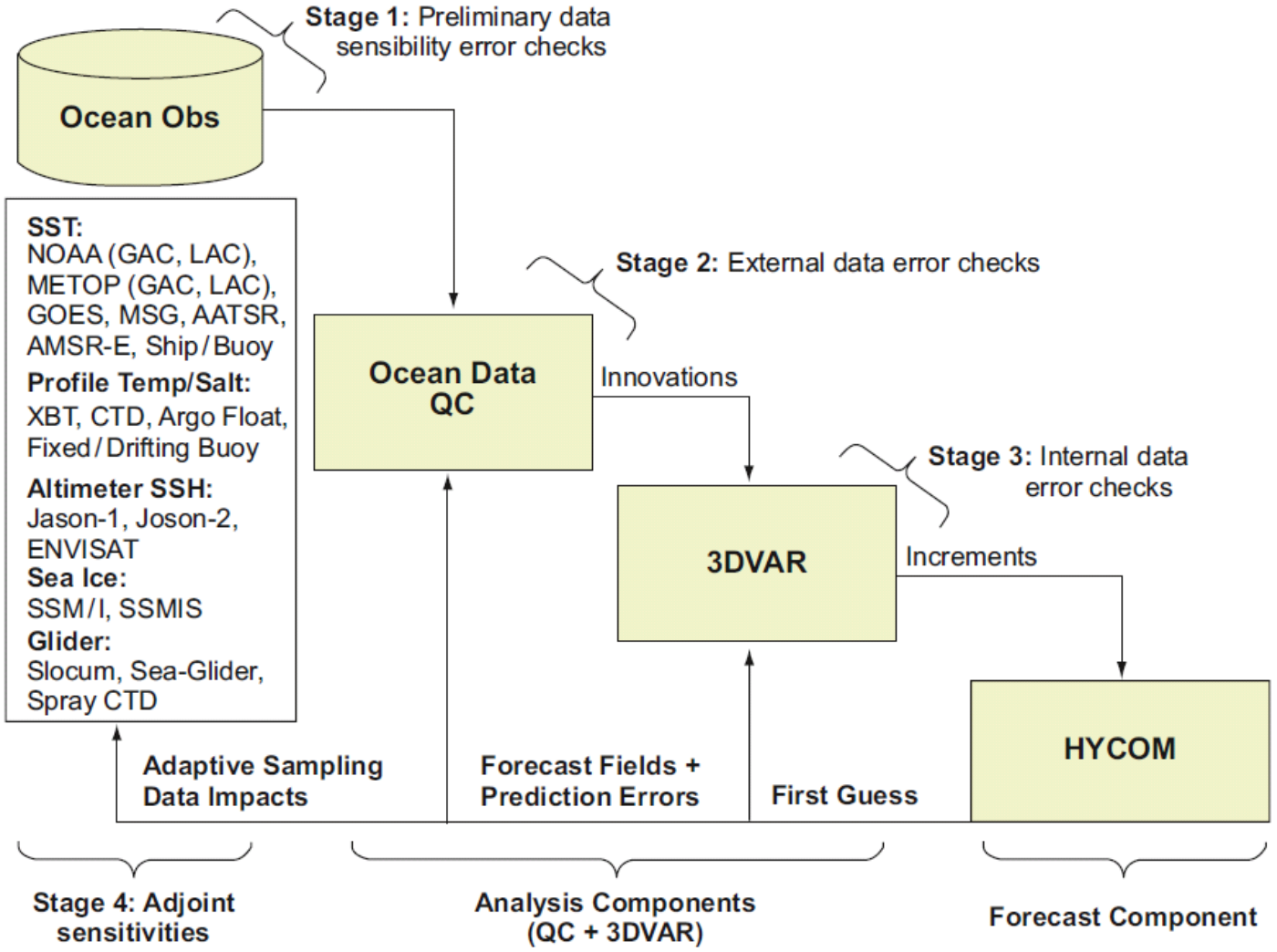


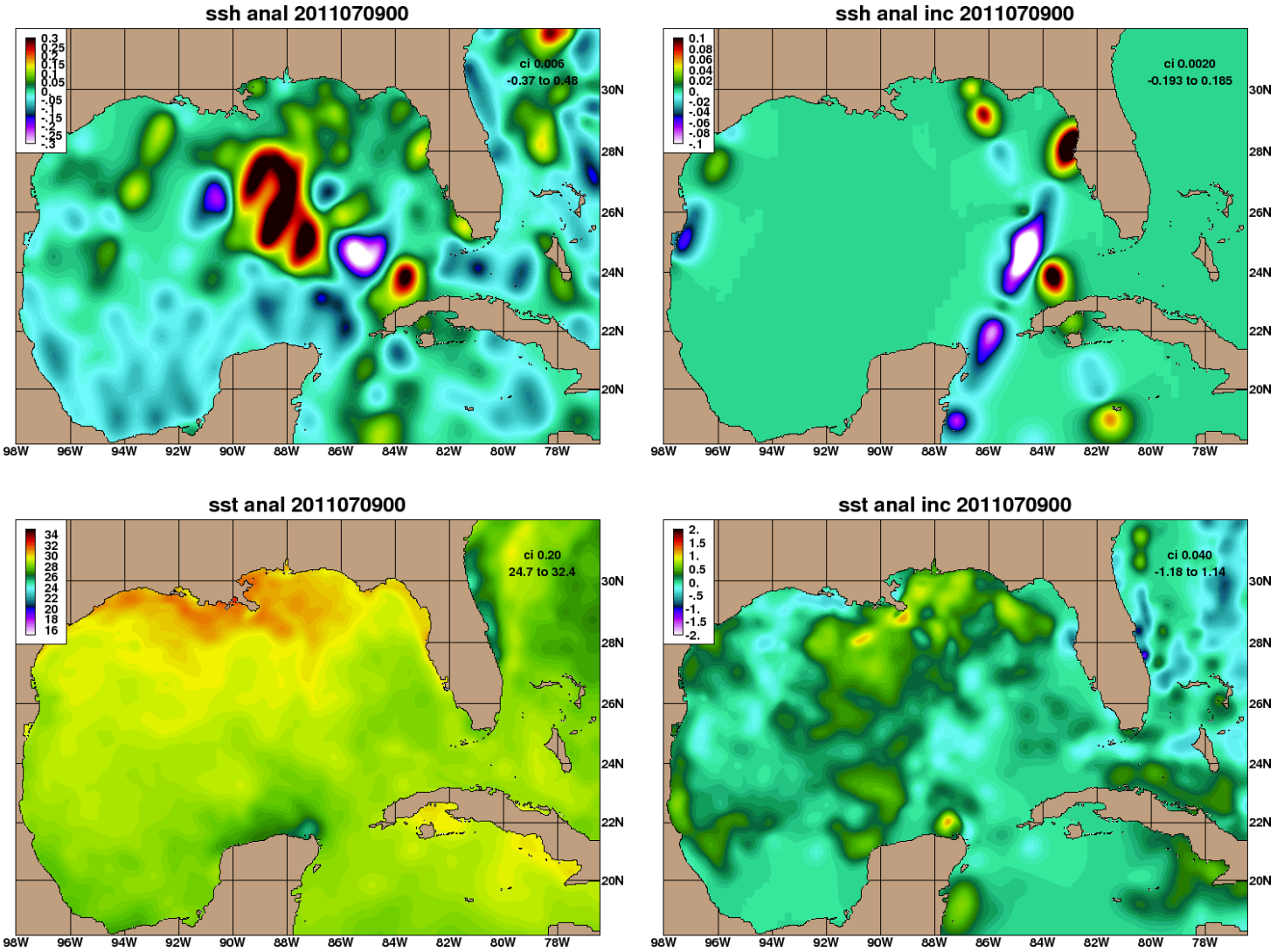
# Ocean Data Assimilation

## (Navy Coupled Ocean Data Assimilation: NCODA)



# NCODA Exercises

## (GOMl0.04; 3DVAR w/ SSH, SST)



# Neural Network Application

# Neural Network Applications

(status)

- Neural Network (NN) technique applied to ocean color applications — gap-filling, consistent ocean color, etc.
- NN: robust, flexible, accurate, and computationally cheap
- In-house expertise from Dr. Vladimir Krasnopolsky
- Exploits statistical linkages between ocean biological parameter (e.g., chlorophyll-*a*) and upper ocean variables (e.g., SST, SSH, Argo Temperature & Salinity profiles, etc)

# Neural Network Applications

(status continued)

- Basic premise: **(a)** inputs — SST, SSH, etc., — are stable, and **(b)** relationship between chlorophyll-*a* and inputs holds over time
- NN trained on NASA/VIIRS (2012-2014), applied to 2005-2014 to reconstruct chlorophyll-*a*
- Results: stable over time, accurate (Krasnopolsky, et al., *Computational Intelligence and NeuroScience.,* 2015)

# Neural Network Applications

(results)

- NN trained on daily VIIRS yields promising results
- Good fidelity in western equatorial Pacific
- Significant errors in eastern equatorial Pacific, possibly due to upwelling
- May need more input diagnostic variables from ocean models (upwelling velocities, horizontal advection, etc.)
- NN trained on monthly SeaWiFS, expected (Spring 2017)
- NN trained on SeaWiFS will produce consistent chlorophyll-*a*

# On-going or ToDo List

- Science quality VIIRS products and thermal structure effects
- On-line coupling of NPZD-type ecosystem model
- Added complexities (e.g., 9-component including carbon and dissolved oxygen sub-modules)
- Ocean color (SeaWiFS/VIIRS) data assimilation (2DVAR) into BGC-coupled RTOFS-Global
- NCODA implementation for physical/biogeochemical variables (3DVAR)

# VIIRS Retrievals of *Karenia brevis* Harmful Algal Blooms in the West Florida Shelf Using Neural Networks

**Sam Ahmed and Ahmed El-habashi (PhD candidate) CREST CCNY**

**Collaboration with**

**Drs Rick Stumpf & Michelle Tomlinson NOAA National Ocean Services**



# Outline

I. Background of *Karenia Brevis* (*KB)* Harmful Algal blooms (HABs) in West Florida Shelf (WFS)

II. MODIS uses 678 nm fluorescence channel to detect [Chla] and hence KB. VIIRS has no 678 nm channel new technique needed

***III.*** ***NN*** retrievals of $\boldsymbol{a_{ph443}}$ approx. α [*Chla*] and KB intensity

IV. We devise **filters** to eliminate non KB compatible pixels from retrieved $\boldsymbol{a_{ph443}}$ and residual image indicates *KB* HABs

V. Comparisons *NN KB* HAB retrievals in WFS: against MODIS **Fluorescence based nFLH** techniques

VI. Comparisons of VIIRS ***NN retrievals*** against **in-situ measurements**

VII. Conclusion

# Background of *KB* HABS in WFS

- It has been estimated that $70 million is lost annually as a result of HABs (Fisher et al., 2003). Recent July 4th 2016 bloom had a major effect on economy and health.
- Approximately 5,000 species of phytoplankton, only about 300 of them could cause color change.
- In waters containing *Karenia brevis* (*KB*) greater than $10^4$ cells $L^{-1}$ (high-*chlorophll*-a waters ~1-10 mg $m^{-3}$), ~ 3-4 fold decrease in *Rrs*(λ) compared to waters containing fewer than $10^4$ cells $L^{-1}$ of *KB*.
- Decrease in *Rrs*(λ) for *KB* blooms would cause the water to appear darker since the green reflectance peak at 570 nm is less (green, olive green, black "darker" with high *Chla*). Although a **red reflectance** peak (~685-700nm) due to *chlorophyll* a florescence becomes increasingly, KB blooms do not appear as red in color visually as they do radiometrically because receptors of the human eye are only slightly sensitive to this portion of the visible spectrum

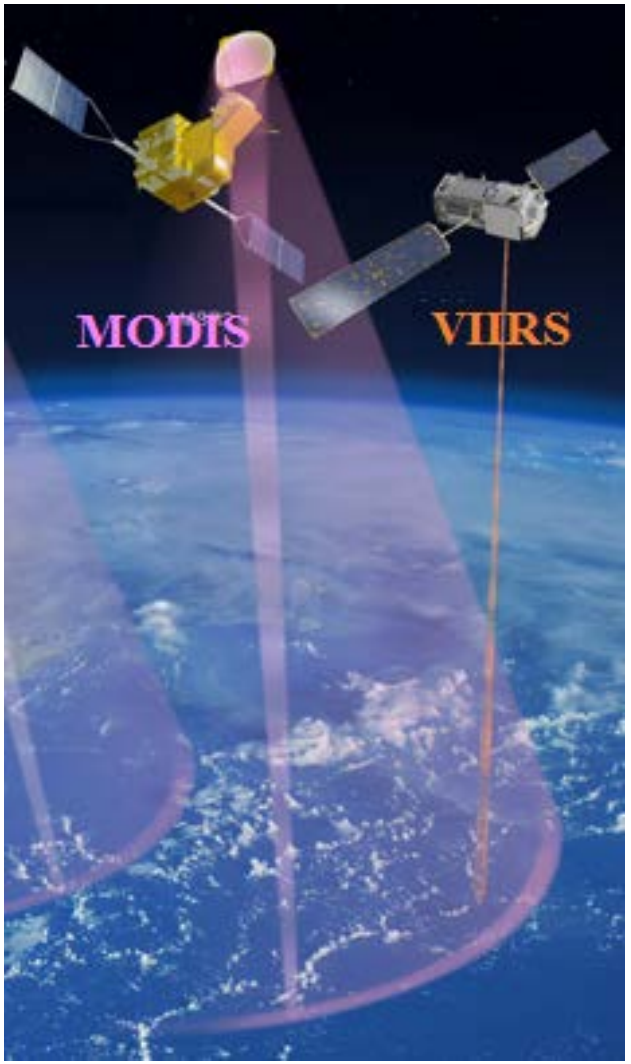





# MODIS & VIIRS satellite capability for *KB* HABs detections

- MODIS Retrieval of *KB* uses *nFLH/RBD* Techniques which require 678nm Fluorescence band

- 678nm band not available on VIIRS providing impetus for *NN* technique, using as input 486, 551 and 671 nm available in VIIRS.



# Neural Networks (NN) Algorithm output retrieves $a_{ph443}$ from 486,551 671nm VIIRS *Rrs* inputs

• **Previous work: Simulated 20,000 random data sets** based on NOMAD range of coastal and oceanic IOPs 10,000 used with 4 component radiative transfer forward bio-optical **model to generate 10,000 sets of Rrs 486,551 and 671 nm**

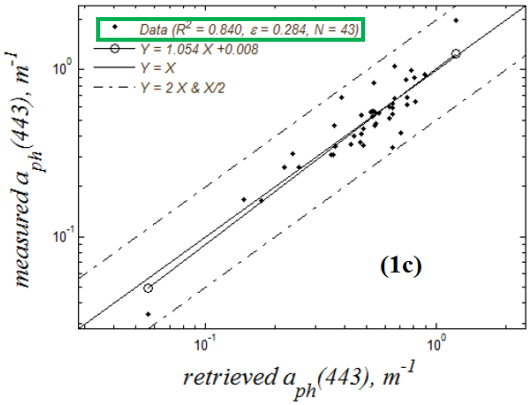
• **NN trained on 10,000 of these to retrieve as output** (*aph, adg, adm* & *bbp* all at 443 nm, which is at the peak of *aph* and thus exhibit most variation with **λ**) ) from *Rrs* inputs at 486, 551 & 671 nm VIIRS bands (note these are **longer λ s** which are not greatly impacted by atmospheric correction). (**$a_g$ and $a_d$ are mutually constrained through an empirically derived relationship based on a study of NOMAD values (Refs)**

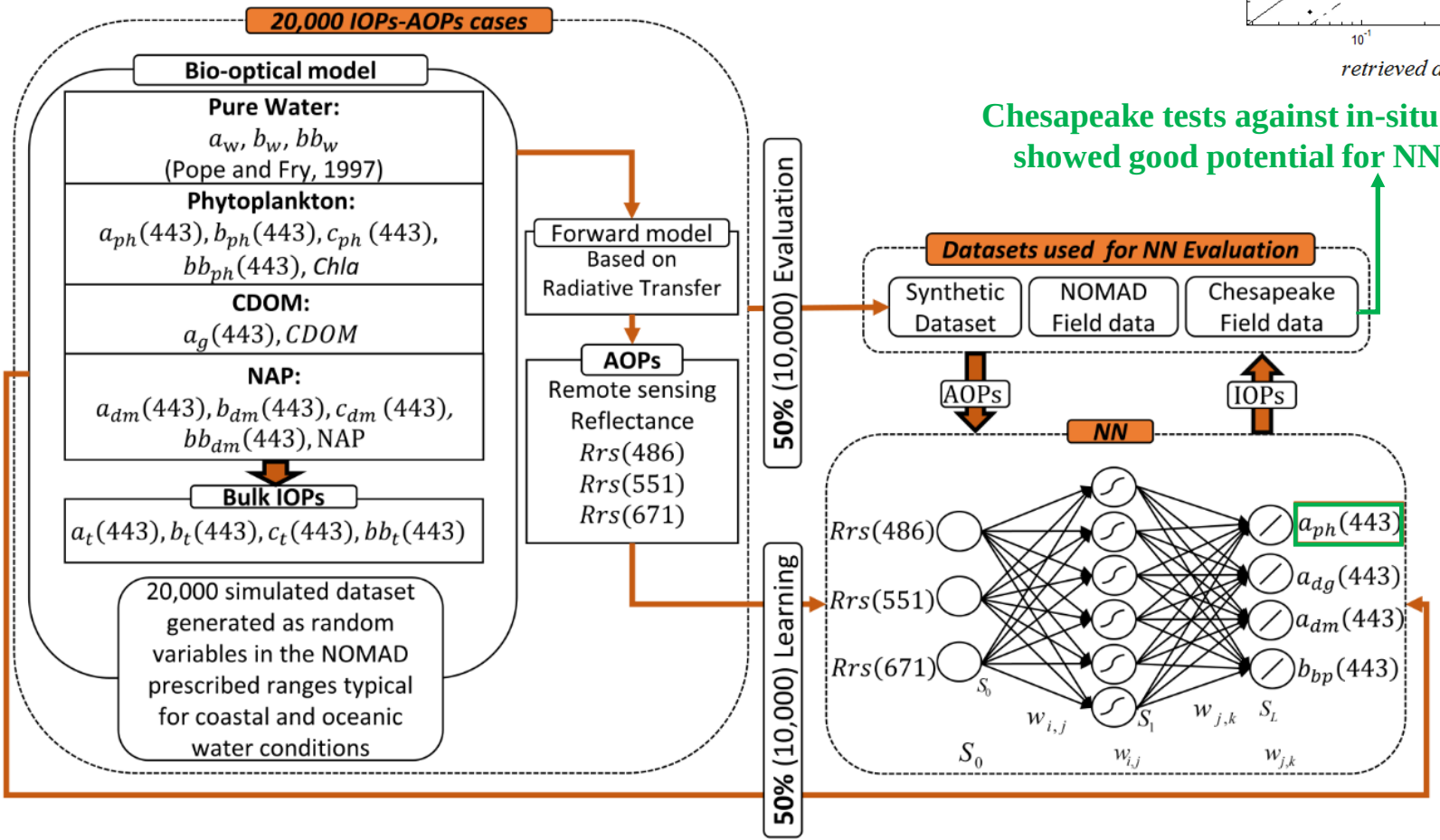
• **Tested** and validated NN retrieval capabilities on remaining **10,000** synthetic dataset, NOMAD field data, and against our field measurements in Chesapeake.

• **We are only interested NN retrievals of $a_{ph443}$ for our KB retrievals**

• **Refs.** Ioannou I., et al. Deriving ocean color products using neural networks. ***Remote Sens. Environ.*** **2013,** *134*, 78–91.
Ioannou I., et al. Neural network approach to retrieve the inherent optical properties of the ocean from observations of MODIS. ***Appl. Opt.*** **2011**.

## NN retrieved $[a_{ph}(443)]$ $R^2$=0.84, n =43




## Chesapeake tests against in-situ measurements showed good potential for NN Retrievals

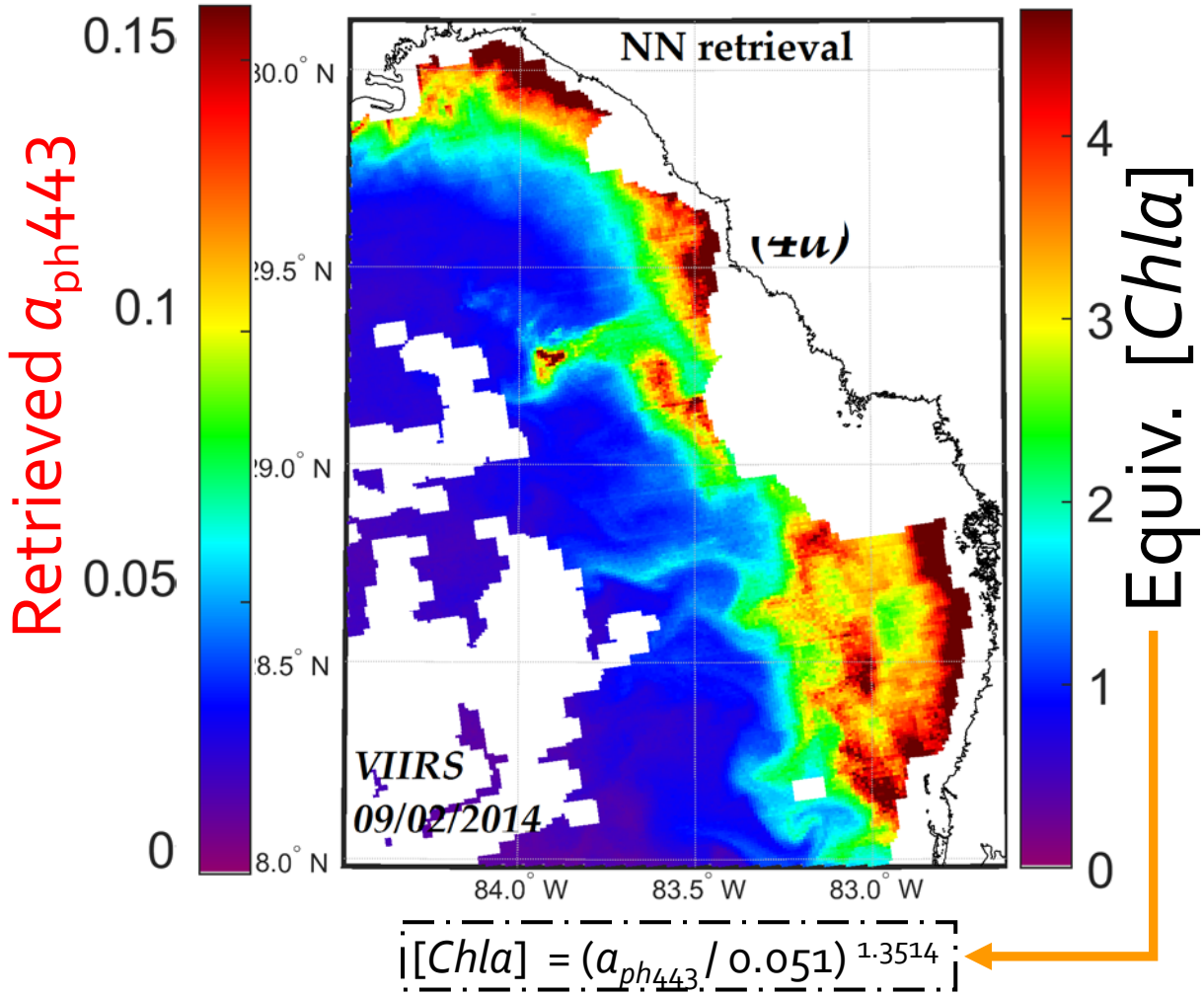
# On 9/2/14 major KB bloom in WFS
# VIIRS *NN* retrievals of $a_{ph443}$ and equivalent [*Chla*] (and α KB intensity)from inputs of *Rrs at* 486, 551 & 671 nm
# Next step: filter out non-kb compatible pixels

**VIIRS Pixels flags applied**

***Using the NASA Level 2, L2gen data processing system, all pixels under the following conditions were considered in the comparison:***

**•Any individual pixel is excluded from the image if it has been flagged land, cloud, failure in atmospheric correction, stray light, bad navigation quality, both high and moderate glint, negative Rayleigh-corrected radiance, viewing angle larger than 60°, and solar zenith angle larger than 70°. Moreover, data of any individual pixels which have water-leaving radiance spectra with negative values in one of the wavelength are also excluded from spatial averaging.**

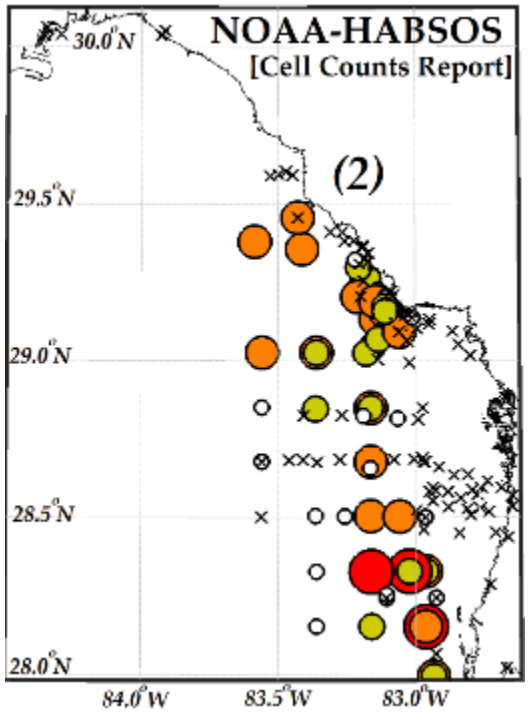
*"Light gray represents cloud cover or invalid flagged data"*




$[Chla] = (a_{ph443} / 0.051)^{-1.3514}$

Above empirical relationship determined from in-situ measurements and reported for the WFS. *Chengfeng Le & Chuanmin Hu, (2013)*

# Filter Development to eliminate non kb compatible pixels. Example of reported *KB* HABS in-situ measurements (8/27/2014-9/17/2014) against which we developed filter criteria and tested our retrievals.




*Cell Counts/L Classification:*
- x *Not Observed*
- ○ *Very Low (1-10,000)*
- ● *Low (10,000-100,000)*
- ● *Medium (100,000-1,000,000)*
- ● *High (1,000,000+)*

## Approach applied in WFS for *KB*-HABs Detections

- **First** we use NN to retrieve aph443 from VIIRS Rrs (486,551,671) ***aph443 is approximately proportional to [Chla].***
- **Then**, in a second critical step, we evolve limiting criteria which make use of two facts (*Cannizzaro, 2009*)

***I.*** *low backscatter* $bb_p551 \leq$ ***max specific value.***
*&Equiv.* $Rrs_{551} \leq 0.006\ sr^{-1}$
***II.*** $a_{ph443} \geq$ ***min specific value.***
$a_{ph443} \geq 0.061\ m^{-1}$
*&Equiv. [Chla]* $\geq 1.9\ mg\ m^{-3}$

*These limiting criteria are applied to retrieved VIIRS retrievals of* $Rrs_{551} \leq 0.006\ sr^{-1}$ *&* $a_{ph443} \geq 0.061\ m^{-1}$
**(to effectively delineate and quantify *KB* )**

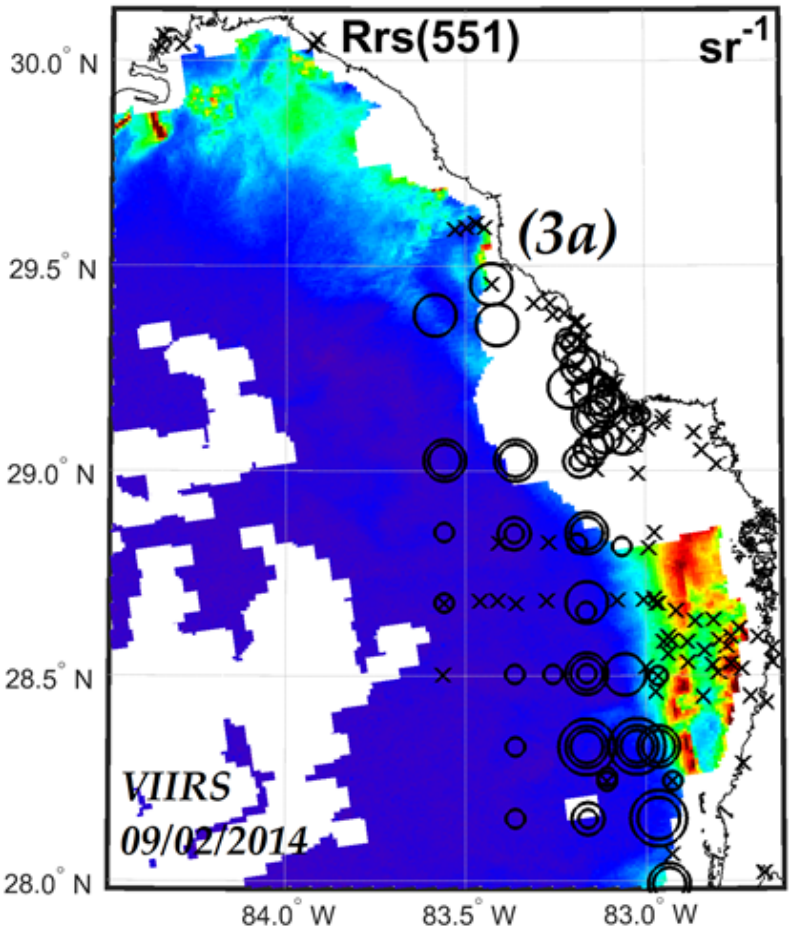
- NOAA HABSOS data with *in situ KB* concentrations, for period 8 August–17 September 2014.

# F1 Filter

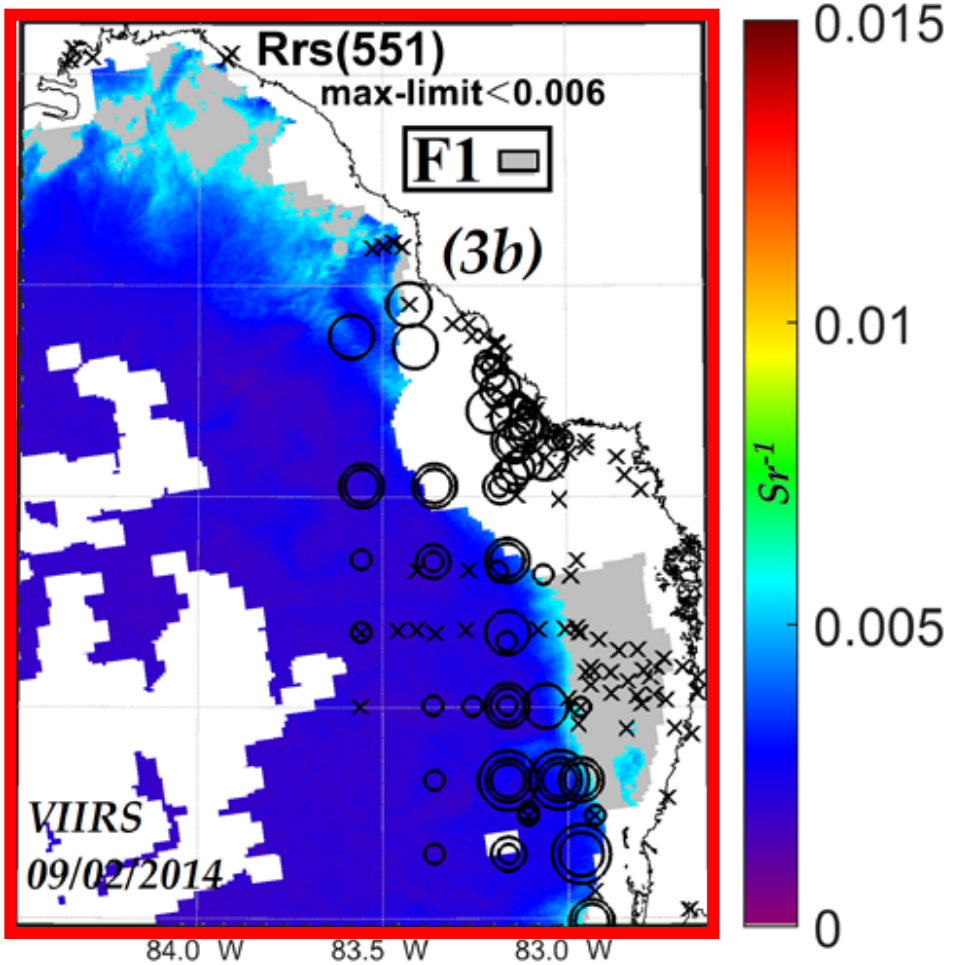
**Known fact *KB* HABs are characterized by low backscatter therefore we devise a filter based on upper limit of backscatter and equivalent $Rrs_{551}$ values to *NN* VIIRS retrievals.**

**Indeed**, K. brevis is an **ineffective backscatterer** due to its large size **(20–40 µm)** and relatively low index of refraction **(1.05)** Instead, **the primary source of** $bb_p r$ in oceanic waters is particles less than **1 µm** (Morel and Ahn, 1991; Stramski and Kiefer, 1991).

*"Dark gray represents F1 mask and Light gray represents cloud cover or invalid data"*




**(3c)** VIIRS $Rrs_{551}$ image. Which we use it as a proxy for bbp, *BY inspection* we find that the highest value of Rrs551 consistent with the existence of KB HABs is $\{Rrs_{551}\} \leq 0.006\ sr^{-1}$




**(3d)** This max value used to generate a mask F1 mask (dark gray), which eliminate all values of $\{Rrs_{551}\} \geq 0.006\ sr^{-1}$ and therefore incompatible with KB HABS, when mask is applied to image residual pixels, are then compatible with KB HABs

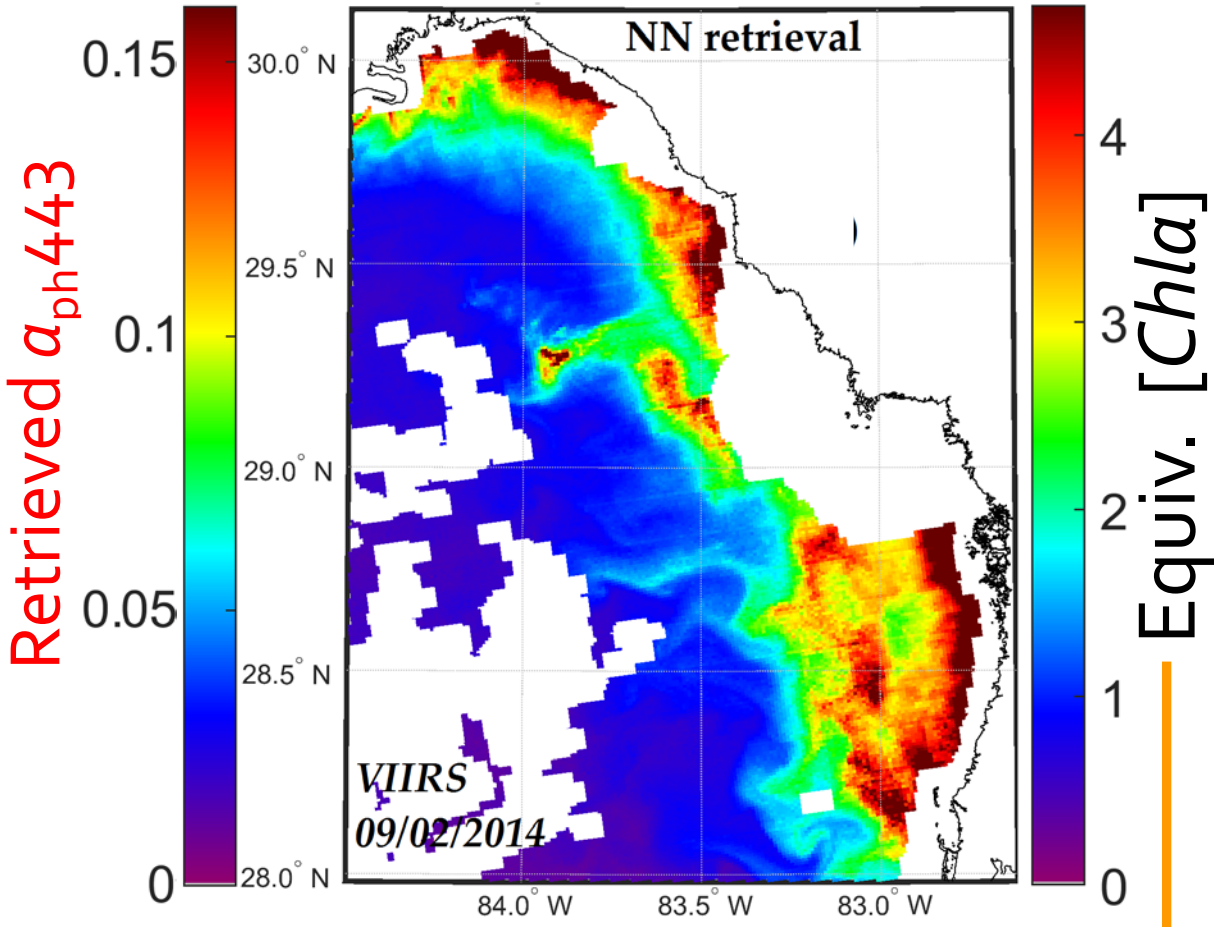
# VIIRS *NN* retrievals of $a_{ph443}$ and equivalent [*Chla*] (and α KB intensity)from inputs *Rrs at* 486, 551 & 671 nm (Similar for MODIS)

## VIIRS Pixels limitations

***Using the NASA Level 2, L2gen data processing system, all pixels under the following conditions were considered in the comparison:***

**•Any individual pixel is excluded from the image if it has been flagged land, cloud, failure in atmospheric correction, stray light, bad navigation quality, both high and moderate glint, negative Rayleigh-corrected radiance, viewing angle larger than 60°, and solar zenith angle larger than 70°. Moreover, data of any individual pixels which have water-leaving radiance spectra with negative values in one of the wavelength are also excluded from spatial averaging.**

*"Light gray represents cloud cover or invalid flagged*



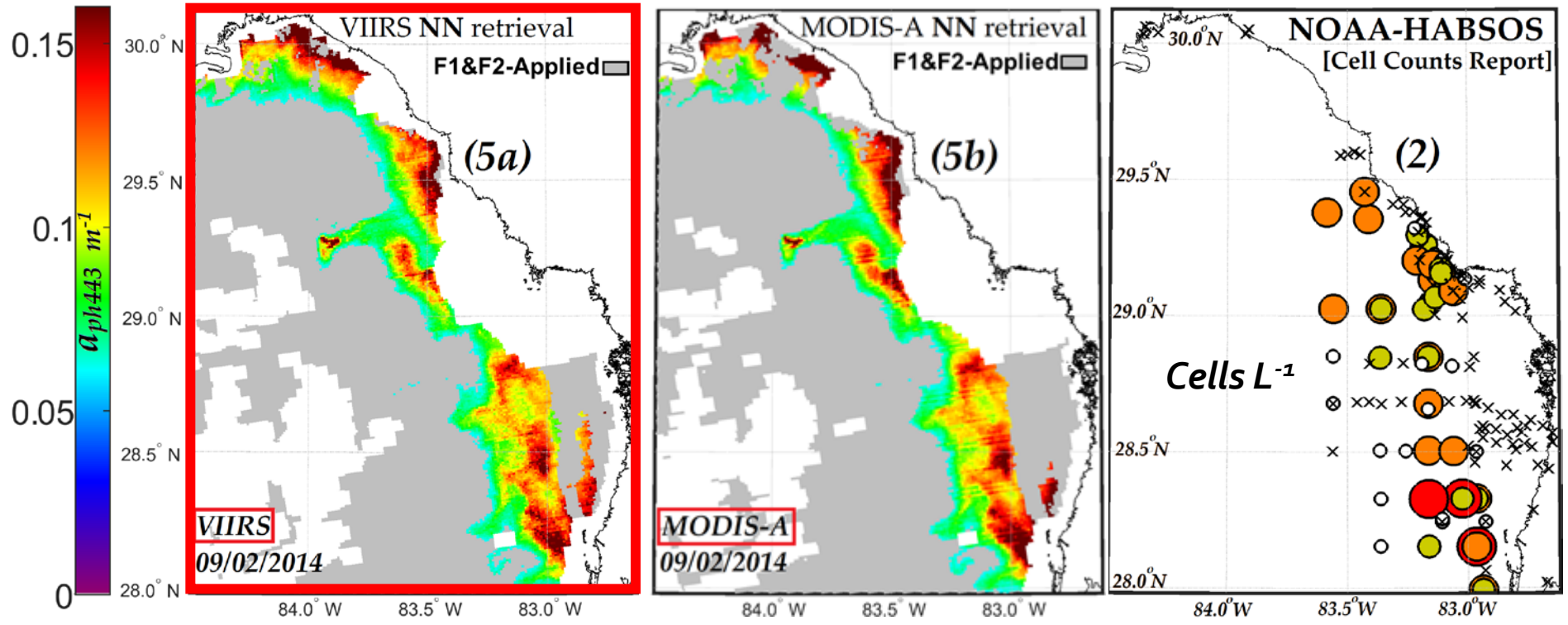

$$[Chla] = (a_{ph443} / 0.051)^{1.3514}$$

Using empirical relationships, which have been determined from in-situ measurements and reported for parts of the WFS. *Chengfeng Le & Chuanmin Hu, (2013)*

# F1 & F2 Filters combined show the extent of *KB* blooms 9/02/2014

**Application of filter F2 based on known minimum $a_{ph}443$ value compatible with *KB* HABs applied consecutively to residual pixels from F1.**

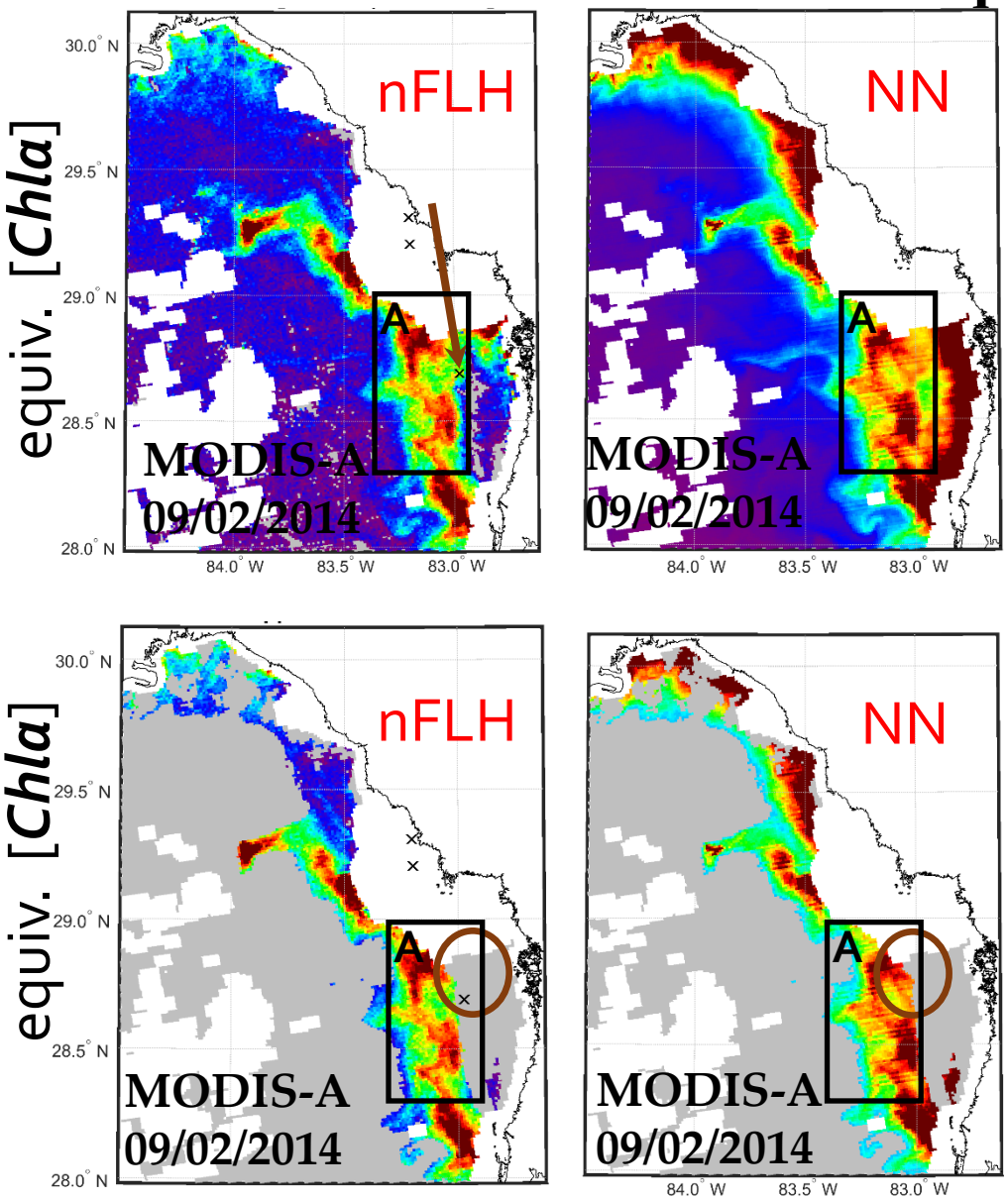
***"Dark gray represents F1&F2 masks and Light gray represents cloud cover or invalid data"***

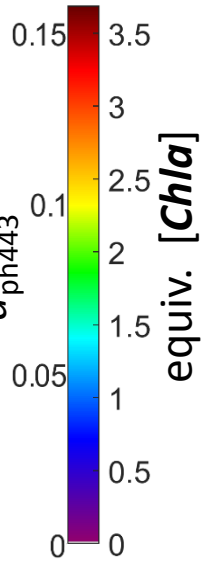


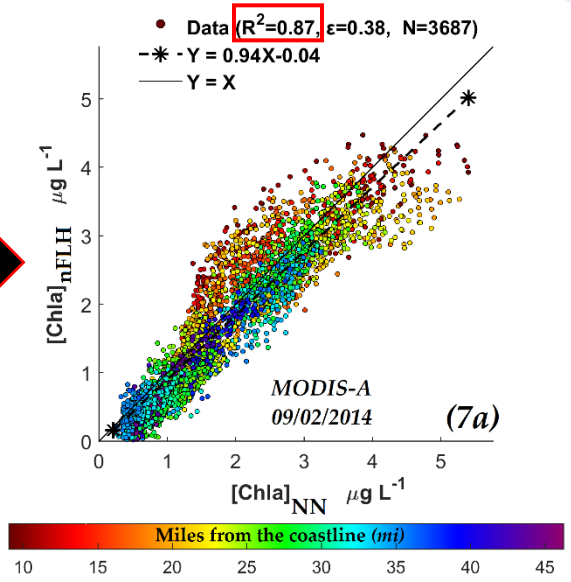

**New residual pixels of both masks satisfy both maximum backscatter and minimum $a_{ph443}$** criteria and there for compatible and represent KB HABs

*Cell Counts/L Classification:*
- x *Not Observed*
- o *Very Low (1-10,000)*
- *Low (10,000-100,000)*
- *Medium (100,000-1,000,000)*
- *High (1,000,000+)*

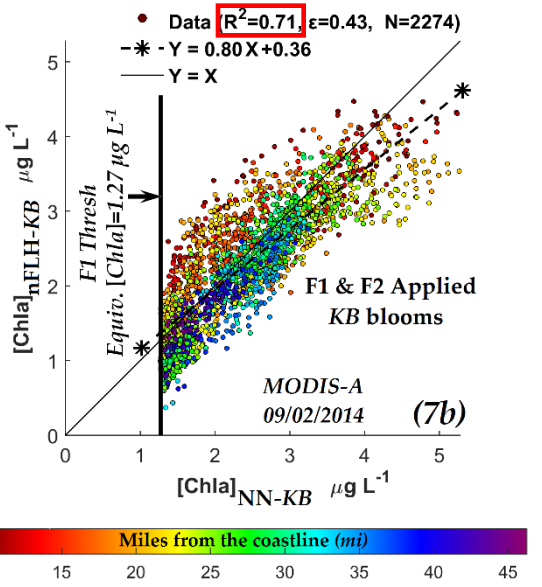
# Comparisons of MODIS NN and nFLH retrievals, offshore area A - Equiv. [*Chla*]




*"Color coding of the dots denotes distance to shore, with red being the closest."*




*"Again, Dark gray represents F1&F2 masks and Light gray represents cloud cover or invalid data"*

**F1 & F2 Applied these eliminate erroneous bloom in *nFLH* image**

SW Florida nFLH equiv. **[*Chla*] = 1.255*(FLH*10)$^{0.86}$** Refs., Hu, C.; *Remote Sens. Environ.* **2005**

# Comparisons of In-situ measurements *Vs.* VIIRS NN *KB*-HABs retrievals (2012-2015)

- **To verify the association between *KB* cell abundance and VIIRS ocean color Level 2 $a_{ph443}$ phytoplankton absorption**

  ***KB* cell abundance** collected by Florida Fish and Wildlife Conservation Commission (FWC), **were combined and compared to VIIRS retrievals, for the period between 2012 and 2015 (94 data points for same day observations).**

- Over range 0.01–3.7 $10^6$ *cells* $L^{-1}$ and $a_{ph443}$ (chlorophyll-a) values from 0.085 to 1.53 $m^{-1}$([Chla]0.6449 to 99 $\mu g\ L^{-3}$) the regression coefficient was 0.32 (Shown next Slide).

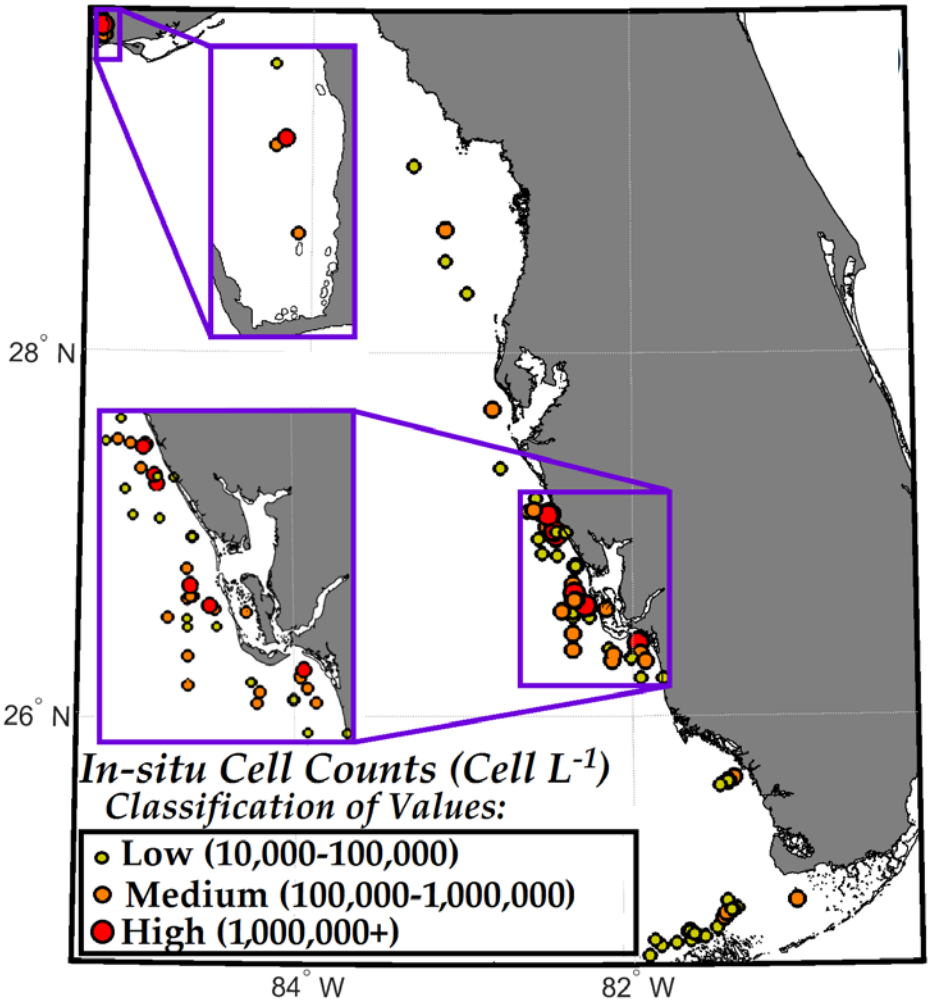
***KB-HABs cell counts limitations applies are those shown below***

**Cell counts under the following conditions were considered in the comparison:**

**•Sample depth ≤ 0.5 meter.**

**•Cell counts ≥ 10,000 cell $L^{-1}$**
**(Low to High blooms)**

**•The nearest pixels used for match-up comparison are those less than (<0.3 mile) to the in-situ locations. Moreover all flags mentioned previously are excluded.**



# In-situ measurements *Vs.* VIIRS NN *KB*-HABs retrievals (2012-2015) w

***KB In-situ observation within the same day of VIIRS image***

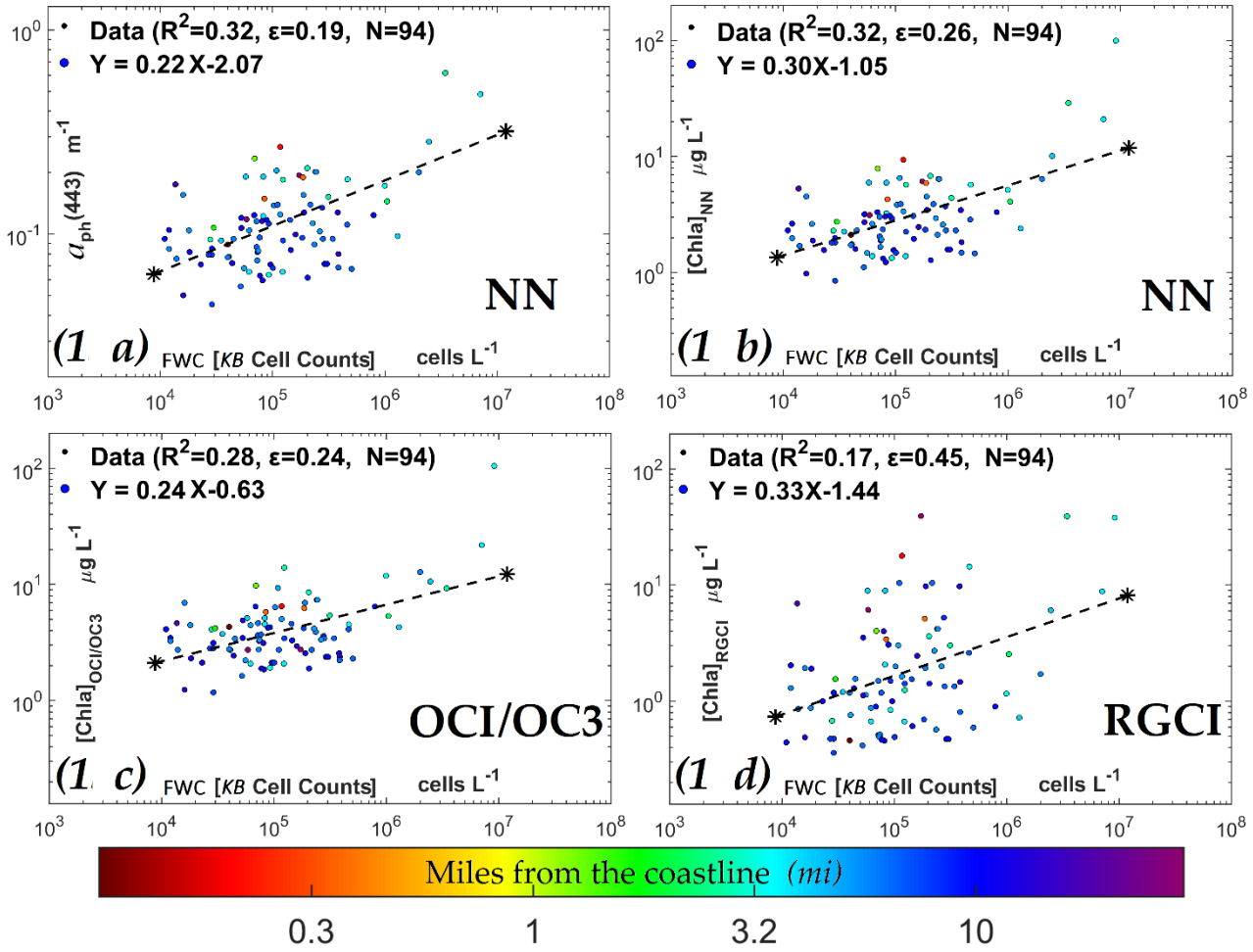



**Fig. 13(a-d): In-situ observation within the same day of VIIRS image: (a)** VIIRS NN retrieved $a_{ph443}$ against In-situ *KB* cell counts; **(b)** VIIRS NN equiv. [*Chla*] against in-situ cell counts; **(c)** VIIRS OCI/OC3 retrieved [*Chla*] against in-situ *KB* cell counts; **(d)** VIIRS RGCI retrieved [*Chla*] against in-situ *KB* cell counts. Color coding of the dots denotes distance to shore, with blue being the closest.

**OCI/OC3 Refs.** NASA's Ocean Color chlorophyll-*a* index : http://oceancolor.gsfc.nasa.gov/cms/atbd/chlor_a/ [O'Reilly, 1998], [Hu, C., Lee, Z.; Franz, B. **2012**]
**RGCI Refs.** Red Green chlorophyll-*a* Index RGCI [*Chla*] retrievals [*Lin Qi, C. Hu* ***2015***]

# Showing impact of temporal changes- In-situ measurements *Vs.* VIIRS NN *KB*-HABs retrievals (2012-2015) limited observation windows

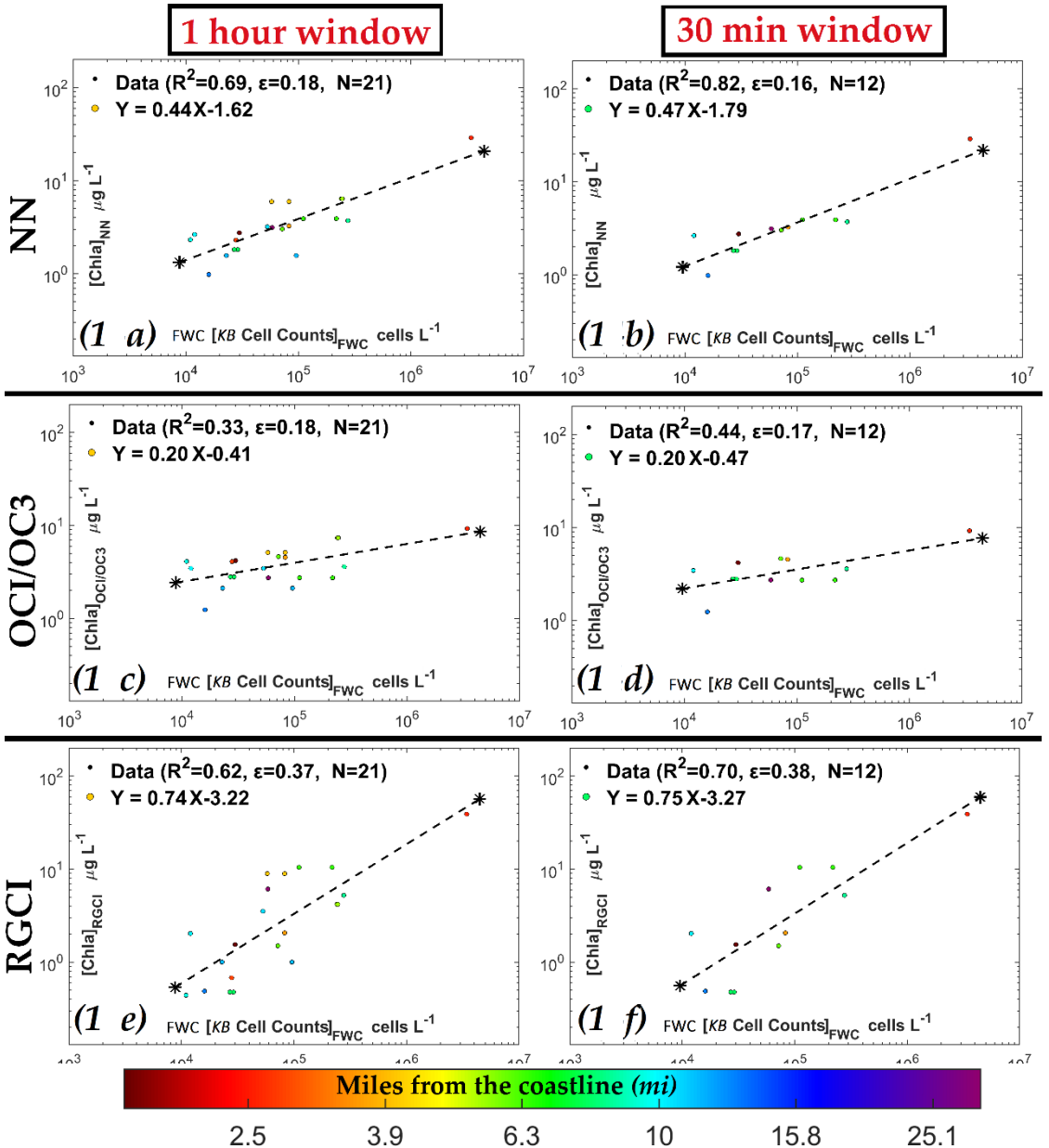
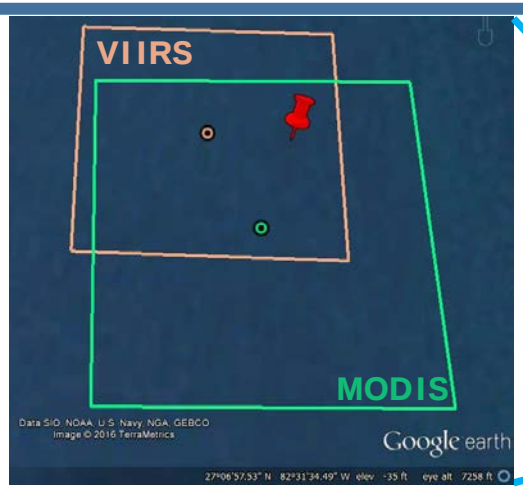
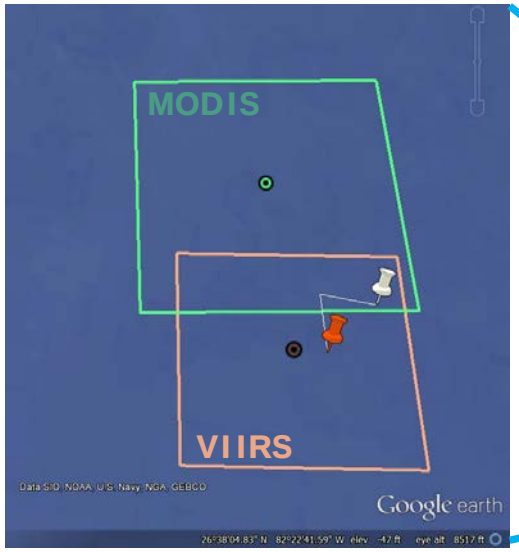


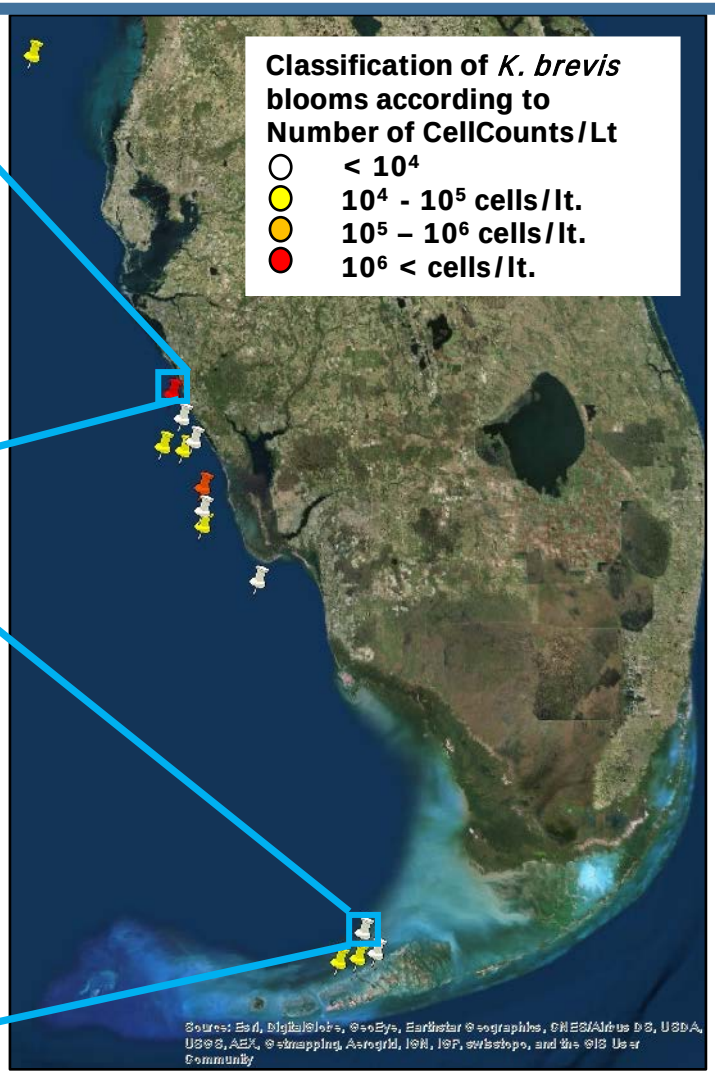

**Fig. 1(a-f):** Retrieved NN equiv. [*Chla*] and OCI/OC3 [*Chla*] and RGCI [*Chla*] against In-situ cell counts for 1 hour and 30 minutes observation time windows. Note that the vertical color bar is indicates distant (mi) from coastline with red being closest to shore.

# Location of 30 minutes coincident Field data (showing VIIRS and MODIS pixels –ongoing analysis)

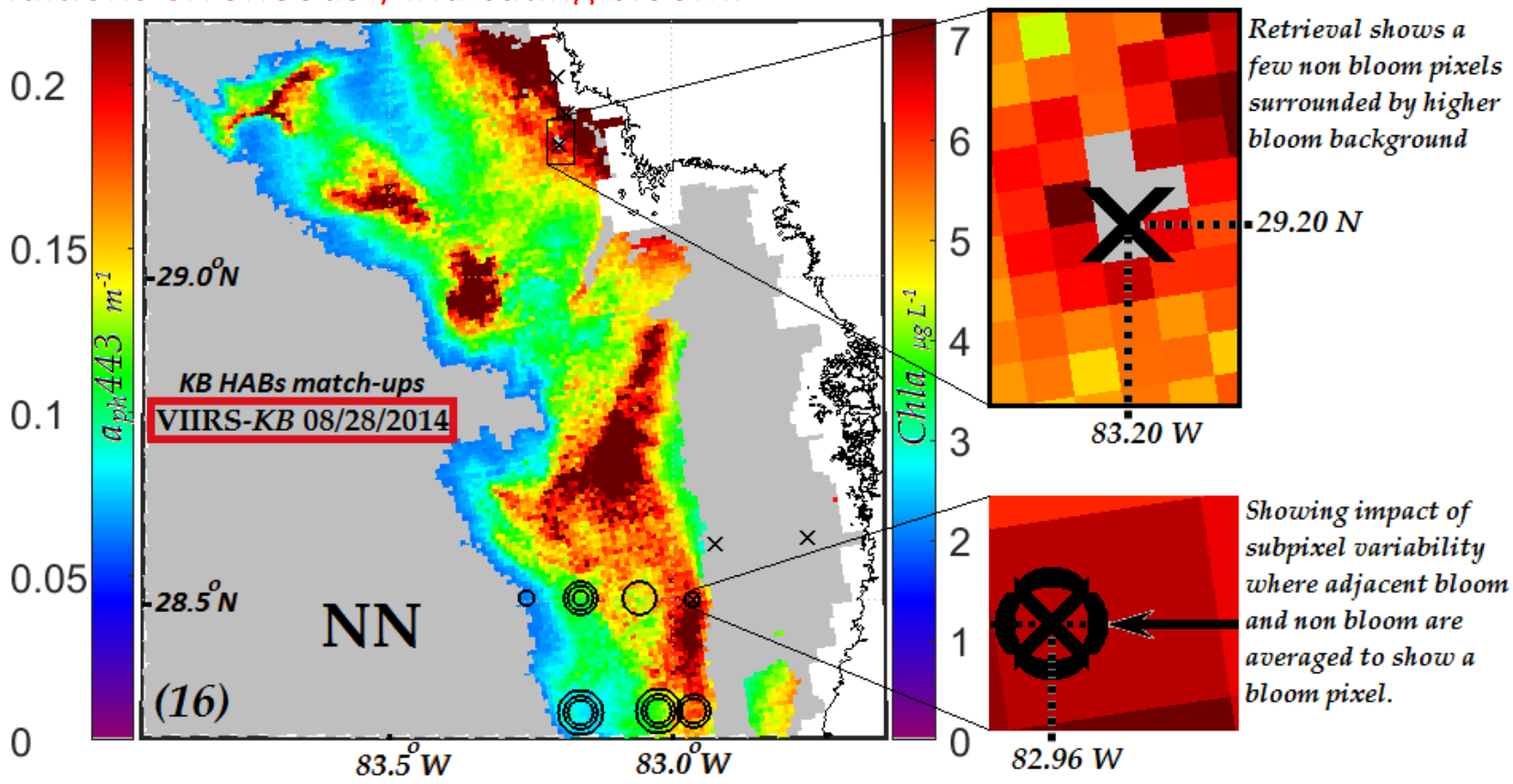
## III. Field Data



# 08/28/2014 bloom: showing adjacent pixel variability and averaging effect of intra-pixel variability non-bloom-bloom conditions erroneously indicating bloom.

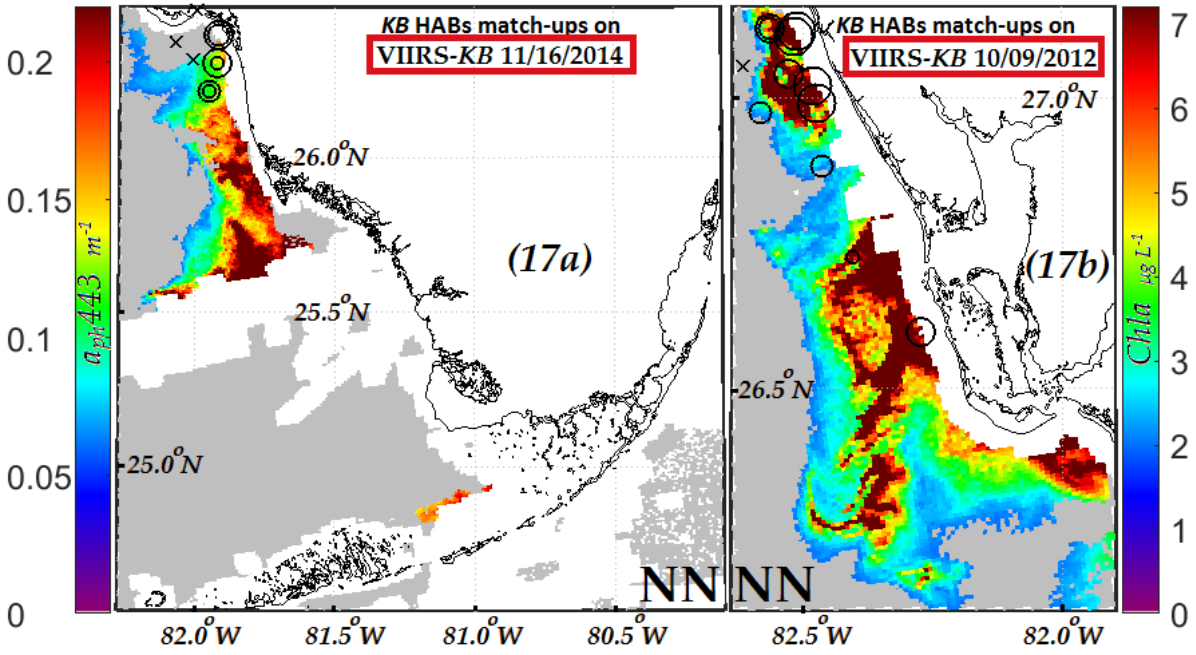



- **Figure 16.** VIIRS-NN *KB* HABs retrievals for blooms date (28 August 2014), showing bloom compatible $a_{ph443}$ and equiv. [*Chla*] values. Notes image are overlaid with cell counts for this date. White areas represent cloud cover or invalid data. There are total of 20 match-ups on that day

*Cell Counts/L Classification:*
- x *Not Observed*
- ∘ *Very Low (1-10,000)*
- ○ *Low (10,000-100,000)*
- ◯ *Medium (100,000-1,000,000)*
- ◯ *High (1,000,000+)*

# 11/16/2014 & 10/09/2012, blooms:

## showing good retrievals including closer to shore




*Cell Counts/L Classification:*

- x *Not Observed*
- o *Very Low (1-10,000)*
- ○ *Low (10,000-100,000)*
- ○ *Medium (100,000-1,000,000)*
- ◯ *High (1,000,000+)*

- **Figure 17.** VIIRS-NN *KB* HABs retrievals on 2 different blooms dates, showing bloom compatible $a_{ph443}$ and equiv. [*Chla*] values. (**a**) 11 November 2014, bloom; (**b**) 09 October 2012, bloom. Notes all images are overlaid with cell counts corresponding for these dates. White areas represent cloud cover or invalid data. There are total of 6 and 12 match-ups respectively for (11/16/2014) and (10/09/2012).

# Conclusion

- *NN* retrievals of *aph*443 from VIIRS appears to be viable technique for detecting and tracking *KB* HABs in the WFS, when combined with retrieved *Rrs*551 and *aph*443 criteria compatible with low *KB* backscatter and minimum *aph*443.

- Retrievals show importance of temporal considerations.

- Further detail comparisons with in-situ measurements are planned and considerations of *subpixel variability* addressed. Factors affecting false positives and negatives remain to be investigated in detail.


- **Acknowledgment:**
- We thank NOAA JPSS and NOAA-Crest for support.





Thank you

# Back up slides

# Assessing Uncertainty Of Ocean Water Bidirectional Reflectance Model

Pengwang Zhai
Assistant Professor,
Physics Department, UMBC

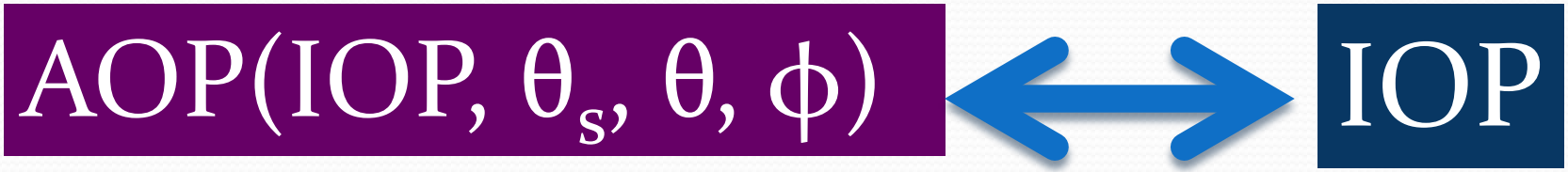
# Quantifying Ocean BRDF

backscattering coefficient

$$L_w(0^+,\theta_s,\theta,\phi,\lambda,W,\mathrm{IOP}) = E_d(0^+,\theta_s,\lambda)\,\Re(\theta',W)\frac{f(\theta_s,W,\mathrm{IOP})}{Q(\theta_s,\theta',\phi,W,\mathrm{IOP})}\left(\frac{b_b}{a}\right)$$

$$\frac{f(\theta_s, W, \mathrm{IOP})}{Q(\theta_s, \theta', \phi, W, \mathrm{IOP})}$$

# Why is f/Q important?




C. D. Mobley, Ocean Optics Web Book, Atmospheric Correction for satellite Ocean Color Radiometry,
"It would be desirable to have an AOP that completely removes the effects of solar zenith angle, viewing direction, atmospheric conditions, and sea state, while retaining a strong dependence on the water IOPs. It would then be possible to compare this AOP for measurements made at different times and/or locations, and thereby extract information about the differences in the water columns for the different measurements."

# Previous work on ocean BRDF

OSA Publishing > Applied Optics > Volume 30 > Issue 30 > Page 4427

Journal Home | About | Issues in Progress | Current Issue

## Diffuse reflectance of oceanic waters: its dependence on Sun angle as influenced by the molecular scattering contribution

André Morel and Bernard Gentili

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Applied Optics Vol. 30, Issue 30, pp. 4427-4438 (1991) · doi: 10.1364/AO.30.004427

OSA Publishing > Applied Optics > Volume 32 > Issue 33 > Page 6864

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## Diffuse reflectance of oceanic waters. II. Bidirectional aspects

André Morel and Bernard Gentili

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Applied Optics Vol. 32, Issue 33, pp. 6864-6879 (1993) · doi: 10.1364/AO.32.006864

OSA Publishing > Applied Optics > Volume 35 > Issue 24 > Page 4850

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## Diffuse reflectance of oceanic waters. III. Implication of bidirectionality for the remote-sensing problem

André Morel and Bernard Gentili

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Applied Optics Vol. 35, Issue 24, pp. 4850-4862 (1996) · doi: 10.1364/AO.35.0048

OSA Publishing > Applied Optics > Volume 41 > Issue 30 > Page 6289

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## Bidirectional reflectance of oceanic waters: accounting for Raman emission and varying particle scattering phase function

André Morel, David Antoine, and Bernard Gentili

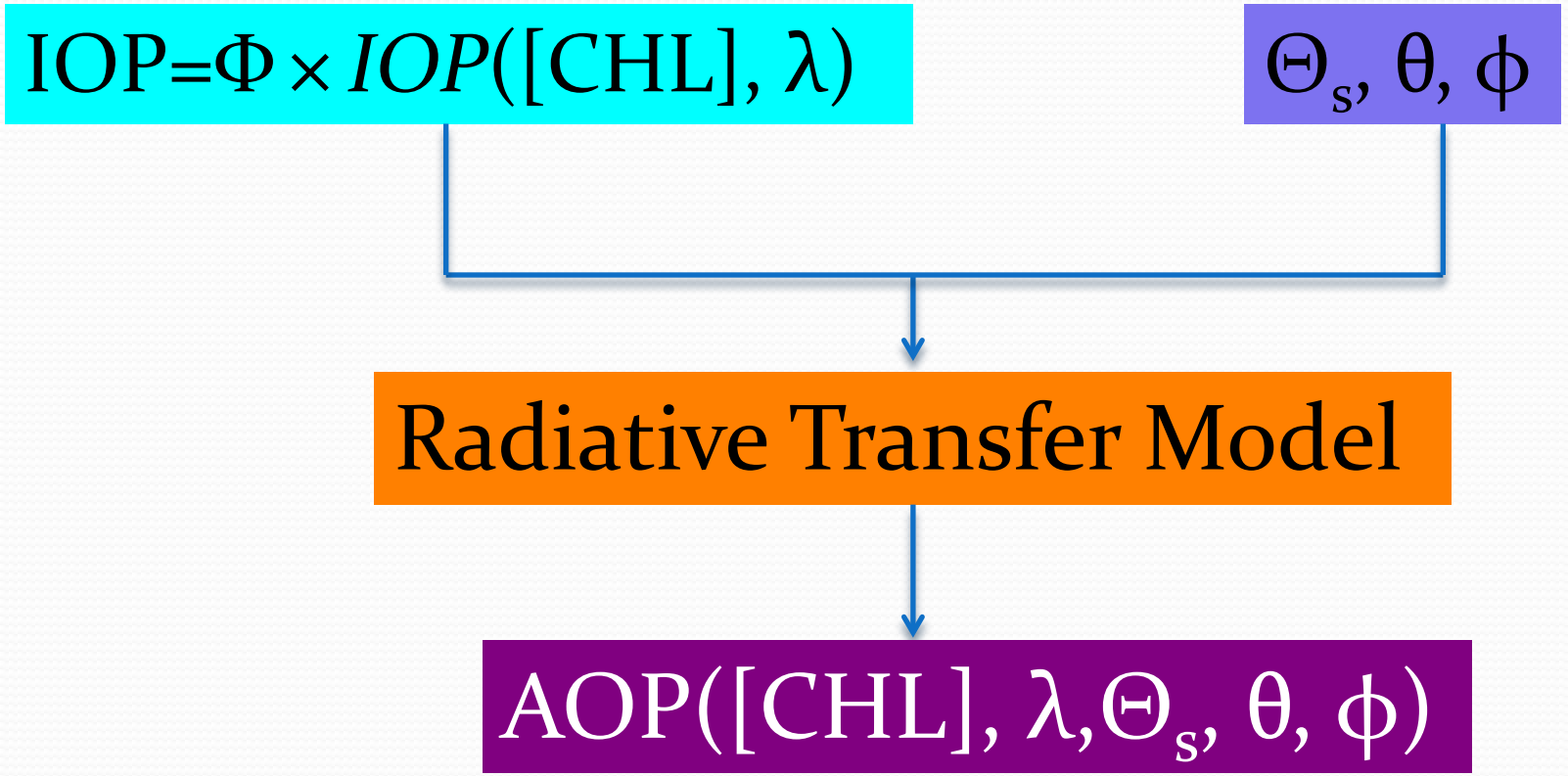
Author Affiliations | Find other works by these authors

Applied Optics Vol. 41, Issue 30, pp. 6289-6306 (2002) · doi: 10.1364/AO.41.006289

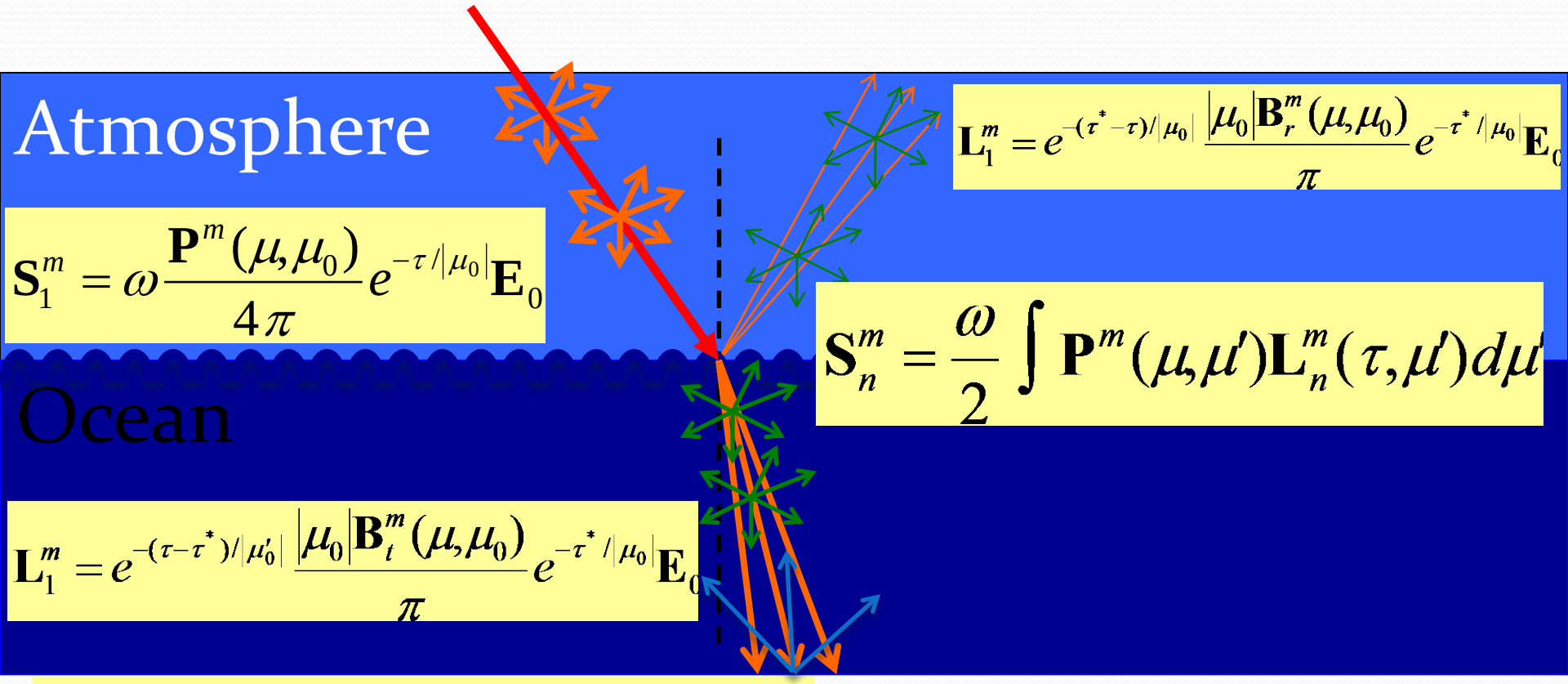
# Unresolved BRDF Issue

- The dependence of $f/Q$ on the IOPs, and viewing geometry was studied in terms of a bio-optical model
- However, the IOP–[Chl] parameterizations are not unique due to the inherent variability of the correlations.
- Mobley et al. (2004) have pointed out that "within Case 1 waters, there is a factor-of-two (and sometimes much greater) variability in the values of optical properties for a given chlorophyll value"
- It is then necessary and important to understand how the f /Q factors respond to different choices of bio-optical models and the natural variability of the IOPs

# How do we address this?



# Vector Radiative Transfer (VRT) Model




$$\mathbf{S}_1^m = \omega \frac{\mathbf{P}^m(\mu,\mu_0)}{4\pi} e^{-\tau/|\mu_0|}\mathbf{E}_0$$

$$\mathbf{L}_1^m = e^{-(\tau^*-\tau)/|\mu_0|}\frac{|\mu_0|\mathbf{B}_r^m(\mu,\mu_0)}{\pi} e^{-\tau^*/|\mu_0|}\mathbf{E}_0$$

$$\mathbf{S}_n^m = \frac{\omega}{2}\int \mathbf{P}^m(\mu,\mu')\mathbf{L}_n^m(\tau,\mu')d\mu'$$

$$\mathbf{L}_1^m = e^{-(\tau-\tau^*)/|\mu_0'|}\frac{|\mu_0|\mathbf{B}_t^m(\mu,\mu_0)}{\pi} e^{-\tau^*/|\mu_0|}\mathbf{E}_0$$

$$\mathbf{L}_n^m(\tau,\mu>0) = \int_{\tau}^{\tau_*} \exp\{-(\tau'-\tau)/\mu\}\mathbf{S}_n^m(\tau',\mu)d\tau/\mu$$

$$\mathbf{L}_n^m(\tau,\mu<0) = \int_{0}^{\tau} \exp\{-(\tau'-\tau)/\mu\}\mathbf{S}_n^m(\tau',\mu)d\tau/|\mu|$$


Zhai, P, Y. Hu, J. Chowdhary, C. R. Trepte, P. L. Lucker, D. B. Josset, "A vector radiative transfer model for coupled atmosphere and ocean systems with a rough interface," J Quant Spectrosc Radiat Transf, **111**, 1025-1040 (2010).

Zhai, P, Y. Hu, C. R. Trepte, and P. L. Lucker, "A vector radiative transfer model for coupled atmosphere and ocean systems based on successive order of scattering method," Opt. Express **17**, 2057-2079 (2009).

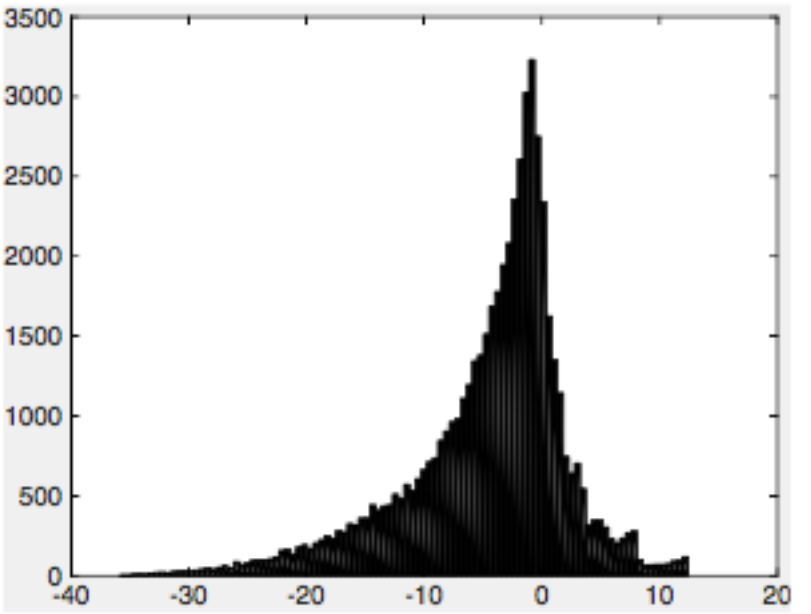
# Key Features of the SOS VRT model

- Full four Stokes parameters solution.
- Full physics coupling of atmosphere and ocean.
- Elastic and Inelastic scattering.
- Handle both coastal and open oceans.
- Analytical single scattering correction (Nakajima and Tanaka 1988) for both atmosphere and ocean.
- Advanced angular interpolation scheme using (Schulz and Stamnes, 2000)
- Flexible detector position.

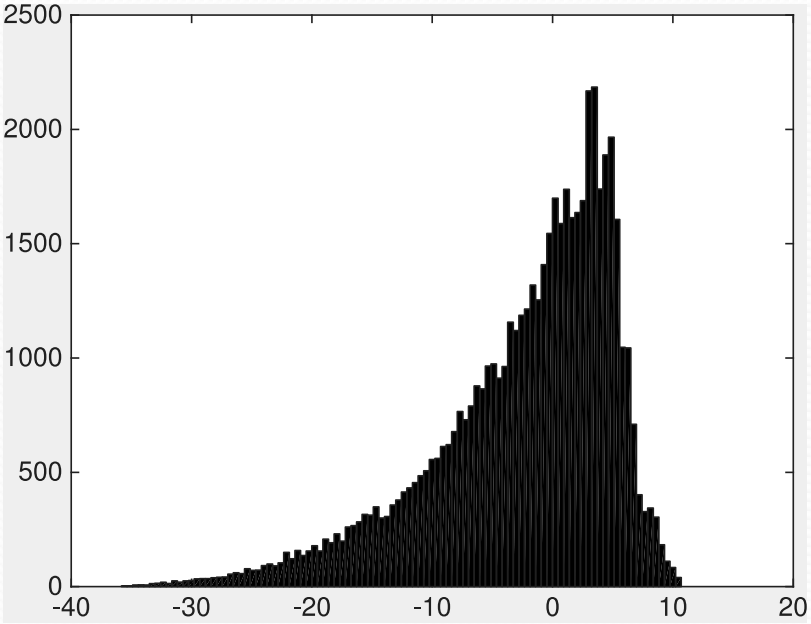
# Simulation Parameters

- Wavelength, $\lambda$ (seven values): 412.5, 442.5, 490, 510, 560, 620, and 660 nm;
- Chlorophyll a concentration (six values): 0.03, 0.1, 0.3, 1.0, 3.0, and 10.0 mg $m^{-3}$;
- CDOM absorption factor, $\Phi$ (five values): 0.1, 0.5, 1.0, 2.0, and 10.;
- Scattering coefficient factor, $\Phi_s$ (three values): 0.5, 1.0, and 2.0;
- Ocean water polarization at 90°, $p(90°)$ (five values): 0.5, 0.6, 0.66, 0.7, and 0.8;
- Solar zenith angle, $\theta_s$ (six values): 0°, 15°, 30°, 45°, 60°, and 75°;
- Viewing azimuth angle, $\phi$ (13 values): 0°–180° with increment of 15°;
- Viewing zenith angle, $\theta$ (17 values): 1.078°, 3.411°, 6.289°, 9.278°, 12.300°, 15.330°, 18.370°, 21.410°, 24.450°, 27.500°, 30.540°, 33.590°, 36.640°, 39.690°, 42.730°, 45.780°, and 48.830°.

# Ocean Water BRDF Uncertainty




Histogram of $\zeta$ Without Raman




Histogram of $\zeta$ With Raman

$$L_w(0^+,\theta_s,\theta,\phi,\lambda,W,\mathrm{IOP}) = E_d(0^+,\theta_s,\lambda)\Re(\theta',W)\frac{f(\theta_s,W,\mathrm{IOP})}{Q(\theta_s,\theta',\phi,W,\mathrm{IOP})}\left(\frac{b_b}{a}\right).$$

$$\zeta = 100\% \cdot \frac{f/Q_{\Phi=\Phi_s=1} - f/Q_{\mathrm{MAG2002}}}{f/Q_{\mathrm{MAG2002}}},$$

# Why the differences?

$$b_p(\lambda, [\mathrm{Chl}]) = b_p(660, [\mathrm{Chl}]) \left(\frac{\lambda}{660}\right)^{\nu}$$

$$\Phi_s 0.347[\mathrm{Chl}]^{0.766} \qquad \nu = 0.5(\log_{10}[\mathrm{Chl}] - 0.3)$$

$$b_p(550, [\mathrm{Chl}]) = 0.3566[\mathrm{Chl}]^{0.766}$$ If [Chl]=1.0 mg/m$^3$

$$\neq$$

$$b_p(550, [\mathrm{Chl}]) = 0.416[\mathrm{Chl}]^{0.766}$$ In Morel 2002.

# Where is 0.416 from?

be taken into consideration. Indeed, (9) can be replaced by a new empirical relationship, derived from a recent and much larger data set, and specifically valid for the oceanic upper layer [*Loisel and Morel*, 1998]; this revised expression, established for $\lambda = 660$ nm, is

$$b_{p660}([\mathrm{Chl}]) = 0.347[\mathrm{Chl}]^{0.766}$$

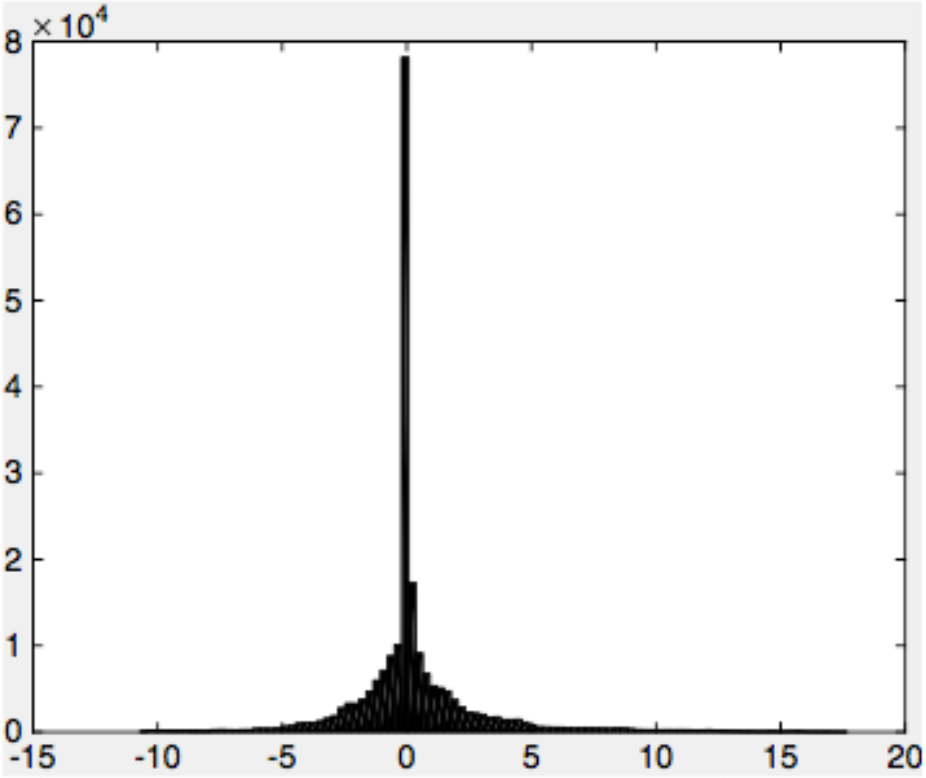
transformed into

$$b_{p550}([\mathrm{Chl}]) = 0.416[\mathrm{Chl}]^{0.766} \qquad (12)$$

at 550 nm if a $\lambda^{-1}$ spectral dependency is adopted for this scattering coefficient.

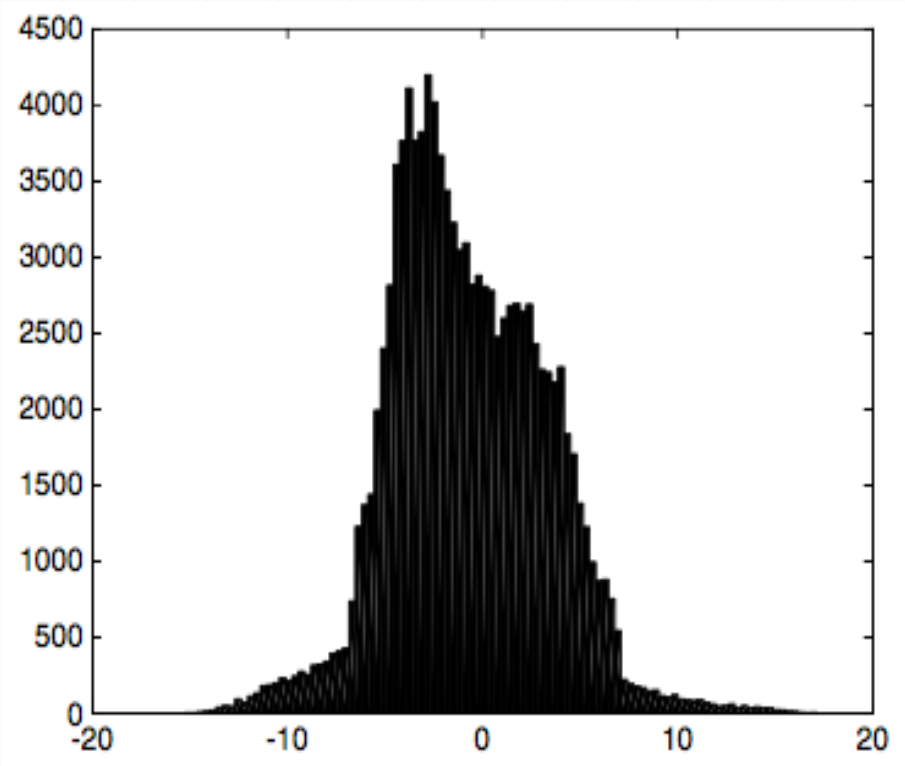
From Morel and Maritorena, JGR, 2002

# Ocean Water BRDF Uncertainty II




Histogram of $\zeta'$.

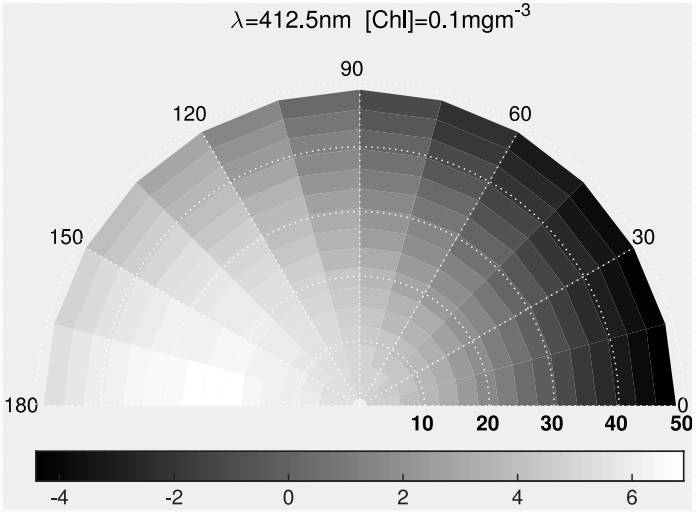
$$\zeta' = 100\% \cdot \frac{f/Q_{\Phi\neq 1,\Phi_s=1} - f/Q_{\Phi=1,\Phi_s=1}}{f/Q_{\Phi=1,\Phi_s=1}}$$

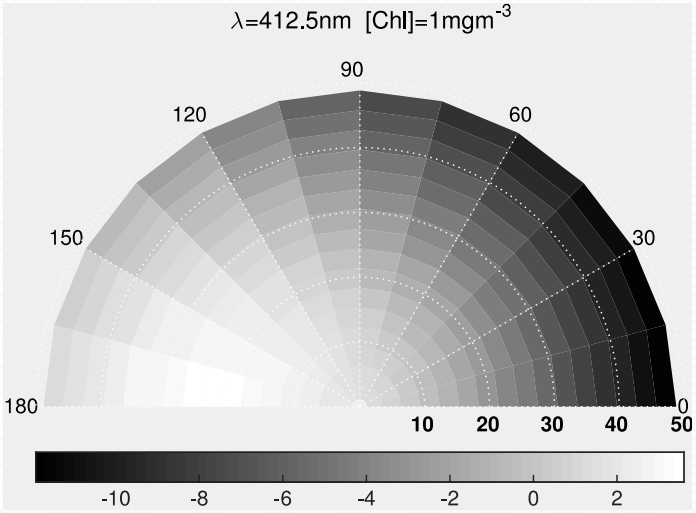


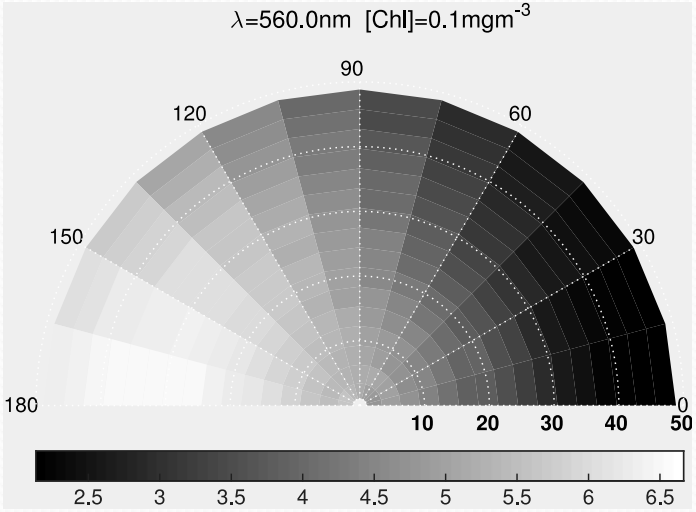

Histogram of $\zeta''$.

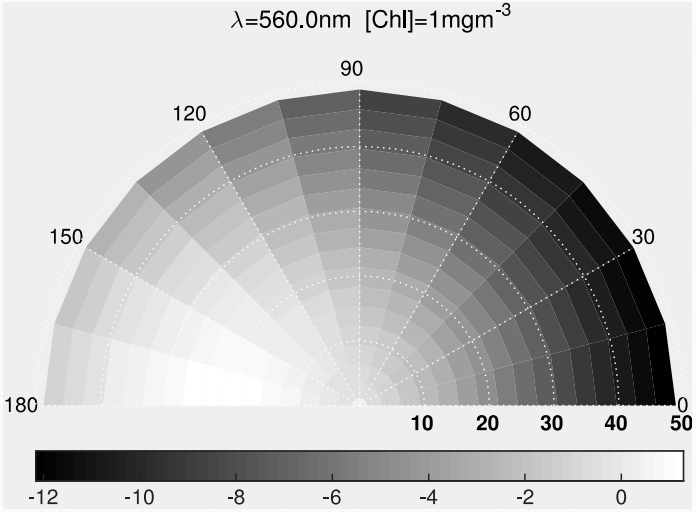
$$\zeta'' = 100\% \cdot \frac{f/Q_{\Phi=1,\Phi_s\neq 1} - f/Q_{\Phi=1,\Phi_s=1}}{f/Q_{\Phi=1,\Phi_s=1}}.$$

# Angular distribution of $\zeta = 100\% \cdot \frac{f/Q_{\Phi=\Phi_0=1} - f/Q_{MAG2002}}{f/Q_{MAG2002}}$,




Solar Zenith Angle 30 Deg.

# Take Home Messages

- A systematic evaluation of the MAG2002 BRDF LUT is performed.
- General consistency is observed.
- Difference remains due to the different radiative transfer modeling details, singles scattering phase functions, IOPs.
- Uncertainty of BRDF simulation are assessed by comparing new simulations and those of MAG2002.
- The BRDF study needs to be continued considering the newest bio-optical model for Case 1 and coastal waters.

# NOAA CoastWatch/ OceanWatch Ocean Color Data Dissemination

Veronica P. Lance* and
Paul M. DiGiacomo
and the NOAA CoastWatch/OceanWatch Team

*Global Science & Technology, Inc.

2016 STAR/JPSS Annual Science Meeting
College Park, MD, 8-12 August 2016

STAR Center for Satellite Application and Research
National Environmental Satellite, Data, and Information Service (NESDIS)

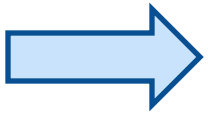
# NOAA CoastWatch/OceanWatch Team

Paul DiGiacomo – Program Manager

| Full Time Technical Team | With Support From |
|---|---|
| Heng Gu | Veronica Lance |
| Phil Keegstra | Emily Smail |
| Sathya Ramachandran | John Stachnewicz |
| Michael Soracco | Ryan Wattam |

# Suomi NPP VIIRS OC Data Products

- Near Real Time (Days 1-14)
  - Global
  - Regional



*Code has been transitioned, OSPO is now producing test data.*

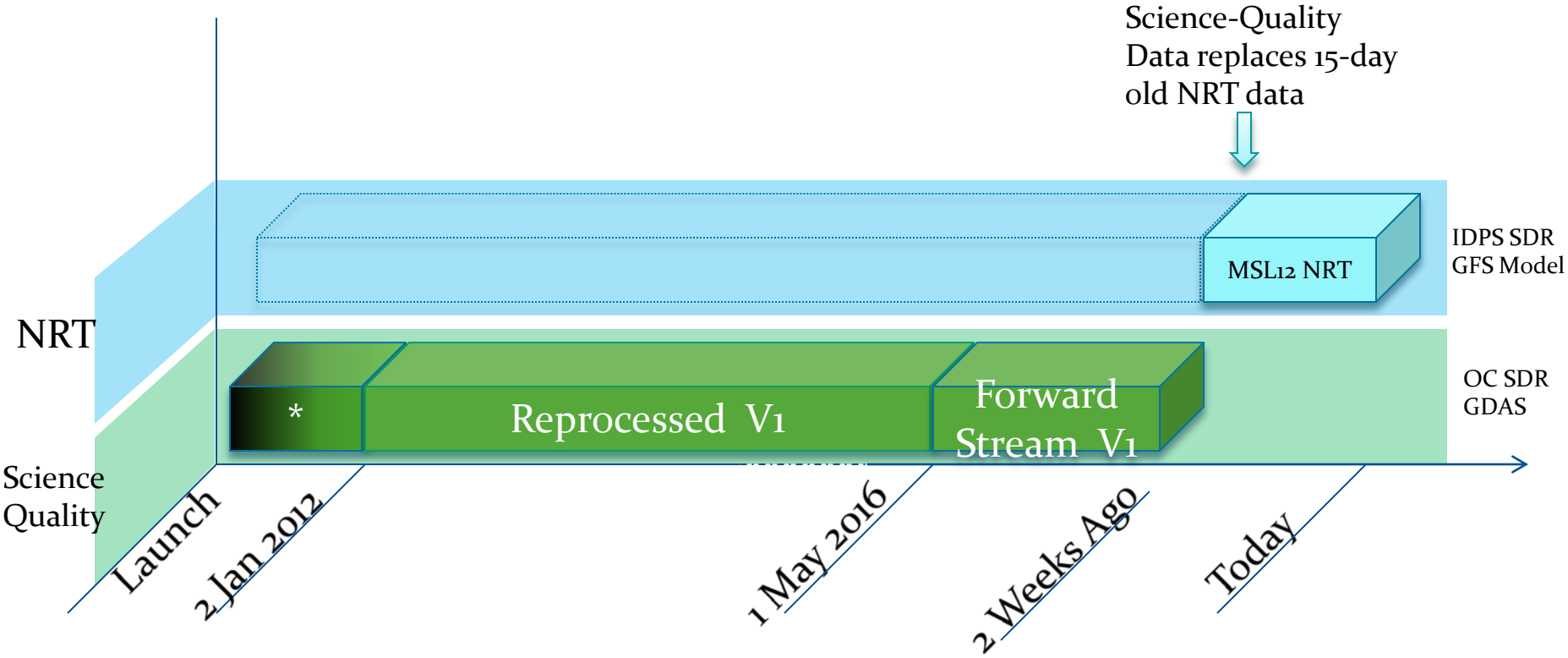
- Science Quality (Day 15 – 2 Jan 2012*)
  - Global
  - Regional

** Data from early mission (since launch Nov. 2011 to 2 Jan 2012) are available only upon special request and will be provided with a quality warning.*

# NRT & Science Quality Data

| Attribute | Near-Real Time | Delayed-Mode/Science-Quality |
|---|---|---|
| Latency: | Best effort, as soon as possible (~12-24h) | Best effort, on a 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 |

# Example "Snapshot"




*Early mission data are not publically distributed due to quality issues. They can be specially requested but will come with a quality warning.

# L2 & L3 Global Products

- Standard:
  - Chlorophyll-a
  - Kd490
  - KdPAR
  - nLw_412
  - nLw_445
  - nLw_488
  - nLw_555
  - nLw_672
  - L2_flags
  - Latitude
  - Longitude
- Experimental:
  - IOPs
  - PAR

*Future inclusion as released by MECB*

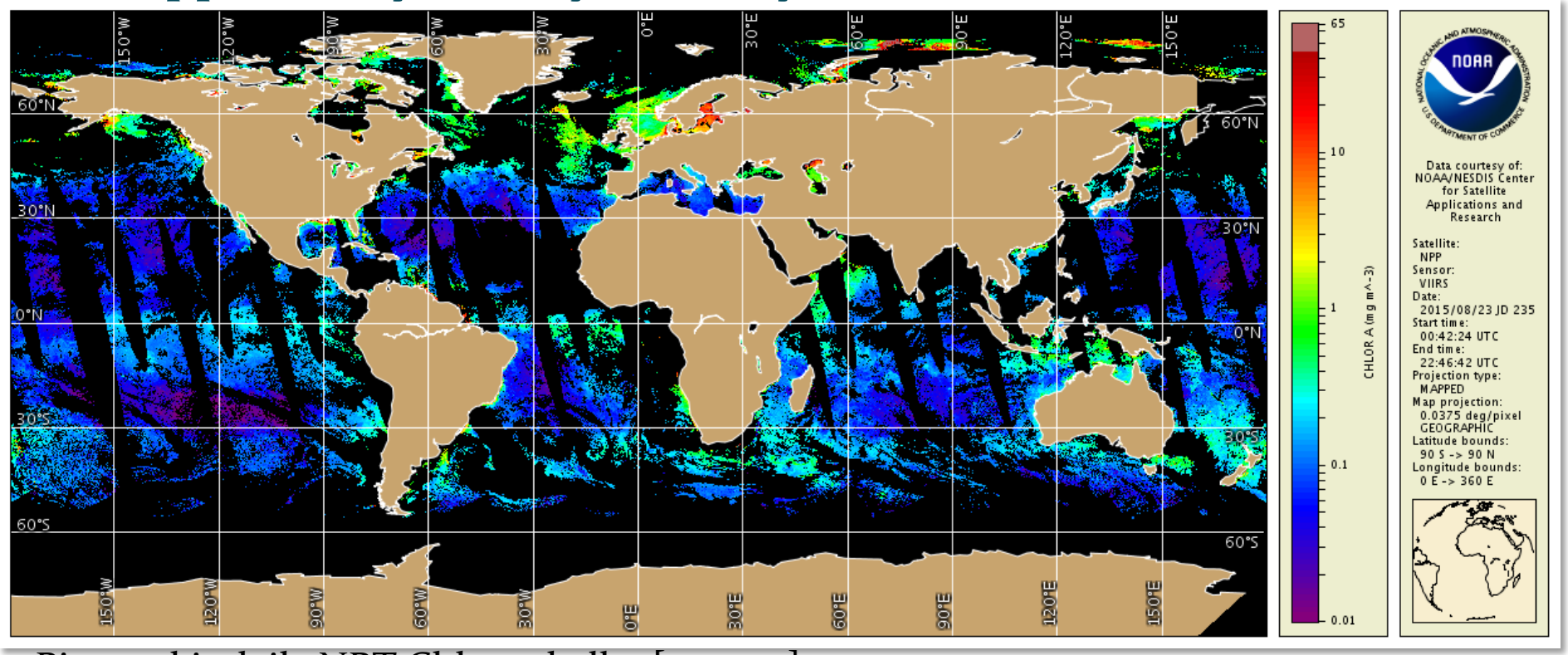
# L2 & L3 Regional Products

- Standard:
  - Chlorophyll-a
  - Kd490
  - KdPAR
  - nLw_412
  - nLw_445
  - nLw_488
  - nLw_555
  - nLw_672
  - L2_flags
  - Latitude
  - Longitude
  - Edgemask
- Experimental:
  - IOPs
  - PAR

  *Future inclusion as released by MECB*
- User Driven ("Customized" routine production; considered upon request):
  - HAB anomaly product
  - $R_{rs}$
  - Special projections
  - Etc.

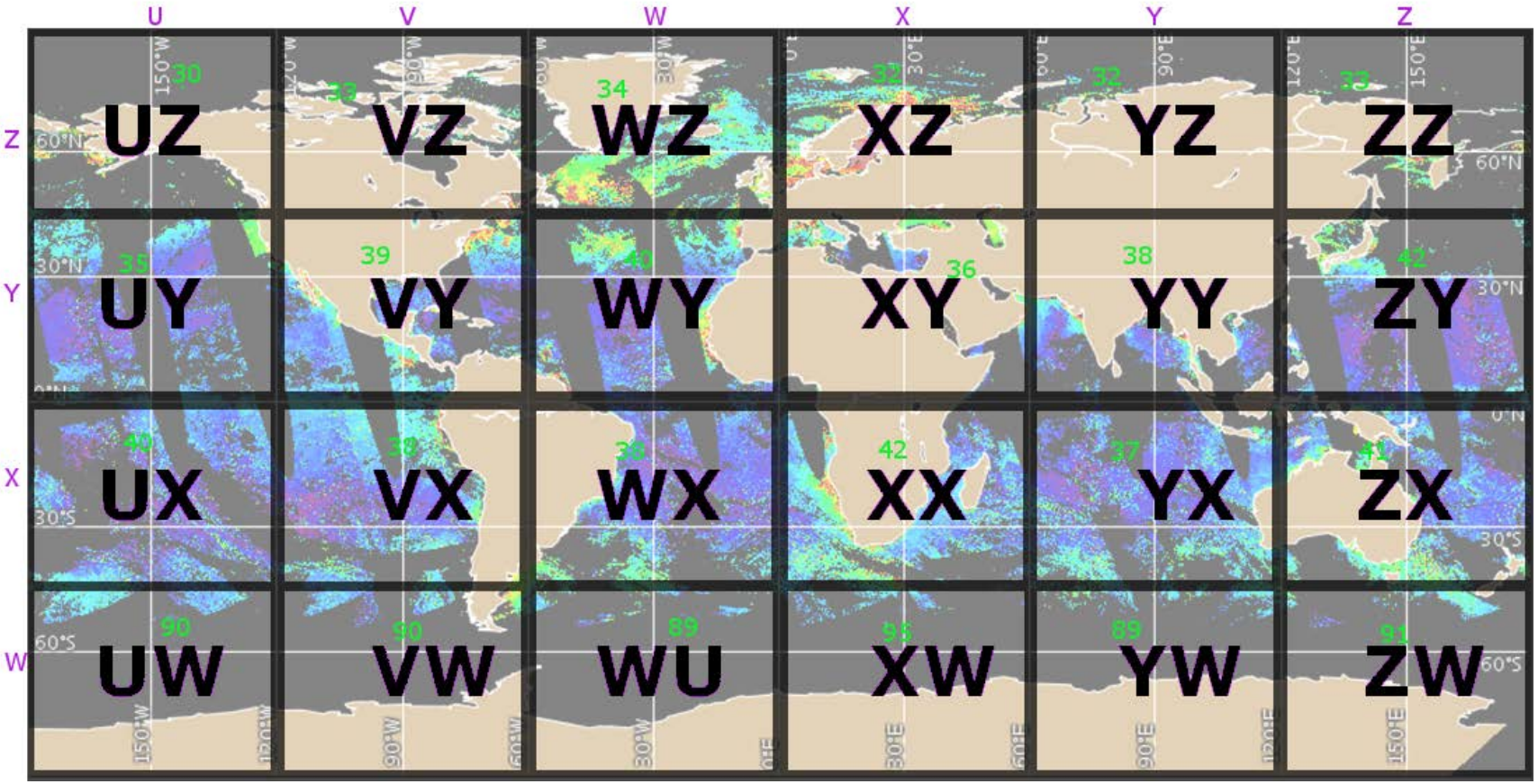
# L3 Global 4km

## (mapped, daily, weekly monthly)



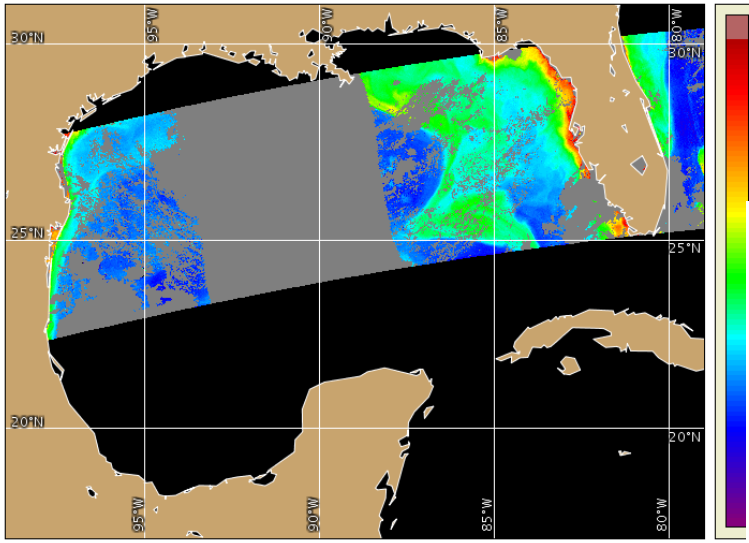

Pictured is daily NRT Chlorophyll-a [mg $m^{-3}$];

# L3 Global 750m Sectors



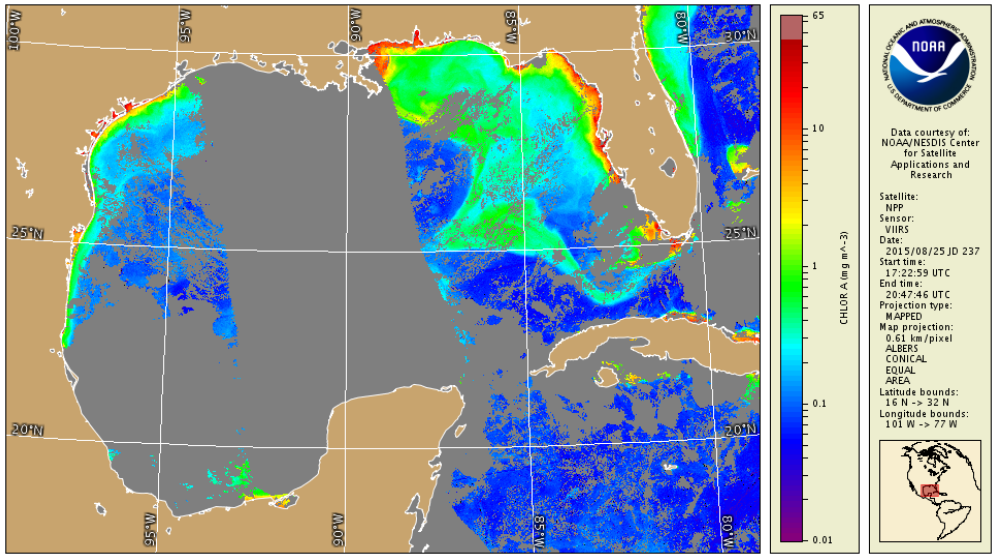
# L3 Regional

- "CONUS" 750m regions: Hawaii, West Coast, Great Lakes, Northeast, Southeast, Gulf of Mexico, Caribbean



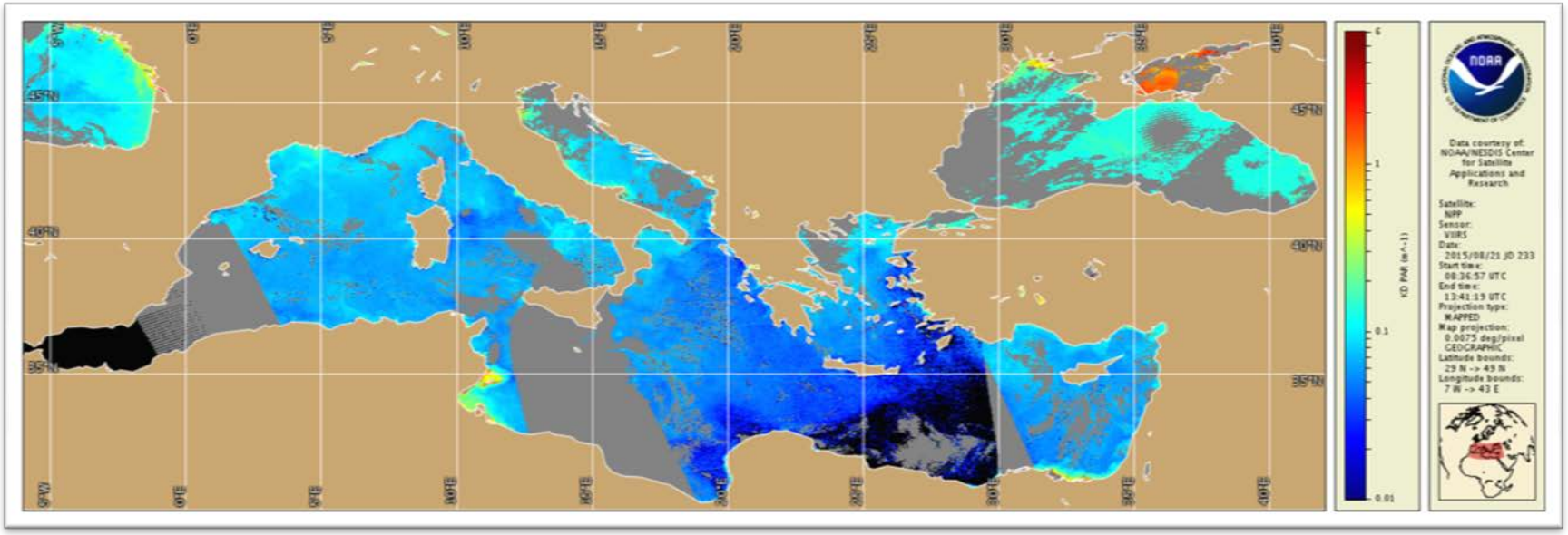

Granule

Daily Merge



# L2 Regional Partners (1)

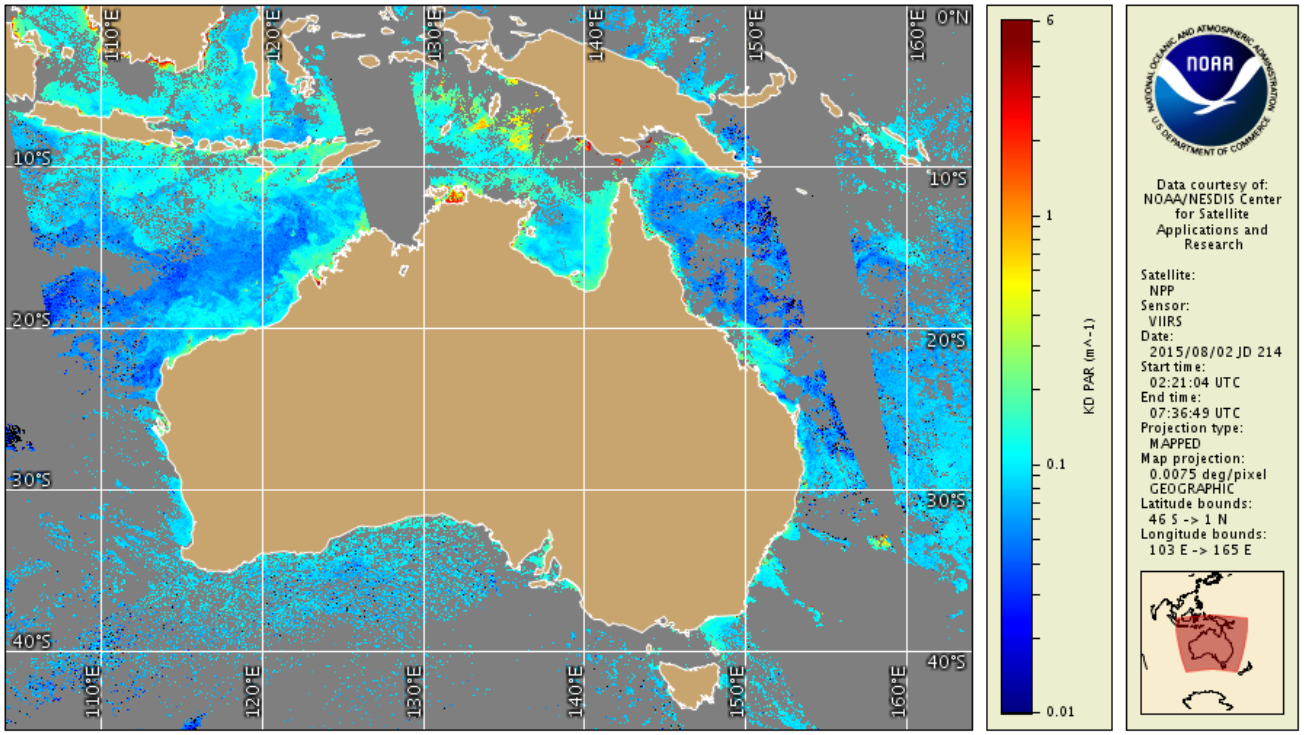
- EUMETSAT
  - Processing and staging of L2 750m Mediterranean datasets
  - EUMETcast (Copernicus Service) broadcasts VIIRS data to EU



Shown: L3 Daily merge, mapped, $k_dPAR$ [$m^{-1}$]

# L3 Regional Partners (2)

- CSIRO
  - Processing and staging of L3 Australia 750m datasets



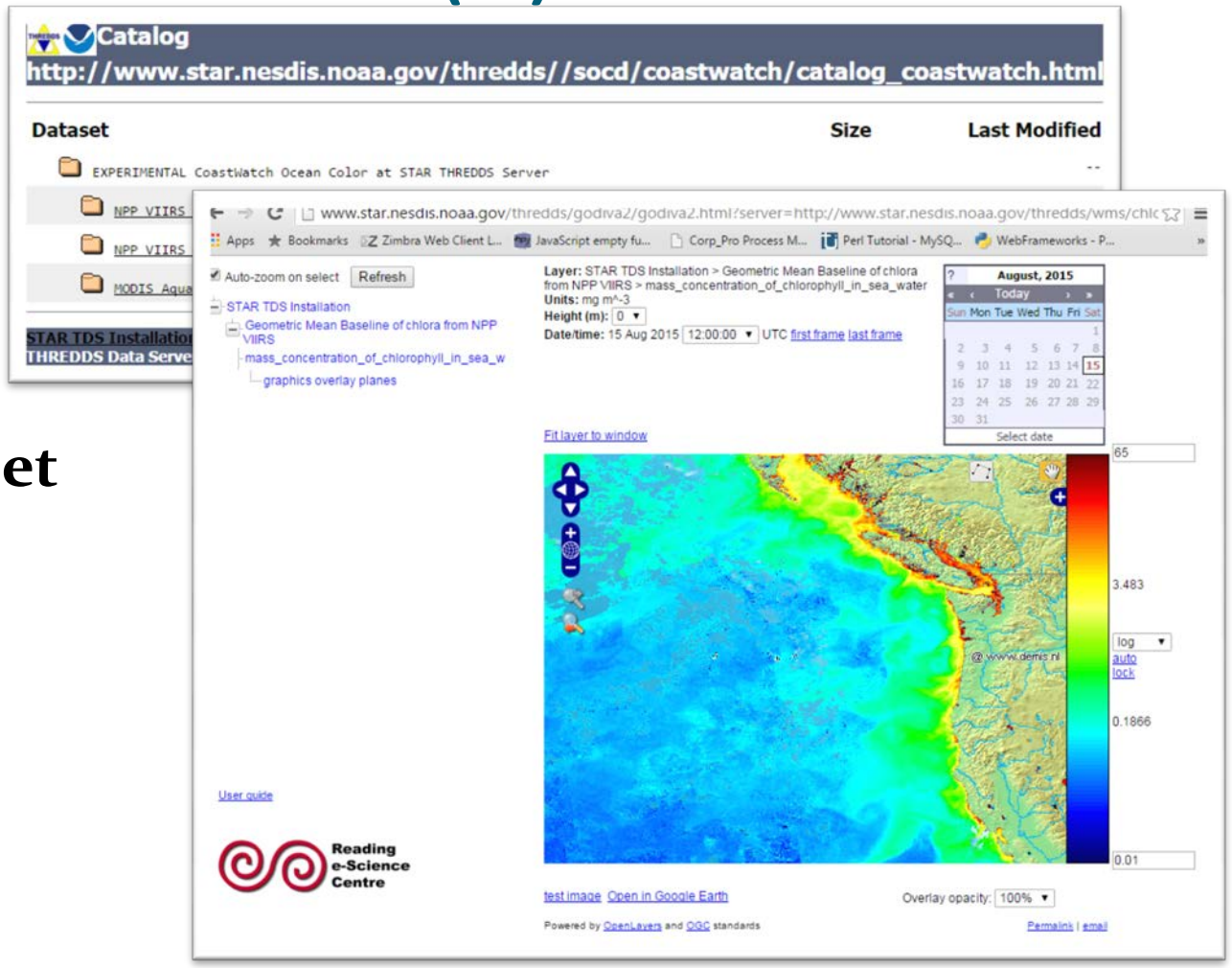

Daily Merge, mapped, $k_d$PAR [$m^{-1}$]

# Data Formats

- Global / Sector:
  - NetCDF (v4 CF)
  - GeoTIFF & PNG
- Regional:
  - NetCDF(v4 CF)
  - GeoTIFF & PNG
  - HDF (v4 with CoastWatch metadata; to be phased out)

# Access & Protocols (1)

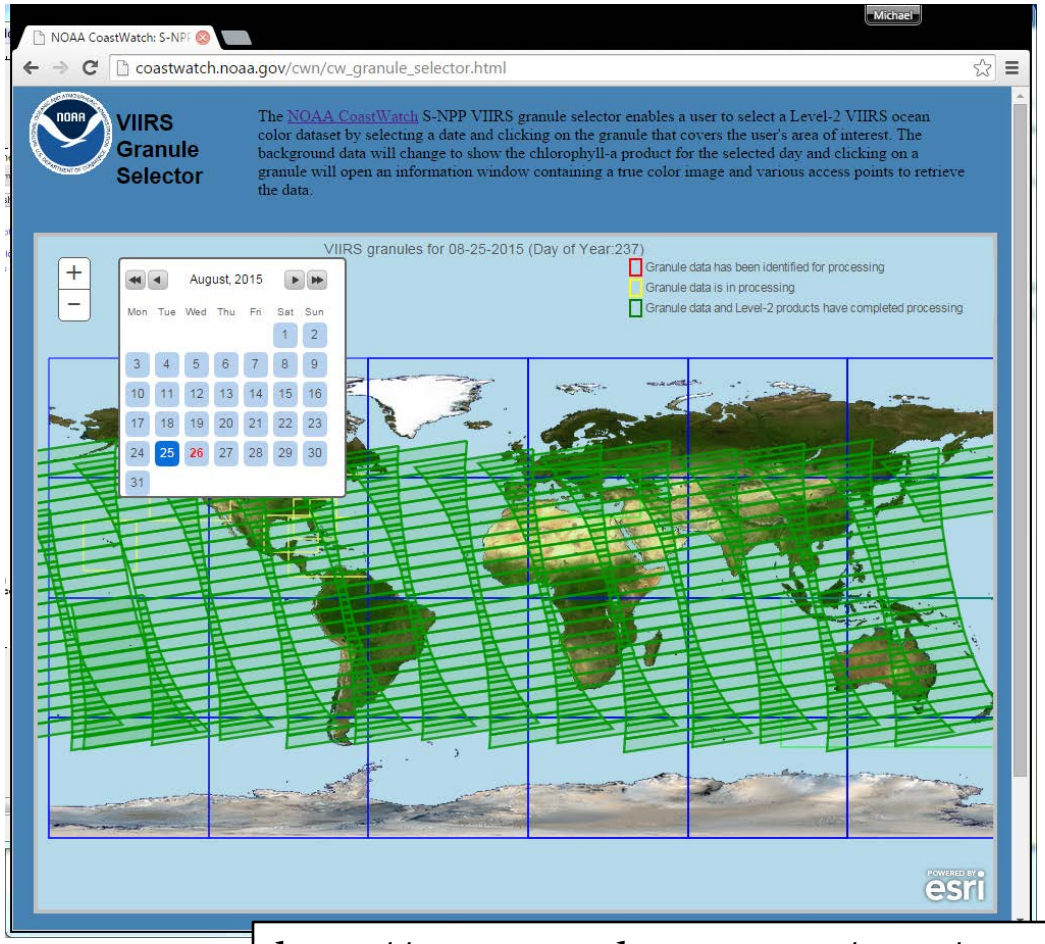
- HTTP
- FTP
- THREDDS
  - **OPENDAP**
  - **NetcdfSubset**
  - **WCS**
  - **WMS**
  - **NCML**
  - **ISO**
  - **UDDC**

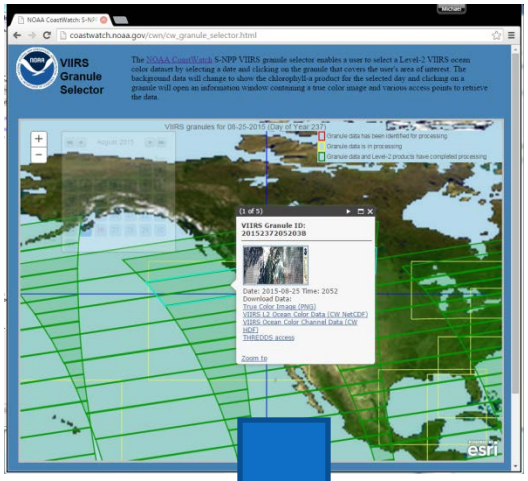


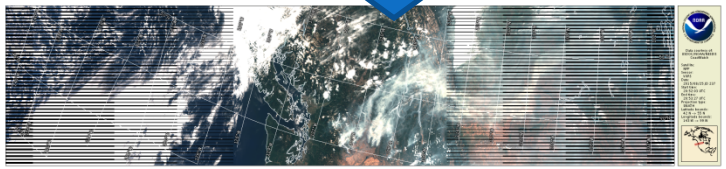
# Access & Protocols (2)

- HTTP:
  - Present: http://coastwatch.noaa.gov
- FTP: ftp://star.nesdis.noaa.gov/pub/socd/mecb/coastwatch/viirs/
  - Present:
    - L2 datasets covering Mediterranean for EUMETSAT
    - L3 for Gulf of Mexico (CW HDF) for support of NOS HAB
  - Soon: FTP access to include THREDDS holdings (Q4 2015)
- THREDDS: http://coastwatch.noaa.gov/thredds

# L2 Granule Selector



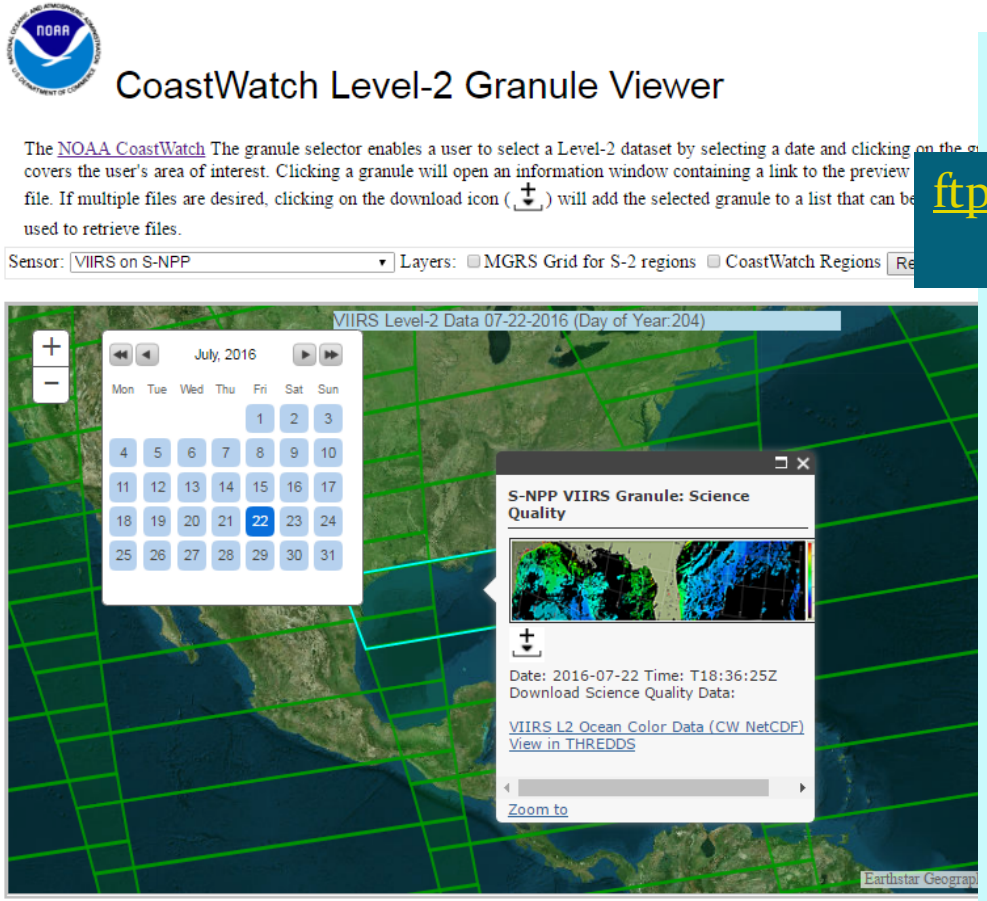



Date: 2015-08-25 Time: 2052
Download Data:
True Color Image (PNG)
VIIRS L2 Ocean Color Data (CW NetCDF)
VIIRS Ocean Color Channel Data (CW HDF)
THREDDS access

http://coastwatch.noaa.gov/cwn/cw_granule_selector.html

# Science Quality 'Life-of-Mission'




- FTP OC 2012 to [Present – 15 days]:

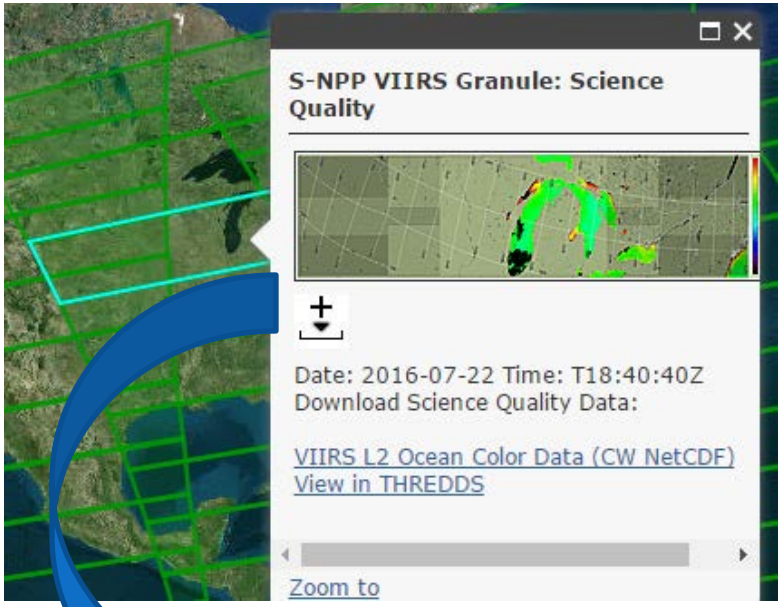
ftp://ftp.star.nesdis.noaa.gov/pub/socd1/mecb/coastwatch/viirs/science/L2/

- Integrated with the same L2 Granule Selector tool
  - Present – 15 days: NRT Granules
  - 15 days old and prior: Science Quality
  - Includes data preview and data cart
- VIIRS SST RAN1 will be included when ready
- OLCI OC will be included when ready for release

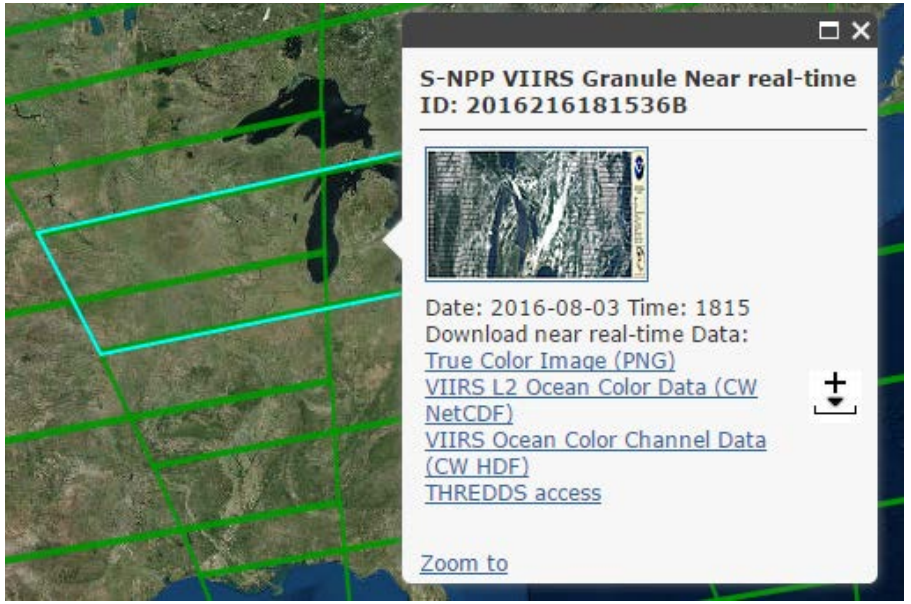
http://coastwatch.noaa.gov/cwn/cw_granule_selector.html

# Example of VIIRS OC Data Cart

Science Quality (forward processing)



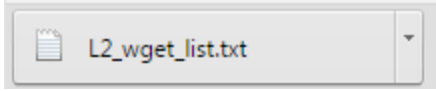

Near real-time







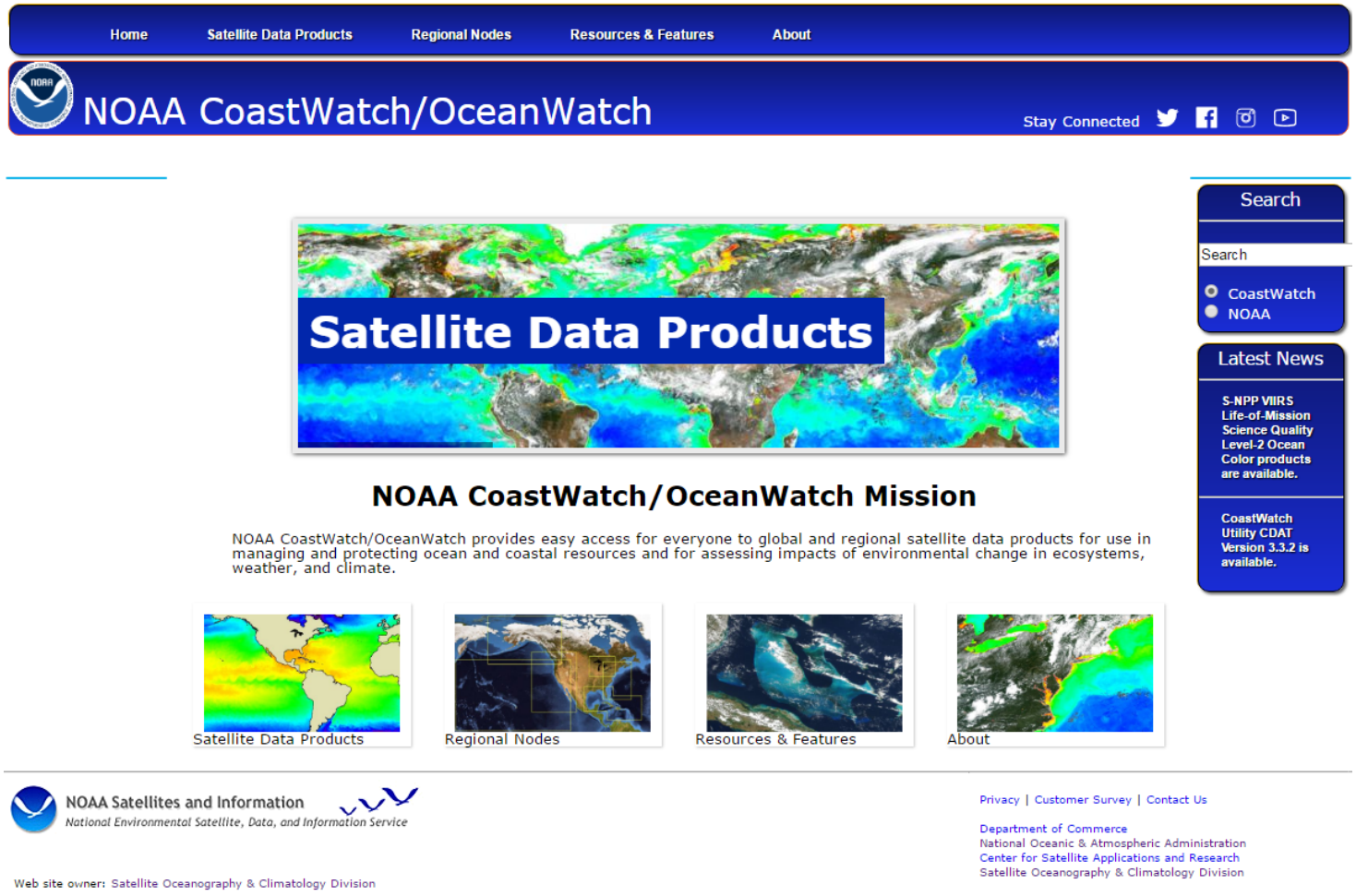
For batch download



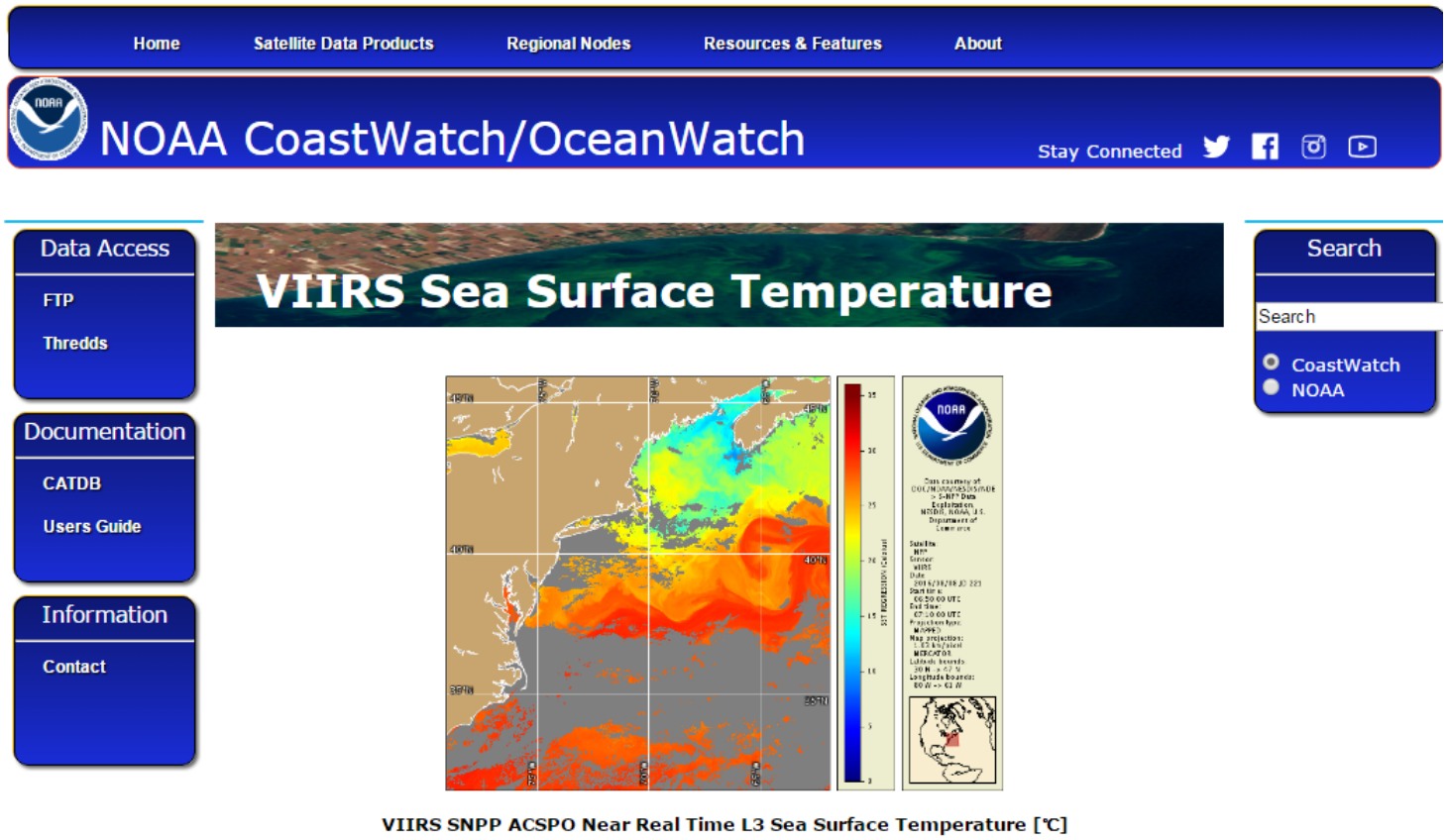
# Data Stewardship and Long-Term Archive by NCEI

- NOAA CoastWatch/OceanWatch is prepared to deliver MSL12 full mission science quality data (L2 and L3) for data stewardship and long-term archiving by NCEI.
- Arrangements among STAR (via CoastWatch), NCEI and CLASS are in progress.

# Website Revamp in Progress (1)



# Website Revamp in Progress (2)



# Sentinel-3A

- A Cooperative Arrangement between the United States and the European Commission and technical arrangements between NOAA and EUMETSAT (and NOAA and ESA for S1 and S2) are all complete.
- NOAA is primary outlet in US for Sentinel 3 marine data.
- EUMETSAT data transfer via terrestrial multicast to NOAA/STAR is now routine. Data will be publically available as soon as EUMETSAT declares so.
- NOAA CoastWatch/OceanWatch to provide near real-time access to global OLCI and SLSTR data products from EUMETSAT. SRAL data also coming into STAR.
- OLCI data complements existing JPSS sensors:
  - 300m spatial resolution
  - Spectral bands meeting NOAA NOS HAB requirements
  - Relieves single point-of-failure for HAB forecasting

# Summary (1)

Both NRT and Science Quality VIIRS-SNPP Ocean Color data are now publically available through NOAA CoastWatch/OceanWatch.

## Science Quality

L2 global, granules:

FTP:

ftp://ftp.star.nesdis.noaa.gov/pub/socd1/mecb/coastwatch/viirs/science/L2/

THREDDS:

http://www.star.nesdis.noaa.gov/thredds/catalog/swathNPPVIIRSSCIENCEL2WW00/catalog.html

Or, you can interactively select and download data (or get your file list for automated commands) using the Granule Selector Tool here:

http://coastwatch.noaa.gov/cwn/cw_granule_selector.html

L3 global 4km mapped:

FTP:

ftp://ftp.star.nesdis.noaa.gov/pub/socd2/mecb/coastwatch/viirs/science/L3/global/

# Summary (2)

Both NRT and Science Quality VIIRS-SNPP Ocean Color data are now publically available through NOAA CoastWatch/OceanWatch.

## Near Real Time

THREDDS OC NRT main page:
http://www.star.nesdis.noaa.gov/thredds/socd/coastwatch/catalog_coastwatch_viirs_global.html

Includes: L2 global granules (swath); L3 global 4km mapped, daily, weekly, monthly merged, and 750m regional sector files

Or, you can interactively select and download data (or get your file list for automated commands) using the Granule Selector Tool here:

http://coastwatch.noaa.gov/cwn/cw_granule_selector.html