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

Robert Arnone¹, Sherwin Ladner², Bill Gibson³, Ryan Vandermuelen⁴, Wes Goode², Jen Bowers²

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

- Stable
- Low Winds
- Optically Clear

Not Chlorophyll!

Response of Shallow waters
- Cooler of Shallow waters

Chlorophyll

Sea Surface Temperature

Response Of SST over shallow Waters
- Cooler of Shallow waters

Dec 4, 7
2 stations within 5 days

Dec 5-6

Green Cay

Freeport
S4
S10

Andros Island
Nassau
Abaco

Map showing locations of stations S4, S10, S5, S6, S7, S9, and S8.

Map showing sea surface temperature with cooler regions indicated in green.
**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
Foster 2015 Cruise Track and Stations Selection

Conditions improved Dec 8
Crossed Gulf Stream twice
<table>
<thead>
<tr>
<th>Station Specs</th>
<th>Optical Profilers</th>
<th>Hyperpro Profilers</th>
<th>Floats</th>
</tr>
</thead>
<tbody>
<tr>
<td>Date - 2015</td>
<td>UTC is +05:00 local</td>
<td>Ship Rosset - profiler- CTD, Chl-Fluorometer, O2</td>
<td>Hyperpro USF</td>
</tr>
<tr>
<td>Julian - Day</td>
<td>start time (UTC)</td>
<td>NASA -IOP Package , acs,ac9,bb9,vsf,SBE (Comments)</td>
<td>Hyperpro- OSU</td>
</tr>
<tr>
<td>Start time (GMT)</td>
<td>Julian date+time</td>
<td>UMB - opticsPackage _CTD, ACS, GOOD VIIRS_MATCHUP - Mike</td>
<td>Hyperpro- Float (PUFF) USM</td>
</tr>
<tr>
<td>Lat (degrees decimal min)</td>
<td>Flowthrough hour Scan count(ship)</td>
<td>Hyperpro - USF</td>
<td>Hyperpro SBA- (BIG BIRD)</td>
</tr>
<tr>
<td>Lon (degrees decimal min)</td>
<td>Sky cover (% clouds)</td>
<td>Hyperpro- OSU</td>
<td>NURADS</td>
</tr>
<tr>
<td>Sea state (feet)</td>
<td>wind direction</td>
<td>Hyperpro- Float (PUFF) USM</td>
<td>Fiber - CUNY</td>
</tr>
<tr>
<td>Water Depth</td>
<td>wind speed (kt)</td>
<td>Hyperpro- Float ( NRL)</td>
<td></td>
</tr>
</tbody>
</table>
Objective 2: Compare Variability in In situ Data Radiometry for Cal Val of VIIRS

Establish protocols

"Floating Hyperpros" - Prosoft 8.1.4
Time changes of the Radiances - Constrained the tilt

Variability with time
5 minutes data

ES

Time

LU

ES

Tilt

Constrained with the tilt

Station 19 - 345-134410

Time Variability
Standard Deviation

2 Instruments
USM / NRL

Prosoft Processing Details
Similar results For 2 Float Hyperpros
Protocols used - for Post Processing

Steps

#1 Edit and load the cal

#2 - Edit to set up parameters

#3 Ready to process.

level 1 → Level 4

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**Remote sensing reflectance**

\[
R_{RS}(\lambda) = \frac{L_w(\lambda)}{E_s(\lambda)}
\]

\(\rho = 0.025\) is the Fresnel reflectance of the air sea interface,

\(n = 1.34\) is the refractive index of seawater.

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

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

**ASD collected data**

Distance above water
- Bow = 2m
- 01 deck = 5m
- 02 deck = 8m

Fore optics 10 and 1 and Viewing angle
Top deck and large fore optics has largest Spot size

**Comparison of Spot Size**

5 Above Water instruments have Differences

<table>
<thead>
<tr>
<th>Institution</th>
<th>USM</th>
<th>NRL</th>
<th>NOAA</th>
<th>USF</th>
<th>CUNY</th>
</tr>
</thead>
<tbody>
<tr>
<td>Foreoptic (degrees)</td>
<td>1</td>
<td>10</td>
<td>10</td>
<td>7.5</td>
<td>8</td>
</tr>
<tr>
<td>Foreoptic (radians)</td>
<td>0.01745329</td>
<td>0.17453293</td>
<td>0.17453293</td>
<td>0.13089969</td>
<td>0.13962634</td>
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<tr>
<td>Sampling Zenith Angle - Water target (degrees)</td>
<td>40</td>
<td>40</td>
<td>40</td>
<td>30</td>
<td>40</td>
</tr>
<tr>
<td>Sampling Zenith Angle - Water target (radians)</td>
<td>0.6981317</td>
<td>0.6981317</td>
<td>0.6981317</td>
<td>0.52359878</td>
<td>0.6981317</td>
</tr>
<tr>
<td>Average Sampling Height Above Water (meters)</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>X, where x = SQRT(h^2 + w^2), and w = h tan b</td>
<td>2.61081458</td>
<td>2.61081458</td>
<td>2.61081458</td>
<td>2.30940108</td>
<td>2.61081458</td>
</tr>
<tr>
<td>Y, where y = x tan a</td>
<td>0.02278423</td>
<td>0.22841668</td>
<td>0.22841668</td>
<td>0.15136614</td>
<td>0.18256594</td>
</tr>
<tr>
<td>Z, where z = h [tan(b) + tan(a)]</td>
<td>3.3836063</td>
<td>3.6781926</td>
<td>3.6781926</td>
<td>2.49105781</td>
<td>3.60957681</td>
</tr>
<tr>
<td>AREA (m^2)</td>
<td>0.12201122</td>
<td>1.40167848</td>
<td>1.40167848</td>
<td>0.62827694</td>
<td>1.08748764</td>
</tr>
</tbody>
</table>
Dec 2015 Cruise

ASD protocol - Results - ASD Requires Spot Size from 2-10 Meters! For the Foster – collect ASD on 01 deck!

Shooting ASD from which deck?
- 2 m - stern
- 5 m - 01 deck
- 8 m - 02 Deck

Coastal 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!

Blue Water Matchups
R_{RS} – Uncertainty in above-water spot size

RRS – Uncertainty in above-water spot size

Station 17 (RRS_WHITE)

Station 3 (RRS_LEE)

10 degree
- 1.4 m stern
- 22 m -02 deck
- 8 m 01 deck

1 degree
- .12 m stern
- 1.95 02 deck
- .76 01 deck

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
Similar Protocols

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

Different % Clouds

Similar Processing on all Systems

**Station 24 Blue Tile**

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

135 degree azimuth
T1430 GMT

**Station 21 Blue Tile**

90 degree azimuth T1910 GMT
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

Dec 2015 Cruise  

Chlorophyll

Cruise track
Coastal waters

Sea Surface Temperature

MSL12 – Chlorophyll
Dec 8

Gulf Stream

400 450 500 550 600 650 700 750 800

RRS

Station 12 - 342-192841

Floaters Agree -

- USM-Float
- NRL-Float
- NASA-3x
- MSL-3x
- MSL_5x
- NASA-5x
- NRI-ASD
- NOAA-ASD g1
- NRL-ASD_w
- NOAA-ASDw

Difference

MSL12 – NASA

At 412nm

Floats Lower Than ASD

0.001
0.002
0.003
0.004
0.005
0.006
0.007
0.008
0.009
0.01
Clear Skies

RRS from Floaters and ASD Consistent.

Gulf Stream St 19  Shingle St 20 – 21

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

Suggests Protocols
VIIRS Matchup

RRS from Floaters and ASD Consistent.

Dec 2015 Cruise

Dec 11

Day 345  Dec 11,  Station 19, 20, 21

Gulf Stream
Front
Upwelling

Gulf Stream
Shingle

Shingle

Dec 11

Dec 12

Dec 11

Upwelling

Gulf Stream
Shingle

Shingle

Dec 11

Dec 12

Dec 11

Upwelling

Gulf Stream

Shingle

Dec 11

Dec 12

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Upwelling

Gulf Stream

Shingle

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Upwelling

Gulf Stream

Shingle

Dec 11

Dec 12

Dec 11

Upwelling
Dec 2015 Cruise

VIIRS and Insitu Matchup - Floating Hyperpro - and ASD

Day 346  Dec 12,  Station 23, 24, 25

At Drifter Release

VIIRS Matchup has Cloud Cover Uncertainty
Define pixels with cloud Shadow!

VIIRS Scattered Clouds Has VIIRS Center Pixel
Along SST frontal boundary
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 ($\lambda$), scattering ($\lambda$), CDOM, spectral slope $\rightarrow$ particle size,
bb - backscattering
CHL

SST

VIIRS

SHIP Flowthrough

Chlorophyll Backscattering

VIIRS Overpass

Absorption 444

NOAA Cal/Val Cruise 12/11/15 345 17-19 GMT

Mean(41,800 Samples) = 28.0% 13.0%
Range = 0.05-56.0%; 0.03-39.0%

VIIRS Comparison

Absorption 444

VIIRS

Ship

Flow
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 to 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

Chlorophyll Difference
-3 Bloom Mg/m3 0 (mg/m3) +3 Decay First Greater

Orbit 1 – Orbit 2

JPSS - Meeting

VIIRS Following Trend
Does VIIRS orbital overlap correctly handle the large sensor angles?

Overlap on Nov 29

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

Chlorophyll

RRS - 443 - 551

WavCIS

Nov 29, 2014
VIIRS Diurnal Changes can identifies Surface Processes in the Ecosystem

1) Phytoplankton Blooms and Decay
2) Water Mass Advection

Surface Currents

- 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 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 an ocean site
3. VIIRS Data matchup Protocols
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
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