On the data quality and quantity of VIIRS/SNPP ocean color data products: from research to applications

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Outline

1. Data quality: standard and non-standard data products
2. Data quantity: not always a zero-sum game
3. Examples on research and applications: algal blooms (harmful and non-harmful, microalgae and macroalgae) and oil spills

VIIRS data sources:

• NOAA/NESDIS/STAR (MSL12 processing)
• NASA GSFC (L2GEN processing)

MODIS data source:

• NASA GSFC (L2GEN processing)
1. Data quality: validation using field measurements

Table 1: Summary of selected \( Rrs \) validation methods and results

<table>
<thead>
<tr>
<th>Citation</th>
<th>Platform</th>
<th>Environment</th>
<th>Sensor</th>
<th>Processing*</th>
<th>CV Threshold (box size)</th>
<th>Temporal overlap (hr)</th>
<th>Accuracy Statistic (547 or 551 nm)</th>
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<tbody>
<tr>
<td>Mélin et al., 2007</td>
<td>Fixed</td>
<td>Coastal</td>
<td>MODIS</td>
<td>SeaDAS 5.0 (~2005.1)</td>
<td>0.2 (3x3)</td>
<td>3.5</td>
<td>MAPD = 14%</td>
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<td>SeaDAS 2005.0</td>
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<td>MODIS</td>
<td>SeaDAS 2005.1</td>
<td>- (-)</td>
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<td>MODIS</td>
<td>SeaDAS 2012.0</td>
<td>0.2 (3x3)</td>
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<td>MAPD ~ 12%</td>
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<td>MODIS</td>
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<td>Coastal</td>
<td>VIIRS</td>
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<td>MSL12</td>
<td>0.2 (3x3)</td>
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<td>MAPD = 14%</td>
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<td>Wang et al., 2014</td>
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<td>Oceanic</td>
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<td>MSL12</td>
<td>- (5x5)</td>
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<td>SeaDAS 2014.0.1</td>
<td>- (3x3)</td>
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<td>MAPD ~ 12%</td>
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MR = Mean Ratio, MAPD = Mean Absolute Percent Difference, RMSE = Root Mean Squared Error, - = not performed or not reported, * Where not specified, approximate processing version reported.

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<td>Chlorophyll out-of-bounds</td>
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<td>Atmospheric correction is suspect</td>
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<td>ALGICE</td>
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<td>SEAICE</td>
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<td>FILTER</td>
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<td>ALTCLD</td>
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<td>BOWTIEDEL</td>
<td>FOG</td>
<td>FOG</td>
<td>VIIRS deleted overlapping pixels [Fog]</td>
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<td>High polarization [SWIR atm. corr. used]</td>
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<td>Failure in any product</td>
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<td>OCEAN</td>
<td>OCEAN</td>
<td>[Pixel is over ocean]</td>
<td></td>
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</tbody>
</table>

* The L3 mask is used for generation of global composite data products.
† Includes additional flag(s) specific to \( C_o \). Also used by Antoine et al. (2008), Melin et al. (2007), Zibordi et al. (2009)
§ Includes additional flag for negative Rayleigh-corrected reflectance. Also used by Ahmed et al. (2013).
Validation using data collected in North America (most data collection supported by NOAA VIIRS cal/val program)

Station locations and partitions

VIIRS NOAA: MSL12 Apr 2017 SDR
VIIRS NASA and MODISA: L2GEN r2018.0

Oligotrophic GOM/Mississippi R. plume
CDOM-rich, coastal Big Bend;
Red tide (8/2014)

Oligotrophic Gulf Stream; Turbid post-H. Matthew-(10/2016)

Validation using data collected in North America (most data collection supported by NOAA VIIRS cal/val program)

From Barnes et al. (2019, RSE)
Validation using data collected in North America (most data collection supported by NOAA VIIRS cal/val program)

Matchup Statistics

From Barnes et al. (2019, RSE)
Validation using MOBY measurements

From Wang and Son (2016, RSE)
Validation using cross-sensor comparison

From Barnes and Hu (2015, IEEE TGRS)
1. Data quality: Summary

- Considering that ~40% of the match-ups pairs were collected in shallow (z=3-8m), optically complex coastal waters with variable bottom types, the overall agreement between field and satellite $R_{rs}(\lambda)$ is impressive! [e.g., Uncertainties in $R_{rs551}$ ~ 20%, only slightly higher than ~15% from previous reports for less complex waters]

- VIIRS performance is comparable to MODISA performance, from either field validation or cross-sensor comparison

- Results are variable between NOAA and NASA VIIRS products, with neither proving consistently more accurate even when considering only common pixels. Yet NOAA products showed 5-10% more matchup points when identical QA criteria were used
2. Data quantity: evaluation of global data products

Motivation:

• Once data quality is confirmed, the ultimate advantage of remote sensing is in its data quantity (i.e., spatial and temporal coverage frequency), otherwise ship-based measurement is always better.

• Then, how to measure this “data quantity”?

• How are different sensors compared with each other? For the same sensor, what differences can result from different algorithms/processings?
2. Data quantity: evaluation of global data products

Measure of “data quantity”
Daily Percentage Valid Observations (DPVOs)

Cloud-free probability over global oceans:
~30% (King et al., 2013)

Then, if a sensor can cover global oceans once a day, do we have 30% DPVOs?

Assessment approach:
- # of valid observations ($N_v$) for each pre-defined 4.6-km grid during each month is stored in global Level-3 bin files
- $\text{DPVO} = N_v / (4.6 \times 4.6 \times 30)$, averaged over global oceans and over many months
DPVOs of NPP/VIIRS Chl (Nov 2011 – Jul 2018)

NOAA MSL12 versus NASA L2gen

MSL12: 9.8%

L2GEN: 5.1%
DPVOs of NPP/VIIRS Chl (Nov 2011 – Jul 2018)
(MSL12 – L2gen)/L2gen * 100%
What caused the difference? Gulf of Mexico diagnostics

- L2GEN DPVO: 14% (18% in winter, 10% in summer)
- MSL12 DPVO: 21% (25% in winter, 17% in summer)

HIGLINT:
- 0.01 for MSL12
- 0.005 for L2GEN
DPVOs of NPP/VIIRS and MODIS AFAI: consistent processing
Daily data from 2006 (Wang and Hu, 2018, IJRS)
2. Data quantity: Summary

• Even at 30% cloudfree probability, DPVOs of MODIS and VIIRS are way below 30%. Clearly, cloud cover is not the only major reason leading to no valid retrievals

• Straylight and sun glint are two other major reasons

• NOAA MSL12 has a different approach to mask straylight (Jiang and Wang, 2013) than NASA L2gen (7x5 dilation). Together with other differences in processing, MSL12 doubles DPVOs from L2gen on global Chl products

• The increases in quantity have significant implications in tracking blooms and other features as well as in reducing product uncertainties

• Finally, these DPVOs indicate observations at 1-km and daily resolutions. Coverage always increases when data are binned in space and/or time
3. Examples in research and applications: HABs

VIIRS red band (662 – 682 nm) encompasses the MODIS red band (662 – 672) and FLH band (672 – 682), therefore carrying information of algae.

From Qi et al. (2015)
3. Examples in research and applications: HABs

VIIRS RGCI reveals similar patterns as MODIS nFLH (Qi et al., 2015)
3. Examples in research and applications: HABs

Monitoring of the 2018 red tide in the eastern GOM

VIIRS RGCI can produce products comparable to MODIS nFLH (Qi et al., 2015).

https://optics.marine.usf.edu/projects/iris.html

VIIRS RGB, 8/18/2018  VIIRS RGCI  MODISA RGB  MODIS nFLH

Then, why bother using VIIRS?
3. Examples in research and applications: HABs

Monitoring of the 2018 red tide in the eastern GOM

VIIRS RGCI can produce products comparable to MODIS nFLH (Qi et al., 2015).
https://optics.marine.usf.edu/projects/iris.html

Between 6/1/2018 – 8/22/2018, VIIRS images useful on 39 days (> 50% of coastal regions covered), but MODIS nFLH images useful only on 16 days.
3. Examples in research and applications: HABs

VIIRS captures phytoplankton vertical migration in the NE Gulf of Mexico

14:00 hour 15:41 hour Difference

Karenia brevis bloom (red tide), from Qi et al. (2017, Harmful Algae)
3. Examples in research and applications: HABs

VIIRS captures phytoplankton vertical migration in the NE Gulf of Mexico
Glider measurement from the same bloom shows thinner surface layer at 15:41 than at 14:00 within a diel cycle of *K. brevis* vertical migration (Hu et al., 2016)

Blue: 14:00; red: 15:41
3. Examples in research and applications: HABs

OCView provides an excellent tool to track blooms in near real time (Mikelsons and Wang, 2018, EOS)
3. Examples in research and applications: HABs

OCView Chl anomaly imagery show a *Synecococcus* bloom (Lapointe et al., Marine Biology, submitted)
3. Examples in research and applications: macroalgae blooms

- Sensors: MODIST, MODISA, VIIRS
- Products: AFAI (1-km), CI (1-km), FAD (5-km)
- Where: https://optics.marine.usf.edu/projects/SaWS.html
2/4/2016, 18:00 GMT

VIIRS AFAI image

S. fluitans

S. natans
3. Examples in research and applications: macroalgae blooms

VIIRS continuity in monitoring floating macroalgae in the Atlantic
Color represent mean surface density during 2016 for 0 – 22N, 63 – 38W

From Wang and Hu (2018). 0.1 on the color scale means 0.1% instead of 10%
3. Examples in research and applications: oil spills

How much sun glint is required to detect thin oil films?

MODIS detects slicks but VIIRS doesn’t

Sun and Hu, 2016
3. Examples in research and applications: oil spills

How much sun glint is required to detect thin oil films?

VIIRS detects slicks but MODIS doesn’t

MODIST requirement: $L_{GN} > 10^{-5}$ sr$^{-1}$; VIIRS requirement: $L_{GN} > 10^{-6}$ sr$^{-1}$

VIIRS/MODIS altitudes: 829/705 km; 18% increase in coverage within 60° view angle

VIIRS/MODIS Swaths: 3060/2330 km: 31% increase in all view angle

Sun and Hu, 2016
Summary and Conclusions

• VIIRS/SNPP data products from both NOAA MSL12 and NASA L2GEN show robust performance in northern GoM and N Atlantic waters, similar to MODIS performance

• MSL12 leads to ~10% global DPVO at 1-km resolution, compared to ~5% from L2GEN. This is mostly attributed to their different treatments in stray light and sun glint

• Both data quality and quantity of VIIRS, especially from MSL12, are sufficient for research and applications, as shown in the studies of HABs, macroalgae, and oil spills

• NOAA OCView provides a unique tool for near real-time tracking of anomaly features
Validation using data collected in North America
(most data collection supported by NOAA VIIRS cal/val program)

Temporal distributions

Figure 2: Distribution of (a) *in situ* samples, and (b-d) satellite / *in situ* matchups according to (left column) month and (right column) year. For b-d, lighter color shows any satellite matchups, while darker color excludes matchups identified by the “current” L2 flags (Table 2).
**Validation using data collected in North America**

(most data collection supported by NOAA VIIRS cal/val program)

Matchup results partitioned by time difference

<table>
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<th>MODISA</th>
<th>VIIRS NASA</th>
<th>VIIRS NOAA</th>
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<td><img src="image2" alt="Graph 2" /></td>
<td><img src="image3" alt="Graph 3" /></td>
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<tr>
<td><img src="image4" alt="Graph 4" /></td>
<td><img src="image5" alt="Graph 5" /></td>
<td><img src="image6" alt="Graph 6" /></td>
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<td><img src="image7" alt="Graph 7" /></td>
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<tr>
<td><img src="image10" alt="Graph 10" /></td>
<td><img src="image11" alt="Graph 11" /></td>
<td><img src="image12" alt="Graph 12" /></td>
</tr>
</tbody>
</table>

**Figure 7:** UPD (blue; left axes), MRD (red; right axes), and data quantity (bottom row) for matchup data according to various thresholds of temporal difference between satellite and *in situ* measurements. Data from MODISA (left column), VIIRS NASA (center column), and VIIRS NOAA (right column) are separated by waveband (from top row: 410, 443, 486, 551, and 671 nm), and partitioned into low Ca (dotted lines / squares; water types 1-7) and high Ca (solid lines / circles; water types 8-23). Data partitions with N < 10 are excluded. Unlike Figures 4-6, axis limits are not the same for all wavebands.
Validation using cross-sensor comparison

From Barnes and Hu (2015, IEEE TGRS)
A simple fix using relaxed straylight flag (Hu et al., 2019, JGR)

March 2005

(a) default flag

(c) relaxed flag

(e) default/relaxed ratio

July 2005

(b) default flag

(d) relaxed flag

(f) default/relaxed ratio
3. Examples in research and applications: HABs

VIIRS captures phytoplankton vertical migration in the NE Gulf of Mexico

Rrs spectral changes in 100 minutes (left) agree with previous field measurement (right)

From VIIRS measurements, July 30, 2014
From Schofield et al. (2006, JGR)