Validation of the VIIRS Ocean Color

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ABSTRACT

The Joint Polar Satellite System (JPSS) launched the Suomi National Polar-Orbiting Partnership (NPP) satellite including the Visible Infrared Imager Radiometer Suite (VIIRS) on October 28, 2011which has the capability to monitor ocean color properties. Four months after launch, we present an initial assessment of the VIIRS ocean color products including inter-comparisons with satellite and in situ observations. Satellite ocean color is used to characterize water quality properties, however, this requires that the sensor is well characterized and calibrated, and that processing addresses atmospheric correction to derive radiometric water leaving radiance (nLw_λ). These radiometric properties are used to retrieve products such as chlorophyll, optical backscattering and absorption. The JPSS ocean calibration and validation program for VIIRS establishes methods and procedures to insure the accuracy of the retrieved ocean satellite products and to provide methods to improve algorithms and characterize the product uncertainty. A global monitoring network was established to integrate in situ data collection with satellite retrieved water leaving radiance values from ocean color satellites including Moderate Resolution Imaging Spectroradiometer (MODIS), MEdium Resolution Imaging Spectrometer (MERIS) and VIIRS. The global network provides a monitoring capability to evaluate the quality of the VIIRS nLw_λ in different areas around the world and enables an evaluation and validation of the products using in situ data and other satellites. Monitoring of ocean color satellite retrievals is performed by tracking the "gain" at the Top of the Atmosphere (TOA) and then performing a vicarious adjustment fo reach site. VIIRS ocean color products are compared with MODIS and MERIS retrieved nLw and chlorophyll, and have been shown to provide similar quality. We believe that VIIRS can provide a follow-on to MODIS and MERIS equivalent ocean color products for operational monitoring of water quality. Additional research, including an assessment of stability, a full characterization of the sensor and algorithm comparisons is underway. Weekly sensor calibration tables (look up tables) are produced by JPSS and an evaluation of their impact on ocean color products is ongoing.

Keywords: *Ocean Color, VIIRS, Satellite Chlorophyll, NPP, Vicarious Calibration,*

1. INTRODUCTION

The VIIRS sensor on the Suomi National Polar-Orbiting Partnership (NPP) satellite has five spectral channels centered at 410, 443, 486, 551 and 671nm that are used to characterize spectral ocean color. Current ocean color sensors in space used for monitoring the biochemical properties of ocean water including Moderate Resolution Imaging Spectroradiometer (MODIS) and MEdium Resolution Imaging Spectrometer (MERIS) are near the end of their lifetimes. NPP VIIRS can provide continuity of these data products if sufficient sensor characterization and calibration are performed, including assessing the stability and consistency of ocean products. This effort includes continual validation of the VIIRS color products in a wide variety of ocean conditions and assessing the accuracy of ocean color processing. The retrieval of ocean color spectrometry, i.e., normalized water leaving radiance (nLw_λ) requires that sensor calibration is tightly connected to the accurate removal of atmospheric radiance, surface glint and stray light. These sources of noise must be accurately removed from the top of the atmosphere radiances (Lt_λ) measured by the sensor. These procedures have been applied to present MODIS and MERIS satellites and accurate products have been retrieved. The JPSS calibration and validation team has developed an infrastructure to evaluate VIIRS ocean Environmental Data Records (EDRs): routinely nLw_λ and chlorophyll are routinely evaluated against existing satellites and in situ data measurements. Ocean color products are based on nLw_λ from which specific products such as chlorophyll, backscattering coefficients, absorption coefficients, and diffuse attenuation coefficients are computed. Therefore the radiometric retrieval of the nLw_λ is considered essential for the production of any ocean color product.

Continuity of the ocean color products between ocean color satellites is required for climate studies, as well as to enhance the operational products used in ecological monitoring and forecasting, such as accurately monitoring ocean water quality and determining changes along our coastlines. These operational needs address community services such as the detection of harmful algal blooms, fishery hypoxia and ocean contaminants. All of these operational needs depend on the electro-optical system performance of the remote sensor, as well as the integration of products and validation in ecological forecast models. The utility of having multiple sources (looks per day) of ocean color products enhances our ability to retrieve cloud free conditions and monitor diurnal changes in water quality. In addition, inter-satellite product comparisons are essential for data continuity into the future.

Since its launch on October 28, 2011, the VIIRS sensor has been actively characterized using an on-board calibrator to determine look up tables (LUTs) for sensor calibration used to produce Sensor Data Records (SDRs) and Environmental Data Record (EDR) products. The ocean color EDR products have been generated in combination with LUTs to examine the impact that the evolving LUTs have on EDR ocean color products. Ocean color products are most sensitive to sensor LUTs, since a significant amount of the signal (~90% of the Lt) is from the atmosphere and must be removed during atmospheric correction. We use the ocean color products of nLw as a monitor to test the calibration accuracy of the sensor and the impact of changes in the LUT.

Here we present the methods used to evaluate the VIIRS ocean color products and provide an initial comparison to current ocean color sensors and in situ matchups. We describe the procedures that are currently in place to monitor ocean color products and track the stability of the sensors and algorithms. These procedures are designed to track the ocean color product validation and provide a rapid assessment for ocean operational applications.

2. GLOBAL OCEAN COLOR VALIDATION NETWORK

The JPSS calibration validation (cal-val) team established a network of twenty-seven areas around the world (so called “Golden Regions”) to monitor and characterize the stability of the VIIRS ocean color products. Some of these regions represent areas where observations are routinely being collected such as the The Aerosol Robotic Network – Ocean Color (AERONET-OC) sites(1), regions with optical buoys used for vicarious calibration such as The Marine Optical Buoy (MOBY) and BOUée pour l'acquiSition d'une Série Optique à Long termE (BOUSSOLE), and regions where ship measurements are being collected on a routine basis, such as Hawaii Ocean Time-series (HOT), Bermuda Atlantic Time-series Study (BATS), and California Cooperative Oceanic Fisheries Investigations (CalCOFI). Additionally, six stable oligotrophic regions such as North/South Atlantic and Pacific gyres, Easter Island and South Indian gyre will be used for inter-comparisons with MODIS and MERIS. The Satellite Validation Navy Tool (SAVANT)(3), developed and hosted by NRL, provides a central processing and distribution hub for the ocean color data covering all Golden Regions. Currently, we have assembled the in situ data in near real time (with only several weeks time lag) from AERONET-OC (12 sites) and MOBY (2) data into an online Structured Query Language (SQL) database. Additionally, daily MODIS, MERIS and VIIRS satellite data for these regions is collected and processed to retrieve statistics of nLw_λ and other ocean color products. Satellite retrievals are assembled in a SQL database to perform validation matchups, track trends in both in situ data as well as from multiple satellite comparisons. This SQL database of satellite products and in situ data is distributed to team members on a routine basis.

Currently, several JPSS team members are hosting Web based matchup and validation monitoring tools, including “Ocean Color Validator” at Oregon State and “Ocean Color Product Validation” at City College (CUNY).

The match-up procedure adopted by NRL closely follows the National Aeronautics and Space Administration (NASA) Ocean Biology Processing Group (OBPG) procedures(4). Some of the exclusion criteria are: size of satellite box, time differences (satellite-in situ), wind speed, solar/sensor angles, value of AOD (Aerosol Optical Depth), minimum percentage valid pixels, coefficient of variance, processing flags, and data quality. An example of the matchup of MODIS and VIIRS channels at 412 and 443 nm is shown in Figure 2.

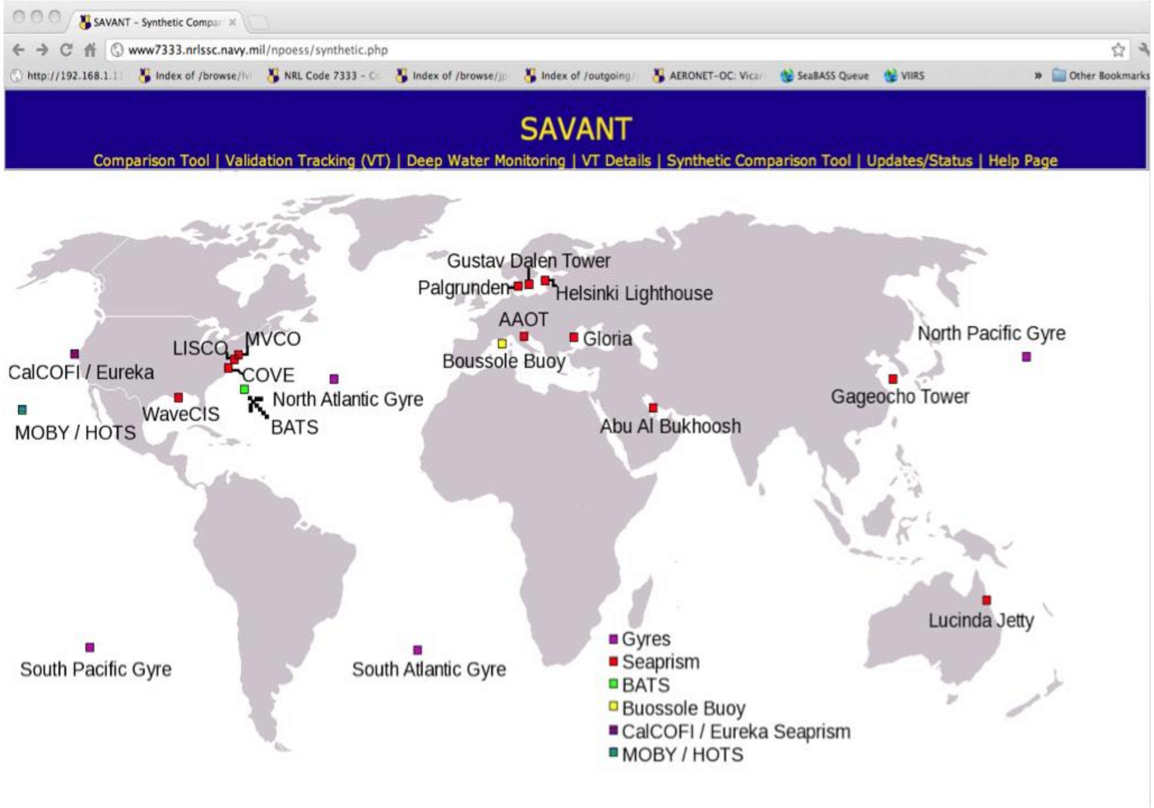

Figure 1: Network of 27 global regions used for ocean color satellite validation.

The matchup of in-situ data with satellite data required a derivation of the uncertainty in the in-situ data. This uncertainty in based on the instrument characteristics [e.g., SeaWiFS Photometer Revision for Incident Surface Measurements (SeaPRISM), Hyperspectral Profile (HyperPRO)], the protocols used for data collection, processing schemes, and the quantification measurement uncertainties(5,6). Additionally, the uncertainty is based on the spatial and temporal variability of the locations of the in situ and satellite data. Certain ocean locations are better than others for matchup (open ocean, with low AOT and Chl. such as the MOBY site). To address these concerns the cal-val team developed an “uncertainty index”(7). This ongoing study will be used to understand the regional variability and best (lowest uncertainty) data for the AERONET-OC cal-val activity.

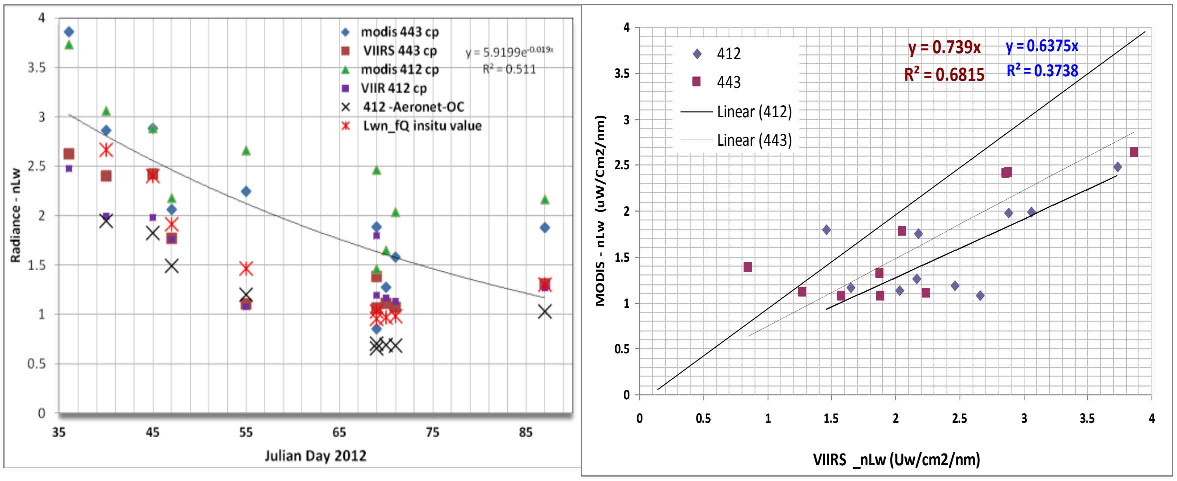

Figure 2: A preliminary matchup of the nLw 412 and 443 VIIRS and MODIS for the Acqua Alta Oceanographic Tower (AAOT), VENICE tower with AERONET-OC nLw (Level 1.5) for March 2012. The right plot shows the nLw correlation of MODIS and VIIRS for 410 and 443 channels at the AAOT site.

3. SATELLITE SENSOR DATA FLOW AND PROCESSING

The processing of VIIRS data was performed using Level Two Generator (L2gen) as part of the Navy's Automated Processing System (APS)(8). We used the ADL v3.01 to process VIIRS data from Raw Data Records (RDR) to Sensor Data Record (SDR) to Environmental Data Record (EDR) using APS. This allowed us to generate the SDR using different LUTs to evaluate the EDRs. This procedure of generating EDRs from RDRs allows for reprocessing. Additionally, we evaluated JPPS operational products from IDPS (Interface Data Processing Segment) processing to EDRs. The VIIRS data was obtained from the Government Resource for Algorithm Verification, Independent Testing, and Evaluation (GRAVITE) portal, which maintains the data flow in near real time for a period of about 34 days. We have archived all RDRs for reprocessing and are presently updating the SQL database with reprocessed VIIRS data. The LUTs that were used came from the JPSS SDR team. These became stable in February 2012 and are updated on a weekly basis on the Operational IDPS. Data are being updated on a daily basis with NRL APS processing. We have noted that the impact of daily LUT updates on the EDR is minimal versus the weekly LUT update. Currently, weekly LUTs updates or epochs are provided by the SDR team. It is critical for ocean color processing that the proper LUT epoch is used to generate the EDR in the evaluation of the match-up products. The NRL cal-val team maintains a history of these epochs in order to determine the trend of the LUT so they can be linked to the trends of EDR matchup within the Golden Regions.

4. MONITORING VICARIOUS GAINS

Monitoring of the water leaving radiance between satellite and observations has been extended beyond the traditional matchup to the top of the atmosphere (using a vicarious approach to monitor for "gains"). This approach enables a more complete matchup and evaluation, by including the ocean color processing, which involves the following atmospheric components: Rayleigh, aerosol optical depth, inert gases, solar and sensor transmission. After identifying a satellite to in-situ data matchup of nLw(λ) (e.g. for spectral water leaving radiance from an AERONET_OC or MOBY site), we propagate the radiance through the atmosphere using satellite (VIIRS, MODIS or MERIS) parameters and processing to determine the vicarious radiance at the Top of the Atmosphere (TOA): $Lt_{(\lambda)v}$ for that satellite. This is then compared with the satellite radiance at the Top of Atmosphere radiance $Lt_{(\lambda)s}$ and a gain computed as the ratio:

$$\text{Gain} = Lt_{(\lambda)\,v} \,/\, Lt_{(\lambda)s}$$

Our objective is to achieve a gain value = 1, where the top of the atmosphere vicarious and satellite radiances are equal. A similar approach is used for the MOBY site for vicarious calibration and the gains are applied to the

LUT(9). By monitoring the gains at different Golden Regions, we can observe any near-real time trends in satellite retrieved $nLw_{(\lambda)}$ and can evaluate the sensor stability and validate the ocean color products. We do not apply these gains to the mission, but monitor the consistency of the value. The approach enables a rapid evaluation of on-orbit calibration and ocean color product stability to support near real time operations.

The vicarious gain is shown for a matchup on day 87 (2012) for the Venice AAOT site where there is VIIRS, MODIS and MERIS data (Figure 3). The VIIRS Chlorophyll image is shown along with the spectral gains. Note that in this example we have loosened the exclusion criteria for the traditional matchup (as described above). In the near future, as more data become available, we will be more selective about data quality and will tighten exclusion criteria. The right side of the figure illustrates the spectral parameters used to determine the top of the atmosphere radiance. These parameters are included in the SAVANT database.

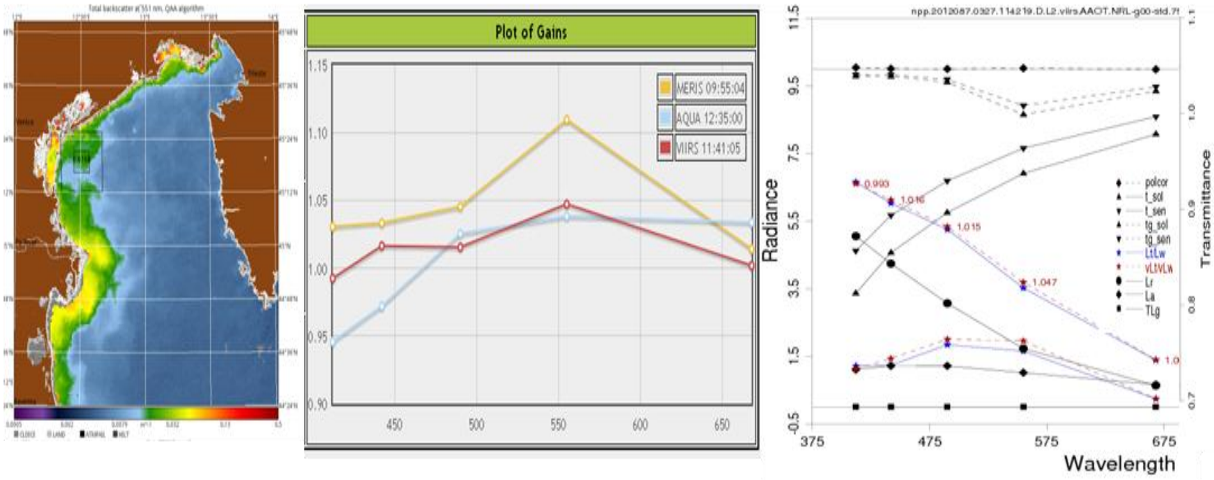

Figure 3: Vicarious gains determined for day 87 for the Venice Site AAOT for VIIRS, MERIS and MODIS.

As discussed previously, there is uncertainty in the in situ observations (nLw) and this will influence the vicarious gain that is computed. Certain ocean regions might have a consistent bias in the gain, which might be associated with the spatial uncertainty of regions resulting from environmental variability in both the ocean color and in aerosol optical depth. This uncertainty is used to constrain our matchup criteria. However, by monitoring the TOA radiances and gain we are able to track the changes in sensors and algorithms. For example, if all the Golden Regions show that the gain bias has changed, then there is likely to be a sensor issue, such as sensor drift or change. The vicarious gain or adjustment has been automated and is performed in real time using the AERONET-OC data sets with available MODIS, MERIS and VIIRS data [10].

Tracking the gains at one of the Venice AERONET–OC Golden Region sites is shown in Figure 4 for VIIRS and MODIS from Feb 1 to Mar 30, 2012. There were 30 match-ups where the gain was computed with unrestricted constraints on the trend. Although we can selectively omit data based on exclusion criteria in SAVANT, for this initial analysis this was not done. The VIIRS processing used the SDR LUT from the epoch for each date as described earlier. We observe in Figure 4 that the trend of the gain is about the value of 1 for both VIIRS and MODIS. In some cases, VIIRS is closer to 1 and in other, MODIS is closer. There are several gains which appear “bogus” and suggest tighter constraints be used for the matchup. We can compute a bias for each satellite (MODIS and VIIRS) channel for the AAOT. The trends of the gains for VIIRS and MODIS are similar and relatively stable for this 2 month period of time. We are monitoring this location and tracking the gain to ensure it does not have a major change. As new LUTs are applied for VIIRS, they should improve the gain and draw it closer to 1. However, this gain tracking is performed at several AERONET-OC sites not just at AAOT. By monitoring at several sites, we will focus on the sensor characterization, and exclude issues with site-specific instruments or changing ocean processes.

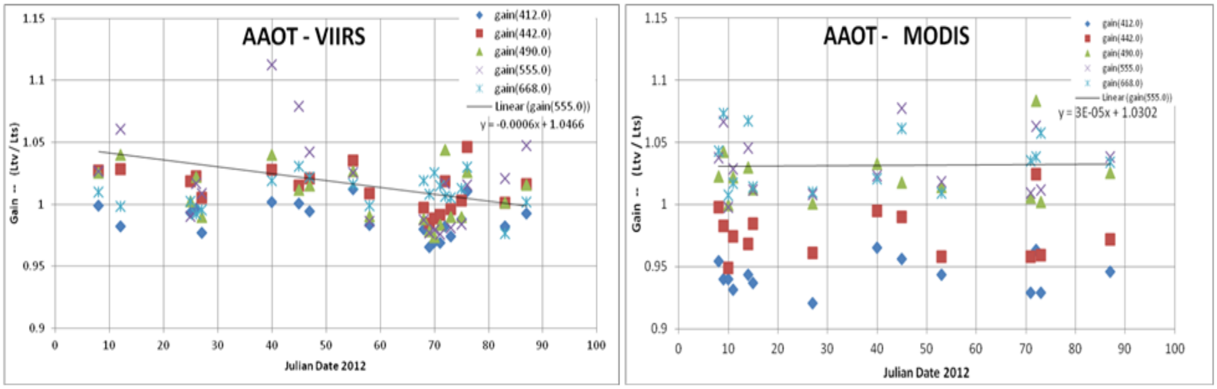

Figure 4: Tracking the gains of the nLw at Venice using VIIRS and MODIS from Jan to March 2012.

We observe similar gains between MODIS and VIIRS channels for the AAOT site (Figure 4). The trend line is shown for the 551 nm channel for the VIIRS and MODIS. VIIRS processing includes the updated LUT, which may impact the Gain. Note VIIRS shows a downward (negative slope) trend toward the gain of one from the beginning of the 2012 suggesting the improvement with the LUT with time. MODIS shows a level trend since the beginning of 2012 with a bias of 1.03 at 547nm at this site. Note also the 412 channel appears closer to a gain of one for VIIRS compared to MODIS.

5. COMPARISON OF VIIRS OCEAN COLOR PRODUCTS

Satellite inter-comparison of VIIRS, MODIS and MERIS ocean products are being evaluated in the Golden Regions and for larger areas such the Gulf of Mexico, West Coast US, East Coast US, and Western Mediterranean. Daily real time processing and inter-satellite matchup are being performed. VIIRS comparison included processing using the L2gen from the Navy's APS and processing from NOAA-IDPS–EDR- VIIRS Ocean Color/Chlorophyll (VOCCO). The APS L2gen processing has additional products including bio-optical properties using the Quasi Analytical Algorithms(11,12), which are used for real time applications.

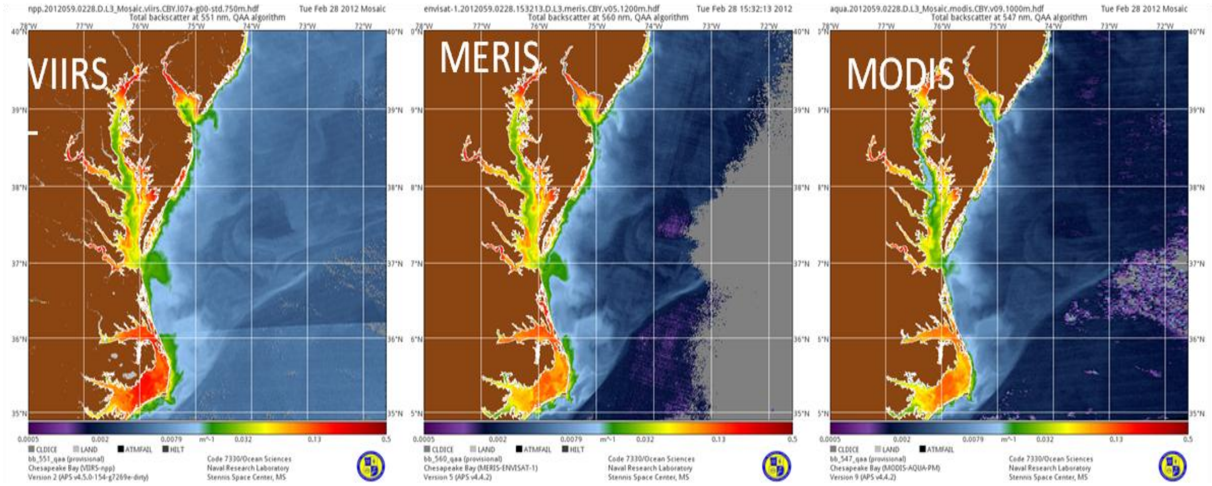

Figure 5: Comparison of the backscattering at 551 coefficient from VIIRS, MERIS and MODIS for Feb 28, 2012.

Examples of the comparison of retrieved backscattering coefficient at 551nm(11,12) for VIIRS, MODIS and MERIS are shown for the US East Coast for Feb 28, 2012 (Figure 5). VIIRS was processed using APS L2gen. Scatter plots of the remote sensing reflectance at 443, 488 and 555nm are compared (Figure 6). Note that 443nm RRS is low for the VIIRS compared with MODIS, whereas the RRS for 488 and 547 align more with the 1:1 line for MODIS and MERIS. These differences are currently under investigation.

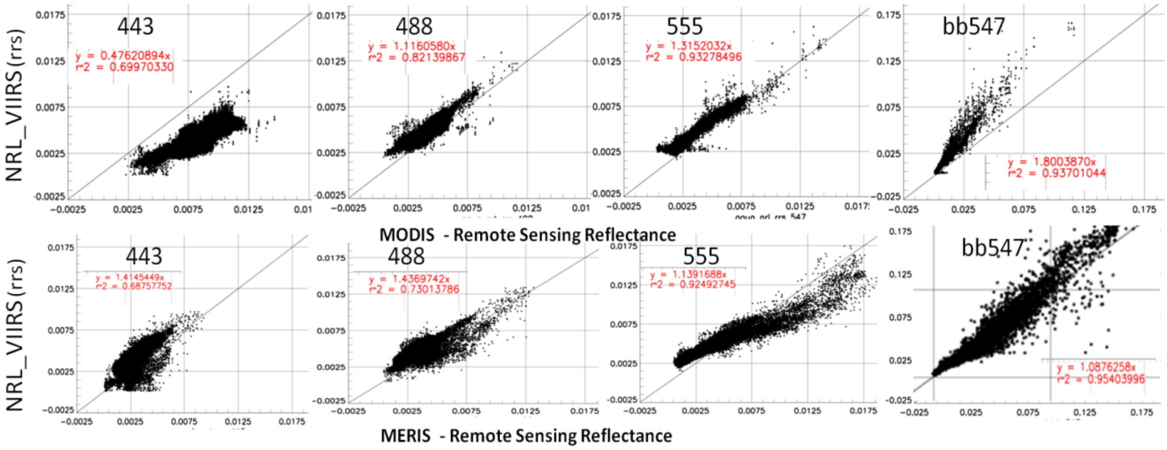

Figure 6: Scatter plots of VIIRS and MODISdata for the US East Coast for February 28, 2012.

6. SOUTH FLORIDA CRUISE COMPARISON

A cruise was conducted in Southern Florida in the Keys from February 29 to March 3, 2012 where above water and in-water measurements were used to collect remote sensing reflectance using an Analytical Spectral Device (ASD) Field Spectrometer and a Satlantic HyperPRO (multicast). Data were collected within 3 hours of overpass. Protocols were used to collect these data to provide accurate validation measurements(13). Nine stations were collected in optically deep water in which we had valid VIIRS and MODIS data (Figure 7). The VIIRS – RRS (remote sensing reflectance) products were processed using both 1) NOAA –IDPS – EDR called VOCCO and 2) L2gen from Navy APS. The MODIS products were computed using the Navy APS.

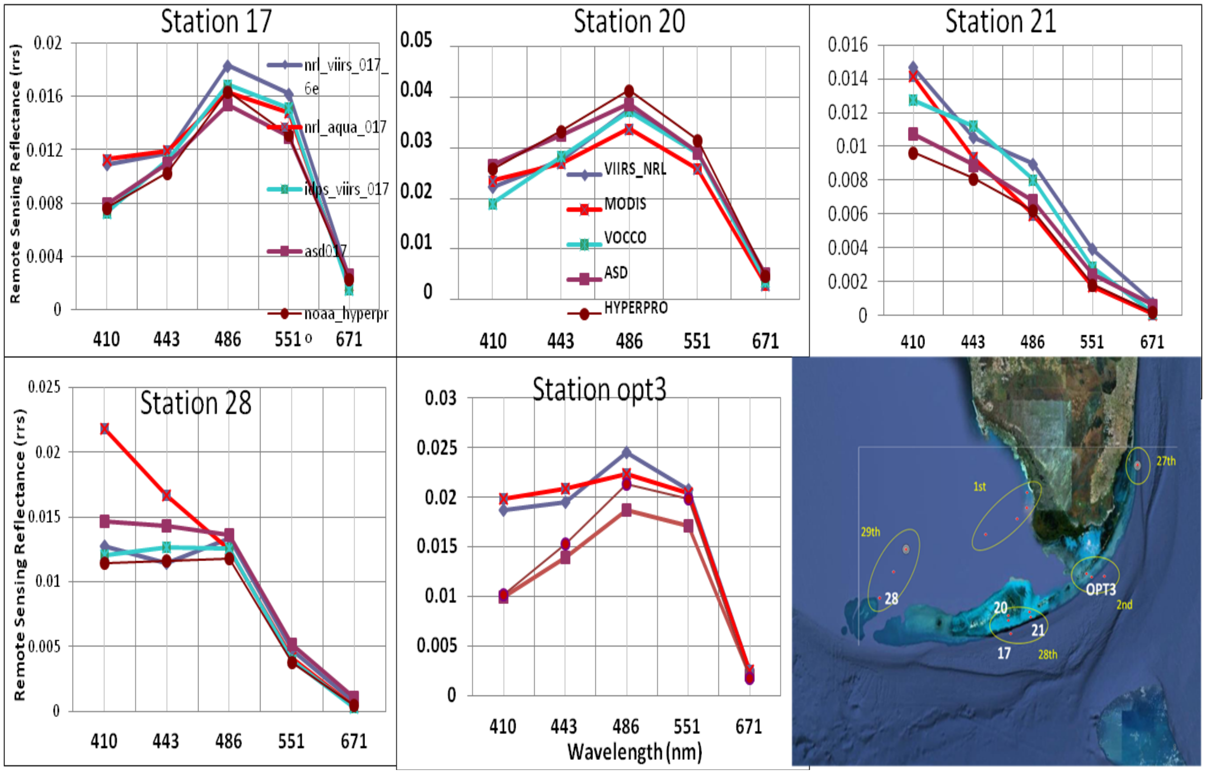

Figure 7: Five stations shown matchup of the remote sensing reflectance for South Florida Cruise. ASD and HYPERPRO curves are insitu data, dark blue and red are (VIIRS APS and MODIS), Light Blue is VIIRS VOCCO.

Table 1: South Florida Cruise Match-up : Correlation coefficient (r^2) and slope for each channel of the spectral remote sensing reflectance between in situ data (ASD and HyperPRO) and with VIIRS (IDPS and L2gen) and MODIS.

	Hyperpro vs IDPS		Hyperpro vs L2GEN		ASD vs L2gen		ASD vs IDPS		ASD vs MODIS		Hyperpro vs MODIS	
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

The location map for the nine stations is on bottom right of Figure 7. These remote sensing reflectance (RRS) match up results are similar between the MODIS and VIIRS with in situ measurements. There are stations where the in situ RRS fell below and above the VIIRS and MODIS (op3 and 20 respectively). The correlation coefficients for the different channels of VIIRS and MODIS are presented in Table 1. This represent the correlation of ASD and HyperPRO to MODIS, VIIRS APS, and VIIRS VOCCO. The slope represents a linear through zero. The r^2 are ~ 0.9 except for MODIS. The differences between the VIIRS processing, IDPS and L2Gen is still being evaluated.

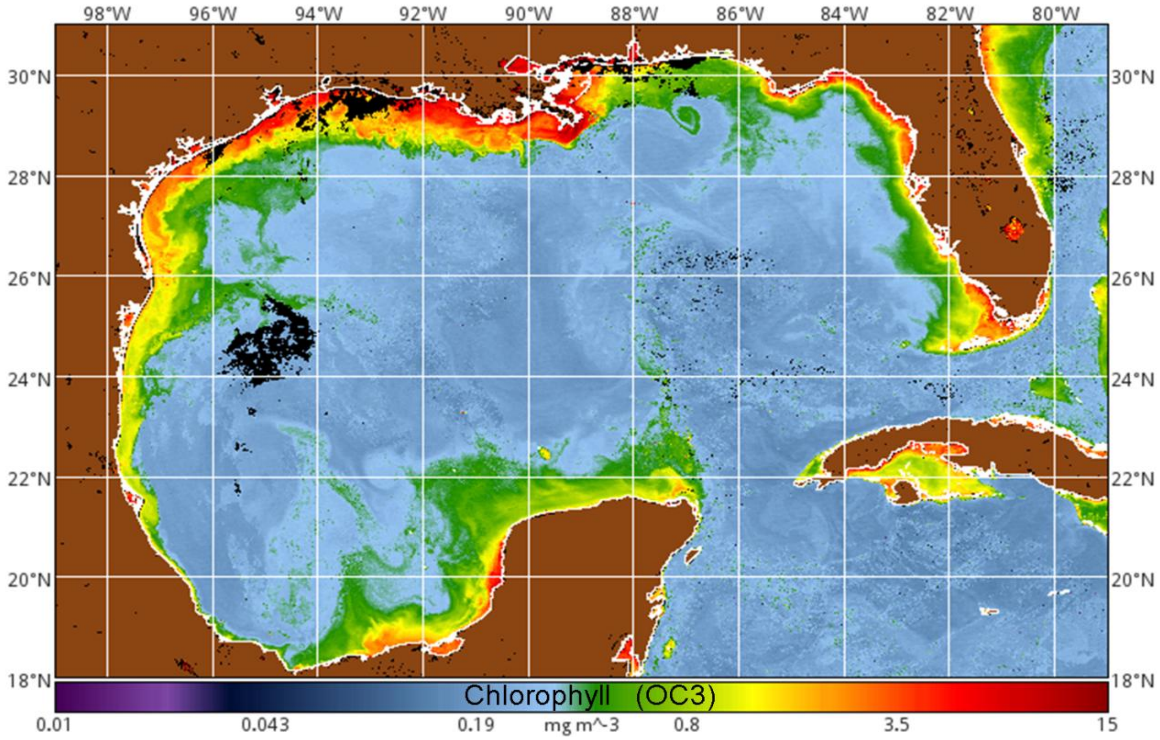

Figure 8: VIIRS chlorophyll product for March 15, 2012, (7 day latest pixel composite).

7. SUMMARY

Ocean color products from VIIRS are being validated against in situ AERONET-OC data, cruise in situ matchup data and inter-satellite comparisons with MODIS and MERIS. VIIRS EDR products are being evaluated using the processing of JPSS operational IDPS and the Navy L2gen Automated Processing System. The sensor appears to be well-behaved and we are evaluating these color products as new calibration tables are being applied and tested during sensor characterization.

The JPSS ocean color cal-val team has constructed a near real-time global network of Golden Regions representing

27 different oceanographic regimes. These locations are being used to track the stability of VIIRS ocean color products by inter-comparison with in situ observations with $nLw_{(\lambda)}$ products from VIIRS, MODIS and MERIS. In situ ocean color data from AERONET–OC and buoys (i.e. MOBY, BOUSSOLE) are being assembled daily into a Web-based SQL database. Ocean color products are processed daily from VIIRS, MODIS and MERIS for Golden Region locations and entered into the SQL database. Matchup of the satellite products and in situ data are monitored in near-real time to evaluate VIIRS ocean color products.

Additionally, we are tracking the vicarious gains at specific global regions by propagating water leaving radiances to the top of the atmosphere radiance. Tracking these gains at AERONET_OC sites is used to determine regional bias in ocean color water leaving radiances. These are used to assess the uncertainty of the ocean color products generated between different satellites. Results indicate that the VIIRS gains are similar to the MERIS and MODIS gains for the difference channels. Further analyses of the vicarious gains are being done at the buoy sites.

An initial evaluation based on five months following the launch of Suomi NPP has shown positive comparisons. As the sensor becomes better characterized with weekly updates of the LUTs, the quality of the VIIRS ocean color products can be better defined. The example image (Figure 8) of the Gulf of Mexico shows the capability of the present LUT for determining the ocean chlorophyll structure and the utility for operational products.

Validation ship cruises have begun in the Southern Florida Keys. Results confirm good matchup of the water leaving radiance between ship, MODIS and VIIRS data. Additional cruises are planned for continued validation.

7.1 Acknowledgements

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