Sensitivity of calibration "gains" to ocean color processing in coastal and open waters using ensembles members for NPP- VIIRS.

R. Arnone[1], R. Vandermeulen[1] ,S. D. Ladner[2], J. Bowers[3],
P. Martinolich[3], G. Fargion[4], M. Ondrusek[5]

[1] Dept. of Marine Science, University of Southern Mississippi, Stennis Space Center, MS 39529
[2] Naval Research Laboratory, Stennis Space Center, Mississippi, MS 39529
[3] QinetiQ North America, Stennis Space Center, Mississippi, MS 39529
[4] San Diego State University, San Diego, CA 92115
[5] NOAA NESDIS, College Park, MD 20740

ABSTRACT

The sensitivity of ocean color products to variations in vicarious calibration gains at Top of Atmosphere (TOA) shows varying impacts in different water types for Suomi- NPP VIIRS. Blue water vicarious gains from MOBY *in situ* data, which is used for global open waters, and green water gains derived from complex coastal WaveCIS AERONET waters, have a different impact on spectral normalized water leaving radiances and the derived ocean color products (inherent optical properties, chlorophyll). We evaluated the influence of gains from open and coastal waters by establishing a set of ensemble-processed products. The TOA gains show a non-linear impact on derived ocean color products, since gains affect multiple ocean color processing algorithms such as atmospheric correction, NIR iterations, etc. We show how the variations within the ensemble TOA gain members spatially impact derived products from different water types (high CDOM, high backscattering, etc). The difference in color products derived from the Blue and Green water gain show a spatial distribution to characterize the product uncertainty in coastal and open ocean water types. The results of the ensemble gain members are evaluated with *in situ* matchups. Results suggest the sensitivity of the ocean color processing for open ocean verses coastal waters.

Keywords: Satellite, SNPP VIIRS, Ocean Color, Optics, Validation, Vicarious Calibration

1. INTRODUCTION

Ocean color products derived from satellites are extremely sensitive to the sensor calibration. Vicarious calibration methods are used to enable a major improvement to providing a channel "gain" for ocean color processing[9]. This approach uses in-situ observations of the water leaving radiance (nLw) at the water surface to determine the "gain" at the top of the atmosphere that must be applied to satellite processing so as to retrieve the in-water observation (nLw). The method is highly dependent on the accuracy of the insitu data, in addition to the criteria used to select precise satellite data and in-situ data to perform the vicarious gain [7,12]. The MOBY data set off Hawaii has been used as a standard for a number of years for MODIS, SeaWIFS, and VIIRS satellites for vicarious calibration because of the spatially homogeneous waters and the precise MOBY inwater instrumentation [8]. The MOBY site is considered an open water "blue" water site from which a long time series of satellite matchups are used to determine satellite channel "gains" using ocean color processing. The vicarious calibration approach is used to track the satellite sensor stability and enable continuity of ocean color products between several satellites. Using these vicarious MOBY gains, ocean color products for global waters including the coastal, shelf, inland lakes are produced.

The objective of this paper is to determine the sensitivity of ocean color products to various gains applied to the VIIRS SNPP sensor. How do "gains" obtained from the open blue water site at MOBY and "gains" obtained from the coastal green site at WaveCIS impact ocean color products? Because there are significant differences in the ocean color spectra between "blue" and "green" water, we will investigate how using these different in-situ spectra for gains, will impact derived products. We will evaluate the differences in derived products processed with a blue and green water gain and determine the impact on products in the Gulf of Mexico which represents a wide variety of water types from open ocean to extremely turbid.

2. BACKGROUND

The VIIRS –SNPP satellite is used in this study to assess the impact of the "gain" on ocean color products. These products include the spectral Remote Sensing Reflectance (RRS), chlorophyll concentration, and Inherent Optical Properties (backscattering and absorption) [2]. VIIRS processing was performed using NRL' Automated Processing System [15] (APS), which runs a version of the NASA l2gen software on the level 1 (SDR) from NOAA – CLASS. The processing included standard atmospheric correction methods with an NIR iterative correction for coastal waters [2, 4]. A vicarious calibration was applied inverting the same processing to propagate in-situ water leaving radiances to the top of the atmosphere (vLt) and establish the spectral ratio or "gain" as vLt/Lt [3, 7]. The determination of the vicarious gains used and the criteria constrained for the selection of the gains is highly restricted and required careful removal of selected satellite and in-situ matchups. These details of the procedure and how this is performed are outlined by Bowers et al 2014 [(7)].

The data sets used for the computation of the MOBY Blue water gains included 25 points from January 2012 to Mar 2013 . The WavCis site is a located west of the Mississippi river delta and is characterized by elevated sediment and the dissolved organic matter (CDOM)[2]. The AERONET – OC ([13,14]) at the site reports screened Lw(λ) data on a daily basis and is calibrated by NASA annually. The SeaPrism 1.5 Level data used is not as well characterized as the MOBY data (pre and post calibrated data is Level2.0). However because of the stronger ocean color coastal signals the instrument has been show to perform well. Operational need use level 1.5 because if is available daily.

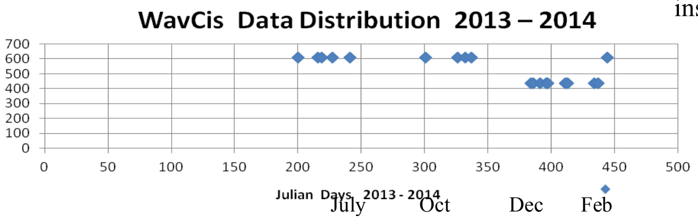
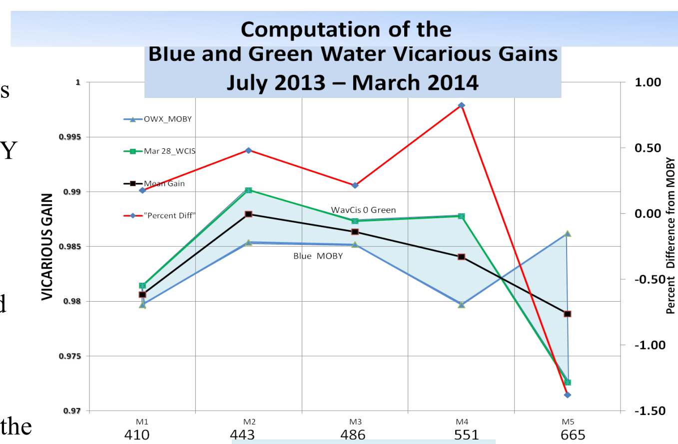


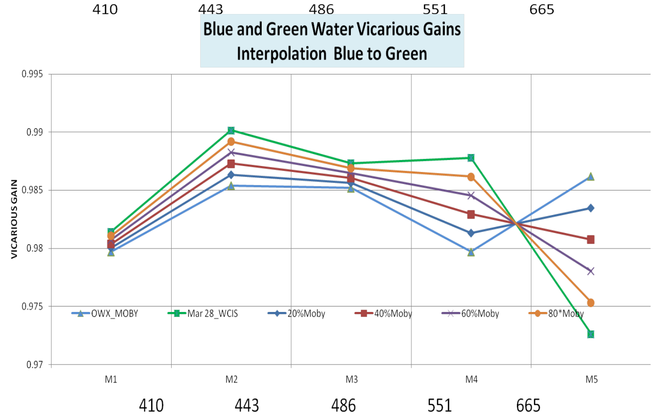
Figure 1- The green water gains were computed from the WaveCis AERONET site in the Northern Gulf of Mexico from July 2013 to Feb 2014 and included 21 points after constraints were applied (see Bowers et al 2014) [7].

3. RESULTS

The top of the atmosphere gains applied to the SNPP VIIRS that were evaluated in this study can from the MOBY blue water and the WaveCis Green water gains are shown in **Figure 2** to the right. The gains for VIIRS spectral channels at 410, 443, 486, 551, 665 with the MOBY and WaveCis Gains are shown with the shaded area being the difference. Note a gain of one indicates no adjustment is required. The blue gains are lower than the green gains except for the 665 nm channels where a major difference occurs. The blue (410 channel) shows similar gains. The red line and the right axis indicate the percent difference between the blue and green gains. Differences are small ranging from + 0.3 to 0.7% with the highest of -1.4% at 665 nm. Although these differences are small, they impact the entire ocean color processing system including atmospheric correction and NIR iteration, glint removal, cloud and turbid water flagging, and derived water RRS.

To evaluate these impacts on the ocean color products we linearly interpolated between these blue to green gains for each channel. These six ensemble members gains were established as percentages of green gain from blue gain (0, 20, 40, 60, 80 100%) where 0 %= MOBY gain and 100% = green gain(**Figure 3** on the right). These gains were applied to several Gulf of Mexico scenes however and the derived ocean color products evaluated. .





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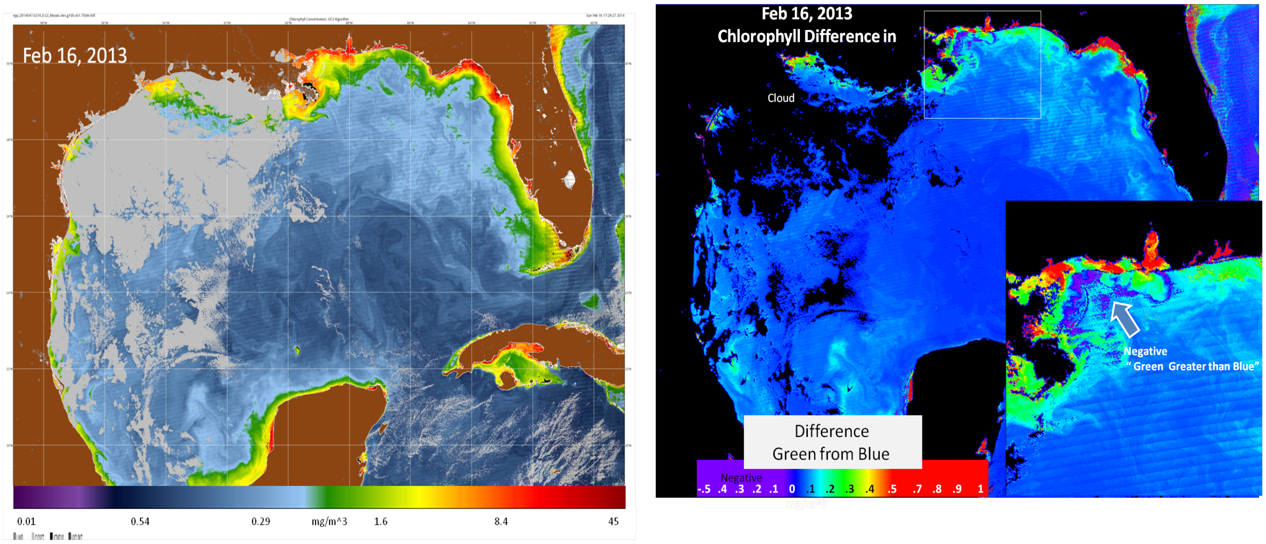
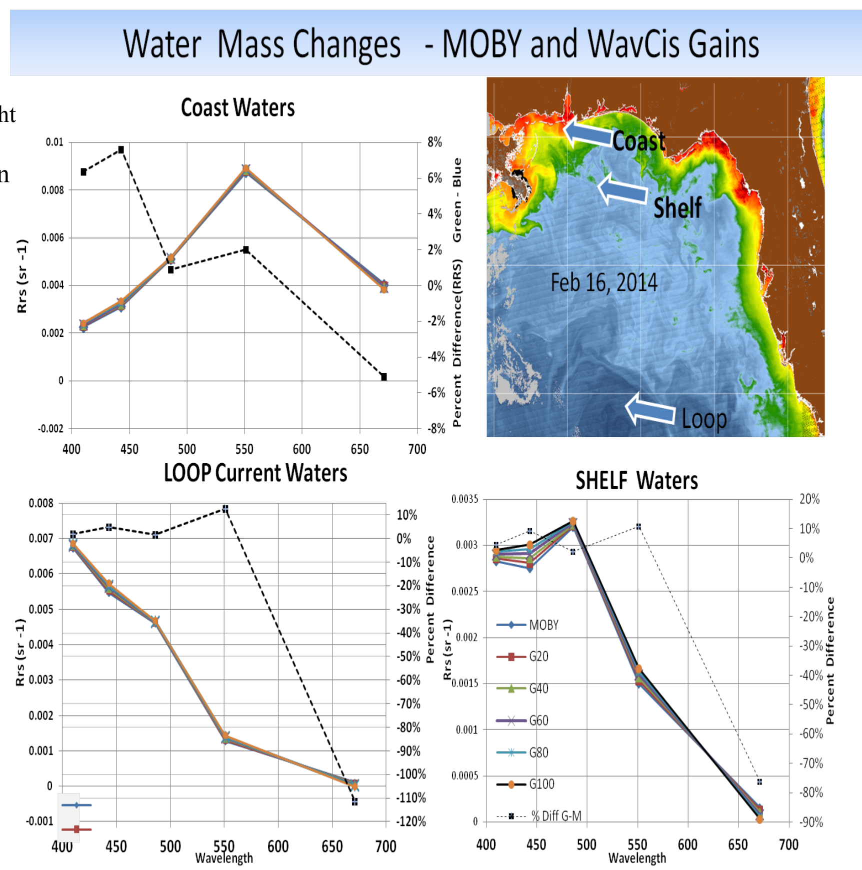


Figure 4. A. SNPP chlorophyll product for Feb 16 , 2013 processed using blue and green gains. B. The difference in chlorophyll (mg/m3) between that processing using the values from the green gain processing minus the blue gain. The subset is the Mississippi Delta coastal area. The scale shows minimal difference (0) in mg/m^3 in dark blue difference represented for open ocean waters. The purple areas indicate negative chlorophyll difference, where the Blue gain produced high chlorophyll than the Green gain. The red show areas of increased chlorophyll with the green gain. (Color copies http://parrotfish.ssc.usm.edu/~owx/pubs)

To quantify the spectral changes between the gains several 8 X 8 pixel box averages were calculated for three water masses representing open ocean water (LOOP Current), shelf, and coastal water off of the Mobile Bay plume. **Figure 5** shows the locations of the water masses and the spectral responses of all 6 gain ensembles ranging from blue , 20, 40, 60, 80 % green. The percent difference of green to blue is shown on the right axis (dotted line).

The largest differences are shown in the 443 channel in the shelf waters. The percent difference from the green to blue gain for the channels in each of these water masses is shown in the right axis for the water masses plots. The LOOP water shows a very small spectral difference (< 8%) except in the 661 nm channel (110%). The largest percent difference occurs in the 661 channels since this is a small value. The 486 nm channel has the smallest difference in all waters masse.

To characterize how these spectral differences impact the ocean chlorophyll and backscattering properties, we examined a transect across coastal to offshore waters of the chlorophyll and backscatter properties.



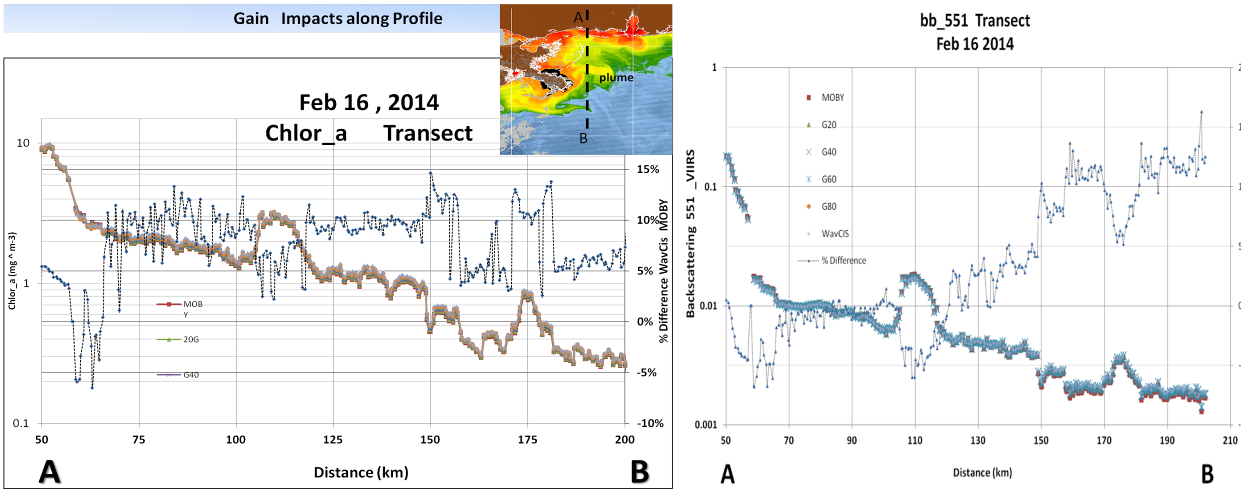


Figure 6 - Transect from coast (A) to offshore waters (B) show impacts of gains on chlorophyll and bb551 products A) shows a chlorophyll profiles of the 6 ensemble gains. The transect location is in the upper right inset. B) shows bb551 transect. To enhance the differences, the right axis of each plot shows the percent difference of the green to blue gain of these products.

The chlorophyll transect (Fig 6A right scale) shows a +5 to12% difference of the gains in waters ranging from .2 – 2 mg/mg in offshore waters and +-5% in coastal areas. This is a small difference compared to the accuracy of the product. The backscattering profile (Fig 6B right scales) shows a 15 % difference offshore and <5% in coastal waters . The differences in gains do not indicate a clear relationship with the concentration and how different impacts on different water masses. The blue and green gains appear to have similar results in blue waters.

To characterize the impact of the blue and green gain on water type, a scatterplot of the difference in chlorophyll products is plotted against concentration from the MOBY gain chlorophyll (Figure 7 a). (This is a scatterplot of figure 4 a and 4b). The color density represented the number of values. The scatterplot should identify if the gain difference impacts higher or lower concentration. This figure does not clearly show that the gains differences impact higher chlorophyll values more or less that low chlorophyll concentrations. Note the majority of the data has a minimal difference near 0- 0.03 mg/m3.

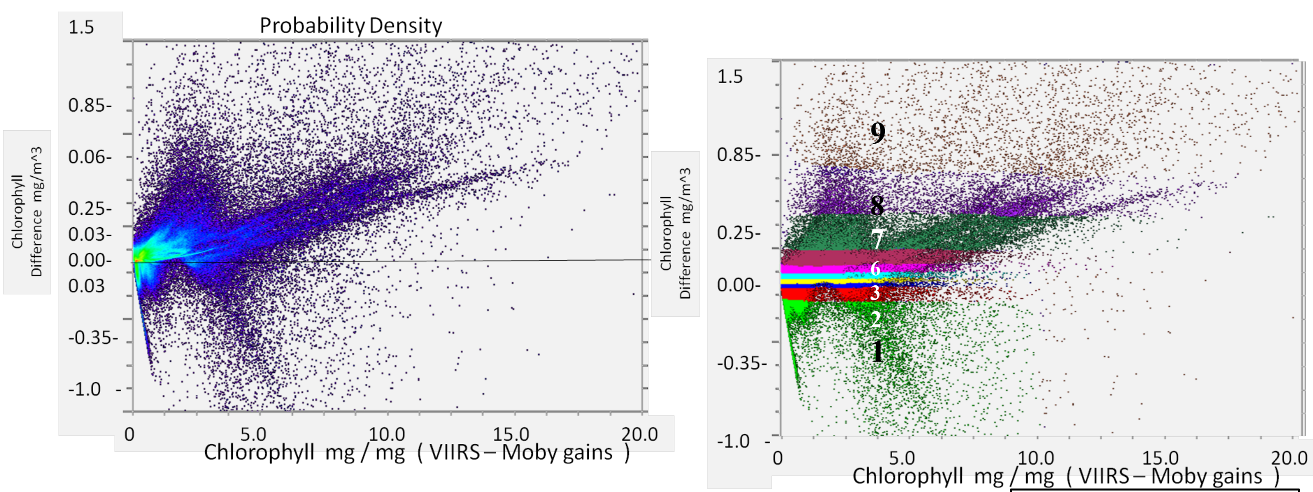


Figure 7 – A. Scatterplot of difference of chlorophyll using blue and green gains is related to the chlorophyll concentration derived from the Blue gain for Feb 16. B. Regional Difference color map

Chlorophyll Differences

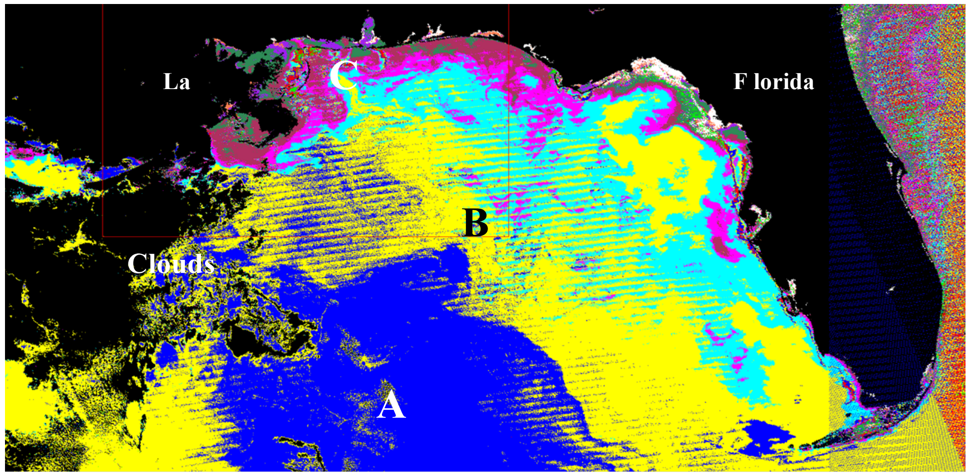
1. -1.0 - -.06 = Green
2. -0.05 -0.0 = Red
3. 0.0 - 0.03 = Blue
4. 0.03 - 0.06 = Yellow
5. 0.06 - 0.1 = Lt Blue
6. 0.1 - 0.15 = Magenta
7. 0.15 - 0.25 = Maroone
8. 0.25 - 0.5 = Purple
9. 0.75 - 1.5 = Coral

To characterize where these chlorophyll differences occur, a region of interest analysis was performed on the scatter plot. Nine regions were defined based on differences ranging from-1.0 to +1.5 mg/m3 and color coded using the table on the right.

These ranges were applied to the scatterplot and the locations on the Feb 16 image (Figure 7b). Color copies: http://parrotfish.ssc.usm.edu/~owx/pubs)

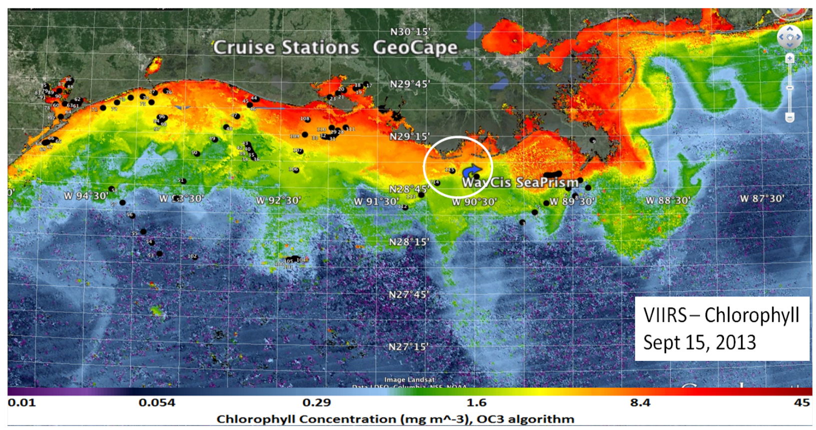
A classification map of the gain differences for chlorophyll was applied to the Northern Gulf of Mexico Figure 8.

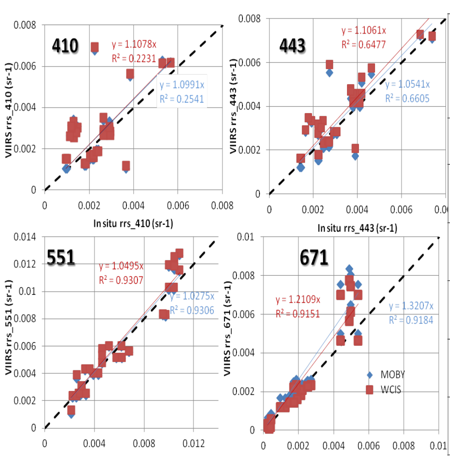
Figure 8 – Gain difference classification map for chlorophyll for Feb 16, 2014. The regional locations of where these differences occur in the image are shown. The differences in (green – blue) gains from 0 to .03 mg/m3 is shown in the blue region (A) representing the open ocean LOOP current waters. The progression to the shelf waters (B) (yellow and light blue) there is a increase in the difference. The larger differences are shown in the coastal waters (C) where some negative differences are shown (i.e. Green gain produced is less than Blue gain).



The evaluation of blue and green gains in nLw and IOP products was validated using in-situ data collection from the GeoCAPE cruise (Sept 10- 22, 2013) in the Northern Gulf of Mexico close to the WaveCIS AERONET site [10, 1].

Figure 9 – GeoCape stations locations plotted on VIIRS Chlorophyll are in coastal waters. The location of the WaveCIS AERONET is circled. There were 40 matchup points of VIIRS and in-situ data. Matchup methods used and collection methods for these sets are outlined in Ladner et al 2014 (this issue). These in-situ measurements included in-situ nLw(λ) using the Hyperpro and above water radiometer following protocols for satellite calibration and validation.





	Moby Gain (Blue)		WavCis Gain (Green)	
	R^2	Slope	R^2	Slope
410	0.2541	1.099	0.2231	1.107
443	0.6605	1.054	0.6477	1.106
486	0.8456	1.0558	0.8478	1.0298
551	0.9306	1.0275	0.9307	1.0495
671	0.9184	1.3207	0.915	1.2109

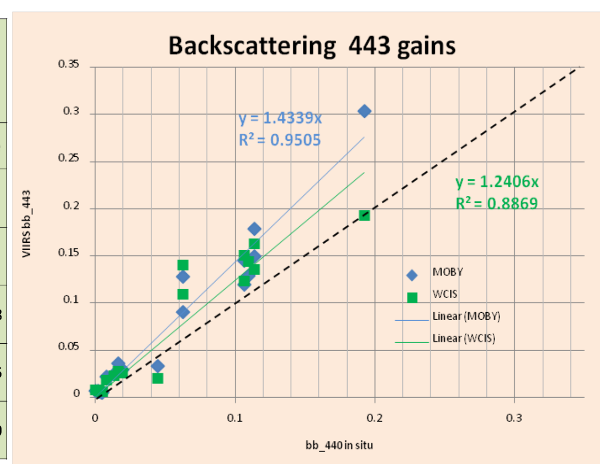


Figure 10 A) Scatterplots of insitu Remote Sensing Reflectance (RRS) with VIIRS RRS using the blue and green gain for 4 channels. Table shows the regression (R^2) and slope. The green gain shows slope closer to the 1. B) –In-situ backscatter 443 and VIIRS bb443 products using the blue and greens gains is illustrated. The slope of the green gain is closer to the 1 to 1 line.

The results of the regression analyses of the RRS for coastal waters show that the impact of the blue and green gains has little impact of the blue 410 channel and a larger impact of the 671 channels. The blue gain shows an elevated 671 RRS compared to the green gain. The evaluation of the backscattering products with in-situ scatterplot (Fig.10B) indicates the blue gain shows high bb443 and the green gain is closer to the in-situ one to one line, although the r^2 for the blue gain is higher. The matchup shows the higher bb443 are impacted more than the lower bb443 values, which we believe associated with the increase in the 671 channels from the green gain.

4. CONCLUSIONS

An evaluation of the impact of the vicarious gains applied to the VIIRS SNPP was demonstrated using the Blue water gains derived from the MOBY in Hawaii and Green water gains derived from the WaveCIS AERONET Sites in the Northern Gulf of Mexico. These gains represent a highly constrained satellite and in-situ data matchup in 2013 (7). These gains were applied to selected scenes in the Gulf of Mexico to determine the impact of the blue water and the green water gain on derived ocean color products including the remote sensing reflectance, chlorophyll and backscattering. The gains were very similar and the green gains were slightly less (closer to 1) than the blue gains except for the 661 channel where the blue channel was higher. The results indicate that although the gains were similar and applied at the top of the atmosphere, there were differences in the ocean color products which were slightly higher in coastal waters than in the open ocean waters. This can be attributed to the changes in the 671 channel.

There was not a clearly defined relationship between how products derived from blue or green gain are directly related to a specific products concentration. Because the gain will affect the entire ocean color processing steps form atmospheric correction to NIR iterations to the ocean color products, the difference in the blue to green is not directly coupled to concentration. The differences in the open ocean regions appear to have smaller impacts than the gains from the coastal waters.

The evaluation of the gains was compared with in-situ measurements in the coastal waters for in-water RRS and backscattering. The results suggest slightly improved comparison with the green gains in coastal waters. Future efforts will examine other coastal sites to determine is different coastal site have similar vicarious gain as compared with the blue water gains.

5. ACKNOWLEDGEMENTS

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