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Comparison of Satellite Optical Properities with *in situ* data

APS v2.8

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Comparison of Satellite Derived Optical Properties with *in situ* Measurements

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ABSTRACT

Optical properties (remote sensing reflectance, R_{rs}; total absorption, a; and beam attenuation, c) derived from the SeaWiFS, MODIS/Terra, and MODIS/Aqua sensor are each compared with NRL's large *in situ* data base of remote sensing reflectance measurements collected by hand-held spectroradiometer(s) and total absorption and beam attenuation surface averages from a Wetlabs multi-spectral attenuation meter (ac9) in profile mode.

The results show that the blue region of the spectrum has the least correlation with the *in situ* reflectance data. As one moves toward the red portion of the spectrum, the data has a greater correlation. These differences can be associated with the residual reflectance (glint) in the *in situ* data and the atmospheric correction in the remote sensing data.

The total absorption measurement has the least correlation between the satellite derived values and *in situ*, especially for $a > 0.5$. Of the three satellite algorithms used is this comparison, the quasi-analytical algorithm (QAA) performed the best.

The beam attenuation measurements had poor correlations when viewed ‘‘globally’’, but appeared to have better estimates when some data regional data (New York Bight) is removed. This may be explained by the derivation of scattering from backscattering which requires a knowledge of the VSF.

7 September 2004

1. INTRODUCTION

SeaWiFS, MODIS/Terra and MODIS/Aqua† data have been obtained by NRL from various sources and processed in-house using the Automated Processing System (software version 2.8). These data sources include the NASA Goddard DAAC, the NASA Direct Broadcast at Goddard, the NASA Direct Broadcast at Stennis Space Center, the NOAA real-time bent-pipe and NRL Code 7330's own receive station at the Stennis Space Center.

Code 7330 has collected various *in situ* optical properties since 1994. Above-water reflectance using either an Analytical Spectral Devices field-portable FieldSpec® spectroradiometer or University of Florida Spectrix spectroradiometer have been collected from many regions including Gulf Of Mexico, New Jersey, Adriatic Sea and Monterey Bay. During these same cruises, NRL frequently collected optical profiles with an ac9.

This report will compare these optical properties (remote sensing reflectance, R_{RS}; total absorption, a; and beam attenuation, c) derived from the MODIS and SeaWiFS sensors to the *in situ* measurements. It will describe the collection of the data and the results of those match ups.

2. IN SITU DATA

NRL Code 7333 has created a data base to contain all the *in situ* data. The data base consists of two parts: (1) a PostgeSQL data base that allows easy searching and analysis of the data; and (2) a simple directory structure of the data stored in the SeaBASS (2002) data format. The directory data base contains all data including calibration files, raw sensor files, *etc.*; where as, the SQL data base contains only the processed and quality controlled results.

The SQL data base also contains data from other organizations, including NAVOCEANO and NASA's SeaBASS data sets.

For this comparison, three types of optical properties of sea water were collected, processed, and stored in the SQL data base for match ups with the satellite data. These include above-water remote sensing reflectance, and total absorption and beam attenuation measurements collected from ac9 profiles.

† SeaWiFS data is available since October 1997; MODIS/Terra data is available since November 2000; and MODIS/Aqua data is available since November 2002.

2.1. Remote Sensing Reflectance

The remote sensing reflectance *in situ* measurements used in this comparison was derived from NRL Code 7333's *in situ* SQL data base. This data was recently reprocessed to adhere to the recently published Ocean Optics Protocols For Satellite Ocean Color Sensor Validation, Revision 4.

The majority of the reflectance data was collected using one of several Analytical Spectral Devices field spectroradiometers. The standard protocol for this data collection included a set number of measurements (usually 5) of the sky, the water, and a plaque (gray card) of known reflectance. The ASD data was processed using in-house software to estimate the remote sensing reflectance just above the water surface.

The remaining reflectance data was collected using a Spectrix field spectroradiometer and processed with a different software package. The original ASD processing package was modified to adhere better to the latest version of the Ocean Optics Protocols and to process the Spectrix data. This provided uniform processing of all reflectance data.

To compute the reflectance, the sensor response signal, S, is obtained from n readings from each target and normalized to a consistent integration time (1 sec).

$$S = \frac{\sum_{i=0}^{n} C I_N / I_i}{n}$$

Here, C represents the uncalibrated data read from the instrument, I_i is the integration time used for that reading, I_N is the normalized integration time (1 sec), and n is the number of readings (3, 5, or 9 in practice depending on instrument protocol and conditions during collection).

Following, Chapter 2 of the Optics Protocols, these can express the water-leaving radiance, L_w, and incident spectral irradiance, E_s, in terms:

$$L_w = F_L[S_{sfc} - \rho S_{sky}], \quad E_s = \frac{\pi F_L S_g}{R_g}$$

Here, F_L is the unknown instrument radiance response calibration factor (which will fall out) and R_g is the plaque's bi-directional reflectance function (albedo).

Thus the R_{RS} can be computed from the uncalibrated data using the following equation (correcting sky using Fresnel reflectance ρ of 0.021):

$$R_{RS}(\lambda) = \frac{S_{sfc}(\lambda) - \rho S_{sky}(\lambda)}{\pi S_g(\lambda)/R_g(\lambda)}$$

One of the problems associated with the above-water collection of remote sensing reflectance is the residual reflectance of the sky (known as glint). There are several different methods which attempt to remove this contamination. Each correction method has been implemented into the processing software and results for each is automatically generated.

In coastal waters, the assumption that $R_{RS}(750)$ should be zero is not true. There is reflectance from particles at red and near-IR wavelengths. In the Carder-Steward (1985) correction method, the positive reflectance at this wavelength is simply subtracted from this entire spectrum. This is also known as the ‘‘white’’ correction as it assumes that the correction is not spectrally dependent.

Measurements of water-leaving radiance or remote-sensing reflectance using above-water methods (such as hand-held radiometers) suffer from the unavoidable inclusion of surface-reflected radiance in the measured value. Gould et al. (2001) present procedures to correct for this reflectance, by partitioning the total, measured value into water and surface components. Two methods are described: the "Path 1" method does not require ancillary in situ measurements to effect the correction, the "Path 2" method utilizes in situ absorption and scattering measurements (from an ac9, for example) to refine parameter estimates and improve the correction.

The procedure is based on reflectance measurements at near-infrared wavelengths and known relationships between reflectance, absorption, and backscattering. Two equations are solved simultaneously to estimate the two parameters (A, B) required for the correction. The A parameter is coupled with the measured sky reflectance to account for the spectrally-variable reflected sky light, and the B parameter accounts for the spectrally-flat sunglint and reflected cloud light.

For Path 1, start by calculating $C_b(735)$

$$C_b(735) = \frac{(R_{sfc}(715) - R_{sfc}(735))(a_w(715)a_w(735))}{a_w(735) - a_w(715)}$$

and

$$R_r(735) = \frac{R_{sfc}(735)a_w(735) - R_{sfc}(715)a_w(715)}{a_w(735) - a_w(715)}$$

Assuming a Fresnel of 2.1%, compute the residual spectrally-flat sun glint and reflected cloud light (B) by $R_r(735) - 0.021R_{sky}(735)$. Now, our corrected $R^{¢}_{RS}$ is simply

$$R^{¢}_{RS}(\lambda) = R_{sfc}(\lambda) - 0.021R_{sky}(\lambda) - B$$

For Path 2, start with the same calculations for $C_b(735)$ and $R_r(735)$ above. Now using the *in situ* scattering data, compute $b(\lambda)/b(735)$ using linear regression of the *in situ* data to obtain the *in situ* shape. And, using the *in situ* absorption values and the relationship, $R_{RS}(\lambda) = Cb_b(\lambda)/a(\lambda)$, compute the remote sensing reflectance at 412, $R^*_{RS}(412)$. The star (*) indicates that this reflectance corresponds to that of the what *in situ* data estimates. This allows the calculation of the A term rather than assuming a value of 0.021.

For use in the satellite match up, the *in situ* collected reflectance is weighted by the response function for each given satellite band. As indicated by the Ocean Optics Protocols, the *in situ* reflectance data must be normalized to allow a direct comparison. In a personal communication with Zhongping Lee, this normalization factor would reduce the reflectance data by approximately 9 percent, based on the standard method of data collection. The largest difference between normalized and unnormalized reflectance will occur in the high latitude areas (per. comm. Alan Weidemann). The NRL *in situ* reflectance data base contains no data at such high latitudes. Therefore, for this particular match up, normalization has been ignored. It may be revisited at a later stage.

All collected reflectance data was processed using this common software and then quality controlled (by hand) to remove any reflectance data that showed errors during collection. The remaining reflectance data was registered into the SQL data base.

2.2. Total Absorption and Beam Attenuation

Total absorption and beam attenuation measurements were collected from profiles of ac9 instruments. The data was averaged for the first meter in water depth during the up cast.

The ac9 instrument is an optical instrument manufactured by Wet Labs to measure the spectral absorption, a, and beam attenuation, c, at nine wavelengths in the ocean (the eight SeaWiFS wavelengths plus 532 nm) . The data collected by the instrument requires some post-processing to attain final data values for these two properties.

Using standard protocols, the ac9 instrument is initialized so that pure water is removed. Thus, the output of the instrument does not account for the absorption and scattering of pure water. The design of the instrument causes a slight contamination of the absorption measurement due to the failure of the instrument to collect all of the scattered light. The Zaneveld Method is used to correct the measured absorption data for the scattering errors.

$$a_{t-w}(\lambda) = a_m(\lambda) - \frac{a_{mts}(\lambda_{ref})}{c_{mts}(\lambda_{ref}) - a_{mts}(\lambda_{ref})} [c_m(\lambda) - a_m(\lambda)]$$

As noted above, the instrument is initialized to actually measure $a_t - a_w$, so that a_w must be added into the final results. We use the Pope and Fry (1997) values for pure water absorption.

3. REMOTE SENSING DATA

The remote sensing data used in this comparison was obtained from several sources and processed using the Automated Processing System (software version 2.8). The APS is an in-house processing system for ocean color data. For MODIS data, the software to determine radiometerically and atmospherically corrected remote sensing reflectance from the top-of-the-atmosphere was obtained from the University of Miami. For SeaWiFS data, the software was obtained from the 3rd reprocessing of SeaWiFS (SeaDAS 4.0). In both software suites, NRL Code 7333 implemented its reflectance-based near infrared correction. The SeaWiFS processing also included an iteration method from Rick Stumpf to correct the resulting reflectance spectrum by estimating the 412 reflectance values and a vicarious calibration (Ladner, et. al 2002) against a defined set of reflectance measurements.

As each scene was processed it was registered into an SQL data base. This data base retains information about the location and time of the scene in addition to such characteristics as the processing version and geophysical input parameters like winds and ozone concentration (that is, was a daily MET/OZONE combination used or was a climatology used).

The APS defines different processing versions for each of the satellite data streams. The SeaWiFS data processed by APS v2.8 has a processing version value of 2.6. The MODIS/Terra and MODIS/Aqua data has a processing version value of 1.2.

3.1. Absorption

The total absorption was derived of each of the satellites using three different algorithms. The first algorithm was created by Arnone and divides the waters into two cases (I and II) based on the remote sensing reflectance at the red channel (670 nm for SeaWiFS and 667 nm for MODIS). For Case II waters ($R_{rs}(670) > 0.0003$), the relationship

$$R_{rs} = \frac{b_b}{a_t}$$

is used. In th

The second algorithm for total absorption is the semi-analytical algorithm from Carder, et. al (1997). In this algorithm, the remote sensing reflectance is used to compute two control parameters ($a_{dg}(400)$ and $a_{ph}(675)$). From, these two parameters, the total absorption spectrum is computed by the sum of the individual components (a_{dg}, a_{ph}, and a_w).

It must be noted that Carder's model and implementation differs between the two sensors. The MODIS satellite has thermal bands that allow the simultaneous calculation of sea surface temperature (sst) on a pixel-by-pixel basis. Using the sst, the model computes the nitrogen-depletion temperature which determine the packaging effect in the a_{ph} portion of the a spectrum.

The third algorithm for total absorption is known as the quasi-analytical algorithm from Lee, et. al (2002). In this algorithm, the remote sensing reflectance is used to compute total absorption directly.

3.2. Beam Attenuation

The algorithms discussed in the previous section also compute b_b either directly from remote sensing reflectance (Carder, QAA) or from the $R_{rs} = b_b/a$ relationship (Arnone). From b_b, the total scattering coefficient, b, is computed using Petzold. This scattering is summed with the total absorption, a, from the respective algorithm, to yield the beam attenuation, c.

4. METHODS

NRL Code 7333 has implemented an SQL data base for both the *in situ* and remote sensing data. To perform the comparison presented here, a software package was written that combines the two data bases to form match ups between the *in situ* measurements and the remote sensing data. The software has the capability to search the *in situ* data base using time, location, and parameter (reflectance, absorption, attenuation, etc.). The user may restrict the *in situ* data used in the match up by these and several other parameters.

Once the *in situ* data has been obtained, each station is matched with a corresponding remote sensing data file by geographical location and time. The user has the capability to restrict the acceptable time difference between the satellite overpass and that of the *in situ* collection.

Additionally, the user may restrict the data using a series of flags, such as high sensor zenith and high solar zenith angle. These flags are used to filter out poor satellite remote sensing retrievals.

Once the data collections are made, the software can produce plots of comparisons and generate some statistics including root mean squares.

In this study, *in situ* data was limited to within three hours of the satellite overpass (plus or minus) for a maximum window of six hours. Additionally, it was was restricted with start times (to maximize total throughput) of November 1997 for SeaWiFS; November 2000 for MODIS/Terra; and November 2002 for MODIS/Aqua. These times match the data's earliest availability for each sensor.

In this study, the remote sensing data (for each sensor) was restricted to the particular processing version for APS v2.8. That is, v2.6 for SeaWiFS and v1.2 for MODIS/Terra and MODIS/Aqua. A list of satellite passes that match the time/location of the corresponding *in situ* data were processed using APS v2.8 for the following regions only (Gulf Of Mexico, New York Bight, Monterey Bay, Northern Adriatic, Southern California, and Cariaco Basin). During processing, the climatological MET/OZONE data was used since this is the current normal processing of real-time data.

The SeaWiFS data was obtained from the following stations: HMBR (Monterey and Southern California), HNAV (Gulf Of Mexico and New York Bight), HROT (Adriatic), and HCAR (Cariaco Basin). The HNAV data was collected by NRL's in-house receive station. The HROT data was obtained via NAVOCEANO from the NAVEURMETOCCEN regional processing and collection center of Rota, Spain. The remaining data was obtained from the Goddard DAAC from various HRPT stations.

The MODIS data was obtained from the Goddard DAAC to provide a consistent processing and radiometric calibration. All MODIS Level-1B data came from Collection 4. No data from the NOAA NRPTE (real-time bent pipe) or the NASA-SSC direct broadcast were used in this study.

For this match up, the total absorption measurments from both the satellite and *in situ* ac9 were limited to a range ($0.001 < c < 1.0$). This removed some of the most turbid waters† from the match up.

For this match up, the beam attenution measurments from both the satellite and *in situ* ac9 were limited to a range ($0.01 < c < 4.5$). This removed some of the most turbid waters‡ from the match up.

5. RESULTS

5.1. SeaWiFS Remote Sensing Reflectance

The SeaWiFS-derived remote sensing reflectance is compared with *in situ* R_{rs} measurements obtained or processed in two different ways. The first series of plots are comparisons of *in situ* reflectance with SeaWiFS derived reflectance at 443 nm, 490 nm, and 555 nm. The data obtained from NASA's SeaBASS and that from NRL's data base using the "white" reflectance correction method are grouped as one complete reflectance data base. The second series of plots will examine the use of the Gould Path 2 algorithm. This algorithm requires coincident total absorption measurements with the raw reflectance which, in some cases, is not provided by the SeaBASS data base. All *in situ* data since November 1997 is included in this matchup.

Complete Reflectance Data base

The table below shows the number of stations for each area processed.

Station Locations		
Gulf Of Mexico	Black	43
Southern California	Yellow	38
New York Bight	Cyan	17
Monterey Bay	Green	8
Northern Adriatic Sea	Red	7
Cariaco Basin	Blue	2

The data from Southern California consists mostly of R_{RS} data collected by Haili and Wang for the Scripps Institu of Oceanography during the November 2002 CALCOFI experiment using a SIMBAD06 instrument. One station was contributed from the February 2003 IMECOCAL experiment using the same instrument. That data had Elsi, Alguirre, Frouin, and Poteau as investigators. The data was obtained from the NASA SeaBASS data base.

The data from Cariaco Basin (off Venezuela) was collected by Mueller-Karger, Hu, Arias, Varela, and Odriozola for University of South Florida and FLASA/EDIMAR (Venezuela) during a September 2003 CARIACO experment cruise using a speccan.

The remaining data was collected by Arnone, Gould, Ladner, Goode, Martinolich, Smith, and Wiedemann of Naval Research Laboratory since November of 1997 for many different experiments including LEO-15, COPE-I, COPE-II, *etc*.

† For a May 2002 cruise in Mobile Bay, the *in situ* measurement for a station was > 11!

‡ For a May 2002 cruise in Mobile Bay, the *in situ* measurement for a station was > 14!

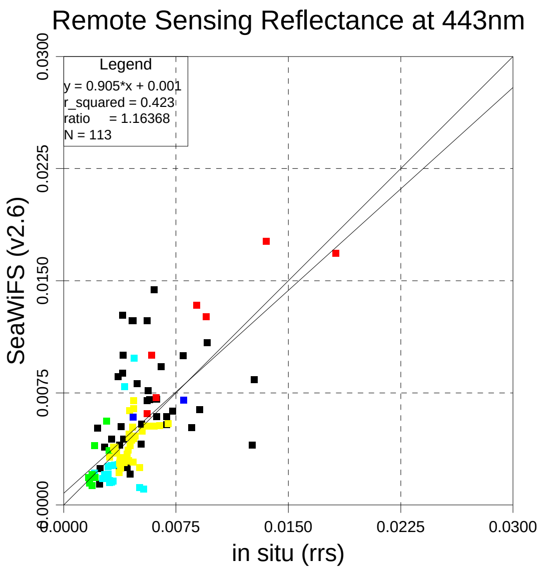

Figure 1. SeaWiFS-derived R_{rs} vs *in situ* R_{rs}

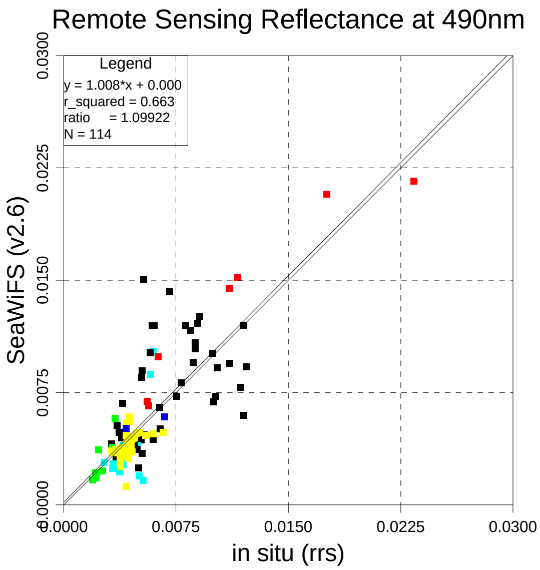

Figure 2. SeaWiFS-derived R_{rs} vs *in situ* R_{rs}

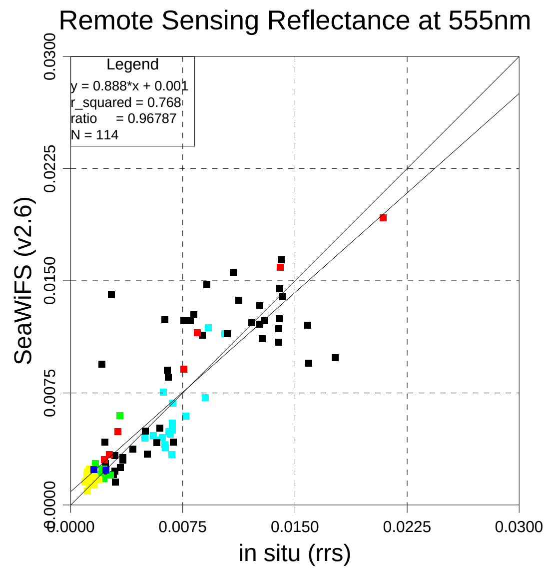

Figure 3. SeaWiFS-derived R_{rs} vs *in situ* R_{rs}

The results above show very good agreement in the green band (555 nm) between the SeaWiFS derived reflectance and that from *in situ*. The agreement reduces as one moves to shorter wavelengths.

Gould Path 2

Using *in situ* total absorption (412 nm), Gould has a method to correct the computed reflectance (see above). The following reflectance match ups compare this computed reflectance to that of the SeaWiFS. Because it is standard protocol during NRL cruises to collect both ac9 profiles and above-water reflectance only those stations from the Gulf Of Mexico and New York Bight region (LEO-15 experiments) are used in this match up.

Station Locations		
Gulf Of Mexico	Black	55
New York Bight	Cyan	17

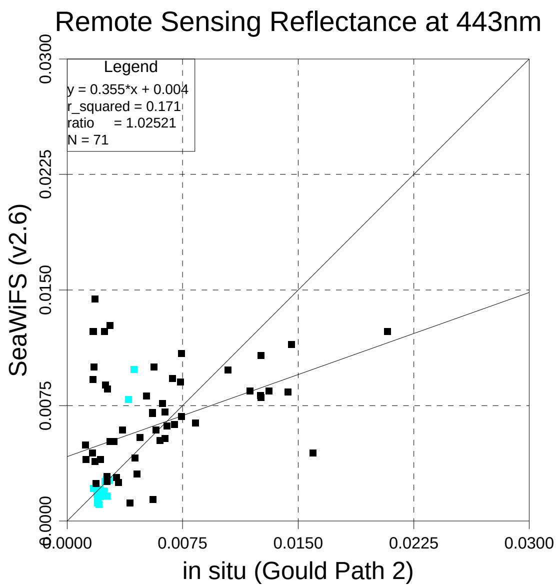

Figure 4. SeaWiFS-derived R_{rs} vs *in situ* R_{rs} (Gould Path 2)

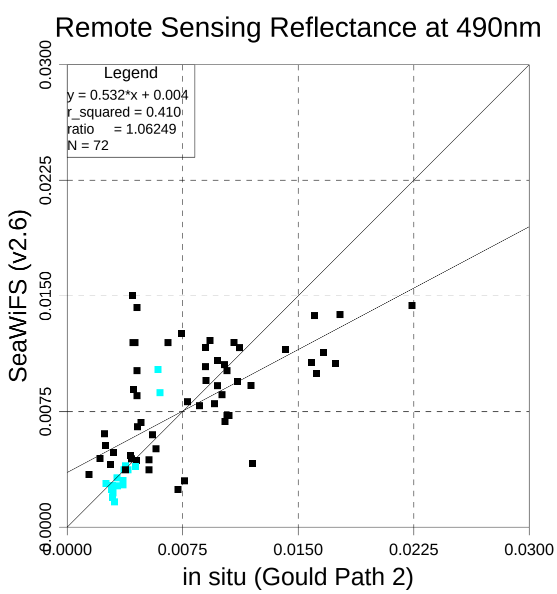

Figure 5. SeaWiFS-derived R_{rs} vs *in situ* R_{rs} (Gould Path 2)

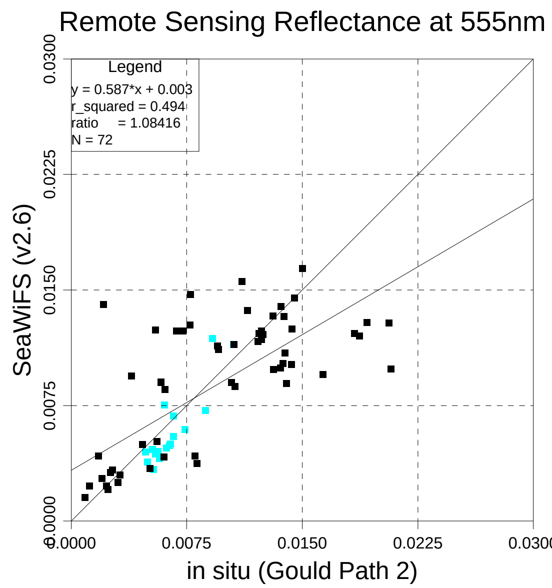

Figure 6. SeaWiFS-derived R_{rs} vs *in situ* R_{rs} (Gould Path 2)

The results above show much less agreement between the *in situ* measurements and the SeaWiFS-derived reflectance than that from the complete reflectance match up above.

5.2. MODIS/Terra Remote Sensing Reflectance

The MODIS/Terra-derived remote sensing reflectance is compared with *in situ* R_{rs} measurements obtained or processed in two different ways. The first series of plots are comparisons of *in situ* reflectance with MODIS/Terra derived reflectance at 443 nm, 488 nm, and 551 nm. The data obtained from NASA's SeaBASS and that from NRL's data base using the ‘‘white’’ reflectance correction method are grouped as one complete reflectance data base. The second series of plots will examine the use of the Gould Path 2 algorithm. This data requires coincident total absorption measurements with the raw reflectance which, in some cases, is not provided by the SeaBASS data base.

All *in situ* data since November 2000 is included in this match up. This slightly reduces the total number of match ups (102) as compared to SeaWiFS (115).

Complete Reflectance Data base

The table below shows the number of stations for each area processed.

Station Locations		
Southern California	Yellow	44
Gulf Of Mexico	Black	30
Northern Adriatic Sea	Red	11
New York Bight	Cyan	10
Monterey Bay	Green	5
Cariaco Basin	Blue	2

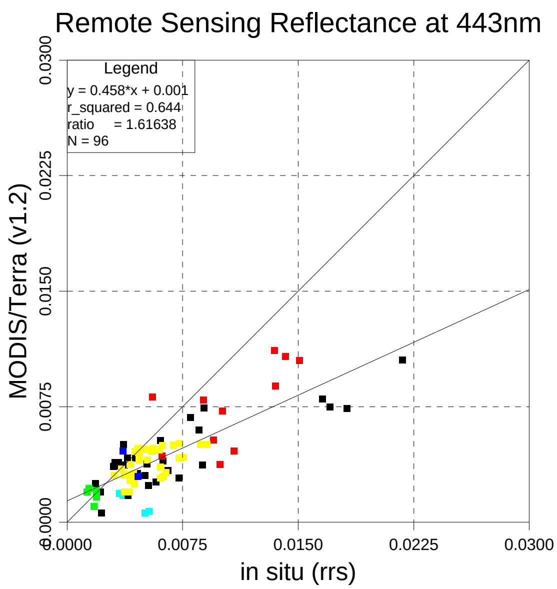

Figure 7. MODIS/Terra-derived R_{rs} vs *in situ* R_{rs}

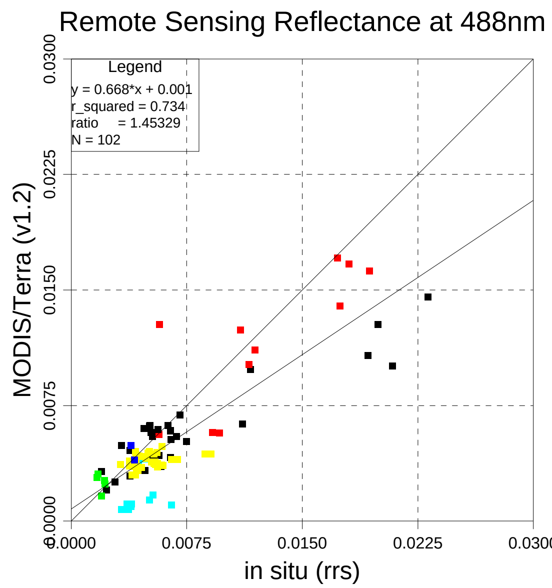

Figure 8. MODIS/Terra-derived R_{rs} vs *in situ* R_{rs}

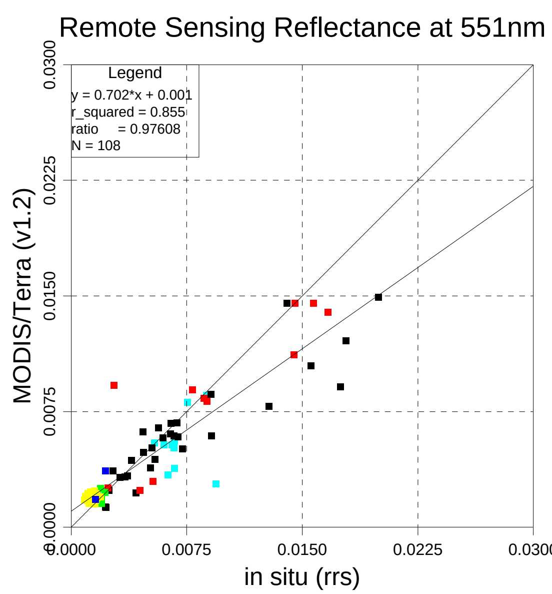

Figure 9. MODIS/Terra-derived R_{rs} vs *in situ* R_{rs}

The results show very good agreement between the *in situ* measurements and the MODIS/Terra-derived reflectance data. The agreement is best in the longer wavelengths. The agreement is better than that of SeaWiFS.

Gould Path 2

Using *in situ* total absorption (412 nm), Gould has a method to correct the computed reflectance (see above). The following reflectance match ups compare this computed reflectance to that of the MODIS/Terra. Because it is standard protocol during NRL cruises to collect both ac9 profiles and above-water reflectance only those stations from the Gulf Of Mexico and New York Bight region (LEO-15 experiments) are used in this match up.

Station Locations		
Gulf Of Mexico	Black	35
New York Bight	Cyan	4

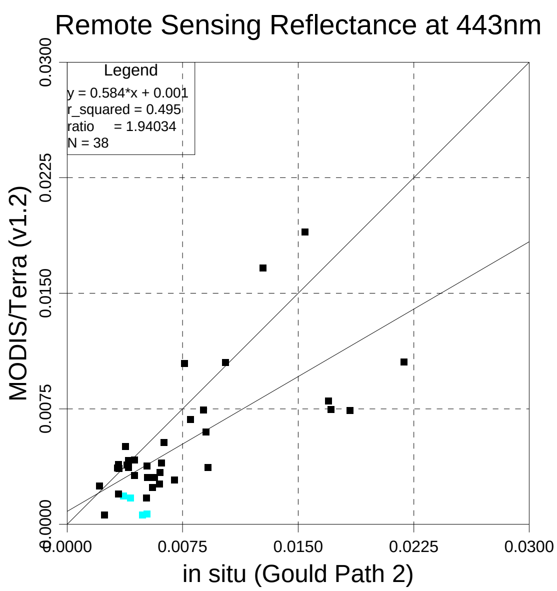

Figure 10. MODIS/Terra-derived R_{rs} vs *in situ* R_{rs} (Gould Path 2)

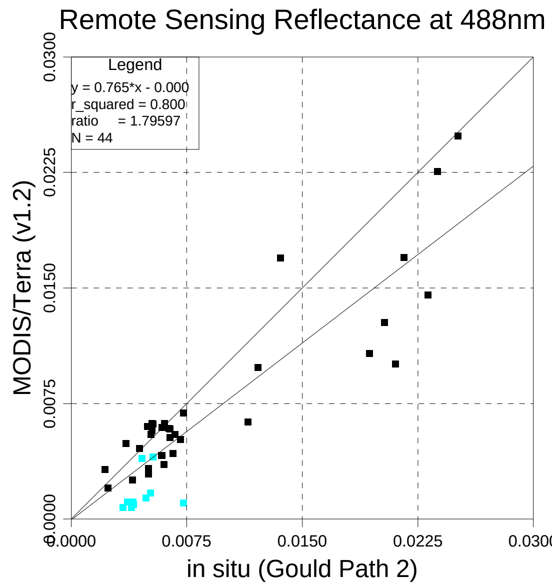

Figure 11. MODIS/Terra-derived R_{rs} vs *in situ* R_{rs} (Gould Path 2)

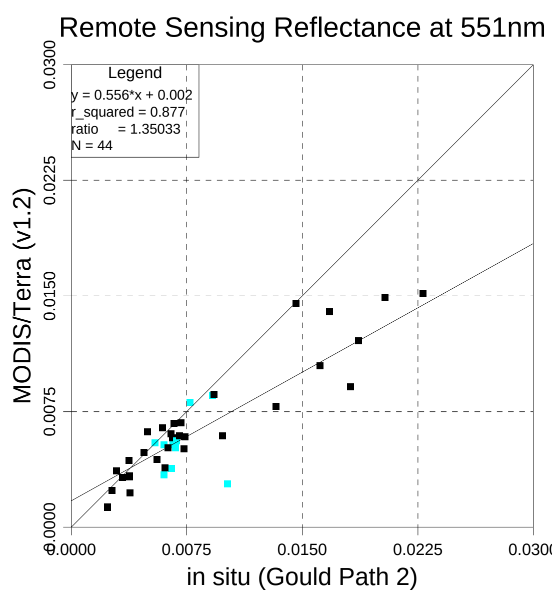

Figure 12. MODIS/Terra-derived R_{rs} vs *in situ* R_{rs} (Gould Path 2)

The results show better agreement between the *in situ* measurements and the MODIS/Terra-derived reflectance data than the same match up did with Sea-WiFS (*vs* Gould Path 2). However, again the MODIS/Terra match up against Gould Path 2 remote sensing reflectance is not as strong than that of the complete reflectance data base above.

5.3. MODIS/Aqua Remote Sensing Reflectance

The MODIS/Aqua-derived remote sensing reflectance is compared with *in situ* R_{rs} measurements obtained or processed in two different ways. The first series of plots are comparisons of *in situ* reflectance with MODIS/Aqua derived reflectance at 443 nm, 488 nm, and 551 nm. The data obtained from NASA's SeaBASS and that from NRL's data base using the ‘‘white’’ reflectance correction method are grouped as one complete reflectance data base. The second series of plots will examine the use of the Gould Path 2 algorithm. This data requires coincident total absorption measurements with the raw reflectance which, in some cases, is not provided by the SeaBASS data base.

All *in situ* data since November 2002 is included in this match up. The greatly reduces the total number of match ups to 57, about one-half the number used in the SeaWiFS or MODIS/Terra match ups.

Complete Reflectance Data base

The table below shows the number of stations for each area processed.

Station Locations		
Southern California	Yellow	32
Northern Adriatic Sea	Red	19
Cariaco Basin	Blue	3
Monterey Bay	Green	2
Gulf Of Mexico	Black	1

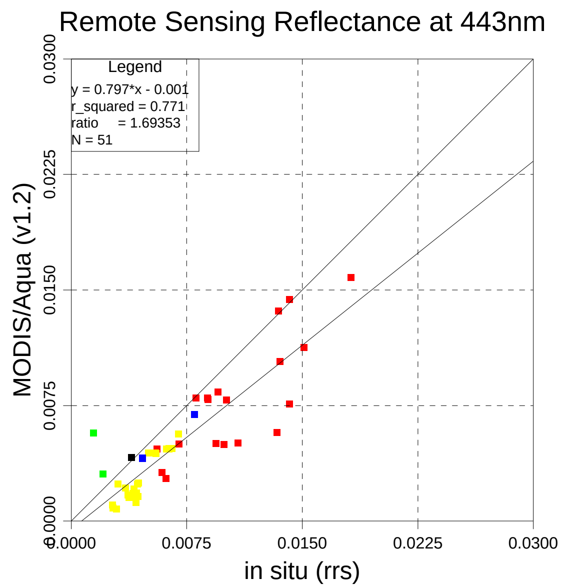

Figure 13. MODIS/Aqua-derived R_{rs} vs *in situ* R_{rs}

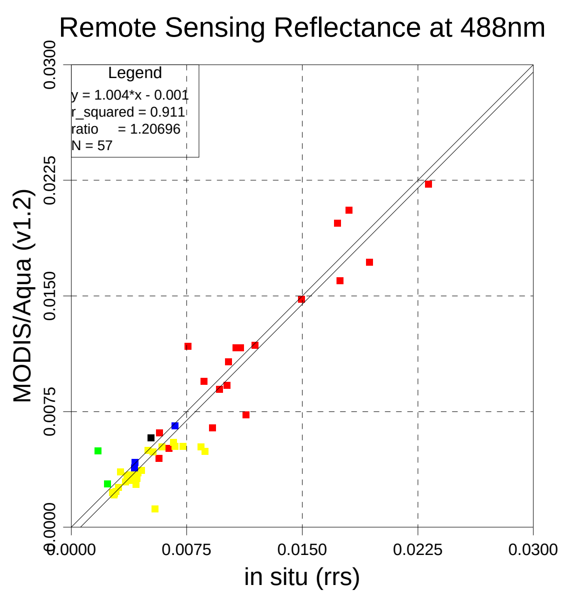

Figure 14. MODIS/Aqua-derived R_{rs} vs *in situ* R_{rs}

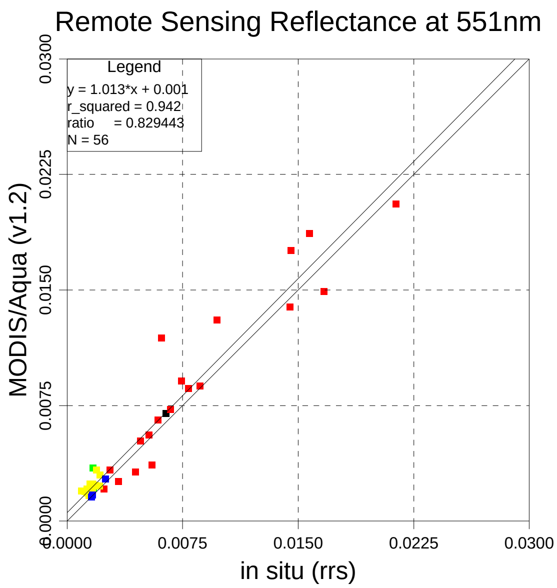

Figure 15. MODIS/Aqua-derived R_{rs} vs *in situ* R_{rs}

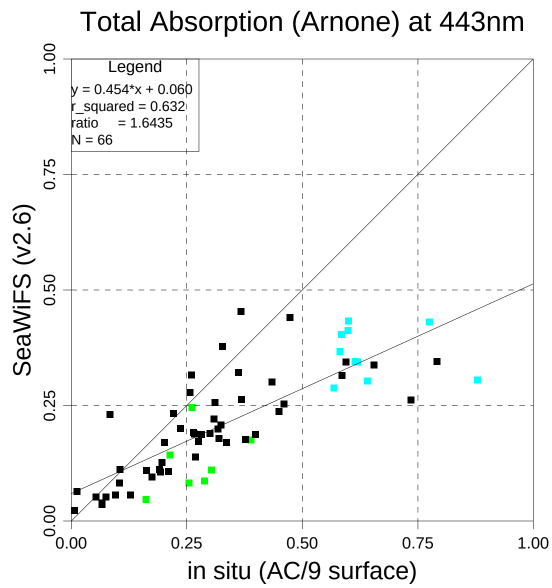

Figure 16. SeaWiFS-derived a (Arnone) vs *in situ* a

The results above show excellent agreement between the MODIS/Aqua-derived reflectance and that from *in situ*. Note, however, that this match up contains very few points from the Gulf Of Mexico. It is dominated by the CALCOFI and Northern Adriatic data.

Gould Path 2

Due to the lack of data match ups (lack of ac9 measurements), the MODIS/Aqua Gould Path 2 match up was *not* performed.

5.4. SeaWiFS Absorption

The SeaWiFS-derived total absorption, a, is compared with surface *in situ* a data collected from ac9 profiles.

A total of 66 ac9 profiles were matched with the SeaWiFS-derived total absorption values. The data primarily consisted of data from the Northern Gulf Of Mexico.

Station Locations		
Gulf Of Mexico	Black	49
New York Bight	Cyan	10
Monterey Bay	Green	7

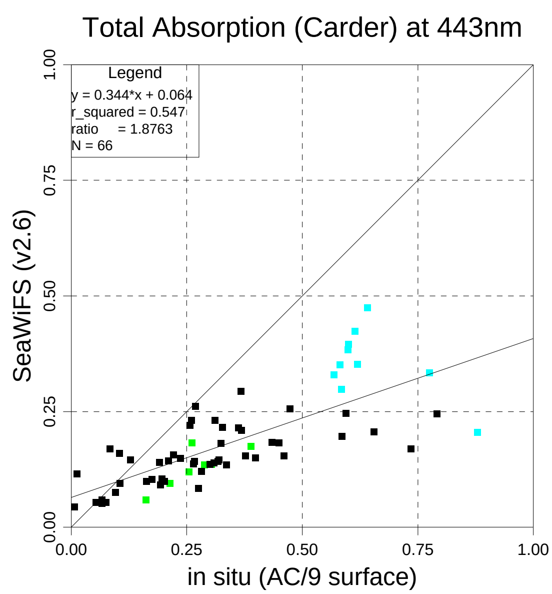

Figure 17. SeaWiFS-derived a (Carder) vs *in situ* a

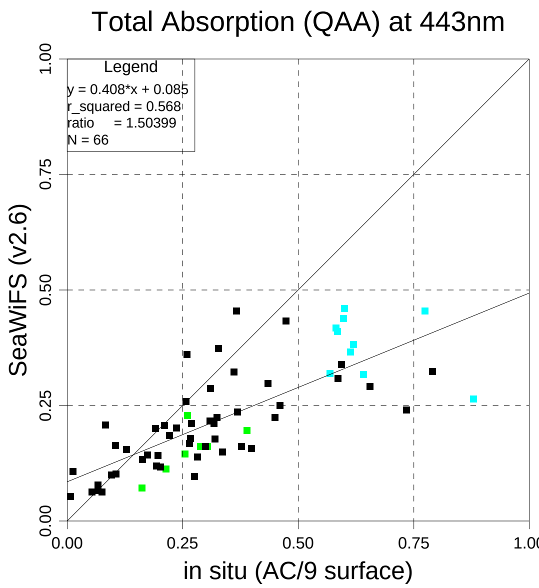

Figure 18. SeaWiFS-derived *a* (QAA) vs *in situ a*

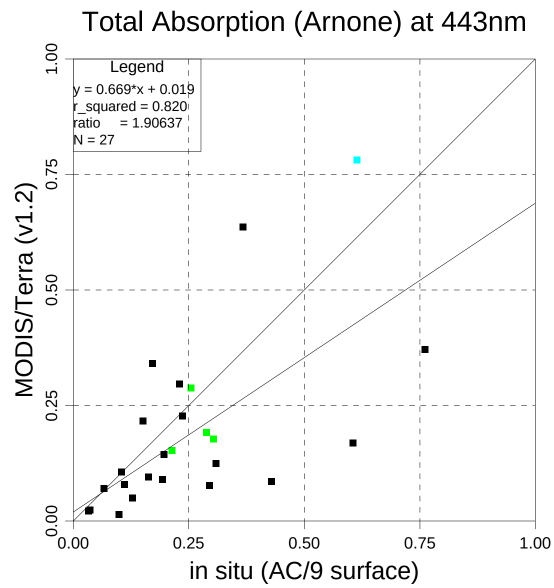

Figure 19. MODIS/Terra-derived *a* (Arnone) vs *in situ a*

The results above show that the QAA algorithm performs the best when computed SeaWiFS derived absorption values compared with the *in situ* values. It has a stronger r^2 and ratio when compared with the Arnone algorithm. SeaWiFS derived absorption using Carder has the least agreement with the ac9 measurments. In all cases, the total absorption appears to be underestimated by the satellite.

5.5. MODIS/Terra Absorption

The MODIS/Terra-derived absorption, *a*, is compared with surface *in situ a* data collected from ac9 profiles.

A total of 34 ac9 profiles were matched with the MODIS/Terra-derived total absorption values. The data primarily consisted of data from the Northern Gulf Of Mexico.

Station Locations		
Gulf Of Mexico	Black	28
Monterey Bay	Green	4
New York Bight	Cyan	2

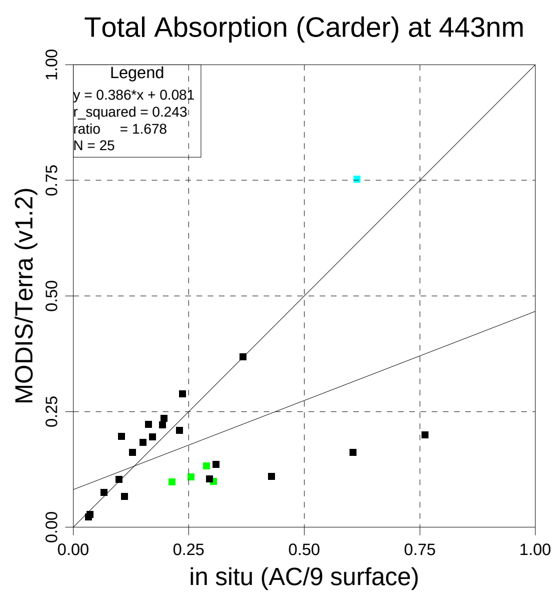

Figure 20. MODIS/Terra-derived *a* (Carder) vs *in situ a*

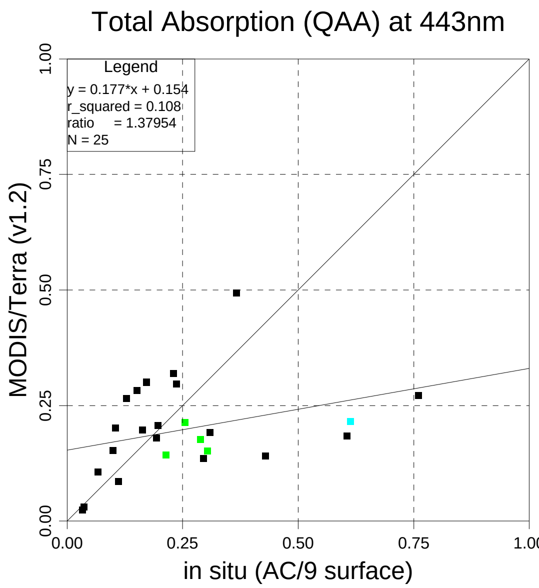

Figure 21. MODIS/Terra-derived *a* (QAA) vs *in situ a*

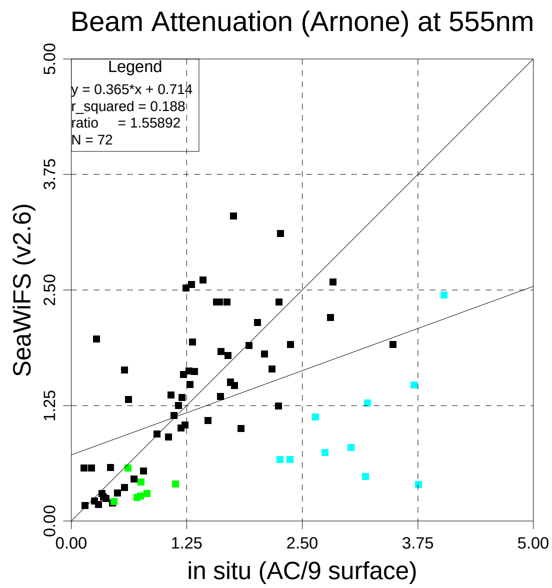

Figure 22. SeaWiFS-derived *c* (Arnone) vs *in situ c*

In this comparison, the Arnone algorithm had the best r^2 value for estimating total absorption from the MODIS/Terra sensor. However, the QAA algorithm has better ratio. The Carder algorithm appears to have two groupings, one of which appears to follow the one-to-one line well. The second group resemebles the SeaWiFS closer.

5.6. MODIS/Aqua Absorption

The MODIS/Aqua-derived absorption, *a*, were **not** compared with surface *in situ a* data collected from ac9 profiles as insufficient profiles were collected.

5.7. SeaWiFS Beam Attenuation

The SeaWiFS-derived beam attenuation, *c*, is compared with surface *in situ c* data collected from ac9 profiles.

A total of 72 ac9 profiles were matched with the SeaWiFS-derived beam attenuation values. The data primarily consisted of data from the Northern Gulf Of Mexico.

Station Locations		
Gulf Of Mexico	Black	55
New York Bight	Cyan	10
Monterey Bay	Green	7

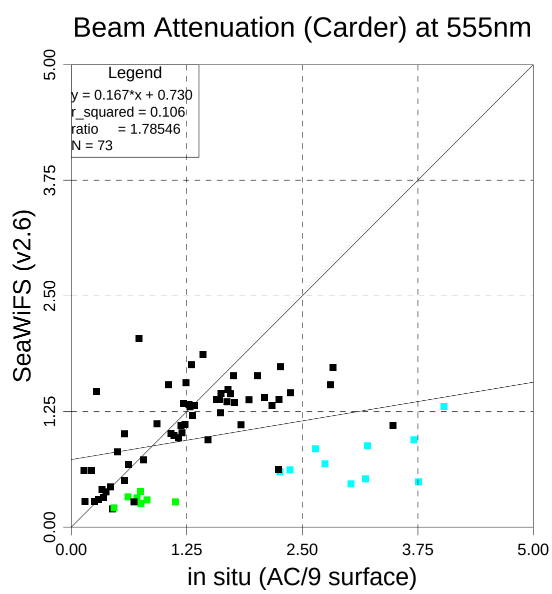

Figure 23. SeaWiFS-derived *c* (Carder) vs *in situ c*

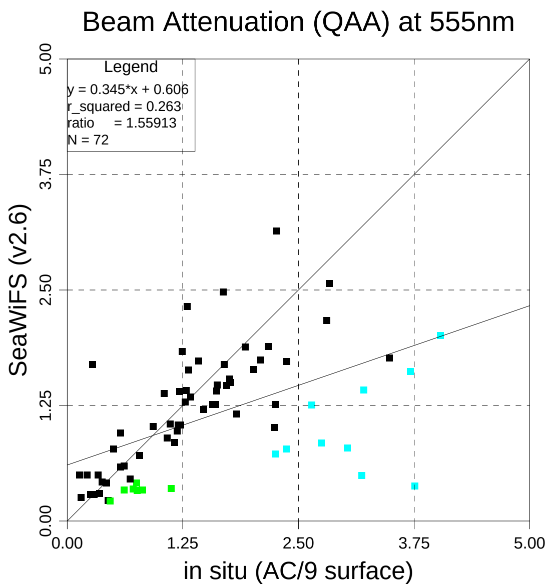

Figure 24. SeaWiFS-derived *c* (QAA) vs *in situ c*

The estimates of beam attenuation from the Arnone and QAA algorithms from the SeaWiFS had reasonable agreement with the *in situ* ac9 measurements. The Carder algorithm also appears to have a good agreement, esp. with the removal of the New York Bight data. In fact, in all cases the removal of the New York Bight data will improve the match ups.

The New York data in the plots were from measurments in Summer of 2001 and showed a much lower b_b/b relationship than many other areas (Ladner, et al 2002). In Ladner's examination of the b_b/b relationship the ratio for this cruise was 0.004. All other cruise values were $0.01 < b_b/b < 0.018$ which are close to the Petzold value of 0.018. This large deviation from Petozold's value explains the difference between the satellite derived beam attenuation values which use the Petzold relationship.

The beam attenuation match up with New York Bight removed improves to r^2 of 0.512, 0.409, and 0.589 for Arnone, Carder, and QAA algorithms respectively. The slope values for each approach unity (0.811, 0.447, 0.696)

5.8. MODIS/Terra Beam Attenuation

The MODIS/Terra-derived beam attenuation, *c*, is compared with surface *in situ a* data collected from ac9 profiles.

A total of 34 ac9 profiles were matched with the SeaWiFS-derived beam attenuation values. The data primarily consisted of data from the Northern Gulf Of Mexico.

Station Locations		
Gulf Of Mexico	Black	28
Monterey Bay	Green	4
New York Bight	Cyan	2

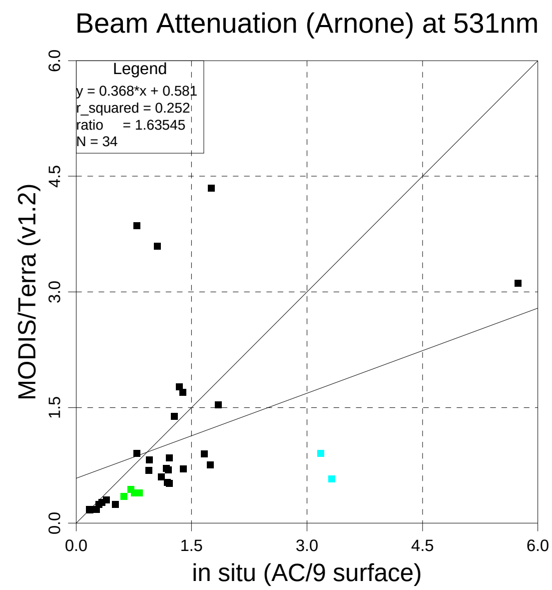

Figure 25. MODIS/Terra-derived *c* (Arnone) vs *in situ c*

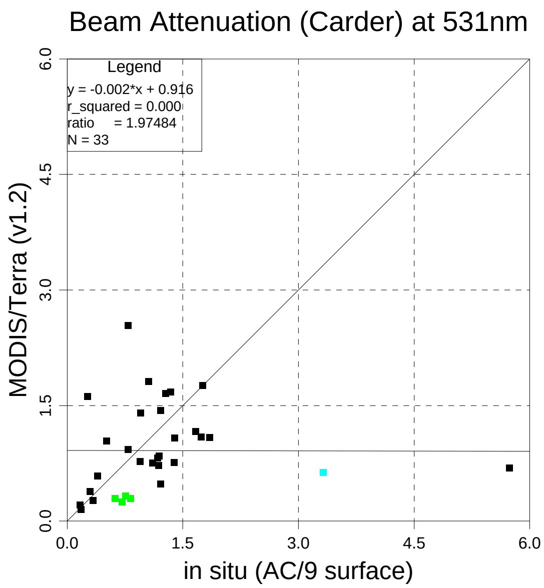

Figure 26. MODIS/Terra-derived *c* (Carder) vs *in situ c*

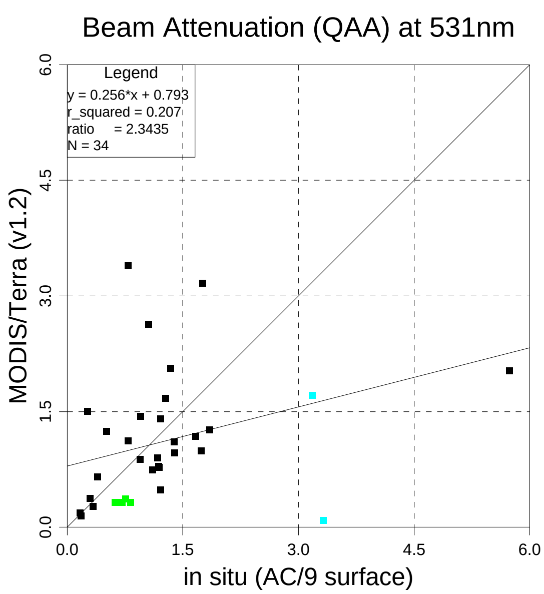

Figure 27. MODIS/Terra-derived *c* (QAA) vs *in situ c*

The estimates of beam attenuation from all three algorithms from MODIS/Terra data had alot of deviation to that of the *in situ* ac9 measurements.

5.9. MODIS/Aqua Beam Attenuation

The MODIS/Aqua-derived beam attenuation, *c*, were **not** compared with surface *in situ c* data collected from ac9 profiles as insufficient profiles were collected.

6. CONCLUSIONS

Satellite derived reflectance, total absorption, and beam attenuation data were compared with *in situ* measurements. The results show very good results from the MODIS and SeaWiFS sensors with reflectance and beam attenuation. The total absorption data had the least agreement (esp. at high values > 0.2).

6.1. Remote Sensing Reflectance

The results show that the blue region of the spectrum has the least correlation with the *in situ* data. As one moves toward the red-end of the spectrum, the data has a greater correlation. These differences can be associated with the residual reflectance (glint) in the *in situ* data and the atmospheric correction in the remote sensing data.

The MODIS/Aqua has the greatest agreement with the *in situ* reflectance; SeaWiFS has the least agreement. In both cases, where the Gould Path 2 algorithm was used (SeaWiFS and MODIS/Terra), the agreement was poor.

Algorithms which use ratios of the center bands, like 488 and 551 used with the diffuse attenuation and chlorophyll-a algorithms should show be reasonable results. Those algorithms that use the 412 band, like Carder's inherent-optical-properties, would be more suspect.

6.2. Total Absorption

The total absorption derived from the satellite (SeaWiFS and MODIS/Terra) are generally lower than that from the *in situ* ac9 measurements. The QAA appears to before better than the other two algorithms used in this study (Arnone and Carder).

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