PRE-LAUNCH PERFORMANCE ASSESSMENT OF THE VIIRS OCEAN COLOR / CHLOROPHYLL ALGORITHM

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Introduction

The Carder Semi-analytical ocean color algorithm [1] was employed as the initial ocean color algorithm for use with MODIS on EOS-Terra and Aqua [2]. This algorithm has, with only minor modifications, been selected by NGST as the ocean color algorithm for the VIIRS sensor on NPP/NPOESS. This poster will report on the testing and pre-launch performance assessment of the current VIIRS Ocean Color/Chlorophyll (OCC) algorithm, based on application of the OCC algorithm to both global *in situ* and synthetic datasets. Performance results are presented for the retrieval of chlorophyll-a as well as the retrieval of the key absorption and scattering inherent optical properties (IOP), which are frequently overlooked in ocean color retrievals but potentially provide the best approach to improved retrieval of biogeochemical parameters, like chlorophyll.

VIIRS Ocean Color Algorithm (Carder *et al.*, 1999)

Carder Semi-Analytic Algorithm (Initial Terra/MODIS and Aqua/MODIS algorithms)

Remote-sensing reflectance (with several approximations),

$$R_{rs} \cong \text{constant} \cdot \frac{b_b(\lambda)}{a(\lambda)}$$

The total backscattering coefficient $b_b(\lambda)$ can be spectrally partitioned into components due to water, $b_{bw}(\lambda)$, and particles, $b_{bp}(\lambda)$, i.e.,

$$b_b(\lambda) = b_{bw}(\lambda) + b_{bp}(\lambda)$$

b_{bp} is modeled using the Angstrom law

$$b_{bp}(\lambda) = X\left(\frac{555}{\lambda}\right)^Y, \text{ with } X = X_0 + X_1 R_{rs}(555), \text{ and } Y = Y_0 + Y_1 \frac{R_{rs}(445)}{R_{rs}(488)}$$

where X_0, X_1, Y_0, and Y_1 are empirical constants derived using linear regression.

Absorption coefficient can be spectrally partitioned into components due to water, a_w, phytoplankton, a_{ph}, and Dissolved Organic Matter (detritus and gelbstoff), a_{dom}

$$a(\lambda) = a_w(\lambda) + a_{ph}(\lambda) + a_{dom}(\lambda), \text{ and } a_{dom}(\lambda) = a_d(\lambda) + a_g(\lambda)$$

$b_{bw}(\lambda)$ is given by Morel (1974) and $a_w(\lambda)$ is from Pope and Fry (1997)

Phytoplankton absorption spectra can be written with empirical functions a_0, a_1, a_2, a_3 as

$$a_{ph}(\lambda) = a_{ph}(675) \cdot a_0(\lambda) \cdot \exp\left\{a_1(\lambda) \cdot \tanh\left[a_2(\lambda) \cdot \ln\frac{a_{ph}(675)}{a_3(\lambda)}\right]\right\}$$

DOM absorption coefficient, $a_{dom}(\lambda)$, is modeled with the exponential spectral slope

$$a_{dom}(\lambda) = a_g(400) \exp[-S(\lambda - 400)]$$

where S is the given spectral slope.

Combining the above equations and using spectral $R_{rs}(\lambda)$ ratios of 412:445 and 445:555, $a_{ph}(675)$ and $a_g(400)$ may be solved. When no solution is found, the following empirical algorithms are used

$$a_{ph}(675)_{emp} = 0.328 \cdot \left(10^{-0.919 + 1.037\rho_{25} - 0.407\rho_{25}^2 - 3.531\rho_{35} + 1.702\rho_{35}^2} - 0.008\right)$$

$$a_g(400)_{emp} = 1.5 \cdot \left(10^{-1.147 - 1.963\rho_{15} - 1.01\rho_{15}^2 + 0.856\rho_{25} + 1.579\rho_{25}^2}\right)$$

where ρ_{15}=log[R_{rs}(412)/R_{rs}(555)], ρ_{25}=log[R_{rs}(445/R_{rs}(555)], and ρ_{35}=log[R_{rs}(448)/R_{rs}(555)].

The semi-analytic chlorophyll-a concentration is

$$Chla = A[a_{ph}(675)]^B$$

When $a_{ph}(675)$ > 0.03/m, the following empirical algorithm is used

$$Chla_{emp} = 10^{c_0 + c_1\rho_{35} + c_2\rho_{35}^2 + c_3\rho_{35}^3}, \text{ where } \rho_{35} = \log[R_{rs}(488)/R_{rs}(555)]$$

where A, B, and c_0, c_1, c_2, c_3 are empirical constants.

Error Measures for Reporting Performance

Error measures used to report performance of the chlorophyll-a retrieval are the mean normalized bias in percent for accuracy error,

$$Mean = \frac{1}{N}\sum_i^N \left[\frac{Chla_{retrieved} - Chla_{known}}{Chla_{known}} \cdot 100\%\right]_i$$

and the root mean square error or standard deviation in percent for the precision error,

$$Std = \frac{1}{N-1}\left(\sum_i^N \left(\left[\frac{Chla_{retrieved} - Chla_{known}}{Chla_{known}} \cdot 100\%\right]_i - Mean\right)^2\right)^{\frac{1}{2}}$$

Quantitative performance of the IOP-a retrievals was based on the Root-Mean-Square-Error (RMSE) and the correlation coefficient of determination (R^2), both calculated in log space

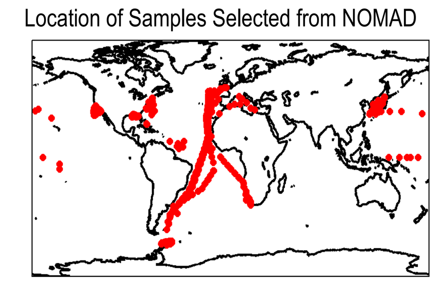
$$RMSE = \left(\frac{\sum_{i=1}^N \left[\log(IOP_i^{retrvd}) - \log(IOP_i^{knwn})\right]^2}{N-2}\right)^{1/2}$$

Testing with In Situ Datasets

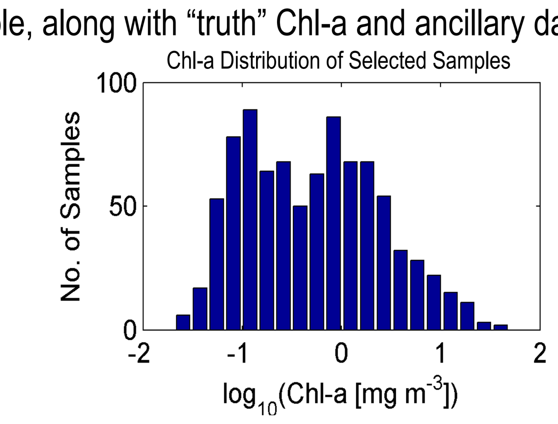
Testing with NOMAD

- Used NASA bio-Optical Marine Algorithm Dataset (NOMAD), Version 1.3
- Dataset of ~3,500 samples was filtered to select 877 with valid values for the spectral water-leaving radiance and surface irradiance in VIIRS bands M1-M4 (i.e., NOMAD wavelengths of 411, 443, 489 and 555 nm)
- R_{rs} was generated for each sample, along with "truth" Chl-a and ancillary data

Location of Samples Selected from NOMAD



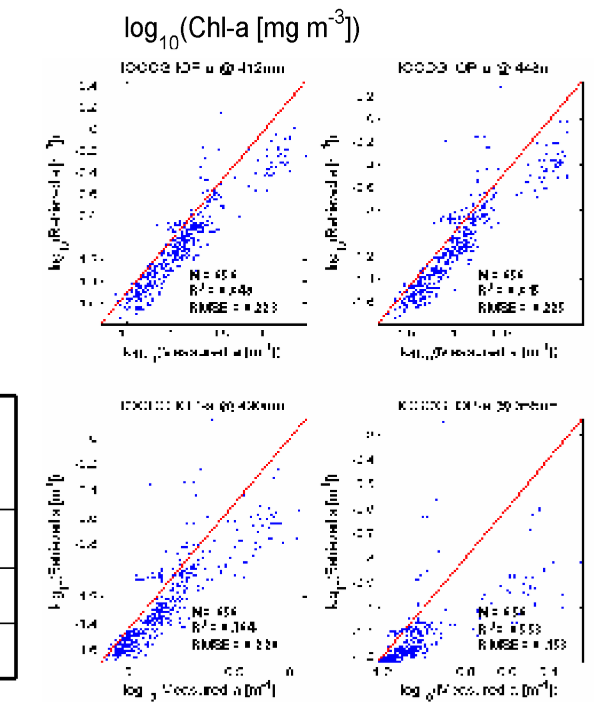
Chl-a Distribution of Selected Samples



- Results show a slight offset bias, but no slope bias
- The VIIRS algorithm achieves performance measures comparable to the Carder-MODIS algorithm

Comparison of Carder-MODIS and VIIRS OCC Algorithms for IOP-a on IOCCG In Situ Dataset

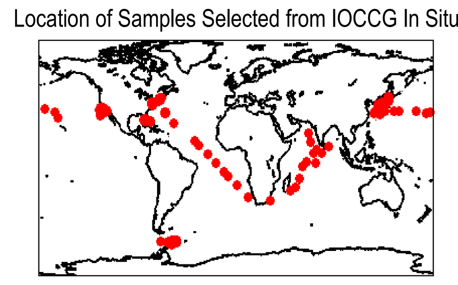
	R^2 Carder-MODIS	RMSE Carder-MODIS	R^2 VIIRS	RMSE VIIRS
a(410)	0.826	0.197	0.849	0.223
a(440)	0.831	0.205	0.815	0.225
a(490)	0.789	0.206	0.764	0.220



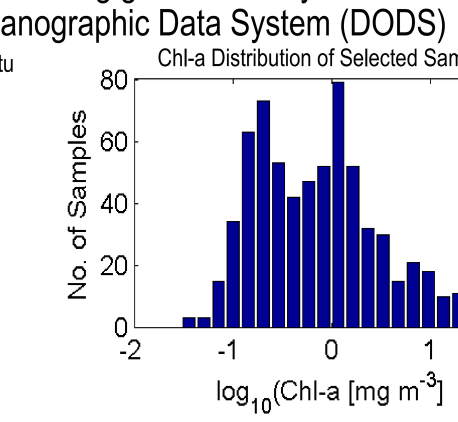
Testing with IOCCG In Situ Dataset from SeaBASS

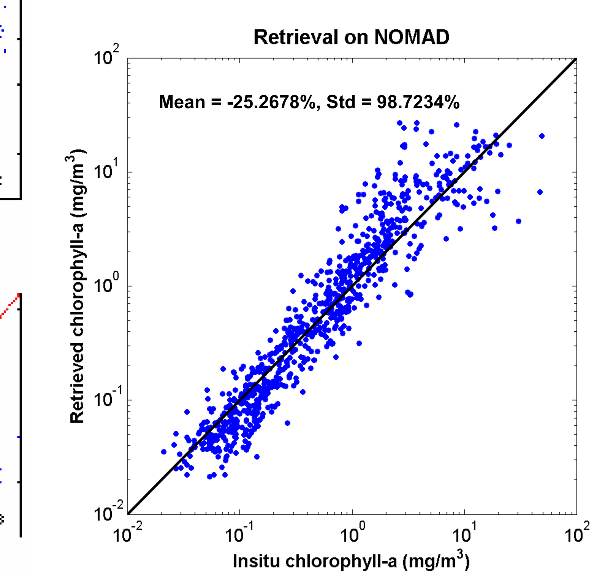
- The IOCCG in situ dataset [5] is an extraction from NASA's SeaWiFS Bio-optical Archive and Storage System (SeaBASS)
- Dataset of 656 samples provides values for the R_{rs} in VIIRS bands M1-M4 (i.e., SeaWiFS wavelengths of 412, 443, 490 and 555 nm), as well as Chl-a and band-dependent values of IOP-a
- Ancillary SST values were predicted using global monthly-mean OISST data obtained from the Distributed Oceanographic Data System (DODS)

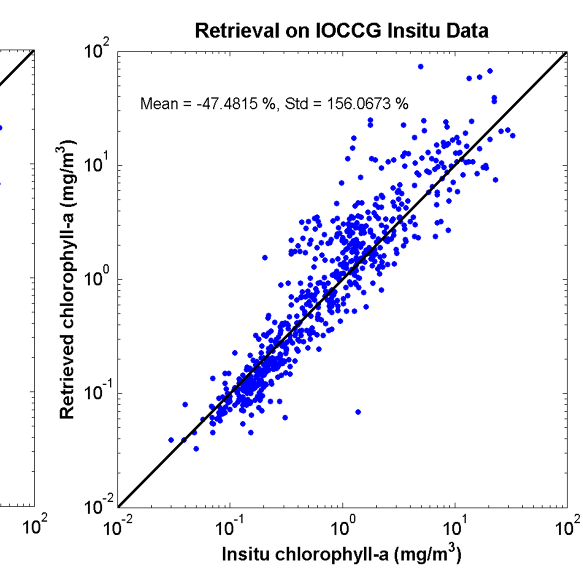
Location of Samples Selected from IOCCG In Situ



Chl-a Distribution of Selected Samples



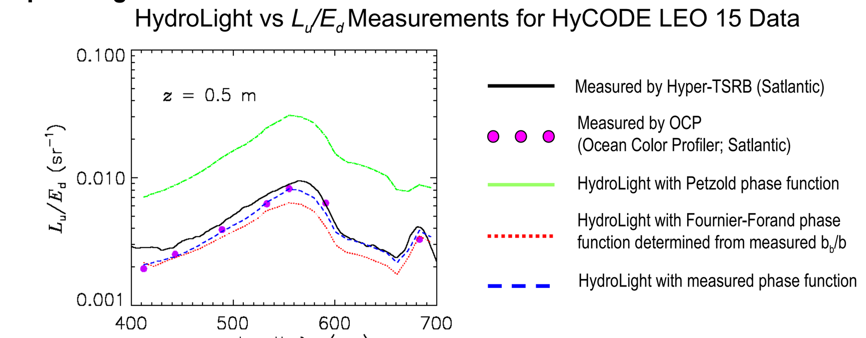




Generating Realistic Ocean R_{rs}

- **H-BRDF computes ocean BRDFs on a tabular format suitable for input to atmospheric RTMs (e.g., MODTRAN4, SBDART and 6SV)**
  - **Uses core code of HydroLight, a validated, "industry standard" ocean RTM employed by optical oceanographers for over a decade, to compute in-water radiance distributions**
  - **Given a set of ocean IOP and the near-surface wind speed, H-BRDF outputs separate BRDFs for computing the water-leaving, surface reflected, and total upwelling radiances at the ocean surface**

HydroLight vs L_u/E_d Measurements for HyCODE LEO 15 Data



- **For realistic evaluation of the ACO and OCC algorithms, it is necessary to include the inherent variability in IOP that occur in the ocean**
- **Bricaud Database used for particle absorption**
  - **Database contains 1,129 measured chlorophyll-specific absorption spectra (phytoplankton & detritus), as well as the corresponding total chlorophyll & chlorophyll-a concentrations**
  - **Measurements are for tropical and mid-latitude Case 1 waters, with a mix of mesotrophic, oligotrophic, and eutrophic water types**
    - **Majority of chlorophyll values < 1mg/m³**
  - **Variability in absorption spectra for a given chlorophyll concentration is included, random noise is not needed**
    - **Measured a_p spectra near Chl=0.2 mg/m³ agree "on average" with the new particle absorption model from Bricaud *et al.***
- **CDOM absorption and particle scattering must rely on "average" IOP models (random variability added)**

Distribution of Total Chlorophyll

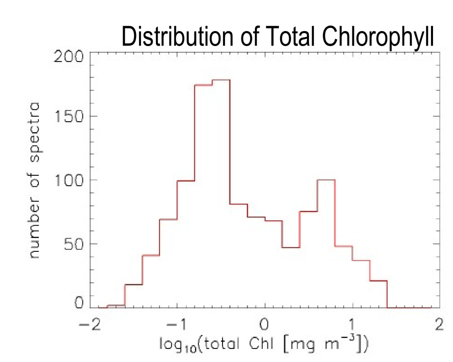
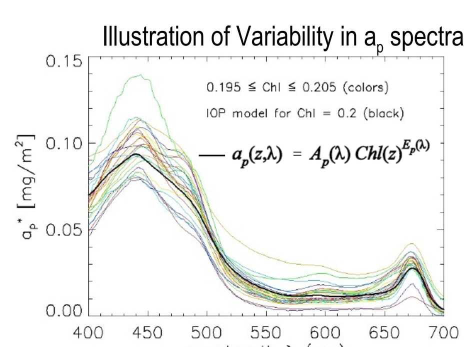
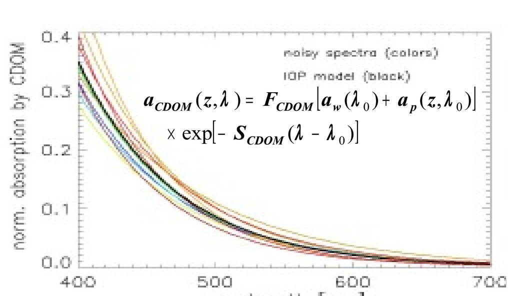


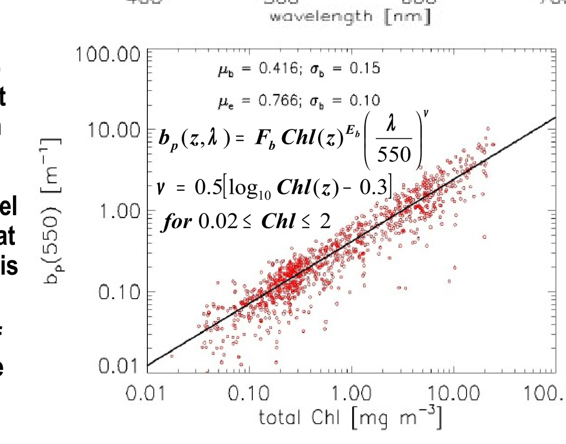
Illustration of Variability in a_p spectra



- **The CDOM absorption and particle scattering predicted from "average" IOP models for a given a_p spectrum & Chl value are uniquely determined**
- **Coefficients of the "average" IOP models have been replaced by normally-distributed random variables that are included to match observations**
- **Use standard model For CDOM absorption, with**
  - **S_{CDOM}, the spectral slope parameter, assumed to have a mean of 0.015 and a std. of 0.002**
  - **With less information about the range of F_{CDOM}, the fraction of total absorption due to CDOM at λ_0, is assumed to be normally distributed with μ_F=0.2 & σ_F=0.02**
- **Use most recent particle scattering model of Morel et. al, (2002), with a wavelength dependence n that depends on Chl for values less than 2mg/m³ and is zero for values above that**
- **Scattering phase function is the weighted sum of small and large-particle phase functions, with the partitioning based on Chl value**

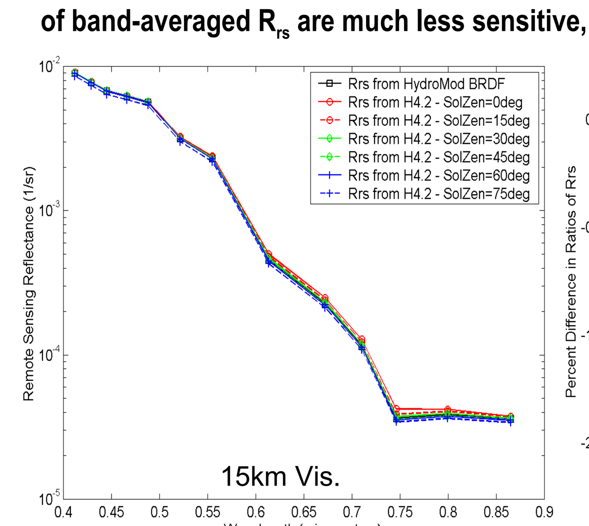
$$\beta_p(\Psi, Chl) = \alpha_s(Chl)\beta_s(\Psi) + [1 - \alpha_s(Chl)]\beta_l(\Psi),$$
$$\text{where } \alpha_s = 0.855[0.5 - 0.25\log_{10} Chl]$$

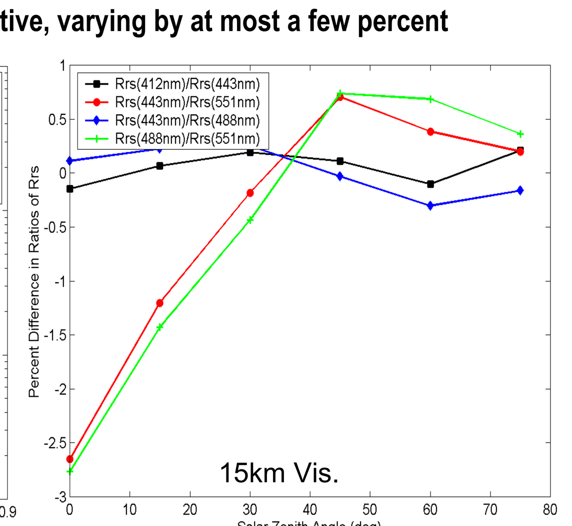




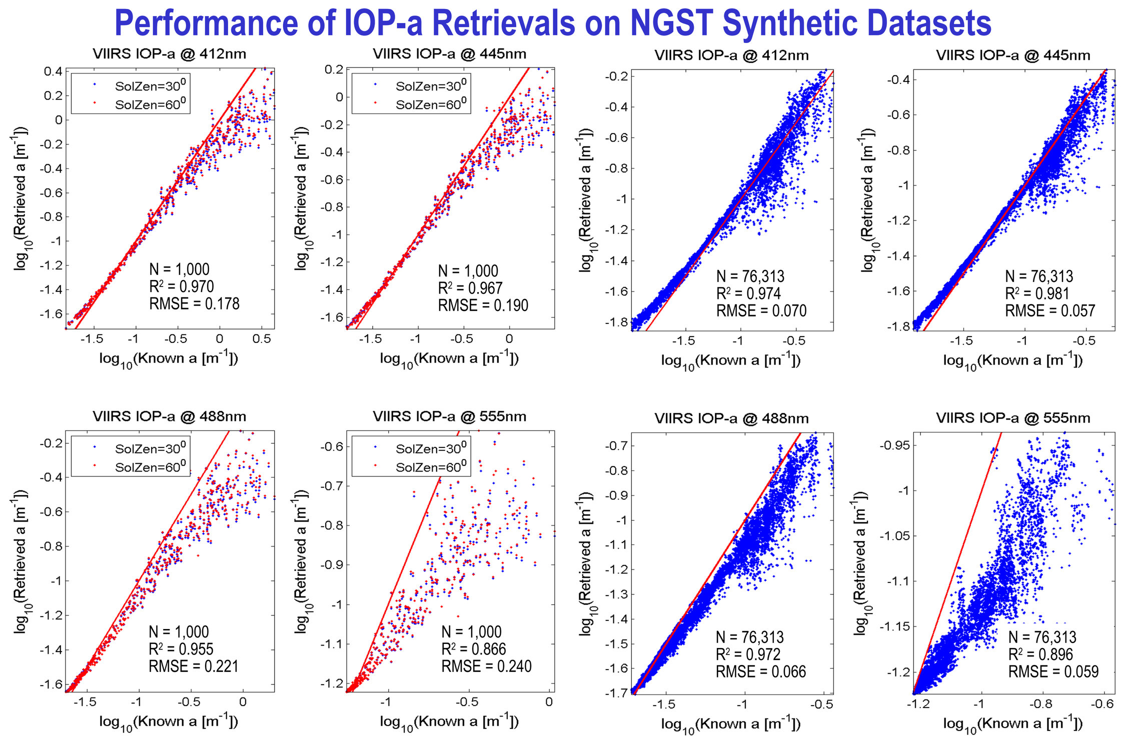
Can Use Water-Leaving BRDF to Assess OCC Performance for Perfect Case

- **R_{rs} is computed from the water-leaving BRDF of H-BRDF by assuming a hemispherical downwelling irradiance distribution at the ocean surface**
- **Variation in R_{rs} can range from 8 to 12% as a function of the solar zenith angle, ratios of band-averaged R_{rs} are much less sensitive, varying by at most a few percent**





Performance of IOP-a Retrievals on NGST Synthetic Datasets



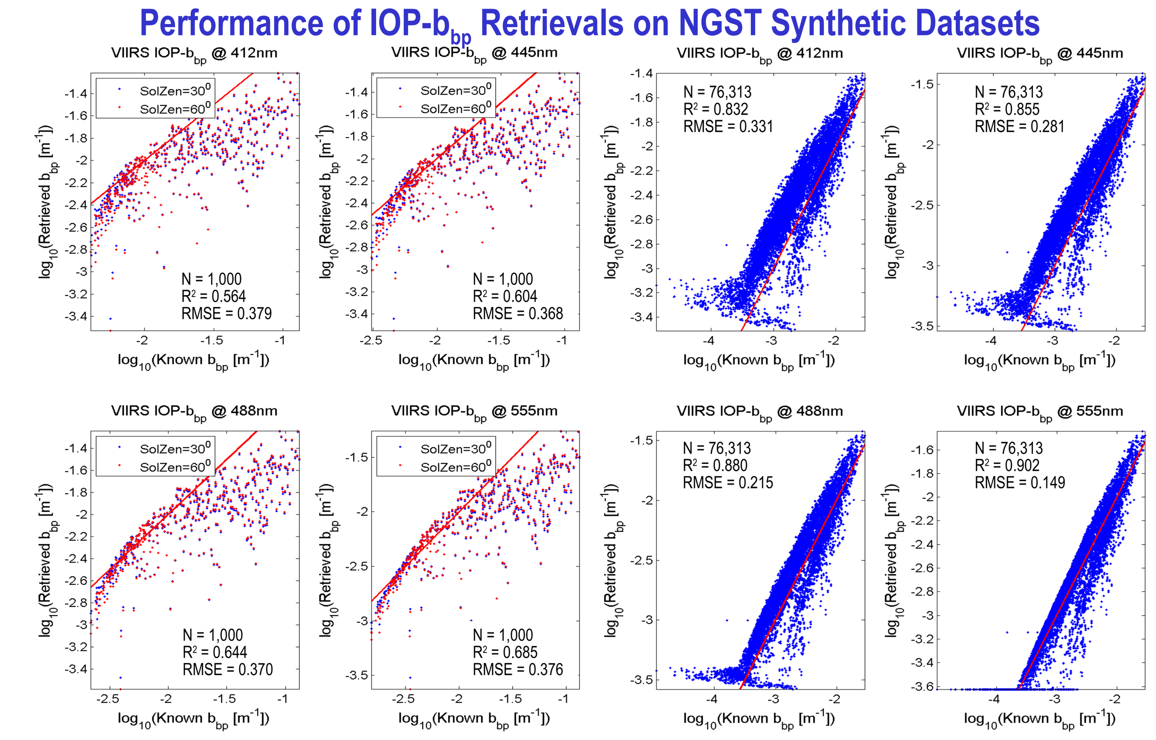
Testing with Synthetic Datasets

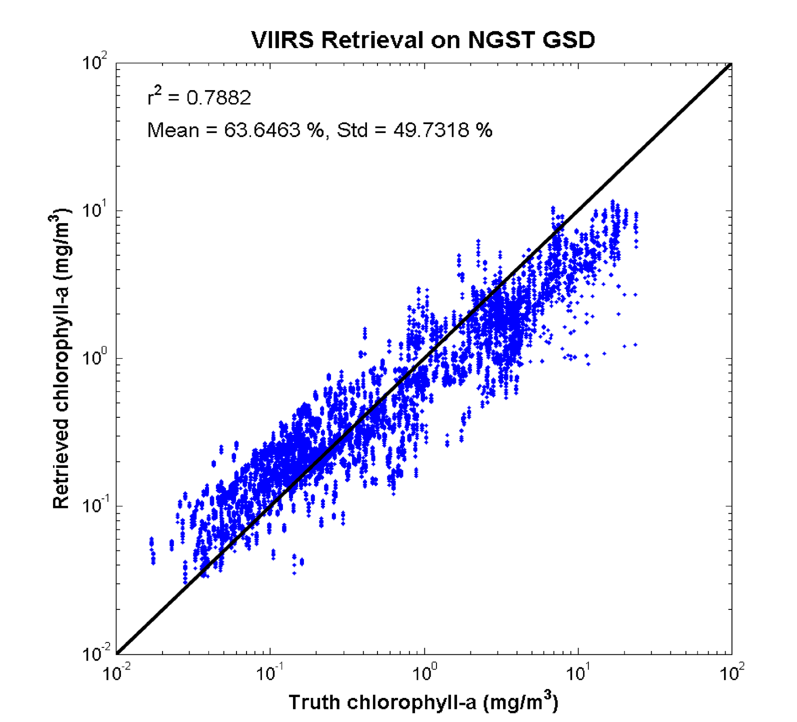
Favorable Performance with the VIIRS Ocean Color Algorithm

- **The IOP-a retrieval performed well on the NGST synthetic dataset, with RMSE < 0.07 and R^2 > 0.95, and nearly the same performance on the IOCCG synthetic data**
- **The IOP-b_{bp} retrieval showed reasonable performance with both synthetic datasets, but performed better on the NGST synthetic dataset with R^2 ranging from 0.8 to 0.9**
- **The chlorophyll retrieval showed a larger bias compared with the two *In Situ* datasets, but a smaller precision error**

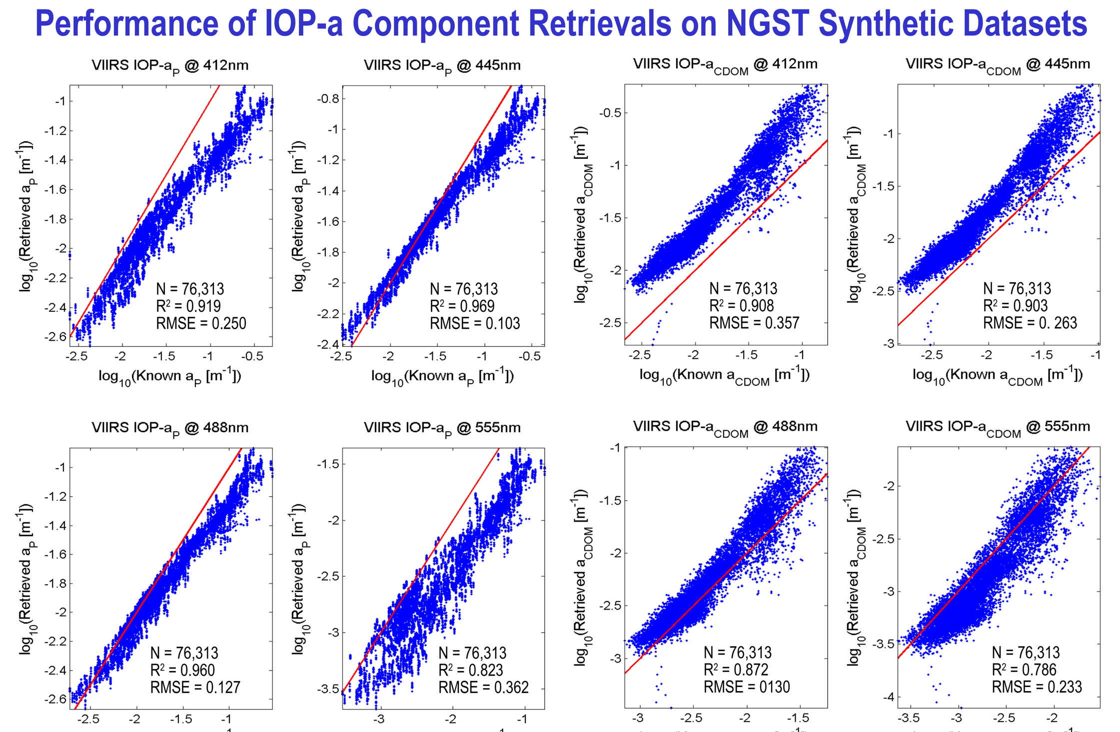
	R^2 Carder-MODIS	RMSE Carder-MODIS	R^2 VIIRS on NGST Synthetic	RMSE VIIRS on NGST Synthetic	R^2 VIIRS on IOCCG Synthetic	RMSE VIIRS on IOCCG Synthetic
a(412)	0.990	0.071	0.974	0.070	0.970	0.178
a(445)	0.993	0.059	0.981	0.057	0.967	0.190
a(488)	0.993	0.065	0.972	0.066	0.955	0.221

Performance of IOP-b_{bp} Retrievals on NGST Synthetic Datasets





Performance of IOP-a Component Retrievals on NGST Synthetic Datasets



Summary of VIIRS Ocean Color Performance

- The performance results obtained with these datasets represent an optimal retrieval of chlorophyll-a and absorption and scattering IOP, since it is based on *in situ* or synthetic remote-sensing reflectance spectra without the added error due to imperfect atmospheric correction or sensor noise and bias, which will obviously make the retrieval error worse.
- From standalone testing of the VIIRS OCC algorithm with both *in situ* and global synthetic datasets, we have found that the algorithm appears to be working correctly and that it achieves performance measures that are comparable to other state-of-science algorithms.
- There appears to be a small slope bias in the retrieval of chlorophyll-a with the current VIIRS OCC algorithm in both synthetic and *in situ* results, while the precision error is consistent with that obtained from heritage sensors like MODIS and SeaWiFS
- The retrieval performance of the absorption IOP, IOP-a, by the OCC algorithm appears to be quite good, equaling or exceeding the performance of most of the state-of-science algorithms reported in IOCCG Report No. 5 [5].
- Retrieval performance for the particle backscattering IOP, IOP-b_{pb}, is still somewhat uncertain. While the performance results on the NGST synthetic dataset appears to be respectable (0.8 < R^2 < 0.9), the performance on the IOCCG synthetic data was only marginal (0.6 < R^2 < 0.7).
- Since there was no *in situ* data available with IOP-b_{pb} truth, it is not clear whether the difference in observed performance is due to the data or a problem with the algorithm.

References

[1] Carder *et al.*, " Semianalytic MODIS algorithms for chlorophyll-a and absorption with bio-optical domains based on nitrate-depletion temperatures", J. Geophys. Res., 104, 5403-5421.

[2] Carder *et al.*, "Performance of the MODIS semi-analytical ocean color algorithm for chlorophyll-a", Adv. in Space Res., 33, 1152-1159, 2004.

[3] Carder *et al.*, MODIS Ocean Science Team Algorithm Theoretical Basis Document, ATBD 19: Case 2 Chlorophyll a, Version 7, 2003.

[4] Mobley, C.D. and L.K. Sundman, Hydrolight 4.3 Users' Guide and Technical Documentation. Sequoia Scientific, Inc., Bellevue, Washington 2005. See also C.D. Mobley, *Light and Water*, Academic Press, 1994.

[5] Mobley, C.D., FINAL REPORT: HydroMod Software Development, Validation, and Simulations, Sequoia Scientific, Inc., Bellevue, WA, 2005.

[6] IOCCG (2006). Remote Sensing of Inherent Optical Properties: Fundamentals, Tests of Algorithms, and Applications. Lee, Z.P. (ed.), Reports of the International Ocean-Colour Coordinating Group, No. 5, IOCCG, Dartmouth, Canada, 2006.