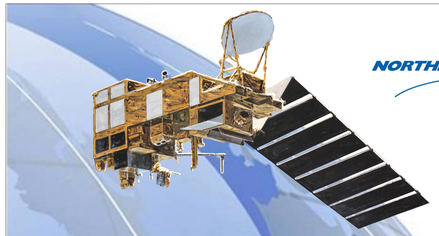
# Validating Ocean Color with Optical Closure using HydroLight-BRDF


## By Patty Pratt (NGAS) & Bruce Hauss (formerly NGAS)

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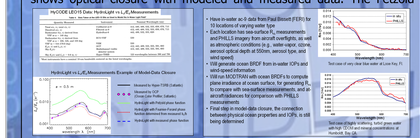
**ABSTRACT:**
HydroLight-BRDF is an extension of the well known application HydroLight created by Dr. Curtis A. Mobley and Sequoia Scientific Inc. This tool is used by Northrop Grumman to create valid models of the ocean using a wide variety of built-in validation data. The product of the application provides a BRDF of the water-leaving radiance which can then be coupled to any atmospheric Radiative Transfer Model to ascertain predicted Top-of-the-atmosphere radiances. Since the BRDF can also be used in conjunction with the surface irradiance, it can be utilized in validating the performance of the retrieval of ocean color for NPP. Using this tool for Optical closure, one can compare results from any two sensors, satellites, airborne and in-situ instruments for validation. This paper describes the processes, benefits and methods used in adapting this simulation tool for product validation.

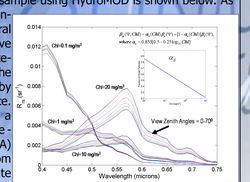

**HISTORY/ TOOL VERIFICATION:**
The HydroMOD tool couples HydroLight (overview above) with an RTM like MODTRAN and was used to generate the Northrop Grumman Aerospace Systems Global Synthetic Database known as (GSD), a part of the EVEREST program. This new simulation tool represented a tremendous leap in the generation of a global test data set by providing better coverage over the open ocean. Previously and commonly there were just over 1000 samples over the open ocean. The HydroMOD tool allows for continuous global coverage and serves as a test set for various satellite sensor systems. The NPP Calibration and Validation (CalVal) team are continuing to implement HydroMOD, which now can be coupled to any RTM; hence simplification of the name to H-BRDF because of the flexibility of the output product. The underlying tool is widely used by scientists worldwide and is now the basis of an integral tool for simulating global data sets. Several studies were done for verification of this tool and sample data are shown above. Each of these is an example of solving an optical closure problem. The first is an example of a comparison with HyCode on an experimental cruise called LEO-15 that shows optical closure with modeled and measured data. The Petzold phase function obviously gives an inaccurate representation of the measured phase data. However the Fournier-Forand phase function shows that the measured data are valid when a different modeled phase function is used. Without the H-BRDF tool, one may not have been able to close this optical comparison. The second comparison is from imagery from PHILLS, an airborne hyperspectral over Humboldt Bay CA and shows agreement. The tool is expected to be useful in ocean color chlorophyll matchups and a sample using HydroMOD is shown below. As the in-situ chlorophyll concentration increases, the spectral signal shifts to the curve peaked near 555nm. Remote-sensing reflectance ($R_{rs}$) is the upwelling radiance divided by the downwelling irradiance. Each of these curves has a different top-of-the-atmosphere radiance (TOA) and the using the BRDF from HydroLight tool can compute the TOA by the coupling of any surface reflectance for any given atmosphere and any viewing .

**HydroLight Overview**
- HydroLight solves the 1-D (depth dependent) unpolarized RTE for oceanic environments
- User-supplied inputs:
  - scattering and absorbing properties of the water body
  - boundary conditions for sea surface and bottom
    - (finite or infinite depth water)
- Outputs:
  - the radiance distribution as a function of depth, direction, and wavelength within an leaving the water body
  - related quantities: irradiances, reflectances, diffuse attenuation functions, etc.
- Widely used (>100 licensed users worldwide) for light calculations related to
  - ocean color remote sensing
  - biological productivity
  - water heating
  - underwater visibility
- Well documented code (Light and Water by Mobley, Academic Press, 1994)
- Software package is a commercial product of Sequoia Scientific, Inc.









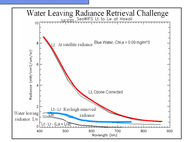

**BACKGROUND/OVERVIEW:**
H-BRDF is an in-house; validated proprietary software developed for NGAS, The primary benefit is the coupling of the in-water optical properties describing the water-leaving radiance with an atmospheric RTM (e.g. 6SV, CORT, or MODTRAN) to then create ocean-atmosphere TOA radiances. The origins of H-BRDF begin with the development of HydroLight a 1-D RTE for water-leaving radiance which has become an industry standard over the past decade. HydroMOD was written to couple the results of specific cases of optical properties to the atmospheric model. An additional version of this was written specifically to incorporate real data to create a simulation of the global oceans. HydroMOD indicates that MODTRAN is being used to generate the final TOA radiance; however, the code has been modified to allow the coupling of any atmospheric RTM.
Since the common output of the tool is a two dimensional data array of the predicted Bidirectional Reflection Distribution Function (BRDF), the code is now referred to by NGAS as HydroLight-BRDF or H-BRDF.
The features of the tool include use of real data and default models for ocean bio-optical properties for missing data, integration tool for RTM's to get Optical Closure, and isolation of errors which can then be filled in with a realistic range of values for the erroneous data.
In addition to the HydroLight 5.0 (developed by Sequoia Scientific Inc.) and subsequent HydroLight developments NGAS plans to develop a specific location to house the data and various tools. This will be called the Biogeochemical Optical Analysis Tool (BOAT). The purpose of the BOAT is to archive real data, climatology, and site characterization. The in-situ data is expected to be produced by the following sites: MOBY, IMOS-Lucinda Jetty Coastal Observatory (LJCO), and BOUSSOLE, though other data and sites will be considered. The BOAT will be capable of housing satellite sub-granules if needed and will have associated tools created in IDL following an HDF5 format for automating ingest and output products.
NSIPS and GRAVITE will support these efforts to a certain extent under the NPP Cal/Val Common Tools task. Ultimately it is expected that the products from H-BRDF and BOAT will allow for testing of performance and anomaly resolution using ASC/NSIPS.

**METHODOLOGY:**
H-BRDF creates a BRDF from the in-water properties, either modeled or measured. When needed, models of various functions that are contained in both HydroLight and H-BRDF can be utilized. These models are well known and used in a broad community of ocean scientists. H-BRDF already contains a set of measured in-water properties for easy implementation of a realistic set of natural variations for determining ranges of unknown properties.
The validation sites such as MOBY, IMOS (ANMN SOCC LJCO and BOUSSOLE) provide near-real time data which is accessible online with some quality controls.
Rrs can be calculated at the surface with measured $E_d$ and compared to the satellite retrieval. In general broad comparisons can be made between any two sensors
*In-situ* measurements can be compared to any satellite for any geometry
For stable atmosphere and water, the window for simultaneous observation is increased; this potentially expands the constraints of the current protocol for collecting Vicarious Calibration data. Both the sensor specifications (e.g. specific band passes) and solar geometries can be eliminated leaving an optimized comparison. H-BRDF coupled with any atmospheric RTM allows for comparisons to be made a various altitudes, from at the surface to airborne sensors to TOA.
Both HydroLight and H-BRDF (HydroLight + atmospheric RTM (i. e. HydroMOD)) can be used to isolate various components. The primary use of these tools allow quality checks for verifying individual components as well as supplying missing data can be computed from actual data providing realistic results allowing utilization of "in complete" cruise data.

**ANALYSIS:**
Data were obtained for in-situ water properties from instruments similar to those on the existing validation sites illustrated below. A BRDF of the surface radiance was produced. The output from this process generates the input for the coupling of the RTM for a chosen atmosphere which yields a Top of the Atmosphere (TOA) radiance across wavelengths (see Figure 1). The RTM used in this case was MODTRAN. The result can then be compared to the actual or predicted TOA result. NGAS has a Global Synthetic Data base that has a distribution of water properties from actual measured water properties which were used to generate the global predictions for VIIRS. Several typical TOA's were generated from the GSD (see Figure 2). The TOA's predicted for the given set of water properties of Figure 1 closely matches the red curve in Figure 2. The next step was to make a new run to compare various atmospheres over the same water properties (see Figure 3). If the atmosphere had anomalous values, the optical closure process would allow the values to be changed for validation purposes without having to collect new data. (Note: Figures 1 and Figure 3 were done with HydroMOD and therefore are computed for a given satellite and solar zenith whereas the BRDF used in the GSD would provide a result valid for multiple viewing angles.) Changes in the water properties can also be made using the H-BRDF tool. Essentially any parameter can be isolated and evaluated individually without the need to discard the good parts of the data. This makes the H-BRDF a robust too, for validation.

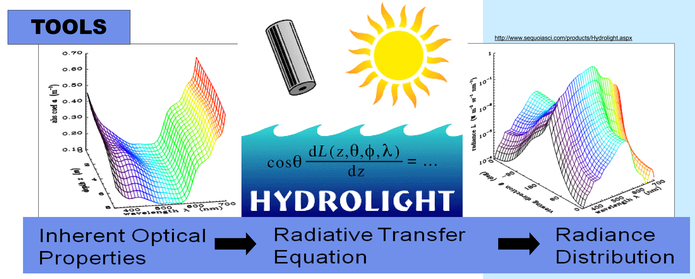
Combined HydroLight (in water) and MODTRAN (atmospheric) code was developed for NGST (now NGAS). This special version of HydroLight computes the BRDF ($\theta',\varphi',\theta,\varphi,\lambda$) for the given water, sea surface, and bottom conditions. The BRDF fully describes the reflectance properties of the ocean; independent of the sky conditions. The ocean BRDF is used as the lower boundary condition in MODTRAN (in the case of HydroMOD) to compute the incident sky radiance. MODTRAN propagates the water-leaving and sea-surface reflected radiances to the sensor. The in water and atmospheric calculations are done separately and are coupled by the ocean BRDF. NPOESS CalVal will use this tool for ocean color validation as shown in this presentation.

## The Goal




**Predict the TOA (red line) from the water –leaving radiance (blue line). The in water properties describe the blue line. When optical closure is achieved, each parameter is validated.**

## TOOLS




**PROCEDURE:**
The measurements are for tropical and mid-latitude Case 1 waters, with a mix of mesotrophic, oligotrophic, and eutrophic water types with the majority of chlorophyll values less than 1mg/m³. Variability in absorption spectra for a given chlorophyll concentration is inherent in this dataset; therefore, no added random noise is needed. Measured $a_p$ spectra near Chl=0.2mg/m³ agree "on average" with the new particle absorption model from Bricaud et al.

**Generating IOP's**
Other parameters such as colored-dissolved-organic matter (CDOM) absorption and particle scattering must rely on "average" IOP models, with random variability added (see Figure 4.). 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" Inherent Optical Properties (IOP) models have been replaced by normally-distributed random variables that have been constrained to match observations using a standard model for CDOM absorption, with $S_{CDOM}$, the spectral slope parameter, assumed to have a mean value of 0.015 and a standard deviation of 0.002. There are a few assumptions made here. There is less information about the range of $F_{CDOM}$, the fraction of total absorption due to CDOM at $l_0$, so it is assumed that it is normally distributed with $m_F$=0.2 & $s_F$=0.02 .
Several scattering models are available. The one used in this process (see Figure 5) was a 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.

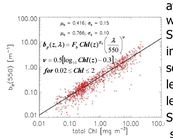



Figure 5 The Backscatter Modeled

**Creating a BRDF**
The combination of the water-leaving and surface-reflected BRDFs provides the total upwelling BRDF supplied to an atmospheric RTM (e.g., MODTRAN) (See Figure 6). The water-leaving BRDF can also be used to provide a reasonable estimate of the remote sensing reflectance (see Figure 7) via the hemispherical-directional reflectance factor (i.e., $R_{rs}(l,q) \sim HDRF(l,q)/p$). While the variation in $R_{rs}$ can range from 8 to 12% as a function of the solar irradiance, ratios of band-averaged $R_{rs}$ are much less sensitive, varying by at most a few percent. HydroLight is an effective tool for IOP analysis and generation of BRDF's.

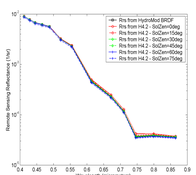



Figure 7 The BRDF is produced and converted to $R_{rs}$

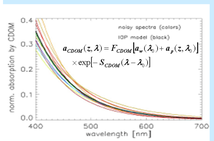



Figure 4 Modeled CDOM with natural variations

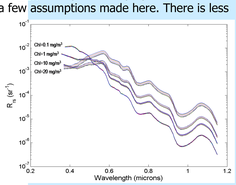



Figure 6

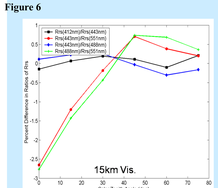



Figure 8 Ratios of $R_{rs}$ show less variation.

## Sample Results

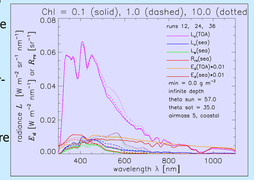



**Figure 1.** Results from a typical HydroLight run and then calculating a TOA from the surface radiance for a given set of water properties.

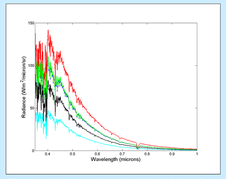



**Figure 2**. TOA results from the NGAS Global Synthetic Database (GSD) for several typical water types whose properties were from in-situ data sets.

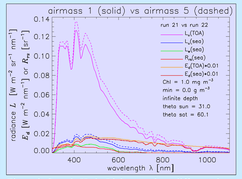
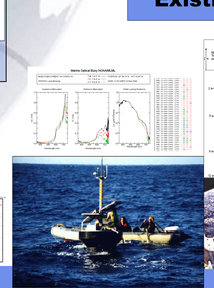



Figure 3. Sample HydroLight run where different airmasses over the same water were used for a comparison. This demonstrates the versatility of the HydroLight suite of tools.

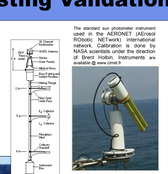
**Listed below are the parameters that are removed for ocean color retrieval**

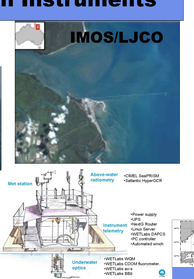
[redacted]

## Existing Validation Instruments

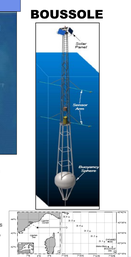


MOBY






BOUSSOLE



**RESULTS/CONCLUSION:**
Ocean Color validation relies on accurate in-situ measurements of water properties. Often instruments that are designed to measure the various parameters have uncertainties greater than what is required for validation. The optical closure process helps ocean color scientists minimize anomalous data, implement strategies for handling new data and establish methods for sorting through the data for the best validation points. In the circumstance where some data are good and other instruments fail, closing an optical loop between data sets can eliminate the biases in the methods. Optical closure also serves as a quality control check. Overall the goal is to house the data in a validation archive BOAT and eventually substantiate the on-orbit performance assessments with quality assurance.
A known set of VIIRS data from the proprietary synthetic model known (GSD) can be utilized for pre-launch verification and demonstration of the end to end match up process as well as validating optical closure methods.
H-BRDF provides the engine that makes this task possible. Coupling the original HydroLight tool with any atmospheric model is the strength of the process. In addition to this extraordinary capability, the output is in the format of a two-dimensional product that supports multiple viewing angles. This eliminates the necessity of re-computing every angle for the same set of water properties.
There are many localized collections of validation data for water parameters (absorption and scattering) and atmospheric properties such as aerosols, humidity, wind and pressure. In addition to standard quality control tools like those developed at NASA's SeaBASS/NOMAD database and similarly IOCCG. Models generated with semi-analytical data can also be used to predict which data are valid. Samples of the generated IOP's and resultant Chlorophylls are compared to historical results with remarkable agreement (see Figures 9&10 right) H-BRDF assures optical closure and verification of the NPP VIIRS ocean color performance.

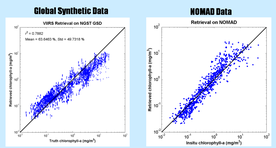



Figure 9 Comparing Synthetic data using HydroMOD

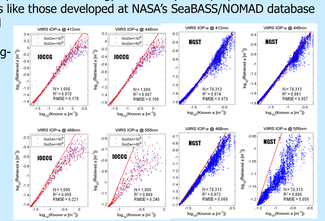



Figure 10 Comparing Synthetic and measured IOP using HydroMOD

## Inputs for Validation:

**HydroLight inputs**
- absorption coef $a(z,\lambda)$ (usually have from ac-9 or spectrophotometer)
- scattering coef $b(z,\lambda)$ (usually have from ac-9)
- scattering phase function $\beta(z,\lambda,\psi)$ (almost never measured, but may have backscatter fraction $\tilde{B} = b_b/b$ from $b_b$ (HydroScat or EcoVSF) and b (ac-9)
- Boundary conditions: sea state (wind speed), sun location and sky conditions (usually model), bottom reflectance (in shallow water)

**HydroLight outputs**
- radiometric variables (radiances and irradiances, usually measure $L_u(z,\lambda)$ and $E_d(z,\lambda)$ at a minimum
- Apparent optical properties ($K_d$, $R$, $R_{rs}$ etc obtained from radiometric measurements). The most common for remote sensing is remote sensing reflectance $R_{rs}$ (often measure $E_d$(air) and $L_u(z)$ and extrapolate upward from underwater $L_u$ , or estimate $R_{rs}$ using above-surface techniques)