# Obtaining Remote-Sensing Reflectance from Multiple Instrument Systems

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## Abstract

Obtaining accurate *in situ* measurements of Apparent Optical Properties (AOPs) is critical to maintaining satellite data quality. One approach to ensure accuracy is to deploy several independent instruments to measure the same phenomenon. During a cruise in June 2012, off the lee coast of the island of Hawaii, repeated profiles were made with two separate radiometric systems, one from Satlantic, Inc. (Hyperpro) and the other from Biospherical Instruments, Inc. (C-Ops). The C-Ops is multi-spectral, while the Hyperpro is hyperspectral. Both measure above-water solar irradiance ($E_s$), downwelling in-water irradiance ($E_d$), and upwelling in-water radiance ($L_u$). From these measurements remotely-sensed reflectance ($R_{rs}$) can be calculated and compared with satellite data. All instruments were calibrated shortly before use, and while differences are to be expected due to temporal changes and spectral weighting differences, these should be consistent and minimal. We explore these differences, and compare to data retrieved from the NASA Moderate Resolution Imaging Spectroradiometer onboard Aqua (MODIS Aqua) when available. We also examine data collection and processing protocols for these systems.

## Introduction

Obtaining accurate *in situ* measurements of Apparent Optical Properties (AOPs) is critical to evaluating and maintaining ocean color satellite data quality. One approach to ensure accuracy in the field measurements is to simultaneously deploy (and subsequently compare) several independent instruments to measure the same phenomenon. The NASA's Ocean Biology Processing Group (OBPG) Field Support Group at Goddard Space Flight Center is fortunate to have profilers from two different manufacturers (Satlantic, Inc. and Biospherical Instruments, Inc.), and during a recent cruise had an opportunity to use both of them consecutively.

The manufacturers have chosen differing technologies to obtain similar measurements. The most obvious is the choice of hyperspectral versus multispectral wavelength resolution. The Hyperpro uses a spectrometer to provide calibrated data at from 350 to 800 nm at approximately 4 nm resolution, while the C-Ops uses a micro-radiometer array to provide data at eighteen wavelengths, specifically 305, 320, 340, 380, 395, 412, 443, 465, 490, 510, 532, 555, 565, 625, 665, 683, 710, and 780 nm. Another difference is the shape of the profilers. While Satlantic's Hyperpro has a weighted nose and ballasted wings (Figure 1), the Biospherical Compact Optical Profiling System (C-Ops) has a kite shape (Figure 2), with adjustable weights and ballast. In both systems, the measurement of dark counts is required to subtract electronic noise, and these dark counts are obtained differently by the two manufacturers. Satlantic uses a shutter to automatically obtain dark counts throughout the profile, while Biospherical requires the user to obtain the dark counts before the cast by capping the detectors and running the system's dark count acquisition software, which steps through the three gain stages and tares the depth sensor while on deck.

## Approach

Data were collected during a short cruise off the coast of Hawaii in June, 2012. Both instruments were calibrated at their manufacturers' calibration facilities using NIST-traceable lamps. The profilers were most often deployed consecutively, generally within one hour of each other. However, on one occasion other ship operations were conducted in between the casts, and almost three hours elapsed between the two profiles.

The ship was positioned such that the sun was on the stern, and the profilers were allowed sufficient cable to place them approximately 20 meters behind the ship, out of its shadow, before beginning the profiles. The multi-cast method was used, wherein the profiler is allowed to free-fall once to the end of the cable, and then three times within the upper 20 meters. These four casts are treated as one in order to increase the data density at the surface, where fluctuations primarily due to wave focusing can be problematic (Zibordi *et al*, 2004).

The Satlantic files were processed to level 2s using Satlantic's Prosoft 8.1 software (http://satlantic.com/prosoft), which applies calibration coefficients and dark offsets, merges the underwater radiometers by distance to surface, and then merges these to the reference radiometer by time. Prosoft also eliminates data collected when the profiler tilt was >= 5° from vertical or its velocity was < 0.1 m/s. Matlab files were created from the output of Prosoft, and were further processed using Matlab scripts to join the individual multi-cast files, eliminate negative data, and save to ASCII text files that comply with the format requirements of the NASA SeaWiFS Bio-optical Archive and Storage System (SeaBASS; http://seabass.gsfc.nasa.gov).

The Biospherical output files also have the dark offsets and calibration coefficients applied. These files were then processed using Matlab scripts to apply depth offsets and eliminate data collected when the profiler tilt was >= 5° from vertical or the velocity was < 0.1 m/s, and SeaBASS files were then written.

From the SeaBASS files from both systems, diffuse attenuation coefficients for downwelling irradiance and upwelling irradiance were derived and used to extrapolate $L_u$ to the surface where further calculations account for crossing the water-air boundary. Upwelled radiances were then normalized by $E_s$ from either an above-water sensor or underwater measurements propagated to the surface (Mueller, 2003). Additionally, a BRDF correction was applied to the calculated $R_{rs}$ (Bailey and Werdell, 2006).

## Results

Both profiling systems worked well in the conditions encountered on this cruise. The C-Ops required some adjustment to the weights and ballast to get the tilt and pitch correct, but it was not unduly difficult. The Hyperpro required no adjustments on this cruise, although there have been other occasions where an additional weight is necessary to sink at the desired velocity (0.1 to 0.3 m/s is ideal (Zibordi, *et al*, 2004)).

Agreement in $R_{rs}$ between the two systems was good, well within 10% except on June 3, when it was noted that the sky conditions were changing as we deployed, with more clouds overhead while the Hyperpro was profiling (figure 3). This resulted in lower $R_{rs}$ on this occasion relative to the C-Ops. Looking at the individual spectra (Figure 3), and the combined data (Figure 4), there is a negative bias to the C-Ops data at 510 nm, while at other wavelengths the distribution is close to random about the 1:1 line. The source of this bias at 510 nm is currently unexplained, as it is not apparent in the $L_w$ or the $E_s$ data (Figures 5 and 6).

It should also be noted that the agreement in $R_{rs}$ (Figure 4) is much better than the agreement of either $L_w$ or $E_s$ (Figures 5 and 6). This indicates either that the sky conditions were different when the two sensors were deployed, or that there are consistent biases in the instrument systems that become negligible when evaluating ratios, like $R_{rs}$.

To compare any *in situ* data with satellite measurements, we had to relax the suggested exclusion criteria defined by Bailey and Werdell (2006). Specifically, our single satellite-to-*in situ* matchup on June 4 had only 20% of the 5x5 satellite pixel box filled with data rather than the suggested 50%. This was also the day that other ship operations took place between the Hyperpro and C-Ops casts, which separated them by almost 3 hours. Nevertheless, the remote-sensing reflectance measurements of the *in situ* instruments match well, while the satellite data are 17.9, 18.5, 14.7, 23.5, and 23.5% higher than the C-Ops at 412, 443, 488, 531, and 547 nm, respectively. In the red wavelengths, the absolute values are so low that percentage difference becomes meaningless (Figure 3).

## Conclusions

We have shown that good agreement *in situ* $R_{rs}$ is obtainable using commercial, off-the-shelf instruments and standard acquisition and processing procedures. These data can be useful for vicarious calibration of satellite data. With only one matchup, and an unfortunately poor one at that, it is difficult to reach any conclusion regarding the comparison of MODIS Aqua and *in situ* $R_{rs}$ collected on this cruise.

To improve future instrument system comparisons, the following suggestions are given: 1) Inter-calibration before and after deployment using the same lamp and calibration facility to take into account any small changes in sensor response. 2) Timing the profiles such that temporal changes in environmental conditions are lessened. Ideally, the two instrument systems would be deployed at the same time. In practice, personnel limitations and ship's safety concerns do not often allow this. 3) Using the same parameters and software to process data. As much as possible, this imperative was implemented on these data; after preliminary processing with proprietary software, the same software was used to produce secondary data products. 4) Increase the length of cruises. Longer cruises increase the likelihood of satellite matchups. This, like item (2), is easier to suggest than to implement. 5) Hyperspectral data could be interpolated to better match the filter response of the multispectral *in situ* or satellite data. This was not done in the current study – a nearest-neighbor approach was used instead.

## Acknowledgements

We appreciate Allison Sweeney's invitation for our group to participate in this cruise. We also thank the captain and crew of the R/V Kilo Moana for their assistance and support.

## References

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**Table 1:** Time (Hawaii, GMT – 10), location, and conditions for casts.

| Day | BSI time | Satl time | Latitude | Longitude | Percent Clouds | Wind Speed (m/s) | Notes |
|---|---|---|---|---|---|---|---|
| 6/2 | 13:05 | 14:42 | 19.427 | -156.313 | 50 | 4 | Station near Hawaii |
| 6/3 | 13:09 | 14:15 | 19.557 | -156.313 | 40 | 3.5 | Clearer sky for BSI. |
| 6/4 | 13:17 | 10:46 | 19.470 | -156.355 | 20 | 4.5 | Clouds on horizon, clear overhead. Aqua matchup |
| 6/6 | 13:08 | 12:26 | 19.432 | -156.333 | 80 | 2.5 | Thick overcast, sun in and out. |
| 6/8 | 14:03 | 15:11 | 20.654 | -157.343 | 30 | 5.5 | Clouds on horizon, clear overhead. Station near Lanai |

**Figure 1:** The author (left) preparing to launch the Satlantic Hyperpro aboard the R/V Kilo Moana.

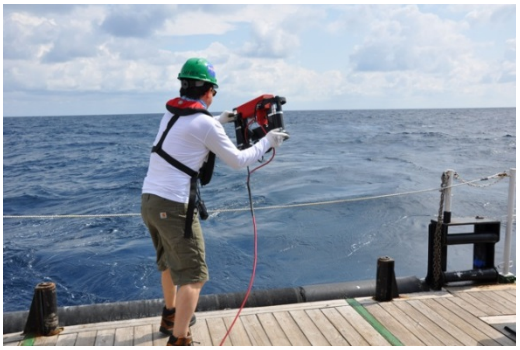

**Figure 2:** Dr. Joaquin Chaves deploying the Biospherical C-Ops.

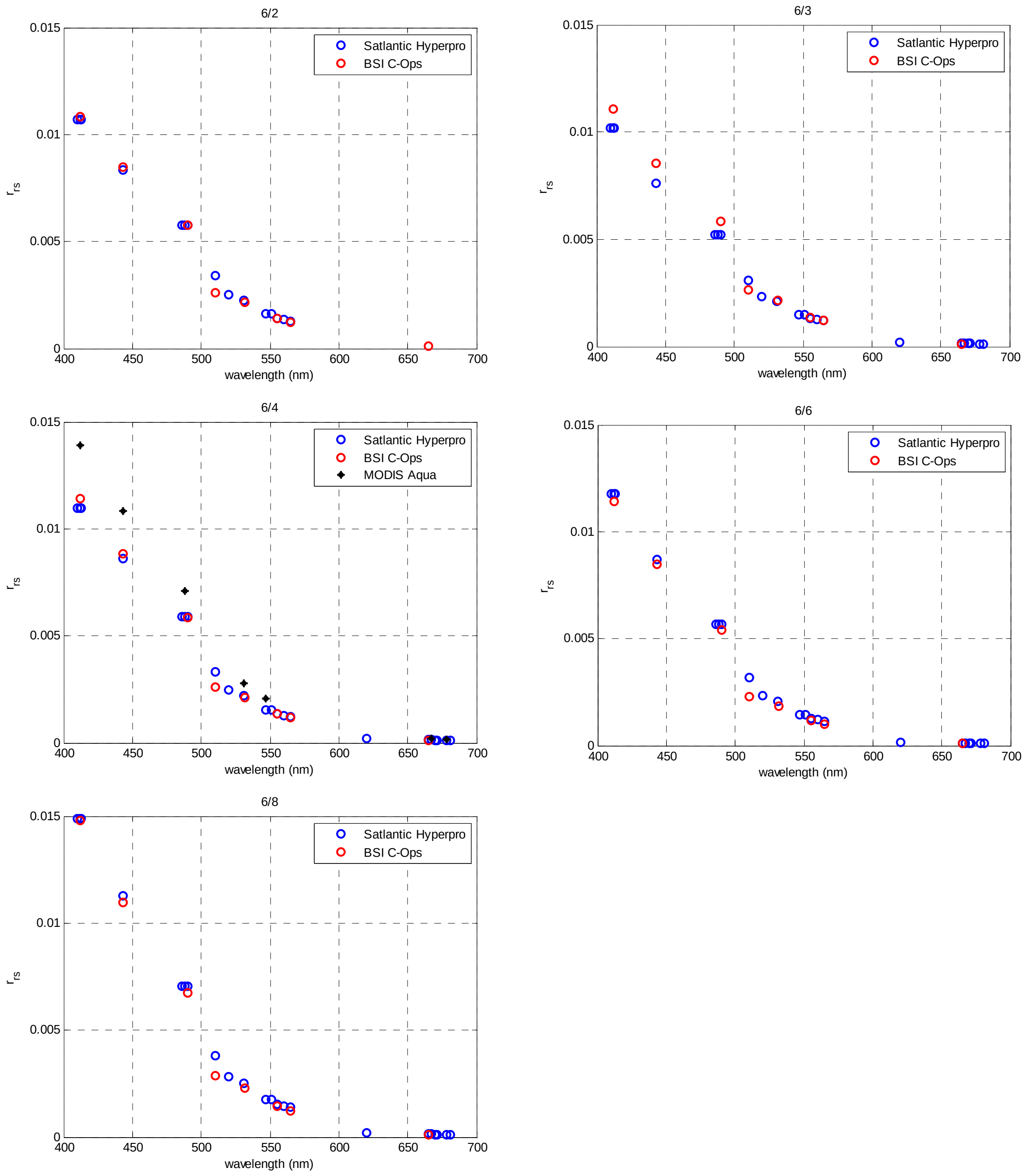

**Figure 3**: *Rrs* spectra from each of the Biospherical/Satlantic matchups, with MODIS Aqua data presented on the 6/4 panel.

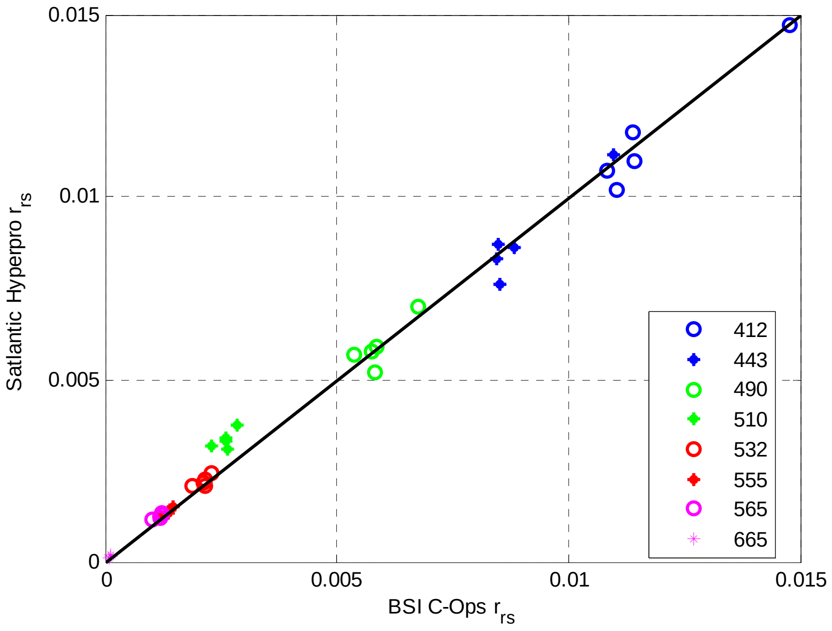

**Figure 4:** One-to-one plot of all *Rrs* matchups. Hyperspectral Satlantic wavelengths have been matched to multispectral BSI wavelengths.

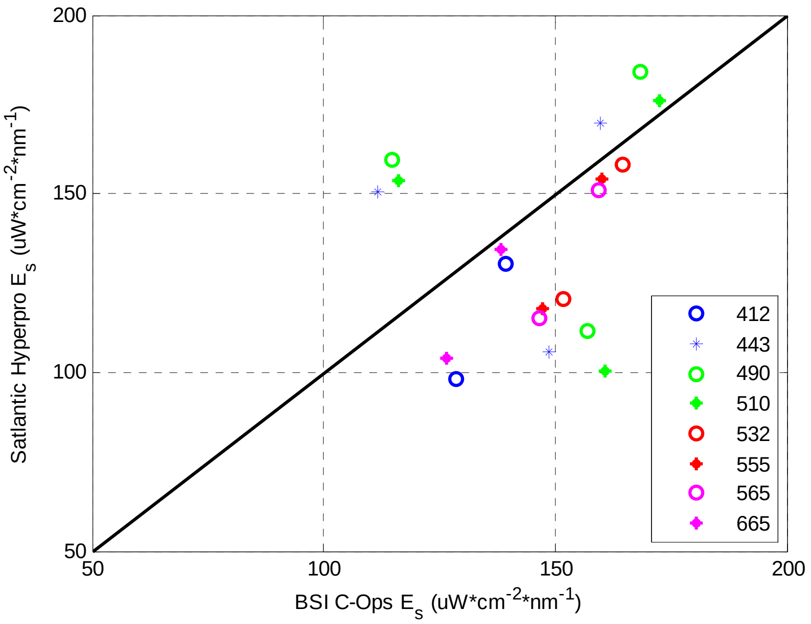

**Figure 5:** One-to-one plot of all $E_s$ matchups. Hyperspectral Satlantic wavelengths have been matched to multispectral BSI wavelengths.

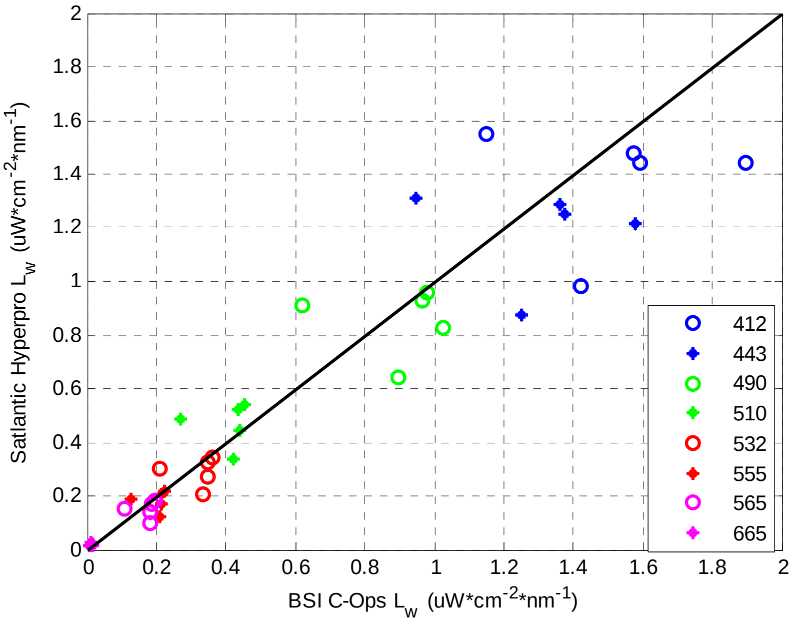

**Figure 6:** One-to-one plot of all *L$_w$* data. Hyperspectral Satlantic wavelengths have been matched to multispectral BSI wavelengths.