Stray Light Characterization for MOBY

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MOBY & MOS

MOS--
Dichroic beamsplitter and two single grating CCD spectrographs;
High resolution (<1 nm);
Wide coverage (345 to 955 nm);
Robust calibration procedures;
Profiler and buoy operation.

MOBY--
Fiber optic coupling to MOS;
Time series since 1996;
SeaWiFS and MODIS overpasses;
Band-averaged Lw’s reported;
Satellite gain coefficients.
MOBY Calibration Procedures

Science requirements: 5% nLw

MOBY is currently 4% to 8%; achieved using rigorous, multi-step approach

Features:

Pre- and Post Calibrations

E and L sources NIST-traceable

Sources recalibrated every 50 h

Sources verified during use with SLMs (NIST-designed radiometers)

Daily scans of three internal sources (blue and red LED; lamp)

Monthly measurements with stable, diver-deployed lamps
“Stray Light” in Filter Radiometers

Relative spectral responsivity, $\rho(\lambda_0, \lambda)$
Separate function for each channel (band)
Describes response to flux at $\lambda \neq \lambda_0$

Measurement Equation

$$S(\lambda_0) = R(\lambda_0) \int \rho(\lambda_0, \lambda) L(\lambda) d\lambda$$

Common Simplification

$$S(\lambda_0) = R(\lambda_0) L(\lambda_0) \delta \lambda$$

$S = $ Measured signal
$R = $ System response
$L = $ Spectral radiance
$\delta \lambda = $ Bandwidth of channel
$\lambda_0 = $ Wavelength of channel
$\lambda = $ Wavelength of flux
Result of (Over)Simplification

The ratio of the signals is not proportional to the ratio of the spectral radiances at $\lambda_0$ because the out-of-band contribution is different.

It depends on $L(\lambda)$!

For this example, FR 1 would be incorrect by about 5.7%; FR 2 by about 0.8%.
Marine Optical System (MOS)
Spectrographs & Monochromators

The image appearance in monochromatic light depends on instrument parameters and other effects (the example is not well focused).

Signal = In-band + Out-of-Band

Haze and diffuse scatter contribute to the specular flux. For a grating, this compromises the desired optical interference effect.
Filter Radiometer Measurement Equation

\( \rho(\lambda_0, \lambda) \) and \( L_c(\lambda) \) are known. Thus \( R(\lambda_0) \) and the fraction of signal from the out-of-band (“stray light”) can be determined.

\[
R(\lambda_0) = \frac{S_c(\lambda_0)}{\int \rho(\lambda_0, \lambda) L_c(\lambda) \, d\lambda}
\]

The correct \( L_u(\lambda) \) solves the equation

\[
S_u(\lambda_0) = R(\lambda_0) \int \rho(\lambda_0, \lambda) L_u(\lambda) \, d\lambda
\]

Note this requires knowledge of \( L_u(\lambda) \) at all wavelengths—a) additional channels and deconvolution or b) delta-function for \( \rho(\lambda_0, \lambda) \).

In MOS, the equivalent of \( R(\lambda_0) \rho(\lambda_0, \lambda) \) is not known, but we have lots of (1024) channels.
Spectrograph Measurement Equation

\[ S(\lambda_i) = \int R(\lambda) z(\lambda_i - \lambda) L(\lambda) d\lambda = R(\lambda_i) L(\lambda_i) \delta \lambda + \sum R(\lambda) z(\lambda_i - \lambda) L(\lambda) \Delta \lambda \]

= In band + Out of band

\( z(\lambda_i - \lambda) \) is the slit scatter function.

We use an iterative solution to find the system response, followed by an iterative solution for the in-water measurements.

First, we must characterize the optical systems (MOS and MOBY).
Experimental

<table>
<thead>
<tr>
<th>Tunable Lasers</th>
<th>Tuning Range [nm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ti:Sapphire</td>
<td>690 to 900</td>
</tr>
<tr>
<td></td>
<td>380 to 430</td>
</tr>
<tr>
<td>Dye Laser</td>
<td>580 to 600</td>
</tr>
<tr>
<td></td>
<td>610 to 690</td>
</tr>
<tr>
<td>Discrete Lasers</td>
<td>Wavelengths [nm]</td>
</tr>
<tr>
<td>HeNe’s</td>
<td>543, 594, 612, 633</td>
</tr>
<tr>
<td>Ar-Ion</td>
<td>458, 488, 514</td>
</tr>
<tr>
<td>Diode Lasers</td>
<td>412, 440, 645, 660, 675, 690</td>
</tr>
</tbody>
</table>
Characterization using Tunable Lasers

Laser-illuminated integrating sphere:
←←→Result at single wavelength

This source is:
Monochromatic (width << $\delta\lambda$);
Uniform, stable, and bright;
Radiance is measured (trap detector).

Fine Scans

The laser wavelength is varied by up to 10 nm in steps of about 0.1 nm (60 to 100 measurements). One column will be near the center of this scan.

Gives $\delta\lambda$ and a fit to an analytical function for $z(\lambda_i - \lambda)$
Reflection Peaks

Interreflection of 2\textsuperscript{nd} order causes secondary image (MOS is designed to operate in 1\textsuperscript{st} order).
Effect on System Response

Corrected and Uncorrected System Response

Ratio
Colored Source (CS) for Validation

Filtered Sphere Source

$L(\lambda)$ from measurements with double grating monochromator;

MOBY/MOS measurements of the CS serve as test Lu data sets;

Different glass filters to correspond to Case I or Case II waters; interference filters to test modeling of the reflection peaks.
Result for MOBY215
SeaWiFS Match-Ups

![Graph showing SeaWiFS data match-ups with different wavelengths (412 nm, 443 nm, 490 nm, 510 nm, 555 nm, 670 nm) over sequential days. The graph displays the ratio of radiance corrected/uncorrected data over the years 1997 to 2001.](image)
Summary

Correction of 6.8% to –3.0% for SeaWiFS bands

Improved accuracy of MOBY-derived satellite calibration coefficients

Same set of stray light correction parameters (from MOBY217) “works” with all MOBY/MOS205—can go backwards and forwards

Analysis of MOBY/MOS204 and MOS202 (profiler in MOCE cruises) is underway

Thanks to:

MODIS, SeaWiFS, SIMBIOS, NOAA, NIST, CCG