Hyperspectral radiometric device for accurate measurements of water leaving radiance from autonomous platforms for satellite vicarious calibrations (aka HYPERNAV)

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Goals

• Next-generation hyperspectral radiometric sensors for calibration/validation.
• Utilize autonomous floats as a platform to collect hyperspectral radiometric to minimize uncertainty.
• Develop an end-to-end system/strategy for new ocean-color satellite calibration – including float deployment, radiometric data quality assurance, data delivery and satellite inter-comparison.

HyperNav autonomous float system advantages

• Risk reduction approach to the vicarious calibration program for PACE and other missions.
• Deployment floats at the start of a satellite mission - Rapid characterization of in flight satellite radiometer.
• Provide radiometric measurements across a broader range of solar angles and geographic regions, to assess the satellite dependencies on out-of-band response, BDRF, etc.
• Augments other moored cal/val sites throughout satellite lifetimes, enables rapid collection of vicarious calibration data.
HyperNav Summary

- Free-fall radiometric profiling device – dual hyperspectral upwelling radiance.
- Extends capabilities of existing HyperPro product.
- 350nm – 900nm, ~2nm spectral resolution.
- Ability to resolve Fraunhofer lines.

HyperNav system - Navis float, Hyperspectral Lu x2

- CTD, optics, tilt, roll, pitch, telemetry.
- Precise pressure sensors for accurate radiance determinations.
- Ability to measure upwelling radiance to just below the sea surface (~10-20cm).
- Park at depth to minimize fouling.

HyperPro Freefall Profiler

Self shading Modeling results

Surface spectra for Lu sensors

Upcoming schedule 2017
Data Delivery/Management System implementation
Radiometric Characterizations at NIST
Field Deployments
Final report and recommendations (Sept. 2017)

<table>
<thead>
<tr>
<th>Wavelength [nm]</th>
<th>0.1</th>
<th>0.5</th>
<th>1</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>412</td>
<td>0.9965</td>
<td>0.9916</td>
<td>0.9876</td>
<td>0.9691</td>
</tr>
<tr>
<td>490</td>
<td>0.9969</td>
<td>0.9934</td>
<td>0.9908</td>
<td>0.9798</td>
</tr>
<tr>
<td>555</td>
<td>0.9942</td>
<td>0.9918</td>
<td>0.9901</td>
<td>0.9795</td>
</tr>
</tbody>
</table>

Sensor depth = 11.6 cm

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## Requirements Matrix

<table>
<thead>
<tr>
<th>REQUIREMENT</th>
<th>CAPABILITY</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spectral Range 350-900 nm</td>
<td>350 to &gt;900 nm</td>
</tr>
<tr>
<td>Resolution &lt; 3 nm</td>
<td>&lt;=2.2nm (350-800nm), &lt;=2.35nm (800-900nm)</td>
</tr>
<tr>
<td>Radiometric Uncertainty &lt; 4% in blue-green</td>
<td>&lt; 4% in the blue-green. TBD for red. Uncertainty due to extrapolation from L(z) to L(0).</td>
</tr>
<tr>
<td>Radiometric Stability O(1%) per Deployment</td>
<td>System will park at 1000 m depth, inhibiting biofouling.</td>
</tr>
<tr>
<td>Autonomous Field Operation</td>
<td>Excellent history of long-term float deployment. Float scheduling can be updated after deployment.</td>
</tr>
<tr>
<td>Fully Lab and Field Characterized</td>
<td>Radiometers will be fully characterized (stray light, temp, linearity, etc) Calibrated with NIST-calibrated lamps.</td>
</tr>
<tr>
<td>Fully Autonomous Data Delivery to Enable the NASA Mission Science.</td>
<td>A full end-to-end system with automated Prosoft processing scripts.</td>
</tr>
</tbody>
</table>
Design of Radiometric System

1. Dual heads -> sun-side radiometer & intercomparison.
3. Right-angle design -> near surface.
4. Reduced errors in extrapolation to Lu(0-).
5. Tilt sensors for alignment and to monitor position.
7. Depolarizer to remove uncertainty in the fore optics.
8. 2.3 nm nominal resolution, 350-900 nm

Supercomputer simulations of shading vs zenith, azimuth, depth, wavelength, chl-a using SimulO software by Edouard Leymarie (LOV)
Radiometric Field Test

TSRB Mode, Oct 7 2016, 11:30 AM local

HyperPro extrapolation to Lu(0-) uses spectral k estimation (Austin Petzold 1981 & Morel 2001)
HYPERNAV System Overview

<table>
<thead>
<tr>
<th>SENSOR</th>
<th>LOCATION</th>
<th>PURPOSE</th>
</tr>
</thead>
<tbody>
<tr>
<td>OCR-504</td>
<td>Top of Navis mast</td>
<td>(380nm, 490nm, 590nm, PAR) Validation, sky conditions</td>
</tr>
<tr>
<td>MCOMS</td>
<td>Base of radiometer</td>
<td>(Chl, 700 BB, FDOM) Data validation</td>
</tr>
<tr>
<td>Pressure</td>
<td>Base of radiometer</td>
<td>High accuracy &amp; resolution depth for surface extrapolations</td>
</tr>
<tr>
<td>Temperature and Salinity</td>
<td>Top of Navis mast</td>
<td>For use with pressure for depth calculation</td>
</tr>
<tr>
<td>Tilt/Compass</td>
<td>Radiometer body</td>
<td>Quality control, orientation to the sun</td>
</tr>
<tr>
<td>Tilt</td>
<td>Radiometer heads</td>
<td>Head alignment and monitoring</td>
</tr>
</tbody>
</table>

Key Aspects:
• Dual independent radiometers – relative drift
• Lu very close to surface
• Hyperspectral
• Improved pressure accuracy
• Minimization of self shading
• Ability to extend at surface acquisition time
• Tilt data utilization for power saving

Courtesy of LOV, E. Leymarie
# Uncertainties Matrix

<table>
<thead>
<tr>
<th>SOURCE</th>
<th>TARGET @412nm</th>
<th>TARGET @443nm</th>
<th>TARGET @500nm</th>
<th>TARGET @550nm</th>
<th>TARGET @665nm</th>
<th>METHOD OF VALIDATION</th>
<th>MITIGATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calibration</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Irradiance standard</td>
<td>1.04</td>
<td>0.94</td>
<td>0.84</td>
<td>0.78</td>
<td>0.68</td>
<td>Provided by NIST</td>
<td>Use NIST calibrated lamp</td>
</tr>
<tr>
<td>Reflectance target</td>
<td>1.8</td>
<td>1.8</td>
<td>1.8</td>
<td>1.8</td>
<td>1.8</td>
<td>Provided by manufacturer</td>
<td>Use corrections for 0-45deg</td>
</tr>
<tr>
<td>Reproducibility</td>
<td>1.6</td>
<td>1.6</td>
<td>1.6</td>
<td>1.6</td>
<td>1.5</td>
<td>Repeated calibrations</td>
<td>Careful lab procedures</td>
</tr>
<tr>
<td>Instrument</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Immersion factor</td>
<td>0.3</td>
<td>0.3</td>
<td>0.3</td>
<td>0.3</td>
<td>0.3</td>
<td>Theory and experiment</td>
<td>Careful lab procedures</td>
</tr>
<tr>
<td>Linearity</td>
<td>0.3</td>
<td>0.3</td>
<td>0.3</td>
<td>0.3</td>
<td>0.3</td>
<td>NIST beam conjoiner</td>
<td>Characterize and correct</td>
</tr>
<tr>
<td>Stray light</td>
<td>0.10</td>
<td>0.09</td>
<td>0.06</td>
<td>0.04</td>
<td>0.09</td>
<td>NIST laser scanning</td>
<td>Characterize and correct</td>
</tr>
<tr>
<td>Thermal effects</td>
<td>0.01</td>
<td>0.00</td>
<td>0.01</td>
<td>0.02</td>
<td>0.07</td>
<td>At cal station over 4-30°C</td>
<td>Characterize and correct</td>
</tr>
<tr>
<td>Polarization effects</td>
<td>0.5</td>
<td>0.4</td>
<td>0.1</td>
<td>0.1</td>
<td>0.5</td>
<td>Int. sphere and polarizer</td>
<td>Depolarizer</td>
</tr>
<tr>
<td>Wavelength accuracy</td>
<td>0.4</td>
<td>0.4</td>
<td>0.4</td>
<td>0.4</td>
<td>0.4</td>
<td>Provided by mfr., verified w/ Fraunhofer lines</td>
<td>Quality control on spectrometers</td>
</tr>
<tr>
<td>Field</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wave focusing</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
<td>Field measurements</td>
<td>High frame rate at surface</td>
</tr>
<tr>
<td>Self-shading</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>Monte Carlo</td>
<td>Model corrections</td>
</tr>
<tr>
<td>Tilt effects</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>Tilt sensors in heads</td>
<td>Only send data w/ good tilts</td>
</tr>
<tr>
<td>Surface extrapolation</td>
<td>0.65</td>
<td>0.65</td>
<td>0.65</td>
<td>1.13</td>
<td>4.84</td>
<td>Modelling</td>
<td>High accuracy pressure</td>
</tr>
<tr>
<td>Biofouling (6 mnths)</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>Retrieval of floats, post cal</td>
<td>Park in aphotic zone</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>3.1</strong></td>
<td><strong>3.1</strong></td>
<td><strong>3.0</strong></td>
<td><strong>3.1</strong></td>
<td><strong>5.6</strong></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- **Measured**
- **Rough estimate, need improved estimate**
- **Estimated, to be measured**
Next Steps

Continued Radiometric Characterizations
• Immersion Coefficients – Lab Experiments (Zibordi 2005)
  Calculate using T and S measured by Navis float
• Thermal – Lab Experiments (correction function)
• Spectral Stray Light – NIST (correction function)
• Linearity – Lab & NIST (Goal: accuracy to <0.1%)

Continued Float Field Testing
• Testing at MOBY, Hawaii
• Behavior at the surface - data transmission
• Behavior during transmission, bladder inflated
• Real data transfer (end-to-end system operation)
• Post calibration (recovery) to document stability
• Quantify uncertainty due to deployment biofouling, etc.
Thank You