Bridging instrument and science capabilities and performance

IOCS 2023 SAT Meeting
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Antonio Mannino

Contributions from: Steve Persh, Ryan Vandermeulen, Sean Bailey & Boryana Efremova
Outline

- Instrument capabilities and expected performance
  - Daily science operations and calibrations
  - Spectral
  - SNR
  - Radiometric uncertainties
- On-orbit calibration
- GLIMR Data Product Science Performance & Modeling ($\rho_w$)
- Validation of Science Data Products
- Peak into Cloud statistics
- Science Data Segment – Algorithm Tool
Daily Observing & Calibration Science Operations

Daily Fall/Spring schedule

<table>
<thead>
<tr>
<th>Time of Day (hh:mm; UTC)</th>
<th>Sample Duration (min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10:30</td>
<td>30</td>
</tr>
<tr>
<td>12:02</td>
<td>30</td>
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<tr>
<td>13:35</td>
<td>30</td>
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<tr>
<td>15:07</td>
<td>30</td>
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<td>16:39</td>
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<td>18:11</td>
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<td>19:43</td>
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<td>21:15</td>
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</tr>
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<td>22:48</td>
<td>30</td>
</tr>
<tr>
<td>0:20</td>
<td>30</td>
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</table>

*Anticipated PACE overlap

Schedule affords up to 5-7 daily matchup areas with PACE OCI year-round

Bridging instrument and science capabilities and performance
Modeled GLIMR Spectral Sampling and Resolution

- Spectral Resolution
- Spectral Sampling

Chl-a Fluorescence bands:
- 675.6 nm ± 3.75 nm
- 678 nm ± 6.1 nm
- 680.3 nm ± 3.8 nm

252+ discrete channels
Modeled GLIMR Spectral Sampling and Resolution

- Spectral Resolution
  - 1.7 to 3 nm
  - 1 to 1.8 nm
  - 0.63 to 1 nm
- Spectral Sampling
  - 1 to 1.8 nm
  - 1.8 to 3 nm
  - 3 to 5 nm
  - 1.7 to 3 nm
  - 1 to 1.7 nm
  - 0.63 to 1 nm
  - 3 to 6 nm
  - 5 to 10 nm

252+ discrete channels

Bridging instrument and science capabilities and performance
Modeled SNR as of June 2023

Wavelength (nm)

SNR per band

Ltyp (W m^{-2} um^{-1} sr^{-1}) & Bandwidth for SNR

SNR

Ltyp

Bandwidth for SNR
Historically, the required performance goal for ocean color products (specifically, water-leaving radiance or reflectance) is 5% uncertainty.

- Top-of-Atmosphere (TOA) radiance requirement ascribed to ocean color instruments is typically 0.5% uncertainty.

- Goal for GLIMR is to achieve ~0.5% uncertainty in TOA radiances in UV-Vis after vicarious calibration.

Small uncertainties at TOA have potentially large impacts on downstream products.
# Modeled TOA Radiometric Uncertainties – End-Of-Life

<table>
<thead>
<tr>
<th>Ocean Color</th>
<th>Atmospheric Correction</th>
<th>Basis-of-Estimate</th>
</tr>
</thead>
<tbody>
<tr>
<td>350-400</td>
<td>400-580</td>
<td></td>
</tr>
<tr>
<td>580-720</td>
<td>720-895</td>
<td></td>
</tr>
<tr>
<td>895-970</td>
<td>970-1040</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Goal uncertainty (%) – 1 sigma</th>
<th>0.5</th>
<th>0.5</th>
<th>0.5</th>
<th>0.5 to 1.13</th>
<th>3.0</th>
<th>2.0</th>
<th>Heritage ocean color for UV-Vis; NIR: from PACE OCI CBE + 20% as its EOL baseline</th>
</tr>
</thead>
<tbody>
<tr>
<td>Instrument On-Orbit Radiometric Uncertainty Estimate (%)</td>
<td>0.485</td>
<td>0.438</td>
<td>0.518</td>
<td>1.12</td>
<td>3.02</td>
<td>1.93</td>
<td>Note: error terms summed by RSS for each header section (3 sections and at top level)</td>
</tr>
<tr>
<td>Gain and Linearity Uncertainties</td>
<td>RSS of K1, K2, K3, K5 and dn uncertainty terms; Radiometric stability, Temp., Linearity, dark counts</td>
<td></td>
<td></td>
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<tr>
<td>K1: Absolute/Vicarious Gain</td>
<td>0.20</td>
<td>0.10</td>
<td>0.10</td>
<td>0.696</td>
<td>2.11</td>
<td>1.67</td>
<td>Heritage; best option; based on PACE OCI uncertainty of vicarious calibration (340-720 nm) and absolute solar calibration (&gt;720 nm)</td>
</tr>
<tr>
<td>Image Artifact Uncertainties</td>
<td>RSS of unc. from Stray light, high-contrasts, crosstalk, OOB, non-uniformity</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Polarization Sensitivity Residuals</td>
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</table>
Science Data Product Performance Modeling Overview

GLIMR-specific INPUTS

Relative Spectral Response

$Geom$ (solz, senz, relaz)

Signal to noise ratio model

PyTOAST

Simulation of GLIMR TOA radiances ($\lambda$, $\theta_0$, $\theta$, $\phi$)

Systematic Uncertainty

0.1%

0.5%

1.0%

{\text{T1300, T1400} \ldots \text{T2300 UTC}}

Systematic Uncertainty: instrument + vicarious calibration uncertainties

Science Data Product Modeling follows the approach implemented for PACE OCI

Bridging instrument and science capabilities and performance
Science Data Product Performance $\rho_w$ – Vicarious Calibr

Requirements

• Apply to bandwidths of 15 nm (or 10 nm over Fluorescence)

Assumptions

• Vic-Cal system(s) for PACE OCI adds 0.1% uncertainty
• Estimated at 0.2% for bands <400 nm

“rho” refers to $\rho_w = \text{water-leaving reflectance}$
Science Data Product Performance $\rho_w$ – Atmos Corr

Assumptions

- Applying current heritage Atmospheric Correction Algorithm (MSEPS: Multi-Scattering Epsilon)
Science Data Product Performance $\rho_w$ – Instrument

Assumptions

- Instrument uncertainty modeling follows PACE OCI (PyTOAST) but adapted to GLIMR (geometries)
- GLIMR CBE SNR
- 0.5% Radiometric Systematic Uncertainty attributed to instrument only (Raytheon’s precision requirement at EOL)
- Accounts for all instrument artifacts (T, polarization, stray light, non-linearity, crosstalk, drift, flat field uniformity, etc.)
- Scenario for entire Gulf of Mexico

NOTE: (1) 0.69% Radiometric Systematic Uncertainty attributed for reference NIR band (870 nm) used to determine AOT as this band is not vicariously calibrated. (2) Approach follows PACE OCI’s rigorously peer-reviewed (PRs, PDR, CDR, SIR, PSR) modeling and analysis
Assumptions

- Instrument uncertainty modeling follows PACE OCI (PyTOAST) but adapted to GLIMR (geometries)
- GLIMR CBE SNR
- 0.5% Radiometric Systematic Uncertainty attributed to instrument (Raytheon’s precision requirement at EOL)
- Added Vicarious Calibration & Atmospheric Correction to instrument on top of instrument uncertainty
- Scenario for deep ocean subset of Gulf of Mexico

No change in performance when model with 2% uncertainty in NIR reference band (from 0.69% relative value from PACE OCI)

**PLRA Threshold Requirements Fully Met and Baseline Met with Minor Exceptions**
Daily Cloud-Free Observations by Season

- GOES-East ABI Cloud mask from 2020.
  - Angular sampling distance: 56 microradian
  - Time resolution: 30 min
  - Subsatellite longitude 75W

The number of cloud-free observations per day are averaged over each season.

by Boryana Efremova
Science Data Segment “news”

- **APT (Algorithm Publication Tool)**
  - APT is the "new" ATBD. While still in beta, it is available and anyone considering an algorithm should get an account and use APT to satisfy the ATBD requirement.
  - [https://www.earthdata.nasa.gov/apt/](https://www.earthdata.nasa.gov/apt/)

- **SOT/SOB process (Science Operations Team/Board)**
  - As the algorithms mature, we'll want the PIs to engage with the SOB/SOT process to get the algorithm into production.
  - The earlier the engagement the better.
BACKUP
Science Data Product Validation

- Validation with data products from other satellite missions
  - PACE OCI, Sentinel 3A/3B/3C/3D OLCI, NOAA-20/21 VIIRS, etc.
- AERONET-OC (SeaPRISM) - https://aeronet.gsfc.nasa.gov/new_web/ocean_color.html
- NASA SeaBASS - https://seabass.gsfc.nasa.gov/ (ESDS-supported)
  - NASA and other field data collections
    - e.g., NASA supports collection of up to 3000 pigment samples annually
  - Perform GLIMR validation matchups and uncertainty estimation
- HYPERNETS - http://www.hypernets.eu/from_cms/summary
- Other federal/state/local government agencies; universities; etc.

VALIDATION APPROACH – Follow heritage and PACE methodologies

GLIMR must rely on other sources of in situ data as field validation efforts were descoped at KDP-C
Cross-(Vicarious) Calibration with OCI

Following methods for polarization sensitive instrument*

- Daily matching of GLIMR pixels with OCI normalized water-leaving radiance ($nL_w$)
  - e.g., 3x3 OCI pixel bins (~3.6x3.6 km)
  - Case 1 waters with depths greater than 1000 m; low AOT and Chl-a; homogeneous AOT and Chl-a
- Inverse processing of GLIMR (L2 to L1B) to bring OCI $nL_w$ to the TOA and output modeled pixel Stokes vectors, $[L_t, Q_t, U_t, 0]^T$, at GLIMR wavelengths and GLIMR solar and viewing geometries.
  - Band radiances adjusted to match GLIMR bands
  - BRDF effects are accounted for in the propagation of the radiances from OCI to GLIMR viewing and path geometries
- Screen TOA pixels (following quality criteria) and generate datasets of radiance pairs $[L_t, Q_t, U_t, 0]^T$ and ancillary information, detector element and time, geographic coordinates, solar and viewing geometries, and glint reflectance.
- Derive $M_{11}$, $M_{12}$, and $M_{13}$ per band and detector element.
- Compute ratio $L_t / L_m^G$ to derive the cross-/vicarious gain coefficients (K1) per band

On-Orbit Calibration approach with OCI understood and mature

Spectral Response Trending

- Potential change in dispersion over time on orbit. Use emission and absorption lines to track any changes

1. Fraunhofer solar emission lines:
   - Will use at least two lines
   - 434.048 nm (Hg), 588.997 nm (Na D₂), 656.281 nm (Ha), 866.217 nm (Ca II)

2. Atmospheric absorption lines:
   - 686.719 nm (O₂ B), 759.370 nm (O₂ A), 822.696 nm (O₂ Z), 898.765 nm (O₂ y)
Multi-Scattering Epsilon (MSEPS)

Step 1
Rayleigh, gas, and glint correction

Step 2
Estimate the optical depth at the longest high radiometric quality band for each relative humidity aerosol model set.

Step 3
From (multi-scattering) Epsilon, find the closest aerosol fine mode fractions (FMF).

Step 4
Calculate the spectral aerosol reflectance for the closest models in relative humidity and FMF space.

Step 5
Calculate the weighted mean of the models to get the final aerosol reflectance and diffuse transmittance.

TOA reflectance


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**Multi-Band Atmospheric Correction (MBAC)**

**Step 1**
Rayleigh, gas, and glint correction

**Step 2**
Estimate the optical depth at the longest high radiometric quality band for each relative humidity aerosol model set

**Step 3**
Calculate the aerosol reflectance for all candidate models

**Step 4:**
\[
\chi^2 \text{ minimization}
\]

\[
\chi^2(RH, f) = \frac{1}{DOF} \sum_{\lambda=400}^{880} \frac{(\rho_{\text{obs}}(\lambda) - \rho_{\text{a}}(\lambda, RH, f))^2}{\sigma^2(\lambda)} \times SW(\lambda)
\]

**Step 5**
Calculate the weighted mean of the models to get the final aerosol reflectance and diffuse transmittance

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Future Directions for PACE and GLIMR AC

- extend MBAC to utilize UV spectral range in UV-dark waters
- include gas absorption in Rayleigh/aerosol LUTs to capture coupling
- include wind speed-dependent glint model in Rayleigh/aerosol LUTs
- improve correction for bi-directional reflectance (BRDF)


- implement ocean-atmosphere simultaneous retrieval (UV-VIS-NIR-SWIR)

Approaches to Accomplish Vicarious Calibration (K1)

- Heritage MOBY approach - *in situ* instrumentation at appropriate field site(s) (e.g., Eplee et al. 2001; Franz et al. 2007; Zibordi & Melin 2017)
  - PACE vicarious calibration site or instrumentation (MarONet; HyperNAV)

- Alternate field site/instrumentation (e.g., Bailey et al. 2008; Zibordi et al. 2015)
  - AERONET-OC data; extrapolate spectrally
  - Hyperspectral sensors: in-water or above-water
    - HypSTAR in development at Tartu with ESA funding
    - Existing COTS with more extensive lab and field calibration

- Ocean surface reflectance model (Werdell et al. 2007)

- Ocean color satellite climatology of South Pacific waters (Franz et al. 2007; Concha et al. 2019)

Many options available to vicariously calibrate GLIMR
AERONET-OC – radiometric calibration alternative

- AERONET and –OC are NASA-funded programs
- Bands: 400, 412.5, 442.5, 490, 510, 560, 620, 665, and 667 nm
- Additional bands at 709, 865, and 1020 nm for quality checks, turbid water flagging, and for the application of alternative above-water methods (Zibordi et al. 2002).
- Most useful sites for GLIMR
  - WaveCIS in Gulf of Mexico
  - USC off southern California
  - MVCO – Cape Cod

https://aeronet.gsfc.nasa.gov/new_web/ocean_color.html
HYPERNETS – on-orbit calibration/validation alternative

- Planned “new hyperspectral radiometer integrated in automated networks of water and land bidirectional reflectance measurements for satellite validation”
- Consortium of institutions coordinated by RBINS (Royal Belgian Institute for Natural Sciences)
- Funded by EU Horizon 2020

http://www.hypernets.eu/from_cms/summary

WATER SITE - Rio de la Plata

Fishermen pier in extremely turbid waters.
Coordinator: CONICET
Coordinates: 34.560865 S and 58.3988167 W.

Embedding of the HYPERNETS sites into water and land surface reflectance validation networks based closely on the existing AERONET-OC and RadCalNet networks.

LAND and WATER validation network

Validation of surface reflectance at all spectral bands of all optical missions
Terrestrial Calibration Sites

- Radiometric Characterization and Calibration of Landsat and portable to GLIMR
  - Derive surface spectral reflectance following established methodology

- Pseudo Invariant Calibration Sites (PICS)
  - Essentially invariant over time
  - Are spatially very uniform, have stable spectral responses over time
  - Atmospheric effects on upwelling radiance is minimal due to high surface reflectance
  - Are in regions where rainfall is extremely limited:
    - Prevents vegetative growth
    - Very sparse human populations
RadCalNet – source of TOA radiances for calibration

- **TOA reflectance**
  - at 30 min intervals from 9 am to 3 pm local time
  - Hyperspectral at 10 nm steps from 400 nm to 2500 nm

- **Railroad Valley Playa**
  - 15 x 15 km usable area
  - 38.50° N, 115.69° W
  - AERONET & RadCalNet

https://www.radcalnet.org/#!/
Bouvet et al. 2019 Rem Sens; https://doi.org/10.3390/rs11202401
USGS ECCOE Radiometric Calibration Sites

- Landsat; AERONET systems
- Lunar Lake Playa, Nevada
  - Dry lake bed; <0.5% reflectance variance
  - 1.5 x 2.5 km usable area
  - 38.4° N, 115.99° W
- Sonoran Desert, Mexico
  - Spatially uniform
  - 15 x 15 km usable area
  - 32.35° N, 114.65° W

- Uyuni Salt Flats, Potosi, Bolivia
  - 25 x 25 km usable area
  - 20.38° N, 66.95° W

Source: https://calval.cr.usgs.gov/apps/sonoran-desert
Source: https://calval.cr.usgs.gov/apps/uyuni-salt-flats