Calibration Program for the Ocean Color Instrument (OCI) on the Plankton, Aerosol, and Cloud ocean Ecosystem (PACE) mission

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OCI calibration overview

- The basic product measured by OCI is the top-of atmosphere (TOA) radiance at different wavelengths
- Three types of calibration/characterization are necessary for ocean color processing:
  - Prelaunch calibration/characterization (absolute/spectral calibration and image artifacts)
  - On-orbit calibration (solar diffuser and lunar measurements)
  - Vicarious calibration (in-situ measurements of water-leaving radiance)

OCI calibration overview

Artifact	Measured Prelaunch	Measured Postlaunch	Applied during L1 processing	Applied during L2 processing
Absolute gain (K1)	Instrument level, TVAC	Solar calibration and vicarious calibration[1]	Yes (calibration equation)	
Temporal response (K2)	Instrument level, reduced accuracy	Solar and lunar calibration	Yes (calibration equation)	
Temperature correction (K3)	Instrument level, TVAC	Solar and lunar calibration[2]	Yes (calibration equation)	
Response vs. scan angle (RVS) (K4)	Instrument level, ambient	Verification with ocean color products	Yes (calibration equation)	
Linearity (K5)	Instrument level, TVAC	Solar calibration[3]	Yes (calibration equation)	
Tilt angle (K6)	Spacecraft level (verification only)	Verification with ocean color products	N/A	
Polarization sensitivity	Instrument level, ambient	Verification with ocean color products		Yes (atmosphere polarization)
Stray light sensitivity	Instrument level, ambient	Verification with lunar cal.		Yes
Crosstalk	Instrument level, ambient	Verification with lunar cal.	Maybe	Yes
Relative spectral response	Instrument level, TVAC	Verification with solar calibration (Fraunhofer and atm. abs. lines)	N/A (part of K1 calculation)	Yes(atmospheric correction)
Offset (DN0)	Every scan	Every scan	Yes	

[1]Vic. Cal.: Visible and some NIR bands only

[2]If seasonal variations are observed in K2

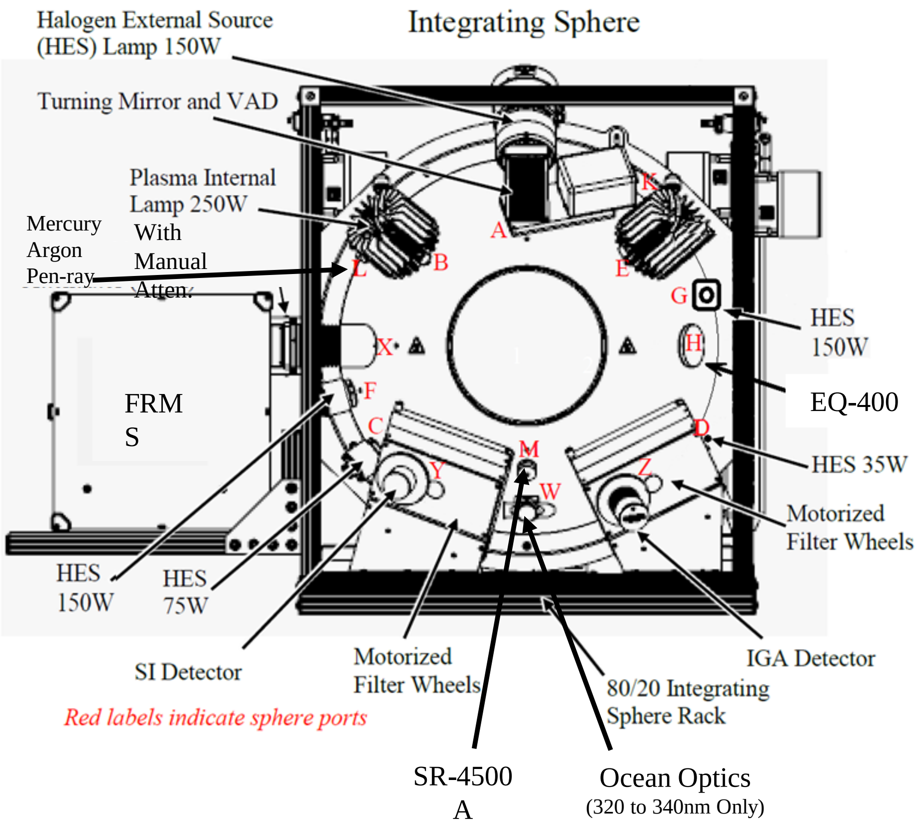
[3]New technique developed for OCI (dim diffuser)

Ground support equipment: 20inch integrating sphere (8inch exit aperture)

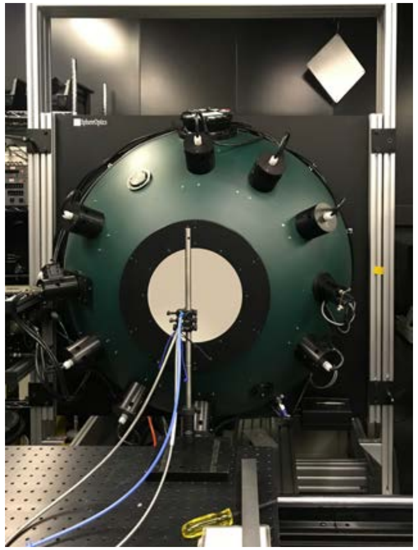
Attachments:

Various light sources (halogen, plasma, EQ-400, attenuators)

and sensors (SR4500, Ocean Optics, FRMS, Filter wheel (Si and InGaAs)



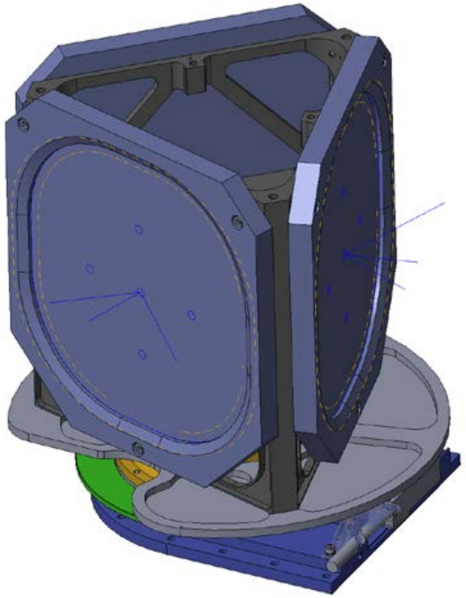
All light sources will be calibrated by NASA GSFC Code 618 Calibration Facility

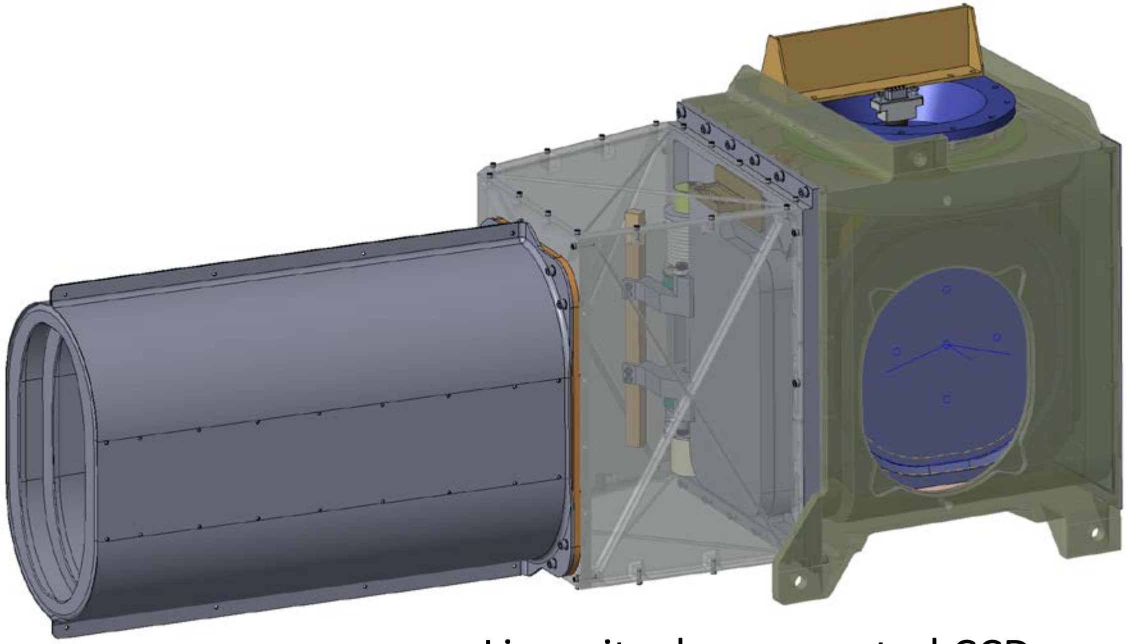


OCI Solar Calibration Assembly

Preliminary design drawings

3 diffuser surfaces: 2 QVD (daily/monthly gain tracking) and 1 dim diffuser (linearity)





Linearity: hyperspectral CCDs accumulate several readout cycles (dim solar diffuser reflectance is lowest radiance, upper limit is saturation)

Calibration Equation for each channel

$$L_m = K_1 * K_2(t) * (1-K_3*(T-T_{ref})) * K_4(\theta) * K_5(dn, T) * K_6(\omega) * dn$$

L_m = radiance measured in a hyperspectral or SWIR band
K_1 = absolute gain factor
$K_2(t)$ = relative gain factor as a function of time t
K_3 = temperature correction factor
T = Instrument temperature measured at relevant location (electronics? housing? T.b.d.)
T_{ref} = Reference Temperature (used during TVAC prelaunch characterization, close to expected on-orbit temperature)
K_4 = response versus scan
θ = scan angle (usually replaced by science pixel number per scan)
K_5 = nonlinearity factor
$K_6(\omega)$ = correction for tilt position ω (+/- 20^o)
DN = digital number measured at a certain θ
DN_0 = average of the digital numbers measured during dark current collection (average of ~40 numbers, once per scan)
dn = DN – DN_0

Note: out-of-band, polarization and straylight/crosstalk correction are handled later in the processing stage (need other information, such as surrounding radiances for straylight, amount of rayleigh/aerosol/glint for polarization)

Absolute calibration K1: 3 uncertainties

$$L_m = \mathbf{K_1} * K_2(t) * (1-K_3*(T-T_{ref})) * K_4(\theta) * K_5(dn, T) * K_6(\omega) * dn$$

- K1 is a single number per band and mirror side, with units [radiance/dn]
- Prelaunch: GLAMR will provide absolute calibration, better than 0.5% accuracy
- Initial on-orbit calibration: solar diffuser will provide absolute calibration with <2% uncertainty
- Vicarious calibration will provide absolute calibration for most bands with 0.1% uncertainty after sufficient number of matchups have been acquired

Temporal calibration K2

$$L_m = K_1 * \mathbf{K_2(t)} * (1-K_3*(T-T_{ref})) * K_4(\theta) * K_5(dn, T) * K_6(\omega) * dn$$

- Daily solar diffuser measurements will provide temporal trending
- A function of time (e.g. exponential, polynomial) will be fitted to the daily measurements
- A monthly solar diffuser (limited exposure) will provide correction to degradation of reflectance of daily solar diffuser
- After more than 2 years, lunar measurements will be used for temporal trending
- K2 uncertainty achieved with SeaWiFS lunar measurements: 0.13% (Eplee et al., Applied Optics, Vol. 51, Issue 36, 2012)
- K2 uncertainty allocation for OCI: 0.17%

Linearity correction K5

$$L_m = K_1 * K_2(t) * (1-K_3*(T-T_{ref})) * K_4(\theta) * \mathbf{K_5(dn, T)} * K_6(\omega) * dn$$

- A monthly solar diffuser (dim target with reflectance of about 2%) will provide linearity correction via special OCI mode
- OCI can hold charge for several cycles, testing the linearity of the electronics (not the detectors)
- Linearity will be evaluated at multiples of 2% in reflectance (2%, 4%, 6%,…100%)

Solar Diffuser Reflectance Degradation

- The monthly solar diffuser (limited exposure) will provide correction to degradation of reflectance of daily solar diffuser, but it will degrade as well
- The degradation pattern of the daily solar diffuser will be used to model the degradation of the monthly solar diffuser (heritage: MERIS, ozone instruments (OMI))
- If the degradation of the monthly solar diffuser is smaller than 0.6% over the mission life (or 2 years), an uncertainty of 0.1% can be achieved with the solar diffuser measurements alone (Meister, On-orbit trending of solar diffuser reflectance, PACE memo, 2017)
- Expected degradation for Quartz-Volume Diffuser: 0.15% (worst wavelength (350nm), based on on-orbit data from OMI/Aura)
- Daily solar diffuser will be used to monitor short term changes. Expected degradation at 350nm: 6.7%

Lunar Calibration

Lunar calibration background:

- Stable exo-atmospheric radiometric source with light levels comparable to TOA Earth observations.
- Moon used as reference by SeaWiFS, MODIS (2), and VIIRS.
- Observations require geometric correction for instrument-Moon and Sun-Moon distances, phase angle, libration angles.
- Frequency of observation: Twice per month (before and after full phase) over a limited range of phase angles (7deg +/- 0.5deg).
- Limitations:
  - Will require image oversampling correction.
  - Inherent scatter in observations (1-2%).
  - Multi-year time series required to identify radiometric trends.

Geometric corrections:

- Complication: Heterogeneous albedo distribution over the lunar surface
- Corrections provided by USGS ROLO Lunar Photometric Model
- ROLO Model used as reference by most Earth-observing instruments

Summary

- OCI will start a rigorous calibration program in June 2019 with the ETU (Flight Unit: summer 2020)
- Goal is to minimize uncertainties due to image artifacts described here in order to achieve overall radiometric uncertainty of 0.5% (excluding absolute calibration)
- OCI will provide excellent temporal stability over mission life time (2 solar diffusers, lunar measurements twice a month)
- Linearity will be verified on-orbit with dim solar diffuser (new approach)