PACE OCI Surface Reflectance (SFREFL)

VERSION v1.0

RELEASE DATE Mar 4th, 2025

KEYWORDS **REFLECTANCE**
Under: EARTH SCIENCE > LAND SURFACE > SURFACE RADIATIVE PROPERTIES

CREATORS Caplan, Skye and Franz, Bryan and Ibrahim, Amir and Bailey, Sean

EDITORS None provided

DOI 10.5067/MD7W4BQ3Z6J2

Table of Contents

Abstract

Spectral surface reflectance is an essential input to terrestrial remote sensing investigations. Retrieving reflectance requires the removal of atmospheric influences from top-of-atmosphere reflectance observations, a process called atmospheric correction. The terrestrial atmospheric correction algorithm for the Ocean Color Instrument (OCI) onboard the Plankton, Aerosol, Cloud, ocean Ecosystem (PACE) satellite is described here. The algorithm, which corrects for gaseous absorption and simple atmospheric scattering over land, is a modified version of the Ocean Biology Processing Group's process for atmospheric correction over water. The surface reflectance product suite SFREFL is an output of this correction, containing surface reflectances for 122 OCI bands spanning the instrument's spectral range. SFREFL is produced as a Level 2 and a Level 3 product, and is used to calculate the vegetation indices provided in PACE's LANDVI product suite.

Plain Language Summary

Monitoring ecosystems on land from space often requires the use of a quantity called surface reflectance, which describes how much light is reflected by the Earth's surface. These measurements come from satellite data, like those produced by the Plankton, Aerosol, Cloud, ocean Ecosystem (PACE) mission - satellites observe the Earth at the top of the atmosphere, so measurements of reflectance are complicated by the gasses and particles that make up the atmosphere as well as interactions between them and the light being studied. To calculate the reflectance as it would be seen at the base of the atmosphere, or the surface, data goes through a process called atmospheric correction; PACE's algorithm for the Ocean Color Instrument's (OCI) atmospheric correction is described in this document. After the surface reflectances are calculated from the algorithm, they can be analyzed for a multitude of properties, some of which describe characteristics of vegetation.

Version description

This is the first version of the ATBD for PACE OCI's terrestrial atmospheric correction algorithm employed by the Ocean Biology Processing Group (OBPG) in the most recent data processing. The algorithm description below corresponds to Version 3 of OCI's SFREFL product, and may be changed with future versions of the data.

1. Introduction

Terrestrial observations rely on accurate measurements of the reflectance of light off of objects on the surface of the Earth. In order to calculate those surface reflectances, atmospheric interferance must be removed from the signal through a process called atmospheric correction. There are many methods used to achieve this goal, and as a non-standard product, OCI's surface reflectance product suite (SFREFL) is investigating three separate algorithms: l2gen, ISOFIT, and MAIAC (Mobley et al., 2016; Thompson et al., 2018; Lyapustin et al., 2011). Currently, SFREFL is being produced and distributed using only the l2gen algorithm as described in this document.

The terrestrial atmospheric correction performed by l2gen derives spectral surface reflectance measurements, $\rho_s(\lambda)$, for 122 bands from the ultraviolet (UV) to the near infrared (NIR). These 122 $\rho_s(\lambda)$ measurements are included as part of the Level 2 (L2) and Level 3 (L3) SFREFL product suite, and are the primary input to the vegetation indices distributed in OCI's LANDVI product suite. Here, the term "surface reflectance" refers to the Hemispherical-Directional Reflectance as described in Schaepman-Strub et al., 2006.

2. Context / Background

2.1. Historical Perspective

OCI's terrestrial atmospheric correction is a modified version of OBPG's remote sensing reflectance (Rrs) algorithm. Development of this atmospheric correction method began with the launch of the Coastal Zone Color Scanner (CZCS) in 1978 on the Nimbus-7 satellite. Initially, these efforts were hindered by a limited number of spectral bands which did not addequately address the complexity of atmospheric conditions and constituents. The launches of the Ocean Color and Temperature Scanner (OCTS) and the Sea-Viewing Wide Field-of-View Sensor (SeaWiFS) in 1996 and 1997, respectively, began an era of improved technology and a deepening understanding of atmospheric interactions. These sensors allowed for substantial progress to be made in the field, with several developments in aquatic atmospheric correction to follow. This era included the introduction of an algorithm by Howard Gordon and Menghua Wang utilizing near-infrared bands to estimate and remove aerosol effects over water (Gordon & Wang, 1994). The algorithm, known as the black pixel assumption, was then expanded upon to better utilize the additional spectral information that hyperspectral ocean color sensors offer in the NIR and Shortwave Infrared (SWIR) bands (Ibrahim et al., 2019, Ibrahim & Mobley, 2024).

The terrestrial version of this algorithm was originally developed for the SeaWiFS mission to generate whole-biosphere measurements, but was simplified to only correcting for Rayleigh scattering contributions. When it was decided in that PACE OCI would produce dedicated terrestrial products, the algorithm was made more robust by including the same absorbing gas corrections as its aquatic counterpart. Aerosol contributions are still excluded from the correction, as the black pixel assumption is invalid over land. Efforts are currently being considered to include a correction for aerosols, however, and may be part of future data versions.

2.2. Additional information

No content available.

3. Algorithm Description

3.1. Scientific Theory

The most useful quantity for terrestrial analyses is the fraction of incoming solar radiation that is reflected by the Earth's surface. However, OCI measures the spectral radiance at the top of the atmosphere (TOA). These measurements do contain the the portion of the signal from the surface, but are complicated by contributions from atmospheric scattering, absorbing gases, and aerosols. Contributions from each of these components are typically removed during atmospheric correction, leaving only the part of the reflectance contributed by the surface. The atmospheric correction for OCI over land, part of OBPG's l2gen processing code, corrects only for Rayleigh scattering and absorbing gases, not aerosols. Additionally, some surface reflectance products include a bidirectional reflectance distribution function (BRDF) correction to account for the differing geometries of each observation. OCI's terrestrial atmospheric correction does not yet account for BRDF effects.

3.1.1. Assumptions

No content available.

3.2. Mathematical Theory

The total radiance L_t measured by a satellite-borne sensor at TOA over land can be described by contributions from the atmospheric path radiance, L_0, and the surface reflectance, ρ_s, while accounting for transmittance as below:

$$L_{TOA} = L_0 + \frac{T_{atm} f_0 \mu_s \rho_s}{\pi[1 - \rho_s S]} \tag{1}$$

Where T_{atm} is the atmospheric transmittance from the surface of the Earth to the top of the atmosphere, f_0 is the solar irradiance, μ_s is the cosine of the solar zenith angle, and S is the spherical albedo. For simplicity, dependences on solar and viewing angles (θ_s, θ_v, ϕ) have not been included. The mixing of radiance terms (beginning with L) and reflectance terms (represented by ρ) can be modified in favor of reflectance if the above equation is normalized by the incident solar radiance, $f_0 \mu_{sol} / \pi$. Solving for ρ_s and splitting the atmospheric component into individual elements results in:

$$\rho_s = \frac{\pi}{f_0 \mu_s} * \frac{\frac{L_t}{tg_s tg_v} - L_r}{t_s t_v t_{O_2} t_{H_2O}} \tag{2}$$

Because the surface reflectance algorithm also has to account for calculations over water, the spherical albedo correction is implemented in a separate step once the pixel is confirmed as land:

$$\rho_s = \frac{\rho_s}{1 + \rho_s S} \tag{3}$$

Where the definitions of each symbol are as below.

Table 1: Definitions of each relevant term in the atmospheric correction algorithm. Spectral radiance L with SI units of mW cm^{-2} μm^{-1} sr^{-1} is used in NASA's processing.

Symbol	Definition
f_0	Solar irradiance based on TSIS-1 Version 2 (Coddington et al. 2023)
μ_s	Cosine of the solar zenith angle
L_r	Radiance contribution due to Rayleigh scattering
L_t	Top of atmosphere radiance
ρ_s	Surface reflectance

S	Spherical albedo
t_{O_2}	The transmittance of diffuse radiation through O_2
t_{H_2O}	The transmittance of diffuse radiation through water vapor
t_v	The diffuse transmittance in the viewing path from sensor to surface
tg_v	The transmittance loss due to absorbing gases for all radiation traveling along the sensor view path
t_s	The diffuse transmittance in the viewing path from Sun to surface
tg_s	The transmittance loss due to absorbing gases for all radiation traveling along the viewing path from Sun to surface

Most of the terms in the above equations are estimated through precomputed radiative transfer simulations or models that depend only on the sensor spectral response, solar and sensor viewing geometry, and ancillary information such as atmospheric gas concentrations. Once is a pixel is identified as "land", the surface reflectance calculation begins with correction of the Rayleigh optical thickness for pressure at each pixel. Then, the path radiance is calculated. It should be noted that path radiance over land is assumed by the algorithm to have only a Rayleigh component. Once the path radiance is retrieved, diffuse transmittances are calculated. Transmittances can be split into contributions from the solar and sensor directions, respectively. The gasses accounted for by tg_v and tg_s are: O_3, H_2O, N_2O, CO_2, CO, CH_4, and O_2. NO_2 contributions will be removed in Version 3 of the SFREFL product.

3.2.1. Assumptions

The algorithm makes several important assumptioins:

1. No aerosols are present and contributing to the TOA reflectance.
2. There is no coupling between the gas absorption and the molecule scattering.
3. The Earth is a Lambertian surface reflecting light isotropically.

3.3. Algorithm Input Variables

Name	Long Name	Unit
rho_t	Top of atmosphere reflectance	sr^{-1}
p	Surface pressure	mbar

Name	Long Name	Unit
Ozone	Column ozone concentration	Dobson unit
Water vapor	Column water vapor concentration	cm
CO	Carbon monoxide	No content available.
N_2O	Nitrous oxide	No content available.
CH_4	Methane	No content available.
CO_2	Carbon dioxide	No content available.
O_2	Oxygen	No content available.

3.4. Algorithm Output Variables

Name	Long Name	Unit
rho_s	Surface reflectance	sr^{-1}

4. Algorithm Availability

4.1. Location of Implemented Algorithm #1

URL https://oceancolor.gsfc.nasa.gov/docs/ocssw/

DESCRIPTION **The surface reflectance algorithm is distributed with the OCSSW package. OCSSW contains all of the science processing software used within OBPG, and can function as a set of command line tools.**

Location of Implemented Algorithm #2

URL **https://seadas.gsfc.nasa.gov/**

DESCRIPTION **Additionally, OCSSW is built into SeaDAS, a software package presented as a graphical user interface (GUI) to assist users in processing data.**

5. Algorithm Usage Constraints

Table 2: Algorithm product name and associated masks in L3. Several masks are not relevant to land processing, but are included here for completion. Definitions for each flag can be found at https://oceancolor.gsfc.nasa.gov/resources/atbd/ocl2flags/. *The LAND mask is inverted to mask any pixels identified as not including land.

Level 2 Product Suite	SFREFL
Level 3 Product Suite	SFREFL
Level 3 Masking	ATMFAIL, LAND*, HILT, HISATZEN, STRAYLIGHT, CLDICE, COCCOLITH, LOWLW, CHLWARN, CHLFAIL, NAVWARN, MAXAERITER, ATMWARN, HISOLZEN, NAVFAIL, FILTER, HIGLINT

The SFREFL product is currently only being produced for PACE OCI. Additionally, as previously mentioned, a correction for aerosols is not included in the atmospheric correction. Although the SFREFL product contains 122 bands, the algorithm can run on each of OCI's 286 bands by running L1B data through the Ocean Color Science Software (OCSSW) package distributed by OBPG with the product name "rhos" and wavelength_3d option set to 315:2258.

The file format for Level 2 and Level 3 data products is described in the Ocean Data Product User Guide (https://oceancolor.gsfc.nasa.gov/resources/docs/format/Ocean_Data_Product_Users_Guide.pdf). Each SFREFL file is distributed in NetCDF format consistent with CF conventions. Specifics pertaining to the contents of each group in a Level 2 file are described in Table 4 below:

Table 3: Table 4: Description of Level 2 SFREFL product including contents of each group.

Level 2 Group	Group Contents
geophysical_data	Retrieved geophysical parameters; Variables: rhos, l2_flags
navigation_data	Geolocation information; Variables: latitude, longitude, and tilt.
processing_control	High level summary of processing workflow used for retrievals; Variables: flag_percentages and input_parameters
scan_line_attributes	Location and observation Information for each scan line; Variables: clat, clon, csol_z, day, detnum, elat, elon, msec, mside, slat, slon, time, year
sensor_band_parameters	Information on spectral bands as applicable to the instrument; Variables: aw, bbw, F0, k_no2, k_oz, Tau_r, vcal_gain, vcal_offset, wavelength, wavelength_3d

Retrieved geophysical parameters in Level 3 products are not contained in a group, and instead are presented as data variables at the top of the data tree along with the latitude ("lat"), longitude ("lon"), and applicable wavelengths ("wavelength"). The processing_control group is present in Level 3 files as well.

6. Performance Assessment Validation

6.1. Performance Assessment Validation Methods

The validation plan for SFREFL is ongoing, and appropriate in-situ data points are being identified and collected. An intiative using Radiometric Calibration Network (RadCalNet) data to validate surface reflectance measurements from PACE OCI has recently begun. Both top-of-atmosphere Level 1B and surface Level 2 reflectances will be measured against suitable RadCalNet data points to support the accuracy of OCI measurements. The first site to be used in these validation efforts will be Railroad Valley (RRV), a playa with well-characterized reflectance over several decades (Czapla-Myers et al., 2008; Czapla-Myers et al., 2020). A box of approximately 48 x 53 pixels (~57.6 x 63.6 km) containing both RRV and its surroundings for spatial context will be analyzed for matchups between in-situ and PACE OCI data. The search criteria for valid pairs includes viable observation geometry (sensor zenith angle < 60°, solar zenith angle < 75°), and time differences between the in-situ and satellite measurements (< 3 hours). Following the Ocean Biology Processing Group (OBPG) standard validation procedure for aquatic products (Bailey & Werdell, 2006), > 50% of OCI pixels in the defined box must also be valid to be included in validation. In other words, pixels associated with any standard quality control flags (e.g., clouds, navigation failure) will be excluded.

6.2. Performance Assessment Validation Uncertainties

As an advanced PACE product, standard uncertainty and error thresholds for surface reflectance were not defined at the start of the mission. Given the instrument characteristics and goals of the mission, it has been determined that following MODIS's accuracy requirements is acceptable as a validation metric (Roger et al., 2015). Thus, the accuracy to achieve for PACE OCI surface reflectance will follow $\pm(0.005 + 0.05 * \rho_\lambda)$ where ρ_λ is the spectral surface reflectance.

6.3. Performance Assessment Validation Errors

No content available.

7. Data Access

7.1. Input Data Data Access

7.1.1. Entry #1

URL	**https://oceancolor.gsfc.nasa.gov/data/download_methods/**
DESCRIPTION	**Input variables from Level 1B data can be downloaded from the ocean color website through the different methods described in the link above.**

Entry #2

URL	**https://oceancolor.gsfc.nasa.gov/resources/docs/ancillary/**

DESCRIPTION Other ancillary data such as pressure, water vapor, and absorbing gas profiles are provided through the link above.

7.2. Output Data Data Access

7.2.1. Entry #1

URL https://oceancolor.gsfc.nasa.gov/data/download_methods/

DESCRIPTION The SFREFL product can be downloaded through the "File Search" method described in the link above, as well as through Earthdata Search. Additionally, python packages such as earthaccess can be used to download these data.

7.3. Important Related URLs

7.3.1. Entry #1

URL https://oceancolor.gsfc.nasa.gov/docs/ocssw/atmocor1__land_8c.html

DESCRIPTION This is a graphical description of the algorithm implementation in OBPG's processing code (l2gen)

8. Contacts

Skye Caplan

ROLES Writing – original draft, Writing – review & editing & Corresponding Author

AFFILIATIONS No affiliations in this document

EMAIL skyelar.a.caplan@nasa.gov

URL https://science.gsfc.nasa.gov/sed/bio/skyelar.a.caplan

UUID https://orcid.org/0009-0004-8003-2551

Bryan Franz

ROLES Writing – original draft & Writing – review & editing

AFFILIATIONS No affiliations in this document

EMAIL bryan.a.franz@nasa.gov

URL https://science.gsfc.nasa.gov/sed/bio/bryan.a.franz

Amir Ibrahim

ROLES Writing – review & editing & Writing – original draft

AFFILIATIONS No affiliations in this document

EMAIL amir.ibrahim@nasa.gov

URL https://science.gsfc.nasa.gov/sci/bio/amir.ibrahim

UUID 0000-0002-3290-056X

Sean Bailey

ROLES Writing – original draft & Writing – review & editing

AFFILIATIONS No affiliations in this document

EMAIL Sean.Bailey@nasa.gov

URL https://science.gsfc.nasa.gov/sed/bio/sean.w.bailey

References

Bailey, S. & Werdell, J. (2006). A multi-sensor approach for the on-orbit validation of ocean color satellite data products. *Remote Sensing of Environment, 102,* 12-23. https://doi.org/doi:10.1016/j.rse.2006.01.015

Czapla-Myers, J., Thome, K., Wenny, B. & Anderson, N. (2020). Railroad Valley Radiometric Calibration Test Site (RadCaTS) as Part of a Global Radiometric Calibration Network (RadCalNet). *IGARSS 2020 - 2020 {IEEE} {International} {Geoscience} and {Remote} {Sensing} {Symposium},* 6413--6416. https://doi.org/10.1109/IGARSS39084.2020.9323665

Czapla-Myers, J. S., Thome, K. J., Cocilovo, B. R., McCorkel, J. T. & Buchanan, J. H. (2008). Temporal, spectral, and spatial study of the automated vicarious calibration test site at Railroad Valley, Nevada. *Earth Observing Systems XIII, 7081,* 70810I. https://doi.org/10.1117/12.795551

Gordon, H. R. & Wang, M. (1994). Retrieval of water-leaving radiance and aerosol optical thickness over the oceans with SeaWiFS: a preliminary algorithm. *Applied Optics, 33(3),* 443-452. https://doi.org/10.1364/AO.33.000443

Ibrahim, A., Franz, B., Ahmad, Z. & Bailey, S. (2019). Multiband Atmospheric Correction Algorithm for Ocean Color Retrievals. *Frontiers in Earth Science, 7,* https://doi.org/ https://doi.org/10.3389/feart.2019.00116

Ibrahim, A. & Mobley, C. (2024). Remote Sensing Reflectance. https://doi.org/10.5067/FQBB0C1K43OJ

Lyapustin, A., Martonchik, J., Wang, Y., Lazlo, I. & Korkin, S. (2011). Multiangle implementation of atmospheric correction (MAIAC): 1. Radiative transfer basis and look-up tables. *Journal of Geophysical Research, 116(D3),* D03210. https://doi.org/ https://doi.org/10.1029/2010JD014985

Mobley, C., Werdell, J., Franz, B., Ahmad, Z. & Bailey, S. (2016). Atmospheric Correction For Satellite Ocean Color Radiometry.

Roger, J. C., Vermote, E. F. & Ray, J. P. (2015). MODIS Surface Reflectance User Guide. https://doi.org/DOI: 10.5067/MODIS/MOD09.061

Schaepman-Strub, G., Schaepman, M., Painter, T., Dangel, S. & Martonchik, J. (2006). Reflectance quantities in optical remote sensing—definitions and case studies. *Remote Sensing of Environment, 103(1),* 27-42. https://doi.org/10.1016/j.rse.2006.03.002

Thompson, D. R., Natraj, V., Green, R. O., Helmlinger, M. C., Gao, B. & Eastwood, M. L. (2018). Optimal estimation for imaging spectrometer atmospheric correction. *Remote Sensing of Environment, 216,* 355-373. https://doi.org/10.1016/j.rse.2018.07.003