Chlorophyll a

VERSION	**v1.1**
RELEASE DATE	**Nov 6th, 2023**
KEYWORDS	**CHLOROPHYLL CONCENTRATIONS** Under: EARTH SCIENCE > TERRESTRIAL HYDROSPHERE > WATER QUALITY/WATER CHEMISTRY > WATER CHARACTERISTICS **OCEAN COLOR** Under: EARTH SCIENCE > OCEANS > OCEAN OPTICS
CREATORS	**Jeremy Werdell and John O'Reilly and Chuanmin Hu and Lian Feng and Zhongping Lee and Bryan Franz and Sean Bailey and Christopher Proctor**
EDITORS	**Guoqing Wang**
DOI	**10.5067/JCQB8QALDOYD**

Table of Contents

Abstract

Plain Language Summary

Version description

1. Introduction

2. Context / Background
   2.1. Historical Perspective
   2.2. Additional information

3. Algorithm Description
   3.1. Scientific Theory
      3.1.1. Assumptions
   3.2. Mathematical Theory
      3.2.1. Assumptions
   3.3. Algorithm Input Variables
   3.4. Algorithm Output Variables

4. Algorithm Availability
   4.1. Location of Implemented Algorithm #1

5. Algorithm Usage Constraints

6. Performance Assessment Validation
   6.1. Performance Assessment Validation Methods
   6.2. Performance Assessment Validation Uncertainties
   6.3. Performance Assessment Validation Errors

7. Data Access
   7.1. Input Data Data Access
      7.1.1. Entry #1
   7.2. Output Data Data Access
      7.2.1. Entry #1
   7.3. Important Related URLs
      7.3.1. Entry #1

8. Contacts

References

Abstract

This algorithm returns the near-surface concentration of the photosynthetic pigment chlorophyll *a* (chlor_a) in mg m^{-3}, calculated using empirical relationships derived from in situ measurements of both chlor_a and spectral remote sensing reflectances (R_{rs}). The implementation is contingent on the availability of three or more sensor bands spanning the 440 - 670 nm spectral range. The algorithm is applicable to all current ocean color sensors. The chlor_a product is included as part of the NASA standard Level-2 OC product suite and the Level-3 CHL product suite.

Plain Language Summary

We use this algorithm to calculate the concentration of a major photosynthetic pigment, chlorophyll *a*, found within aquatic phytoplankton residing in the sunlit layer of the water column. The input data are satellite measurements of various wavelengths of light exiting the water. Chlorophyll *a* absorbs blue, green, and red wavelengths differently depending on its concentration. This changes the intensity of light exiting the aquatic system, which gives the water its color, and allows relationships to be developed that relate light to chlorophyll *a* concentration, which can in turn be used as a proxy metric for phytoplankton biomass.

Version description

This is the first APT version of the chloropyll *a* algorithm employed by the Ocean Biology Processing Group (OBPG). Previous ATBD information for this algorithm was provided by the OBPG through the Ocean Biology Distributed Active Archive Center (OB.DAAC) website. This version describes the algorithm as implemented in the most recent reprocessing (R2022) of the ocean color data.

1. Introduction

This algorithm returns the near-surface concentration of the photosynthetic pigment chlorophyll *a* (chlor_a) in mg m^{-3}, calculated using empirical relationships derived from in situ measurements of chlor_a and spectral remote sensing reflectances ($R_{rs}(\lambda)$). The algorithm is applicable to all current ocean color sensors. The implementation is contingent on the availability of three or more sensor bands spanning the 440 - 670 nm spectral regime. The chlor_a product is included as part of the standard Level-2 OC product suite and the Level-3 CHL product suite.

The current implementation for the standard chlor_a product, as applied in version R2022 of NASA's multi-mission ocean color processing, is a blend between the updated OC3/OC4 (OCx) band ratio algorithm O'Reilly & Werdell, 2019 and the color index (CI) Hu et al., 2019. The combined algorithm and its theoretical basis is described in Hu et al., 2019, and the current implementation is detailed below.

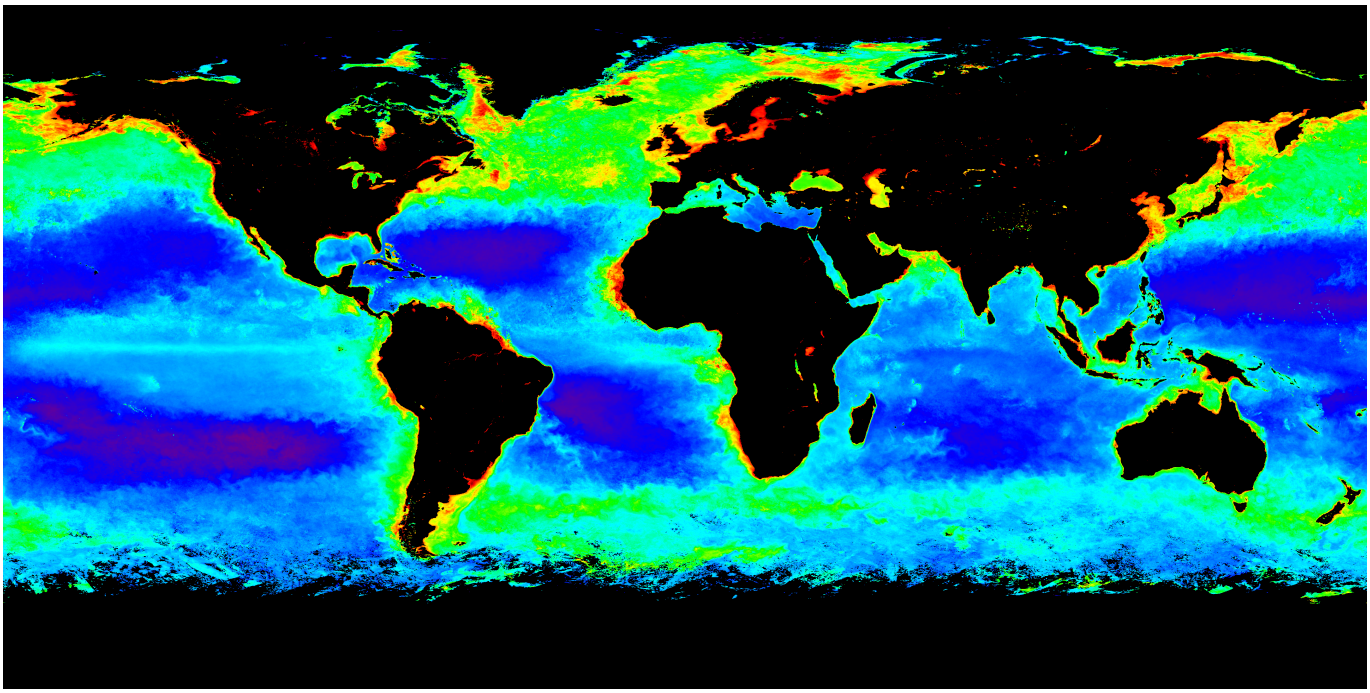

Figure 1: MODIS Aqua chlor_a seasonal composite for Spring 2014

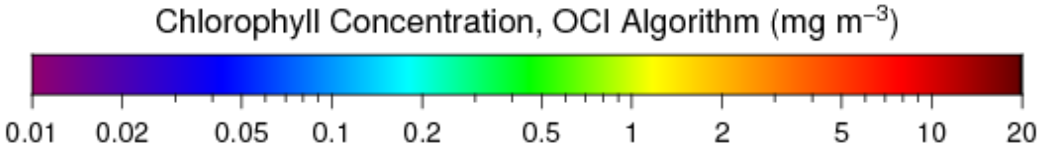

Figure 2: Colorbar for Chlor_a concentration

2. Context / Background

2.1. Historical Perspective

The near surface concentration of chlor_a has been the primary ocean color variable since NASA launched and operated the Coastal Zone Color Scanner (CZCS; 1978-1986). It is, therefore, one of the most historically meaningful products and is generated by all subsequent ocean color missions, including SeaWiFS, MODIS, MERIS, VIIRS, and OLCI.

The original approach to retrieve chlor_a simply considered a ratio of one blue to one green spectral band Gordon et al., 1980. With time, this approach evolved to consider the maximum of several blue $R_{rs}(\lambda)$ as the numerator O'Reilly et al., 1998. Simultaneously, line-height approaches emerged and demonstrated increased accuracy under low chlor_a conditionsHu et al., 2012. The current retrieval approach adopts a hybrid method that considers both band ratios and line-heights Hu et al., 2019.

The chlor_a retrieval algorithm used in NASA OB.DAAC ocean color data reprocessing R2022.0 adopts recent updates in algorithm parameters for both the band ratio and line height components. These updates considered the largest available and most globally representative database Werdell & Bailey, 2005Valente et al., 2016.

2.2. Additional information

Since reprocessing R2014.0, NASA has adopted the hybrid algorithm as the default algorithm for ocean color chlor_a product. In SeaDAS, software package for ocean color data processing (https://seadas.gsfc.nasa.gov/), users can use numerous other algorithms, including the traditional band ratio, to derive chlor_a concentration.

3. Algorithm Description

3.1. Scientific Theory

Broadly speaking, the photosynthetic pigment chlorophyll *a* absorbs blue and red light and, as such, the spectral nature of $R_{rs}(\lambda)$ varies with its concentration. Both OCx and CI exploit such spectral variations in $R_{rs}(\lambda)$ by considering how the relative magnitudes of R_{rs}(blue) and R_{rs}(green) typically decrease and increase, respectively, with increasing chlor_a. OCx does so using the ratio of R_{rs}(blue) to R_{rs}(green), which has been statistically shown to vary with chlor_a. While the choice of numerator (that is, R_{rs}(blue)) in this ratio has evolved over time, the $R_{rs}(\lambda)$ ratio-to-chlor_a relationship has been consistently expressed as a polynomial in log10 space. CI exploits such changes in spectral shape through the difference between R_{rs}(green) and a reference formed linearly between R_{rs}(blue) and R_{rs}(red). The current polynomial expression for OCx spans four orders of magitude (0.01 to 100 mg m^{-3}), whereas CI focuses on chlor_a < 0.3 mg m^{-3}. In current practice, both OCx and CI are computed and then blended using a CI-to-OCI transition zone between 0.25 < CI < 0.35 mg m^{-3}. The combination of these two approaches leads to reductions in errors associated with image artifacts, and provides more consistent cross-sensor, spatial, and temporal chlor_a patterns.

3.1.1. Assumptions

These empirical approaches, through either band ratio or band difference, can partially compensate for some of the $R_{rs}(\lambda)$ input errors because these errors (to a large extent) are spectrally related.

3.2. Mathematical Theory

Inputs:

R_{rs} at 2-4 wavelengths between 440 and 670 nm

Outputs:

$chlor_a$, concentration of chlorophyll *a* in mg m^{-3}

Approach:

The current standard chlor_a product is based on the algorithm of Hu et al., 2019, which combines an empirical band difference approach at low chorophyll concentrations with a band ratio approach at higher chlor_a concentrations. The band difference approach is the color index or CI Hu et al., 2019, and the band ratio approach is based on

the OCx series of algorithms introduced in O'Reilly et al., 1998, with updated coefficients from O'Reilly & Werdell, 2019.

The algorithm proceeds as follows:

1. chlor_a is first calculated using the CI algorithm, which is a three-band reflectance difference algorithm employing the difference between sensor specific R_{rs} in the green band and a reference formed linearly between R_{rs} in the blue and red bands (bands are instrument specific - see Table 1):

$$CI = R_{rs}(\lambda_{green}) - [R_{rs}(\lambda_{blue}) + (\lambda_{green} - \lambda_{blue})/(\lambda_{red} - \lambda_{blue}) * (R_{rs}(\lambda_{red}) - R_{rs}(\lambda_{blue}))] \quad (1)$$

Final calculation of CI chlor_a is done using two coefficients ($a_{0_{CI}}$ = -0.4287 and $a_{1_{CI}}$ = 230.47) specified by Hu et al (2019), where:

$$chlor_a = 10^{(a_{0_{CI}} + a_{1_{CI}} * CI)} \quad (2)$$

2. chlor_a is then calculated following the OCx algorithm, which is a fourth-order polynomial relationship between a ratio of R_{rs} and $chlor_a$:

$$log_{10}(chlor_a) = a_0 + \sum_{i=1}^{4} a_i (log_{10}(\frac{R_{rs}(\lambda_{blue})}{R_{rs}(\lambda_{green})}))^i \quad (3)$$

where the numerator, $R_{rs}(\lambda_{blue})$, is the greatest of several input R_{rs} values and the coefficients, a_0-a_4, are sensor-specific. The coefficients used for the OCx component of the algorithm in standard processing are listed in Table 1 below. In most cases these are taken directly from O'Reilly & Werdell, 2019.

Table 1: Coefficients for the OCx algorithm series in standard processing.

	Algorithm	OCx R_{rs} used (blue/green)	$a_{(0,1,2,3,4)}$
SeaWiFS	OC4, CI	R_{rs}(443>489>510)/R_r	0.32814; -3.20725; 3.22969;

		$_s$(555)	-1.36769; -0.81739
MODIS	OC3M, CI	R_{rs}(443>488)/R_{rs}(547)	0.26294; -2.64669; 1.28364; 1.08209; -1.76828
VIIRS-SNPP	OC3_VIIRS_SNPP, CI	R_{rs}(443>486)/R_{rs}(551)	0.23548; -2.63001; 1.65498; 0.16117; -1.37247
VIIRS-NOAA20	OC3_VIIRS_NOAA20, CI	R_{rs}(445>489)/R_{rs}(556)	0.28153; -2.65472; 1.30882; 1.31521; -2.08622
VIIRS-NOAA21	OC3_VIIRS_NOAA21, CI	R_{rs}(445>488)/R_{rs}(555)	0.24765; -2.54926; 1.55323; 0.39485; -1.54632
PACE OCI	OC4, CI	R_{rs}(442>490>510)/R_{rs}(555)	0.32814; -3.20725; 3.22969; -1.36769; -0.81739
MERIS	OC4E, CI	R_{rs}(443>489>510)/R_{rs}(560)	0.42487; -3.20974; 2.89721; -0.75258; -0.98259
OCTS	OC4O, CI	R_{rs}(443>489>516)/R_{rs}(565)	0.54655; -3.51799; 3.39128; -0.91567; -0.97112
GOCI	OC4,CI	R_{rs}(412>443>489)/R_{rs}(555)	0.28043; -2.49033; 1.53980; -0.09926; -0.68403
HAWKEYE	OC4, CI	R_{rs}(447>488>510)/R_{rs}(556)	0.32814, -3.20725; 3.22969; -1.36769; -0.81739
OLCI	OC4, CI	R_{rs}(443>490>510)/R_{rs}(560)	0.42540; -3.21679; 2.86907; -0.62628; -1.09333
CZCS	OC3, CI	R_{rs}(443>520)/R_{rs}(555)	0.31841; -4.56386; 8.63979; -8.41411; 1.91532

3. For chlor_a retrievals below 0.25 mg m^{-3}, the CI algorithm is used.

For chlor_a retrievals above 0.35 mg m^{-3}, the OCx algorithm is used. In between these values, the CI and OCx algorithm are blended using a weighted approach:

$$chlor_a = \frac{chlor_a_{CI}(t_2 - chlor_a_{CI})}{t_2 - t_1} + \frac{chlor_a_{OCx}(chlor_a_{CI} - t_1)}{t_2 - t_1} \quad (4)$$

with t_1 = 0.25, and t_2=0.35 (edges of the current blending region).

For the CI algorithm, the nearest band to 443, 555, and 670 nm is used for the blue, green, and red band, respectively, for all sensors. For sensors that do not have a band very close to 555 nm, a correction is performed to shift the nearest green band R_{rs} to 555 nm. That correction is as follows:

For spectral bands (λ_0) in the range of 543 –567 nm, $R_{rs}(\lambda_0)$ can be converted to $R_{rs}(555)$ using the following equations, with s_w as a threshold value:

If $\lambda_0 = 555 \pm 2$ nm,

$$R_{rs}(555) = R_{rs}(\lambda_0) \tag{5}$$

If $R_{rs}(\lambda_0) < s_w$,

$$R_{rs}(555) = 10^{(a_1 * log_{10}(R_{rs}(\lambda_0)) - b_1)} \tag{6}$$

If $R_{rs}(\lambda_0) \geq s_w$,

$$R_{rs}(555) = a_2 * R_{rs}(\lambda_0) - b_2 \tag{7}$$

For different spectral bands (λ_0), s_w and a_1, b_1, a_2, and b_2 values are shown in Table 2.

Table 2: Spectral band specific coefficients of s_w, a_1, b_1, a_2, and b_2.

Spectral range (λ_0, nm)	s_w	a_1, b_1	a_2, b_2
543 - 547	0.001723	0.986; 0.081495	1.031; 0.000216
548 - 552	0.001597	0.988; 0.062195	1.014; 0.000128
558 - 562	0.001148	1.023; -0.103624	0.979; -0.000121
563 - 567	0.000891	1.039; -0.183044	0.971; -0.000170

Previous Versions

The OCI blending approach has been used since R2014 following a modified version of Hu et al., 2012. The modification applied a transition zone of 0.15 < CI < 0.2, which differs from that reported in the original paper. Note that the current version uses the CI parameterization described in Hu et al., 2019, with OCx provided in O'Reilly & Werdell, 2019 instead of the OCx version described in the original paper. Prior to R2014, variations of OCx were used to retrieval chlor_a, such as O'Reilly et al., 1998 and O"Reilly et al., 2000.

3.2.1. Assumptions

The hybrid algorithms provide the most consistent and accurate chlor_a product for the global ocean.

3.3. Algorithm Input Variables

Name	Long Name	Unit
R_{rs}	remote sensing reflectance	sr^{-1}

3.4. Algorithm Output Variables

Name	Long Name	Unit
chlor_a	chlorophyll a	mg m^{-3}

4. Algorithm Availability

4.1. Location of Implemented Algorithm #1

URL **https://oceancolor.gsfc.nasa.gov/docs/ocssw/get__chl_8c.html**

DESCRIPTION **This is the source code of SeaDAS for chlor_a product producing. chlor_a products could be obtained from satellite remote sensing data using SeaDAS GUI or command line following the instructions on this**

help page: https://seadas.gsfc.nasa.gov/help-8.3.0/processors/ProcessL2gen.html#PRODUCTS_TAB.

5. Algorithm Usage Constraints

There is no limitation on the chlor_a product usage, but a validation of the corresponding products for a local study area may be necessary.

6. Performance Assessment Validation

6.1. Performance Assessment Validation Methods

After application of the chlor_a algorithms, chlor_a products derived from satellite remote sensing data were validated using in situ data archived in the NASA SeaWiFS Bio-optical Archive and Storage System (SeaBASS; Werdell et al., 2003). Following Bailey & Werdell, 2006, the following search criteria were used to find the satellite-in situ matching pairs: sensor zenith angle <60°, solar zenith angle <75°, 3-hr time difference between in situ and satellite measurements, median value of coefficients of variation (calculated as standard deviation divided by mean) of several products (R_{rs} between 405 and 570 nm, aerosol optical thickness at 869 nm) <15% for the 5 × 5 pixel window centered at the in situ station; >50% pixels in the 5 × 5 box must be valid (i.e., not associated with any of the standard quality-control flags such as straylight and high glint).

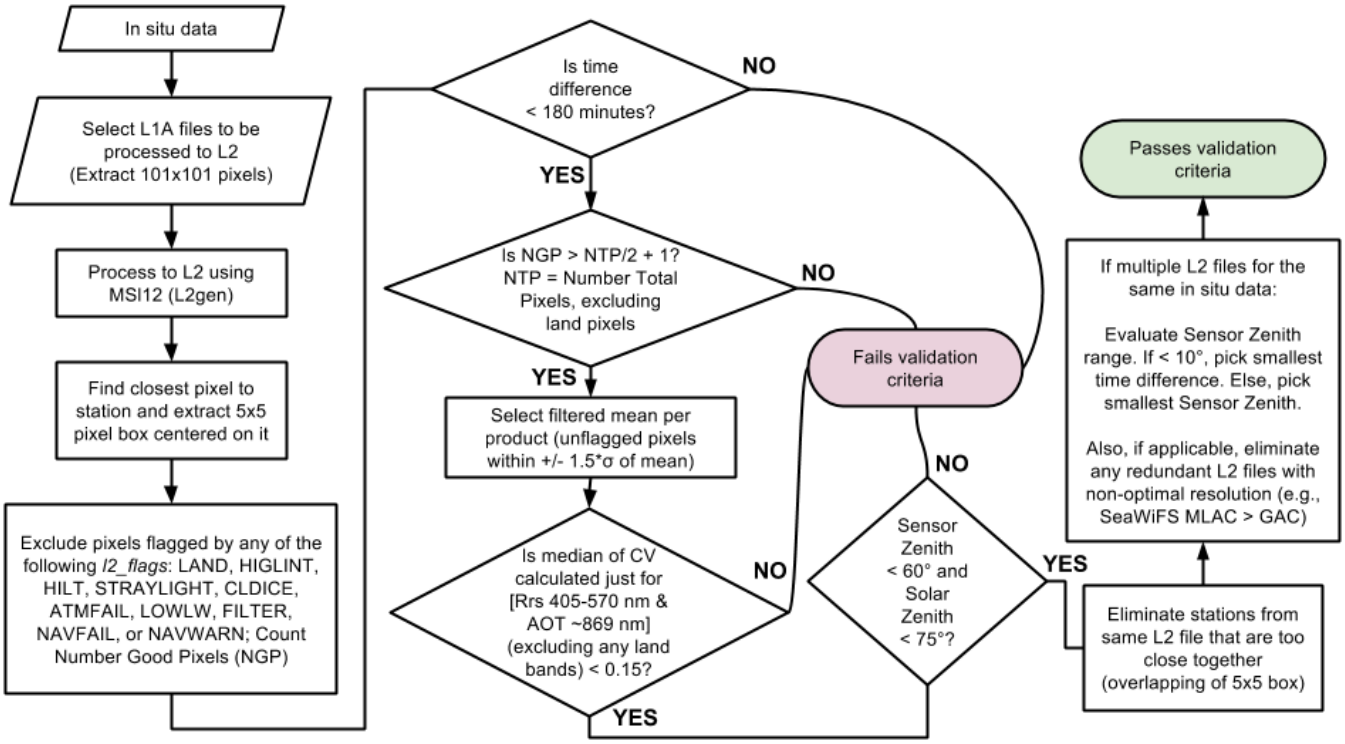

Figure 3: Flowchart of validation processing highlighting the applied exclusion criteria. Adapted and updated from Bailey and Werdell (2006).

This approach of validation is operationally applied by the OBPG to most ocean color sensors. There are a few key recommendations we make from our experience applying the described method to satellite data:

(1) Use a consistently processed in situ data set

(2) Eliminate suspect in situ data (e.g. from optically shallow waters) from the validation set

(3) Use a narrow time window for determining coincidence (i.e. no more than ± 3 h) between in situ and satellite data records

(4) Use native resolution satellite products (i.e. avoid sub-sampled data)

(5) Use the mean of a 5 × 5 pixel box centered on the in situ location

(6) Appropriately mask satellite pixels on the L2 flags

(7) Use a homogeneity test (e.g. CV) to minimize the impact of geophysical variability in the 5 × 5 pixel box on the satellite measurement mean

Following these recommendations will aid in the analysis of the resulting validation results by minimizing the systemic uncertainties.

6.2. Performance Assessment Validation Uncertainties

Sources of uncertainty include those associated with the measurement of in situ R_{rs} and chlor_a, those associated with the retrieved satellite R_{rs}, the algorithm forms themselves (that may not properly represent the data) and their fitting routines, and uncertainties associated with data editing. More details could be found in IOCCG report 18 IOCCG, 2019, Heidi M. Dierssen, 2010, and McKinna et al., 2019.

6.3. Performance Assessment Validation Errors

Based on McClain, 2009, the satellite data product accuracy goals generally accepted by the international community are ± 5% for water-leaving radiances and ± 35% for chlor_a in the open ocean. The PACE mission adopted more rigorous uncertainties for R_{rs} retrieved by its Ocean Color Instrument Ahmad et al., 2018. A number of evaluations have been published, such as the global analyses by Gregg & Casey, 2004 (SeaWiFS chlor_a) and Bailey & Werdell, 2006 (SeaWiFS water-leaving radiances, chlor_a, and K(490)) to name only a very few, and the regional analysis by Zibordi et al., 2006 that compared SeaWiFS, MODIS, and MERIS water-leaving radiances to SeaPRISM observations from the Acqua Alta tower. Overall, these results indicate quite good performance. However, regional differences can be large.

Validation of chlor_a retrievals was performed relative to all available match-ups from SeaBASS. Statistical analysis, scatter plots and frequency distribution comparisons of the satellite to in situ match-ups are provided for each mission (SeaWiFS, MODIS Aqua/Terra, VIIRS SNPP/NOAA20, MERIS, OLCI S3A/S3B) on the following web pages:

https://oceancolor.gsfc.nasa.gov/data/reprocessing/r2022/seawifs/

https://oceancolor.gsfc.nasa.gov/data/reprocessing/r2022/aqua/

https://oceancolor.gsfc.nasa.gov/data/reprocessing/r2022/terra/

https://oceancolor.gsfc.nasa.gov/data/reprocessing/r2022/snpp/

https://oceancolor.gsfc.nasa.gov/data/reprocessing/r2022/noaa20/

https://oceancolor.gsfc.nasa.gov/data/reprocessing/r2022/meris/

https://oceancolor.gsfc.nasa.gov/data/reprocessing/r2022/s3a/

https://oceancolor.gsfc.nasa.gov/data/reprocessing/r2022/s3b/

7. Data Access

7.1. Input Data Data Access

7.1.1. Entry #1

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

DESCRIPTION **Rrs or level 2 remote sensing reflectance are inputs for chlor_a production. They can be downloaded from the ocean color website following the different methods described in the link.**

7.2. Output Data Data Access

7.2.1. Entry #1

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

DESCRIPTION **chlor_a as one of the NASA standard products can be downloaded from the ocean color website following the different methods described in the link.**

7.3. Important Related URLs

7.3.1. Entry #1

URL https://seabass.gsfc.nasa.gov/search#val

DESCRIPTION **SeaBASS validation search provides the satellite chlor_a products versus in situ data validation.**

Entry #2

URL	https://oceancolor.gsfc.nasa.gov/atbd/chlor_a/
DESCRIPTION	chlor_a algorithm description on Ocean Color website.

8. Contacts

Chuanmin Hu

ROLES	Methodology, Corresponding Author & Investigation
AFFILIATIONS	University of South Florida
EMAIL	huc@usf.edu
URL	https://www.usf.edu/marine-science/faculty/faculty-directory/physical-oceanography/chuanmin-hu.aspx

P. Jeremy Werdell

ROLES	Corresponding Author, Methodology, Writing – review & editing & Investigation
AFFILIATIONS	NASA Goddard Space Flight Center
EMAIL	jeremy.werdell@nasa.gov
URL	https://science.gsfc.nasa.gov/sci/bio/jeremy.werdell
UUID	https://orcid.org/0000-0002-3592-0152

Sean Bailey

ROLES	Project administration, Supervision & 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

Ivona Cetinic

ROLES	Writing – original draft & Writing – review & editing

AFFILIATIONS No affiliations in this document

EMAIL ivona.cetinic@nasa.gov

URL https://science.gsfc.nasa.gov/sed/bio/ivona.cetinic

UUID https://orcid.org/0000-0002-1363-3136

Guoqing Wang

ROLES Writing – review & editing

AFFILIATIONS No affiliations in this document

EMAIL guoqing.wang@nasa.gov

URL https://science.gsfc.nasa.gov/sed/bio/guoqing.wang

References

Ahmad, Z., Cetinic, I., Franz, B. A., Karakoylu, E. M., McKinna, L. I., Patt, F. S. & Werdell, P. J. (2018). PACE technical report series, volume 6: data product requirements and error budgets consensus document. *PACE technical report series, 6,*

Bailey, S. W. & Werdell, P. J. (2006). A multi-sensor approach for the on-orbit validation of ocean color satellite data products. *Remote Sensing of Environment, 102(1),* 12--23. https://doi.org/10.1016/j.rse.2006.01.015

Gordon, H. R., Clark, D. K., Mueller, J. L. & , W. A. H. (1980). Phytoplankton Pigments from the Nimbus-7 Coastal Zone Color Scanner: Comparisons with Surface Measurements. *Science, 210(4465),* 63--66. https://doi.org/10.1126/science.210.4465.63

Gregg, W. W. & Casey, N. W. (2004). Global and regional evaluation of the SeaWiFS chlorophyll data set. *Remote Sensing of Environment, 93(4),* 463--479. https://doi.org/10.1016/j.rse.2003.12.012

Heidi M. Dierssen (2010). Perspectives on empirical approaches for ocean color remote sensing of chlorophyll in a changing climate. *Proceedings of the National Academy of Sciences, 107(40),* 17073--17078. https://doi.org/10.1073/pnas.0913800107

Hu, C., Feng, L., Lee, Z., Franz, B. A., Bailey, S. W., Werdell, P. J. & Proctor, C. W. (2019). Improving Satellite Global Chlorophyll a Data Products Through Algorithm Refinement and Data Recovery. *Journal of Geophysical Research: Oceans, 124(3),* 1524--1543.

Hu, C., Lee, Z. & Franz, B. (2012). Chlorophyll aalgorithms for oligotrophic oceans: A novel approach based on three-band reflectance difference. *Journal of Geophysical Research: Oceans, 117(C1),*

IOCCG (2019). Uncertainties in Ocean Colour Remote Sensing. *Reports of the International Ocean Colour Coordinating Group, No. 18,* https://doi.org/10.25607/OBP-696

McClain, C. R. (2009). A Decade of Satellite Ocean Color Observations. *Annual Review of Marine Science, 1(1),* 19-42. https://doi.org/10.1146/annurev.marine.010908.163650

McKinna, L. I. W., Cetini{\' c}, I., Chase, A. P. & Werdell, P. J. (2019). Approach for Propagating Radiometric Data Uncertainties Through NASA Ocean Color Algorithms. *Frontiers in Earth Science, 7,* https://doi.org/10.3389/feart.2019.00176

O"Reilly, J. E., Maritorena, S., Siegel, D. A., O"Brien, M. C., Toole, D., Mitchell, B. G., Kahru, M. et al. (2000). Ocean color chlorophyll a algorithms for SeaWiFS, OC2, and OC4: Version 4.

O'Reilly, J. E., Maritorena, S., Mitchell, B. G., Siegel, D. A., Carder, K. L., Garver, S. A., Kahru, M. et al. (1998). Ocean color chlorophyll algorithms for SeaWiFS. *Journal of Geophysical Research: Oceans, 103(C11),* 24937--24953.

O'Reilly, J. E. & Werdell, P. J. (2019). Chlorophyll algorithms for ocean color sensors - OC4, OC5 & OC6. *Remote Sensing of Environment, 229,* 32--47.

Valente, A., Sathyendranath, S., Brotas, V., Groom, S., Grant, M., Taberner, M., Antoine, D. et al. (2016). A compilation of global bio-optical in situ data for ocean-colour satellite applications. *Earth System Science Data, 8(1),* 235--252. https://doi.org/10.5194/essd-8-235-2016

Werdell, P. J., Bailey, S., Fargion, G., Pietras, C., Knobelspiesse, K., Feldman, G. & McClain, C. (2003). Unique data repository facilitates ocean color satellite validation. *Eos, Transactions American Geophysical Union, 84(38),* 377--387. https://doi.org/10.1029/2003EO380001

Werdell, P. J. & Bailey, S. W. (2005). An improved in-situ bio-optical data set for ocean color algorithm development and satellite data product validation. *Remote Sensing of Environment, 98(1),* 122--140.

Zibordi, G., Holben, B., Hooker, S. B., Melin, F., Berthon, J., Slutsker, I., Giles, D. et al. (2006). A network for standardized ocean color validation measurements. *Eos, Transactions American Geophysical Union, 87(30),* 293-297. https://doi.org/10.1029/2006EO300001