DATA PRODUCT SPECIFICATION FOR PHOTOSYNTHETICALLY ACTIVE RADIATION (PAR)

FROM INSTRUMENTS ON CABLED SHALLOW PROFILERS

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Document Control Sheet

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Signature Page

This document has been reviewed and approved for release to Configuration Management.

OOI Chief Systems Engineer: ______________________________________

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This document has been reviewed and meets the needs of the OOI Cyberinfrastructure for the purpose of coding and implementation.

OOI CI Signing Authority: ______________________________________

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1 Abstract

This document describes the computation used to calculate the OOI Level 1 Photosynthetically Active Radiation (PAR) data product (OPTPARW), which is calculated using the linear calibration equation. This DPS pertains only to the data product produced from the Satlantic and Sea-Bird PAR sensors deployed on the Cabled Shallow Profiler. This document is intended to be used by OOI programmers to construct appropriate processes to create the Level 1 OPTPARW product.

2 Introduction

2.1 Author Contact Information

Please contact help@oceanobservatories.org for more information concerning the computation and other items in this document.

2.2 Metadata Information

2.2.1 Data Product Name

The OOI Core Data Product Name for Photosynthetically Active Radiation (PAR) data product is OPTPARW

The OOI Core Data Product Descriptive Name for this product is PAR (Photosynthetically Active Radiation)

2.2.2 Data Product Abstract (for Metadata)

The OOI Level 1 Photosynthetically Active Radiation (PAR) (OPTPARW) core data product is the spectral range (wavelength) of solar radiation from 400 to 700 nanometers that photosynthetic organisms are able to use in the process of photosynthesis.

2.2.3 Computation Name

Not required for data products.

2.2.4 Computation Abstract (for Metadata)

This computation takes a digital voltage output from the PAR sensor and computes the OOI Level 1 OPTPARW (PAR) core data product using the linear calibration equation provided by the manufacturers. The linear calibration equation is identical between the Satlantic and Sea-Bird PAR sensors.

2.2.5 Instrument-Specific Metadata

There are no instrument-specific metadata that need to be added for the algorithm.

2.2.6 Data Product Synonyms

Synonyms for this data product are

- PAR
- Photosynthetically Active Radiation
- Photosynthetically Available Radiation

2.2.7 Similar Data Products

N/A

2.3 Instruments

The instruments in use include an 'In Water Digital Linear PAR Sensor Model PAR LIN 600m' from Satlantic and an 'In Water to 1000m PAR-SER' from Sea-Bird**.** The PAR sensor measures the spectral range between 400 to 700 nanometers (nm). PAR is normally quantified as micromoles of quanta per square meter per second (μmol photons•m^{-2}•$second^{-1}$), which is a measure of the photosynthetic photon flux (area) density (PPFD). PAR also may reported in units of microeinsteins per second per square meter (μE•m^{-2}•s^{-1}), which is equivalent to μmol photons •m^{-2}• s^{-1}. For information on the instrument from which the Level 1 OPTPARW core data product inputs are obtained, see the PARAD Processing Flow document (DCN 1342-00720). This document describes the flow of data from the PARAD sensor through all of the relevant QC, calibration, and data product computations and procedures.

Please see https://oceanobservatories.org/instruments/ for specifics of instrument locations, platforms, and model numbers.

2.4 Literature and Reference Documents

Satlantic PAR Sensor Operation Manual
(see OOI > Reference Archive > Data Product Specification Artifacts > 1341-00720_OPTPARW > PAR Sensor Manual July 2011.pdf)

Sea-Bird PAR Sensor Operation Manual
(see OOI > Reference Archive > Data Product Specification Artifacts > 1341-00720_OPTPARW > Seabird PAR Sensor Manual April 2018.pdf)

2.5 Terminology

2.5.1 Definitions

Photosynthetically Active Radiation (PAR**):** Photosynthetically Active Radiation (PAR) designates the spectral range (wavelength) of solar radiation that photosynthetic organisms are able to use in the process of photosynthesis. The PAR sensor measures the spectral range between 400 to 700 nanometers (nm). PAR is normally quantified as micromoles of quanta per square meter per second (μmol photons•m^{-2}•$second^{-1}$), which is a measure of the photosynthetic photon flux (area) density (PPFD). PAR also may reported in units of microeinsteins per second per square meter (μE•m^{-2}•s^{-1}), which is equivalent to μmol photons •m^{-2}• s^{-1}. PAR is an important parameter used in energy balance models, ecosystem characterization, and productivity analyses for oceanic and climological studies.

2.5.2 Acronyms, Abbreviations and Notations

General OOI acronyms, abbreviations and notations are contained in the Level 2 Reference Module in the OOI requirements database (DOORS). The following acronyms and abbreviations are defined here for use throughout this document.

PAR	Photosynthetically Active Radiation (400-700 nm)
PPFD	Photosynthetic Photon Flux Density

2.5.3 Variables and Symbols

The following variables and symbols are defined here for use throughout this document.

PAR	Photosynthetically Active Radiation (400-700 nm) in μmol photons•m^{-2}• s^{-1}
Im	immersion coefficient
a_1	scaling factor in μmol photons•m^{-2}• s^{-1} • count-^{1}
a_0	voltage offset in counts

x voltage in ADC counts

The analog sensor measures voltage. The digital version converts the analog voltage onboard to counts (i.e., analog to digital conversion = ADC counts).

3 Theory

3.1 Description

Photosynthetically Active Radiation (PAR) designates the spectral range (wave band) of solar radiation from 400 to 700 nanometers that photosynthetic organisms are able to use in the process of photosynthesis. Each PAR value is an integrated number of the solar radiation at each wavelength between 400 to 700 nm and reported as µmol photons $\bullet m^{-2} \bullet s^{-1}$. PAR is a function of Date, Time, Latitude, Longitude, and Depth. Latitude, Longitude, and Depth are metadata associated with the Level 0 and Level 1 sensor products. The computational technique is a linear conversion from Level 0 counts to Level 1 PAR µmol photons $\bullet m^{-2} \bullet s^{-1}$.

3.2 Mathematical Theory

See section 4.3

3.3 Known Theoretical Limitations

The Satlantic sensor operation is valid for operating temperatures between -40 and 85°C. The Sea-Bird sensor operation is valid for operating temperatures between -40 and 40°C. Typical measurement range for both manufacturers is 0 – 5,000 µmol photons $\bullet m^{-2} \bullet s^{-1}$.

3.4 Revision History

This document was revised in March 2020 to incorporate specifications and details for a newly implemented PAR sensor model from Sea-Bird.

4 Implementation

4.1 Overview

L1 OPTPARW algorithm is a simple linear scaling and offset defined by instrument calibration.

4.2 Inputs

- Level 0 OPTPARW output in ADC counts
- Im, a_1 *and* a_0 are from instrument-specific calibration metadata

All inputs are double precision floating point numbers. It should be noted that though the ASCII output formats differ between the Satlantic and Sea-Bird PAR sensors, the input to the DPA is the same across these models and remains L0 OUPTPARW output in ADC counts. Also of note, in addition to outputting PAR voltage in counts, which are converted to PAR values using the DPA and provided as “Photosynthetically Active Radiation (µmol photons m-^{2} s^{-1}), the Sea-Bird PAR sensor also calculates PAR on-board the sensor and outputs these values in the full ASCII frame. These on-board PAR values are provided in the OPTPARW data stream as “Measured Photosynthetically Active Radiation (µmol photons m^{-2} s^{-1}).

The computation described herein only produces valid results when the inputs are within the range of 0 – 5,000 µmol photons $\bullet m^{-2} \bullet s^{-1}$over the light spectrum of 400 to 700 nm.

Range checks on the inputs are applied as part of the global range check (GLBLRNG, DCN 1341-10004) specified in the PARAD Processing Flow document (DCN 1342-00720). A separate range check on the inputs does not need to be applied.

Input Data Formats:
The Satlantic Digital PAR instrument data format follows the Satlantic Data Format Standard given in the table below. An example output from the Satlantic Digital PAR is

SATPAR0229,10.01,2206748544,234

Field Name	Field Size (bytes)	Description
Instrument	6	A unique 6 character AS formatted string denoting the start of a frame of telemetry. For the Digital PAR sensor, the instrument string is “SATPAR”.
Serial Number	4	An AS/AI formatted string denoting the serial number of the instrument. This field combined with the INSTRUMENT field uniquely identifies the instrument. This combination is known as the frame header or synchronization string.
Comma	1	Comma delimiter
Timer	4 - 10	The field is an AF formatted string indicating the number of seconds that have passed since the end of the initialization sequence. This field is precise to two digits after the decimal.
Comma	1	Comma delimiter
PAR counts	10	An AU formatted value representing the sampled Analog-to-Digital converter counts.
Comma	1	Comma delimiter
Checksum	1-3	The checksum is the two's complement of the least significant byte of the sum of the ASCII codes of all characters in a given frame, up to and including the comma right before the checksum. This includes commas and periods.
Terminator	2	This field indicates the end of the frame. The frame is terminated by a carriage return/line feed pair ($0D_{hex}$ and $0A_{hex}$).

The Sea-Bird Digital PAR instrument data format follows the Sea-Bird Data Format Standard given in the table below. An example output from the Sea-Bird Digital PAR is

SATPRL9999,1.468,22.784,2.2,0.7,27.3,LIN, 34174366,0.092377499,0.1465022,-13,-1011,38,1759,0.773,0,230

The full ASCII output includes:

Field name	Field size, bytes	Description
Instrument	6	AS-formatted string that is the start of a frame
Serial number	4 1 – 10 permitted	AS- or AI-formatted string. the Instrument and Serial number are the frame header.
Comma	1	Delimiter
Timer	5 - 11	AF-formatted value that shows how many seconds have passed since the end of the start sequence. Accurate to three decimal places.
Comma	1	Delimiter
PAR	5 - 9	AF-formatted value that shows the calculated PAR in

		μmol/m²/s
Comma	1	Delimiter
Pitch	3 – 5	AF-formatted value that shows the pitch angle of the sensor in degrees. Accurate to one decimal place.
Comma	1	Delimiter
Roll	3 – 5	AF-formatted value that shows the roll angle of the sensor in degrees. Accurate to one decimal place.
Comma	1	Delimiter
Internal temperature	3 – 5	AF-formatted value that shows the internal temperature of the sensor in degrees C. Accurate to one decimal place.
Comma	1	Delimiter
Analog mode	3	AF-formatted value that shows the analog output mode of operation. LIN = linear mode; LOG = logarithmic mode.
Comma	1	Delimiter
PAR counts	8	AU-formatted value that shows the Analog-to-Digital Converter counts.
Comma	1	Delimiter
ADC volts	11 – 12	AF-formatted value that shows the voltage at the input of the ADC used for PAR measurements. Accurate to nine decimal places.
Comma	1	Delimiter
Votlage out	9	AF-formatted value that shows the voltage output on the analog interface. Accurate to seven decimal places.
Comma	1	Delimiter
X axis	1 – 5	AI-formatted value that shows the raw signed counts from the accelerometer X-axis.
Comma	1	Delimiter
Y axis	1 – 5	AI-formatted value that shows the raw signed counts from the accelerometer Y axis.
Comma	1	Delimiter
Z axis	1 – 5	AI-formatted value that shows the raw signed counts from the accelerometer Z axis.
Comma	1	Delimiter
T counts	1 – 5	AI-formatted value that shows the raw counts from the temperature sensor ADC.
Comma	1	Delimiter
T volts	5	AF-formatted value that shows the voltage at the input of the ADC used for temperature measurements. Accurate to three decimal places.
Comma	1	Delimiter
Status	1 – 3	AI-formatted valued that shows the status of the sensor. Shows as 0.
Comma	1	Delimiter
Checksum	1 – 3	A value that verifies the validity of the data frame.
Terminator	2	This field is the end of the frame, <CR-LF>

4.3 Processing Flow

The specific steps necessary to create all calibrated and quality controlled data products for each OOI core instrument are described in the instrument-specific Processing Flow documents (DCN 1342-00720 for the PARAD instrument). These processing flow documents contain flow diagrams detailing all of the specific procedures (data product and QC) necessary to compute all levels of data products from the instrument and the order in which these procedures should be applied.

A linear fitting function is used to convert between output ADC counts and PAR. The relationship between PAR and counts is described by:

*PAR (*μmol photons •m^{-2}• s^{-1}*)* = Im * $a_1 (x - a_0)$

where Im is the immersion coefficient, a_1 is the scaling factor in μmol photons per m^2 per second per count, a_0 is the voltage offset in counts, and x is the Level 0 output in counts. These values can be found on the sensor calibration sheets and are part of the instrument-specific metadata.

NOTE: CI will specify the instrument-specific attributes (metadata) using a short name as well as a descriptive name. For example, scaling factor will be named 'a_1' and offset will be named 'a_0'.

Note that several QC routines are carried out on these data after the L1 data product has been produced, as shown in the PARAD Processing Flow document (DCN 1342-00720). Specifically we perform a global range test (DCN 1341-10004); a local range test (DCN 1341-10005) based on latitude, longitude, and depth; and a trend test (DCN 1341-10007) to check for the absence of exponential decay with depth in the data. Note that this trend test will automatically catch data that erroneously increase with depth, another sign that the data are suspect and should be flagged. In addition, we evaluate orientation data (distance from vertical) from a tilt sensor located on the shallow profiler science pod using the global range test (DCN 1341-10004) as part of the QC routine of the PAR data. Additional QC that are sometimes performed on these types of data sets, but that are NOT performed on OOI OPTPARW data, include checking near-surface data (0 - 5 m depending on wave height) for wave focusing and defocusing and horizontal light effects.

NOTE: Eric McRae (UW) has redefined the SP-EMS ICD. The orientation data will be in a 3 x 3 matrix such that:

[Oc] = [M] * [Or] where
Oc current orientation vector (X,Y,Z)
M = orientation matrix
* = dot product
Or = Reference orientation vector (X=North, Y=East, Z=Down)

4.4 Outputs

The output of the OPTPARW computation is

- Photosynthetically Active Radiation is in μmol photons •m^{-2}• s^{-1} as a double precision floating point number.

See Appendix B for a discussion of the accuracy of the output.

4.5 Computational and Numerical Considerations

4.5.1 Numerical Programming Considerations

There are no numerical programming considerations for this computation. No special numerical methods are used.

4.5.2 Computational Requirements

- Assuming we are processing the data in near real time and that one sample is a single data point from any PARAD sensor, an example number of samples are as follows.

- Cabled Shallow profilers: This estimate assumes that the PAR sensor will sample at a maximum of 7 Hz (7 samples/second) over a 200 m depth, with a profiler moving at 50 cm/sec rise (7 min up) and a 10 cm/sec return down (33.3 min down). There will be a total of nine profiles per day, allowing for additional time for adaptive sampling. The up-profile would be relatively fast up to measure small-scale vertical gradients in parameters for sensors having relatively rapid sampling times (≥ 1 Hz). The down profiles will be slower and/or stepped to allow time for the slower response sensors (e.g., pH and pCO2 sensors) to make measurements.
- Assuming that PAR data are collected on both the up and down casts for 365 days = 5.5 $*10^7$ samples per year. Additional samples will be collected as part of adaptive sampling efforts.

4.6 Code Verification and Test Data Set

The code will be verified using the test data set provided, which contains inputs and their associated correct outputs. CI will verify that the code is correct by checking that the output, generated using the test data inputs, is identical to the test data density output.

In addition to the test data set in Table 1, PAR test data were generated in an RCA test tank in January 2012. A copy of these data are in the OPTPARW folder on Alfresco:
OOI > Reference Archive > Data Product Specification Artifacts > 1341-00720_OPTPARW > OPTPARW_Test_Data_2012.txt

Table 1. Example of input and output data from the Satlantic PAR sensor.

Im	1.3589
a0	2156849801
a1	2.59E-06

Instrument ID	Seconds since Initialization	Counts	checksum	µmol photons. m^-2. S^-1
SATPAR0226	2.16	2159403328	27	8.976348585
SATPAR0226	2.29	2159400384	24	8.965999618
SATPAR0226	2.43	2159396992	9	8.954075807
SATPAR0226	2.56	2159400384	24	8.965999618
SATPAR0226	2.7	2159407488	16	8.990972126
SATPAR0226	2.83	2159399296	5	8.962174999
SATPAR0226	2.97	2159400384	19	8.965999618
SATPAR0226	3.1	2159404800	36	8.981523069
SATPAR0226	3.24	2159403904	27	8.978373383
SATPAR0226	3.37	2159402240	31	8.972523967
SATPAR0226	3.5	2159403200	39	8.97589863
SATPAR0226	3.64	2159409728	13	8.998846341
SATPAR0226	3.77	2159409792	8	8.999071318
SATPAR0226	3.91	2159408320	26	8.993896835
SATPAR0226	4.04	2159407808	21	8.992097014
SATPAR0226	4.18	2159402304	30	8.972748944
SATPAR0226	4.31	2159402688	20	8.97409881
SATPAR0226	4.45	2159407552	20	8.991197104
SATPAR0226	4.58	2159404160	24	8.979273293
SATPAR0226	4.72	2159403776	16	8.977923428
SATPAR0226	4.85	2159402048	21	8.971849034
SATPAR0226	4.99	2159404544	13	8.980623159

Appendix A Output Accuracy

The accuracy of the OPTPARW (PAR) data calculated as described herein is a function of the accuracy of the input voltage in ADC counts. The typical measurement range is 0 – 5,000 μmol photons $\bullet m^{-2} \bullet s^{-1}$. Digital output resolution is 24-bit ADC data represented in 32-bit offset binary format.

Both Satlantic and Sea-Bird state the following optical specifications in their individual instrument guides:
Calibrated range: 0 – 5,000 μmol photons$\bullet m^{-2} \bullet s^{-1}$

"Cosine Collector" (Satlantic), "Cosine Error" (Sea-Bird): within 3% @ 0 - 60ºC, within 10% @ 60 – 85ºC

Satlantic also states that they have a Calibration Accuracy: ± 5% NIST Traceable (in air)

The DOORS L4-level requirement for accuracy (L4-RSN-IP-RQ-339):
The SSM Instrument for Downwelling spectral irradiance for PAR shall measure with an accuracy of ±5%.

L2 PAR accuracy (L2-SR-RQ-3673):
PAR shall be measured with an accuracy of ±5%.

Appendix B Sensor Calibration Effects

The PAR sensor should be calibrated using a NIST-traceable lamp with a known spectral response or sent back to the manufacturer for calibration. Calibration accuracy is ± 5% NIST Traceable (in air).

The PAR sensor must be placed on the profiler so that it is clear of any shadows or obstruction of surface light and the sensor must be placed level. The profiler should include a tilt meter, so that if the PAR sensor becomes tilted, the tilt meter can allow a back calculation to level light profiles.

Upon deployment, the PAR sensor may be field validated using another PAR sensor on a CTD cast, as well as profiles using absorption and transmissometer instruments. Beam attenuation may be used to estimate diffuse attenuation and then PAR values. Comparison with other PAR sensors should show the same relative pattern with depth, but the spectral response may differ. PAR sensor values should be similar within ±5%.