DATA PRODUCT SPECIFICATION FOR PHOTOSYNTHETICALLY ACTIVE RADIATION (PAR)

FROM WET LABS INSTRUMENT ON COASTAL SURFACE PIERCING PROFILER

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1-00	2014-12-04	Initial Draft	J. Fram
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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 an exponential calibration equation for the WET Labs ECOPARS. There is a Satlantic PAR sensor in the WET Labs ECOPARS instrument, but it uses a different calibration equation than the Satlantic PAR described in DPS 1341-00720. This DPS pertains only to ECPPARS on the coastal surface piercing profilers (CSPP) (PARAD-J). 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 Jonathan Fram (jfram@ceoas.oregonstate.edu or the Data Product Specification lead (DPS@lists.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 an exponential calibration equation provided by the manufacturer, WET Labs.

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 WET Labs instrument is an 'ECO PAR'. The WET Labs PAR defines the spectral range as 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 the Instrument Application in the SAF for specifics of instrument locations and platforms.

2.4 Literature and Reference Documents

WET Labs ECO PAR sensor
User Manual
Edition 5
Date: 2014-05

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 Satlantic PAR sensor defines the spectral range as 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 climatological 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

Sensor operation is valid for operating temperatures between 00 and 30°C. Typical measurement range is 0 – 6,600 µmol photons $\bullet m^{-2} \bullet s^{-1}$.

3.4 Revision History

No revisions to date.

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.

The computation described herein only produces valid results when the inputs are within the range of 0 – 6,600 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 data format for the WET Labs PAR instrument on the CSPP follows the format given in the table below. CI will receive an ASCII file with PAR data for each profile. The file contains a header, data records, and a footer. An example file is:

Source File: C:\data\ooi\CSPP\uCSPP_2014_04_14_deploy\recoveredData\11079505.PPB
Processed: 06/12/2014 19:48:19
Using Version: 1.10
Device: PARS
Start Date: 04/17/2014

Timestamp (s)	Depth (m)	Data		
1397774912.129	23.130	mvs 1		
1397774913.714	23.156	04/17/14	15:42:50	4426
1397774914.851	23.157	04/17/14	15:42:52	4444

```
1397774916.002      23.134  04/17/14        15:42:53        4489
…
1397775112.818      0.676   04/17/14        15:46:10        11065
1397775113.958      0.685   04/17/14        15:46:11        11032
1397775115.966      0.685   mvs 0
1397775115.972      0.685   Ser PARS-365
1397775115.982      0.685   Ver PARS 4.04
1397775115.991      0.685   Ave 355
1397775115.995      0.685   Pkt 0
1397775116.002      0.685   Set 0
1397775116.005      0.685   Rec 1
1397775116.008      0.685   Asv 4
1397775116.011      0.685   Int 00:00:05
1397775116.019      0.685   Dat 04/17/14
1397775116.029      0.685   Clk 15:46:13
1397775116.039      0.685   Mem 1254
```

The header is similar to the header on all of the CSPP files.

- The Source file line refers to the log file the ASCII data were parsed from by the CSPP control software.
- The Processed line lists the date the file was parsed by the CSPP control software
- The Version line refers to the version of the log-to-ASCII parser
- The Device is a WET Labs ECOPARS
- The Start Date line refers to the start of the profile
- The next header line labels the records by Timestamp, Depth, and Data.
- The final header has a timestamp, depth, and mvs 1. mvs 1 indicates that the PAR's shutter was opened. The timestamp is in seconds from 1970-01-01 midnight (i.e. UNIX time). It is time measured by the profiler, not by the PAR. The depth is the depth measured by the profiler's CTD at the timestamp time. There is a vertical offset between the CSPP's PAR location and its CTD pressure sensor. The CTD measures at 16 Hertz.

The data record is tab delimited and includes UNIX time in seconds, CTD pressure in decibars which is equivalent to depth in meters for the outputted precision in shallow water, mm/dd/yy as measured by the PAR, HH:MM:SS as measured by the PAR, and counts as measured by the PAR. Ignore the PAR's date and time data. The profiler's UNIX time stamp should be the time stamp associated with these data. The PAR's clock is known to drift. The profiler's clock is synched to GPS periodically and all other profiler sensor data uses the profiler's time stamp.

The footer is similar to footer on all WET Labs instruments, such as the ECO Triplet.

- The first line of the footer should have mvs 0, indicating that the PAR's anti-fouling shutter has been closed over the instrument's sensor.
- The Ser line is the serial number of the instrument
- The Ver line is instrument's firmware version
- Ave is the number of measured that make up each data record. It is a number between 1 and 655535.
- Pkt is the number of data records collected between each set of measurements (Int). Zero is one data record per interval (Int).
- Set is the number of data records that are output between low-power states. This sensor is run continuously during each profiler, so this setting is irrelevant.
- Rec is whether the sensor's internal memory is on (1) or off (0). All data are streamed to and stored on the profiler's control can, so the data on the sensor are never utilized.
- Asv
- Int is the interval in seconds between sets of data.
- Dat is the PAR instrument's clock at the end of the profile. Again, it should be ignored because time from the profiler's clock should be associated with these data.

- Clk is PAR instrument's clock at the end of the profile. Again, it should be ignored because time from the profiler's clock should be associated with these data.
- Mem

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 * 10 ^ ($(x - a_0)/ a_1$)

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. This information can be found on the WETLabs calibration sheet 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'.

Reference: WET Labs ECO PAR Sensor User Manual, Edition 5, Date: 2014-05. Pag 13.

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.

The PAR's sensor is flat, so data are affected by pitch and roll of the profiler. However, pitch and roll changes are expected to be small (<3 degrees), so at this time the DPS does not include an equation for correcting for profiler wobbling. The orientation data from the CSPP are output from both its VELPT instrument and its winch as heading, pitch, and roll. One would have to take into account the position of those instruments and the PAR instrument on the CSPP in order to produce an orientation matrix similar to the one for the PAR on the Shallow Profiler (DPS 1341-00720). The VELPT orientation data for each profile are in *_PPB_ADCP.txt files and the winch orientation data are in *_WC_HMR.txt files.

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

- CSPPs collect data only during up-casts. It will sample at 1 Hertz, although the instrument is capable of sampling at up to 8 Hz. The uncabled CSPPs will travel approximately 25 cm per second. The cabled CSPP will travel approximately 10 cm/s.
- The uncabled CSPP at the Pioneer sites will profile from 80 and 100 meters depth. The uncabled CSPP at the Endurance Washington shelf site will profile from 80 meters depth. These platforms will profile twice a day when wave height is less than 3 meters, which works out to about 600 times a year.
- The uncabled CSPPs at the Endurance inshore sites will profile from 25 meters depth. They platforms will profile four times a day when wave height is less than 3 meters, but they are currently planned for deployment only from spring through fall, not fall through spring.
- The cabled CSPP will profile from 80 meters. It will profile eight times a day when wave height is less than 3 meters, which works out to about 2400 times a year.

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 RSN test tank in January 2012. A copy of these data are in the OPTPARW folder on Alfresco:
OOI > REFERENCE > Data Product Specification Artifacts > OPTPARW >
OPTPARW_Test_Data_WETLabs_2014-12-04.zip

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

Im	1.3589
a0	4381
a1	2904

UNIX Time in Seconds	Pressure in Decibars	Instrument Date	Instrument Time	Counts	PAR in µmol photons. m^-2. S^-1
1399161588.43	24.809	5/3/2014	16:53:34	4975	2.176371
1399161589.56	24.693	5/3/2014	16:53:35	4999	2.218183
1399161590.70	24.414	5/3/2014	16:53:36	5077	2.359701
1399161591.84	24.053	5/3/2014	16:53:38	5230	2.664053
1399161592.97	23.681	5/3/2014	16:53:39	5413	3.080062
1399161594.11	23.486	5/3/2014	16:53:40	5483	3.255848
1399161595.26	23.507	5/3/2014	16:53:41	5427	3.114443
1399161596.39	23.617	5/3/2014	16:53:42	5344	2.916078
1399161597.53	23.689	5/3/2014	16:53:43	5285	2.782802
1399161598.67	23.603	5/3/2014	16:53:44	5284	2.780596

1399161599.81	23.337	5/3/2014	16:53:46	5344	2.916078
1399161600.94	22.896	5/3/2014	16:53:47	5470	3.22246
1399161602.08	22.339	5/3/2014	16:53:48	5649	3.713869
1399161603.22	21.748	5/3/2014	16:53:49	5835	4.304039
1399161604.35	21.23	5/3/2014	16:53:50	6007	4.932929
1399161711.28	0.549	5/3/2014	16:55:37	11824	496.8257
1399161588.43	24.809	5/3/2014	16:53:34	4975	2.176371
1399161589.56	24.693	5/3/2014	16:53:35	4999	2.218183
1399161590.70	24.414	5/3/2014	16:53:36	5077	2.359701
1399161591.84	24.053	5/3/2014	16:53:38	5230	2.664053
1399161592.97	23.681	5/3/2014	16:53:39	5413	3.080062
1399161711.28	0.549	5/3/2014	16:55:37	11824	496.8257

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 – 6,500 μmol photons $\bullet m^{-2} \bullet s^{-1}$.

Satlantic states the following in their instrument guide: calibrated range: 0 – 6,500 μmol photons$\bullet m^{-2} \bullet s^{-1}$

"Cosine Collector": 0 - 60º 3%

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

Again, the WET Labs PAR has the same sensor as the Satlantic PAR. The sensor is calibrated by Satlantic to the same range and accuracy.

Digital output resolution of the WET Labs PAR is 14-bit (counts from 0 to 16380).

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%.