DATA PRODUCT SPECIFICATION FOR PHOTOSYNTHETICALLY ACTIVE RADIATION (PAR) FROM SATLANTIC INSTRUMENT ON RSN SHALLOW PROFILER

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## Document Control Sheet

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<th>Date</th>
<th>Description</th>
<th>Author</th>
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Signature Page

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

OOI Chief Systems Engineer: __________________________

Date: 2012-03-06

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

OOI CI Signing Authority: __________________________

Date: 2012-03-06
# Table of Contents

1  Abstract .......................................................................................................................... 1
2  Introduction ..................................................................................................................... 1
   2.1 Author Contact Information ...................................................................................... 1
   2.2 Metadata Information ............................................................................................... 1
   2.3 Instruments ................................................................................................................. 2
   2.4 Literature and Reference Documents ....................................................................... 2
   2.5 Terminology ............................................................................................................... 2
3  Theory ................................................................................................................................ 3
   3.1 Description ................................................................................................................. 3
   3.2 Mathematical Theory .................................................................................................. 3
   3.3 Known Theoretical Limitations .................................................................................. 3
   3.4 Revision History ......................................................................................................... 3
4  Implementation ................................................................................................................ 3
   4.1 Overview ...................................................................................................................... 3
   4.2 Inputs .......................................................................................................................... 3
   4.3 Processing Flow .......................................................................................................... 4
   4.4 Outputs ....................................................................................................................... 5
   4.5 Computational and Numerical Considerations ......................................................... 5
   4.6 Code Verification and Test Data Set ............................................................................ 5
Appendix A  Output Accuracy ............................................................................................... 1
Appendix B  Sensor Calibration Effects ............................................................................... 1
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 Satlantic linear calibration equation. This DPS pertains only to the data product produced from the Satlantic, which is on the RSN 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 Kendra Daly (kdaly@marine.usf.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 Satlantic PAR sensor and computes the OOI Level 1 OPTPARW (PAR) core data product using the linear calibration equation provided by the manufacturer, Satlantic.

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 instrument is an 'In Water Digital Linear PAR Sensor Model PAR LIN 600m'. 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 be 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

Satlantic PAR Sensor Operation Manual
Document Number: SAT-DN-00462
Revision: B
Date: 2011-07-06

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 be 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.

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Definition</th>
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<tbody>
<tr>
<td>PAR</td>
<td>Photosynthetically Active Radiation (400-700 nm)</td>
</tr>
<tr>
<td>PPFD</td>
<td>Photosynthetic Photon Flux Density</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Variable</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>PAR</td>
<td>Photosynthetically Active Radiation (400-700 nm) in µmol photons •m⁻²•s⁻¹</td>
</tr>
<tr>
<td>Im</td>
<td>immersion coefficient</td>
</tr>
<tr>
<td>a₁</td>
<td>scaling factor in µmol photons •m⁻²•s⁻¹ • count⁻¹</td>
</tr>
<tr>
<td>a₀</td>
<td>voltage offset in counts</td>
</tr>
<tr>
<td>x</td>
<td>voltage in ADC counts</td>
</tr>
</tbody>
</table>

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 •m$^{-2}$• 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 •m$^{-2}$• s$^{-1}$.

3.2 Mathematical Theory
See section 4.3

3.3 Known Theoretical Limitations
Sensor operation is valid for operating temperatures between -40 and 85°C. Typical measurement range is 0 – 5,000 µmol photons •m$^{-2}$• 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, a₁ and a₀ 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 – 5,000 µmol photons •m$^{-2}$• 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
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:

\[ PAR (\mu\text{mol photons} \cdot \text{m}^{-2} \cdot \text{s}^{-1}) = \text{Im} \times a_1 (x - a_0) \]

where Im is the immersion coefficient, \( a_1 \) is the scaling factor in \( \mu\text{mol photons} \) per \( \text{m}^2 \) 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 Satlantic 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’.


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 $3 \times 3$ matrix such that:

$$[Oc] = [M] \times [Or]$$

where

- Oc current orientation vector (X,Y,Z)
- M = orientation matrix
- $\times$ = 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 $\mu$mol photons $\cdot m^{-2} \cdot s^{-1}$ 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.
  - Shallow profilers on the RSN: 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 ($\geq 1$ 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 $\times 10^7$ 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 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_2012.txt
Table 1. Example of input and output data from the Satlantic PAR sensor.

<table>
<thead>
<tr>
<th>Instrument ID</th>
<th>Seconds since Initialization</th>
<th>Counts</th>
<th>checksum</th>
<th>µmol photons. m^-2. S^-1</th>
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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 •m⁻²•s⁻¹. Digital output resolution is 24-bit ADC data represented in 32-bit offset binary format.

Satlantic states the following in their instrument guide:
Calibrated range: 0 – 5,000 µmol photons•m⁻²•s⁻¹

“Cosine Collector”: 0 - 60º 3%; 60 – 85º 10%
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%.