NEON ALGORITHM THEORETICAL BASIS DOCUMENT (ATBD) – ABOVE CANOPY AND UNDERSTORY/SNOWPACK PHENOLOGY CAMERA

PREPARED BY	ORGANIZATION	DATE
Michael SanClements	FIU	03/24/2014
Josh Roberti	FIU	02/11/2016
Kaelin M Cawley	AQU	05/19/2017

APPROVALS	ORGANIZATION	APPROVAL DATE
Kate Thibault	SCI	04/20/2022

RELEASED BY	ORGANIZATION	RELEASE DATE
Tanisha Waters	CM	04/20/2022

See configuration management system for approval history.

The National Ecological Observatory Network is a project solely funded by the National Science Foundation and managed under cooperative agreement by Battelle. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation.

Change Record

REVISION	DATE	ECO #	DESCRIPTION OF CHANGE
A	03/30/2016	ECO-03726	Initial release of document
B	04/26/2016	ECO-03830	Update document to correct template format
C	07/12/2017	ECO-04881	Added description of photos collected at AQU sites and table for DP1.20002.
D	04/20/2022	ECO-06809	• Revised logo • Added NEON to document title

TABLE OF CONTENTS

LIST OF TABLES AND FIGURES

1 DESCRIPTION

This document contains information about phenology, snowpack, and/or land-water interface images recorded automatically at all NEON sites. Above-canopy phenology, understory phenology, snowpack, and land-water interface dynamics will be monitored via the Stardot NetCam SC CAM-SEC5IR-B. Specifically, the processes necessary to provide imagery for use in phenological and other ecological studies and their associated uncertainties are described.

1.1 Purpose

This document details the process for creating NEON Level 1 data products from Level 0 data, and ancillary data as defined in this document (such as calibration data), obtained via instrumental measurements made by the Stardot NetCam SC CAM-SEC5IR-B. It includes a detailed discussion of measurement theory and implementation, appropriate theoretical background, data product provenance, quality assurance and control methods used, approximations and/or assumptions made, and a detailed explanation of uncertainty resulting in a cumulative reported uncertainty for this product.

1.2 Scope

The scope of this document encompasses the theoretical background and entire algorithmic process used to derive Level 1 data (i.e. above canopy phenology, understory/snowpack phenology, and land-water interface dynamics) from Level 0 data for NEON's ground-based automated digital Stardot NetCam SC CAM-SEC5IR-B (NEON P/N: 0303510000) cameras. This document does not provide computational implementation details.

2 RELATED DOCUMENTS, ACRONYMS AND VARIABLE NOMENCLATURE

2.1 Applicable Documents

AD[01]	NEON.DOC.000001	NEON OBSERVATORY DESIGN
AD[02]	NEON.DOC.005003	NEON Scientific Data Products Catalog
AD[03]	NEON.DOC.005004	NEON Level 1-3 Data Products Catalog
AD[04]	NEON.DOC.005005	NEON Level 0 Data Products Catalog
AD[05]	NEON.DOC.000782	ATBD QA/QC Data Consistency
AD[06]	NEON.DOC.011081	ATBD QA/QC plausibility tests
AD[07]	NEON.DOC.000783	ATBD De-spiking and time series analyses
AD[08]	NEON.DOC.000746	Evaluating Uncertainty (CVAL)
AD[09]	NEON.DOC.000785	TIS Level 1 Data Products Uncertainty Budget Estimation Plan
AD[10]	NEON.DOC.000751	CVAL Transfer of standard procedure
AD[11]	NEON.DOC.000927	NEON Calibration and Sensor Uncertainty Values[1]
AD[12]	NEON.DOC.001113	Quality Flags and Quality Metrics for TIS Data Products

2.2 Reference Documents

RD[01]	NEON.DOC.000008	NEON Acronym List
RD[02]	NEON.DOC.000243	NEON Glossary of Terms

2.3 Acronyms

Acronym	Explanation
AIS	Aquatic Instrument System
ATBD	Algorithm Theoretical Basis Document
CI	NEON Cyberinfrastructure
CVAL	NEON Calibration, Validation, and Audit Laboratory
DAS	Data Acquisition System
DP	Data Product
FDAS	Field Data Acquisition System
GRAPE	Grouped Remote Analog Peripheral Equipment
Hz	Hertz
L0	Level 0
L1	Level 1
QA/QC	Quality assurance and quality control

2.4 Variable Nomenclature

[1] Note that CI obtains calibration and sensor values directly from an XML file maintained and updated by CVAL in real time. This report is updated approximately quarterly such that there may be a lag time between the XML and report updates.

3 DATA PRODUCT DESCRIPTION

3.1 Variables Reported

The above canopy, understory/snowpack, and land-water interface camera related L1 data product (DP) numbers are provided in the file: phe_datapub_NEONDOC001789.txt.

3.2 Input Dependencies

Tables 1, 2, and 3 detail the above canopy, understory/snowpack, and land-water interface phenology-related L0 DPs used to produce L1 DPs.

Table 1. List of digital camera-related L0 DPs that are transformed into L1 DPs (Phenology images: NEON.DP1.00033).

Description	Sample Frequency	Units	Data Product Number
Image captured in the infrared spectrum	15 minutes	NA	NEON.DOM.SITE.DP0.00033.001.01796.HOR.VER.000
Infrared metadata stream	15 minutes	NA	NEON.DOM.SITE.DP0.00033.001.02051.HOR.VER.000
Image captured in the RGB color space	15 minutes	NA	NEON.DOM.SITE.DP0.00033.001.01797.HOR.VER.000
RGB metadata stream	15 minutes	NA	NEON.DOM.SITE.DP0.00033.001.02052.HOR.VER.000

Table 2. List of digital camera-related L0 DPs that are transformed into L1 DPs (Snow depth and understory phenology images: NEON.DP1.00042).

Description	Sample Frequency	Units	Data Product Number
Image captured in the infrared spectrum	15 minutes	NA	NEON.DOM.SITE.DP0.00042.001.01796.HOR.VER.000
Infrared metadata stream	15 minutes	NA	NEON.DOM.SITE.DP0.00042.001.01797.HOR.VER.000
Image captured in the RGB color space	15 minutes	NA	NEON.DOM.SITE.DP0.00042.001.02051.HOR.VER.000
RGB metadata stream	15 minutes	NA	NEON.DOM.SITE.DP0.00042.001.02052.HOR.VER.000

Table 3. List of digital camera-related L0 DPs that are transformed into L1 DPs (Land-water interface images: NEON.DP1.20002).

Description	Sample Frequency	Units	Data Product Number
Image captured in the infrared spectrum	15 minutes	NA	NEON.DOM.SITE.DP0.20002.001.01796.HOR.VER.000
Infrared metadata stream	15 minutes	NA	NEON.DOM.SITE.DP0.20002.001.02051.HOR.VER.000
Image captured in the RGB color space	15 minutes	NA	NEON.DOM.SITE.DP0.20002.001.01797.HOR.VER.000
RGB metadata stream	15 minutes	NA	NEON.DOM.SITE.DP0.20002.001.02052.HOR.VER.000

3.3 Product Instances

A Stardot NetCam SC CAM-SEC5IR-B will be deployed on all core and re-locatable towers at the tower top (Above Canopy Phenology) and a second camera at the tower bottom (Understory/Snowpack Phenology). At aquatic sites, a Stardot NetCam SC CAM-SEC5IR-B will be deployed such that the land-water interface is visible in the image.

3.4 Temporal Resolution and Extent

Every 15 minutes the Above Canopy Phenology Camera, Understory/Snowpack Phenology Camera, and Land-water Interface Camera capture back-to-back RGB (red green blue color space) and IR (infrared) images separated by 30 seconds.

3.5 Spatial Resolution and Extent

A Stardot NetCam SC CAM-SEC5IR-B will be deployed on all core and re-locatable towers at the tower top (Above Canopy Phenology) will capture images of the dominant vegetation type on site. A second camera will be deployed at the tower bottom (Understory/Snowpack Phenology) and will capture images of the snowdepth stakes and any ancillary plant phenology information. At aquatic sites a Stardot NetCam SC CAM-SEC5IR-B will be deployed such that the land-water interface is visible in the field of view. These images may also include a staff gauge and/or other NEON instrumentation.

4 SCIENTIFIC CONTEXT

Phenology is the study of reoccurring life cycle events that are driven by environmental factors (Morrisette et al., 2009). In the context of this document, the targeted events are related to seasonal changes in above canopy and understory vegetation (e.g. onset of growth and leaf senescence). The timing of these events is driven by both short- and long-term variability in climate and is therefore valuable in understanding the effects of climate change (Richardson et al., 2006 and references therein).

At aquatic sites, the land-water interface and water surface will be visible in addition to terrestrial phenology. These images will be useful for assessing the timing of ice-on/ice-off at locations that seasonally experience sub-freezing temperatures.

Automated repeat digital images of plant canopies provide data for the extraction of indices (e.g. green chromatic coordinate (g_{cc}) and excess green (ExG) that can be used to quantify changes in phenological events over time (Sonnentag et al., 2011, Toomey et al., 2015). Additionally, these images will be valuable for constant remote viewing by researchers and field operations staff.

4.1 Theory of Measurement

The Stardot NetCam SC CAM-SEC5IR-B is an automated digital camera capable of capturing RGB and IR images. The Above Canopy and Understory/Snowpack Phenology Camera both capture continuous digital images of the selected areas of interest (i.e. the canopy and snowdepth stakes, respectively).

4.2 Theory of Algorithm

N/A

5 ALGORITHM IMPLEMENTATION

Data flow for signal processing of L1 DPs will be treated in the following order. For steps 2 through 4, please refer to Richardson *et al.* (in prep.).

1. L0 DPs (image and metadata will be sent to the PhenoCam Network)
2. L0 DP images will undergo QA/QC tests per PhenoCam protocols.
3. Regions of Interest (ROIs) within a camera's field of view will be determined by the PhenoCam network
4. Green chromatic coordinate (GCC) within the ROI(s) will be quantified for each image by the PhenoCam network
5. L0 images that pass PhenoCam QA/QC are then considered L1 DP images

6 UNCERTAINTY

Uncertainty of measurement is inevitable; therefore, measurements should be accompanied by a statement of their uncertainty for completeness (JCGM 2008; Taylor 1997). To do so, it is imperative to identify all sources of measurement uncertainty related to the quantity being measured. Quantifying the uncertainty of TIS measurements will provide a measure of the reliability and applicability of individual measurements and TIS data products. No uncertainty estimates are provided for images (i.e., L0 and L1 DPs). Uncertainty estimates for higher level data products that are functions of L1 images, e.g., greenness index, snowpack, etc., will be explained and derived in future ATBDs.

7 FUTURE PLANS AND MODIFICATIONS

Sensor (camera) degradation and drift may be addressed in the uncertainty section.

8 BIBLIOGRAPHY

Joint Committee for Guides in Metrology (JCGM) (2008) Evaluation of measurement data – Guide to the expression of uncertainty in measurement. pp. 120.

Morisette, J. T., A. D. Richardson, A. K. Knapp, J. I. Fisher, E. A. Graham, J. Abatzoglou, B. E. Wilson, D. D. Breshears, G. M. Henebry, and J. M. Hanes. 2008. Tracking the rhythm of the seasons in the face of global change: phenological research in the 21st century. Frontiers in Ecology and the Environment 7:253–260

Richardson, A. D., Bailey, A. S., Denny, E. G., Martin, C. W. and O'keefe, J. (2006), Phenology of a northern hardwood forest canopy. Global Change Biology, 12: 1174–1188. doi: 10.1111/j.1365-2486.2006.01164.x

Richardson A.D., et al. 2015. Tracking Vegetation Phenology across Diverse North American Biomes Using PhenoCam Imagery: A new, publicly-available dataset. American Geophysical Union, Fall Meeting 2015, abstract #B23K-02.

Sonnentag, O., Hufkens, K., Teshera-Sterne, C., Young, A. M., Friedl, M., Braswell, B. H., Milliman, T., O'Keefe, J., & Richardson, A. D. (2012). Digital repeat photography for phenological research in forest ecosystems. Agricultural and Forest Meteorology, 152, 159-177.

Taylor, J. R. (1997) An Introduction to Error Analysis: The Study of Uncertainties in Physical

Measurements. University Science Books, Mill Valley, California. 2nd Ed. pp. 327.

Toomey M. et al. 2015. Greenness indices from digital cameras predict the timing and seasonal dynamics of canopy-scale photosynthesis. *Ecological Applications* 25(1):99-115.