ALGORITHM THEORETICAL BASIS DOCUMENT (ATBD):

NEON IMAGING SPECTROMETER ALBEDO

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Change Record

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A	07/01/2019	ECO-06170	Initial Release

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LIST OF TABLES AND FIGURES

1 DESCRIPTION

Contained in this document are details concerning Airborne Observation Platform (AOP) Albedo measurements made at all NEON sites. Specifically, the processes necessary to convert “raw” sensor measurements into meaningful scientific units and their associated uncertainties are described. NEON Imaging Spectrometer (NIS) data collection is planned for each NEON site annually at 90% maximum greenness or greater.

1.1 Purpose

This document details the algorithms used for creating NEON Level 2 data product Albedo for NEON Imaging Spectrometer (NIS) from Level 1 data, and ancillary data as defined in this document (such as calibration data) obtained via instrumental measurements made by the NIS. 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 exposition of uncertainty resulting in a cumulative reported uncertainty for this product.

1.2 Scope

The theoretical background and entire algorithmic process used to derive NEON Level 2 data product Albedo from Level 1 data for NIS is described in this document. The NIS employed is the NEON Imaging Spectrometer (NIS), JPL AVIRS NextGen Imaging Spectrometer. This document does not provide computational implementation details, except for cases where these stem directly from algorithmic choices explained here.

2 RELATED DOCUMENTS, ACRONYMS AND VARIABLE NOMENCLATURE

2.1 Applicable Documents

AD[01]	NEON.DOC.000001	NEON OBSERVATORY DESIGN
AD[02]	NEON.DOC.002652	NEON Level 1, Level 2 and Level 3 Data Products Catalog
AD[03]	NEON.DOC.000782	ATBD QA/QC Data Consistency
AD[04]	NEON.DOC.011081	ATBD QA/QC Plausibility Tests
AD[05]	NEON.DOC.000783	ATBD De-spiking and Time Series Analyses
AD[06]	NEON.DOC.000746	Calibration Fixture and Sensor Uncertainty Analysis (CVAL)
AD[07]	NEON.DOC.000785	TIS Level 1 Data Products Uncertainty Budget Estimation Plan
AD[08]	NEON.DOC.000927	NEON Calibration and Sensor Uncertainty Values[1]
AD[09]	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
RD[03]	NEON.DOC.001288 NEON Imaging spectrometer radiance to reflectance algorithm theoretical basis document
RD[04]	NEON.DOC.001290 NEON Algorithm Theoretical Basis Document: Imaging Spectrometer Geolocation Processing
RD[05]	NEON.DOC.001210 NEON Algorithm Theoretical Basis Document: NEON Imaging Spectrometer Level 1B Calibrated Radiance

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
PRT	Platinum resistance thermometer
QA/QC	Quality assurance and quality control

2.4 Variable Nomenclature

The symbols used to display the various inputs in the ATBD, e.g., calibration coefficients and uncertainty estimates, were chosen so that the equations can be easily interpreted by the reader. However, the symbols provided will not always reflect NEON's internal notation, which is relevant for CI's use, and/or the notation that is used to present variables on NEON's data portal. Therefore a lookup table is provided in order to distinguish what symbols specific variables can be tied to in the following document.

3 DATA PRODUCT DESCRIPTION

3.1 Variables Reported

The NIS-related L1 DPs provided by the algorithms documented in this ATBD are available via NEON AOP Data Request.

3.2 Input Dependencies

Table 3-1 details the NIS-related DPs used to produce L1 NIS DPs in this ATBD.

Table 3-1: List of NIS-related L0 DPs that are transformed into L1 NIS DPs in this ATBD.

Description	Sample Frequency	Units	Data Product Number
Directional Surface Reflectance	Yearly	%	NEON.DOM.SITE.DP1.30006.001

3.3 Product Instances

The NEON Imaging Spectrometer (NIS) will be deployed at all NEON terrestrial sites and most NEON aquatic sites.

3.4 Temporal Resolution and Extent

Current NEON AOP plans have airborne surveys for sites to be completed annually at 90% or higher of maximum greenness for the lifetime of the Observatory.

3.5 Spatial Resolution and Extent

All sites surveyed contain the airshed(s) for NEON towers and a minimum of 10 km x 10 km surrounding that. Survey areas may be larger than the minimum if adjacent towers create overlapping survey areas, if watersheds extend from the minimum area in an easily surveyed configuration, or if other conditions create targets of opportunity for high value data at minimal or no cost. Albedo is based entirely on NEON Imaging Spectrometer (NIS) reflectance data, which is published as 1 m pixels. Hence, albedo data are produced with 1 m pixels.

4 SCIENTIFIC CONTEXT

NEON's Airborne Observation Platform (AOP) remote sensing payload includes the NEON Imaging Spectrometer (NIS), a visible-to-shortwave infrared (VSWIR) pushbroom sensor; a small-footprint full waveform LiDAR, and a high-resolution digital camera (AD [05]). The instrument payload is mounted onto a common integration plate, the Platform Integration Mount, or PIM (AD [06]). The entire AOP remote sensing payload is integrated onto a de Havilland DHC-6 Twin Otter aircraft configured with a large open downward-looking viewport. The payload is mounted directly on the cabin floor via the seat rails with the sensors viewing in the nadir direction through an open port. Imaging spectrometer data acquired with the NIS instrument supports the creation of derived data products which give unique insight in to the types, abundance, and quality of various land covers, including vegetation (Govender, Chetty, & Bulcock, 2007).

4.1 Theory of Measurement

While much of hyperspectral data is used for distinguishing materials and land cover types, it is also ideally suited to measuring total surface reflectance for the purpose of characterizing energy balance. Albedo is one such measurement and is the ratio of a surface's reflected energy to its incident energy. Light and dark surfaces correspond to high and low albedo, respectively. For opaque surfaces, the difference in energy reflected as compared to the energy incident on that surface is absorbed by the surface, increasing its temperature. (Sabins, Jr., 1978)

4.2 Theory of Algorithm

Because Albedo is defined as the ratio of all reflected energy to all incident energy, its value depends on wavelength, illumination geometry, and viewing geometry of the sensor. Direct and diffuse or scattered illumination must be considered. Reflectance as a function of angle and wavelength must be accounted for. In a laboratory setting, calibrated lamps and integration spheres can be used in conjunction with sensors spanning the full reasonable range of wavelengths in order to get a practical Albedo measurement that is very close to the ideal theoretical measurement. In airborne remote sensing, however, the algorithm used for calculating Albedo must account for the sun as the illumination source, the scattering, absorbing, and re-radiating effects of the atmosphere, and the geometry and band passes of the sensor in order to best approximate a bi-hemispherical reflectance as would be measured in a laboratory setting. To this end, the wavelength-integrated surface reflectance, weighted with the global flux on the ground E_g and described in Eq. 1, is produced as the best practically achievable albedo measurement. (Richter & Schlapfer, 2017)

$$Albedo = \frac{\int_{0.3\,\mu m}^{2.5\,\mu m} \rho(\lambda) E_g(\lambda) d\lambda}{\int_{0.3\,\mu m}^{2.5\,\mu m} E_g(\lambda) d\lambda} \qquad \textbf{Eq. 1}$$

5 ALGORITHM IMPLEMENTATION

Data flow for processing of AOP L1 NIS to produce L2 and L3 Albedo data products will be performed in the following manner.

1. L1 NIS Surface Directional Reflectance (reference here) will be processed through the AOP data processing pipeline for producing L1 directional surface reflectance. In that process, ATCOR is used to also calculate the Albedo as described in Eq. 1.
2. The AOP data processing pipeline will write the Albedo results of step 1 out to GeoTIFF files, one for each flight line.
3. The AOP data processing pipeline will use all L2 Albedo files for a given site to produce a Level 3 geospatial mosaic product optimizing pixel data value assignment using rules implemented to best mitigate error from factors including cloud cover, illumination geometry, and acquisition geometry.
4. The AOP data processing pipeline will write the results of step 3 out to L3 Albedo data product GeoTIFF files using a regular grid (reference to LiDAR grid here).

QA/QC Procedure:

QA/QC procedures for the Albedo data product will include both manual and programmatic approaches as described below:

1. **Plausibility Tests** The plausibility of a given pixel's Albedo value depends on both the value itself and the type of ground cover. For example, a high Albedo value may be quite reasonable for snow or some human-made materials, but would be completely implausible for a dark body of water. NEON Albedo products will be manually spot checked for implausible values. As ground data from field observations become more available, they will be incorporated in to automated QA/QC procedures. As the links between the ground cover, LiDAR data, and NIS data become better understood in the initial years of the Observatory, more discerning automated processing and QA/QC steps will be added.

2. **Sensor Flags** Because Albedo is a derived product, produced from an upstream derived product (SAVI) based entirely on NIS data, the final Albedo product will only have sensor flags as generated for NIS data. Currently, pixels designated as water in the atmospheric correction step generating surface directional reflectance are set to NoData value -9999.
3. **Quality Flags (QFs) and Quality Metrics (QMs)** Manual QA/QC will be performed where uncertainty values are high and/or where data quality or sensor flags indicate potential issues. Checking these areas against imagery will indicate if they are anomalous but acceptable (e.g. unusual land cover) or if there is a data or processing problem.

6 UNCERTAINTY

Uncertainty in albedo measurements derived from remotely sensed data is affected by multiple factors and is associated with 6 main categories:

1) raw remotely sensed measurement error
2) processing and atmospherically correcting the remotely sensed data to get to the required reflectance units for deriving albedo
3) geolocation of the remotely sensed data
4) terrain effects such as slope and aspect
5) land cover effects such as snow or water surface characterization, vegetation structure, and BRDF
6) the model used to derive albedo from the remotely sensed data

Because the NEON albedo data product is derived from the directional surface reflectance data product as produced from the NIS and NEON processing systems, the uncertainties associated with the first three categories are addressed in the Surface Directional Reflectance ATBD. While exact amounts of error in reflectance very with terrain, ground cover, and conditions at acquisition, 8% reflectance is the overall mean expected. (RD[03])

The nature of the surface being imaged and the effect on the albedo measurements derived from the imagery has been the subject of extensive investigation since at least the beginning of extensive earth satellite-based earth observation in the 1970s. While it is impossible to entirely eliminate these effects, they can be minimized to a degree acceptable for retrieval and use of albedo data. Over natural terrain, minimizing solar zenith angles during acquisition has been shown to keep albedo uncertainty in broadband retrieval to less than 8% (Kimes & Sellers, 1985). To this end, NEON AOP data acquisition protocols keep solar zenith angles to 40 degrees or less (RD[05]).

Similarly, the limitations of model-based retrieval of albedo values have also been extensively studied. While it is physically impractical to measure a true bi-hemispherical reflectance, the trade-off of using a weighted wavelength-integrated surface reflectance model as implemented in ATCOR and described in section 4.2 has been found not to unduly contribute, averaging $\pm$ 0.03, to uncertainty in airborne hyperspectral albedo retrievals versus ground based measurements even over the most difficult surfaces, such as snow, ice, and melt ponds (Naegeli et al., 2017).

Until enough data have been collected to allow for a more rigorous calculation of uncertainty in NEON albedo data products and production of an uncertainty raster to accompany them, NEON albedo uncertainty can be considered to have an estimated uncertainty of $\pm$ 0.08 based on the underlying reflectance values, the capabilities of NIS, the data acquisition protocol, and the implemented algorithm.

7 FUTURE PLANS AND MODIFICATIONS

A true characterization of uncertainty in the derived albedo product requires a sufficiently large amount of simultaneously acquired ground data such that several field seasons may be necessary. This is anticipated to be part of the larger NEON AOP validation and ongoing QA/QC efforts and will be included in updates to this and related documents. These efforts will also enable the addition of an albedo error raster to be included with distributed data products. Furthermore, validation and QA/QC efforts may provide sufficient insight to allow for an update or replacement of the current ATCOR albedo retrieval model.

8 BIBLIOGRAPHY

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