NEON ALGORITHM THEORETICAL BASIS DOCUMENT (ATBD): SPECTROMETER MOSAIC

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Change Record

REVISION	DATE	ECO #	DESCRIPTION OF CHANGE
A	07/01/2019	ECO-06170	Initial Release
B	03/25/2022	ECO-06791	• Update to reflect change in terminology from relocatable to gradient sites • Minor formatting updates • Added NEON to document title

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1 DESCRIPTION

The NEON Imaging Spectrometer (NIS) measures the spectral radiance along a series of flight lines covering each survey site. The calibrated radiance is then orthorectified to a set of overlapping "images" projected onto a regular horizontal grid. Each "image" is then processed from absolute radiance to reflectance. The individual images are then mosaicked into a single image by selecting the best pixel at each location from the different images. The mosaic image is then tiled into separate 1 km by 1km images to facilitate access.

1.1 Purpose

This ATBD describes the theoretical background algorithm used to create the reflectance mosaic from the individual reflectance images.

1.2 Scope

This document describes the theoretical background and algorithmic process used to derive the Level 3 mosaic images from the Level 1 individual images. This document does not provide computational implementation details.

2 RELATED DOCUMENTS, ACRONYMS AND VARIABLE NOMENCLATURE

2.1 Applicable Documents

AD[01]	NEON Scientific Data Products Catalog: http://data.neonscience.org/data-product-catalog

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.00129	NEON Imaging Spectrometer Geolocation Algorithm Theoretical Basis Document
RD[04]	NEON.DOC.003314	NIS Imaging Spectrometer Level-1 Processing Procedure
RD[05]	NEON Field Sites	NEON field sites as lists, maps, shape files and kmz's

Note: NEON documents can be found in https://data.neonscience.org/documents

2.3 External Documents

ED[01]	Google Earth: https://www.google.com/earth/
ED[02]	IDL: http://www.exelisvis.com/ProductsServices/IDL.aspx
ED[03]	HDF5: https://www.hdfgroup.org/
ED[04]	NEON HDF5 workshop: http://www.neonscience.org/about-hdf5
ED[05]	NEON ENVI HDF5 plugin: https://neondata.sharefile.com/share/view/s77d0c574b0c4b32a/fo8e0c24-c2d2-480d-81ff-1a72697dff7e

2.4 Acronyms

Acronym	Explanation
AOP	Airborne Observation Platform
ATBD	Algorithm Theoretical Basis Document
DP	Data Product
L0	Level 0: raw data as recorded by the instrument
L1	Level 1: Data that has been calibrated to engineering units
L2	Level 2: Processed L1 data from a single data stream
L3	Level 3: A data product derived from multiple data sources and/or over multiple time periods.
LOS	line-of-sight
NIS	NEON Imaging Spectrometer
QA/QC	Quality assurance and quality control
RGB	RedGreenBlue: refers to a 3-band image approximating what the human eye sees

2.5 Variable Nomenclature

This section is not applicable for this algorithm: no variables are referenced.

3 DATA PRODUCT DESCRIPTION

3.1 Variables Reported

The data products reported here are L3 spectrometer mosaics:

- L3/Spectrometer/Biomass NEON.DOM.SITE.DP3.30016.001
- L3/Spectrometer/FPAR NEON.DOM.SITE.DP3.30014.001
- L3/Spectrometer/LAI NEON.DOM.SITE.DP3.30012.001
- L3/Spectrometer/Reflectance NEON.DOM.SITE.DP3.30006.001
- L3/Spectrometer/VegIndices NEON.DOM.SITE.DP3.30018.001
- L3/Spectrometer/VegIndices NEON.DOM.SITE.DP3.30020.001
- L3/Spectrometer/VegIndices NEON.DOM.SITE.DP3.30022.001
- L3/Spectrometer/VegIndices NEON.DOM.SITE.DP3.30026.001
- L3/Spectrometer/WaterIndices NEON.DOM.SITE.DP3.30019.001

3.2 Input Dependencies

Table 1 details the NIS related L1 DPs used to produce L3 DPs in this ATBD.

Table 1. List of the AOP L1 Products Used to Create the L3 Reflectance Mosaic.

Description	Sample Frequency	Units	Data Product Number
L1 orthorectified spectral reflectance	Once per survey	No units	NEON.DOM.SITE.DP1.30006.001 http://data.neonscience.org/data-product-view?dpCode=DP1.30006.001

3.3 Product Instances

The NIS is part of the AOP instrument package. Images are collected as part of each site survey. Most core and gradient sites are surveyed once per year at 'peak greenness'. See the following like for the survey schedules:
https://www.neonscience.org/data-collection/flight-schedules-coverage
There may be other surveys including the aquatic sites and assignable-assets surveys.

3.4 Temporal Resolution and Extent

Each site is surveyed nominally once per year. One spectrometer and one camera image mosaic is produced each year for each site.

3.5 Spatial Resolution and Extent

The mosaic is created at 1.0-meter resolution. The mosaic extends over the entire flight box, typically at least 10 km by 10 km.

4 SCIENTIFIC CONTEXT

The NEON Airborne Observation Platform (AOP) contains three sensors: a hyperspectral imager (**N**EON **I**maging **S**pectrometer (**NIS**), a waveform lidar and a digital RGB camera. The principal instruments are NIS, which is used to determine state of vegetation, and the lidar, which is used to determine canopy height and elevation changes. Both the NIS and the lidar data are processed to 1-meter spatial resolution. The digital camera images, which are processed to 0.1-meter resolution, are used to provide context to the NIS and lidar data: there are no other scientific products derived from the digital camera images. The plane flies a series of N-S passes (called flight lines, in white) designed to cover the site. The N-S flight lines are designed to provide 30% overlap in the camera images between adjacent lines (side lap). The E-W flight line is for calibration purposes: this flight line is not included in the mosaic.

Figure 1 shows the outlines of the orthorectified NIS images collected over SJER on 03/28/2017. Because of variations in the aircraft attitude (roll, pitch and yaw) and altitude, the edges of the images are not straight lines (Note: the NIS is a pushbroom imager.)

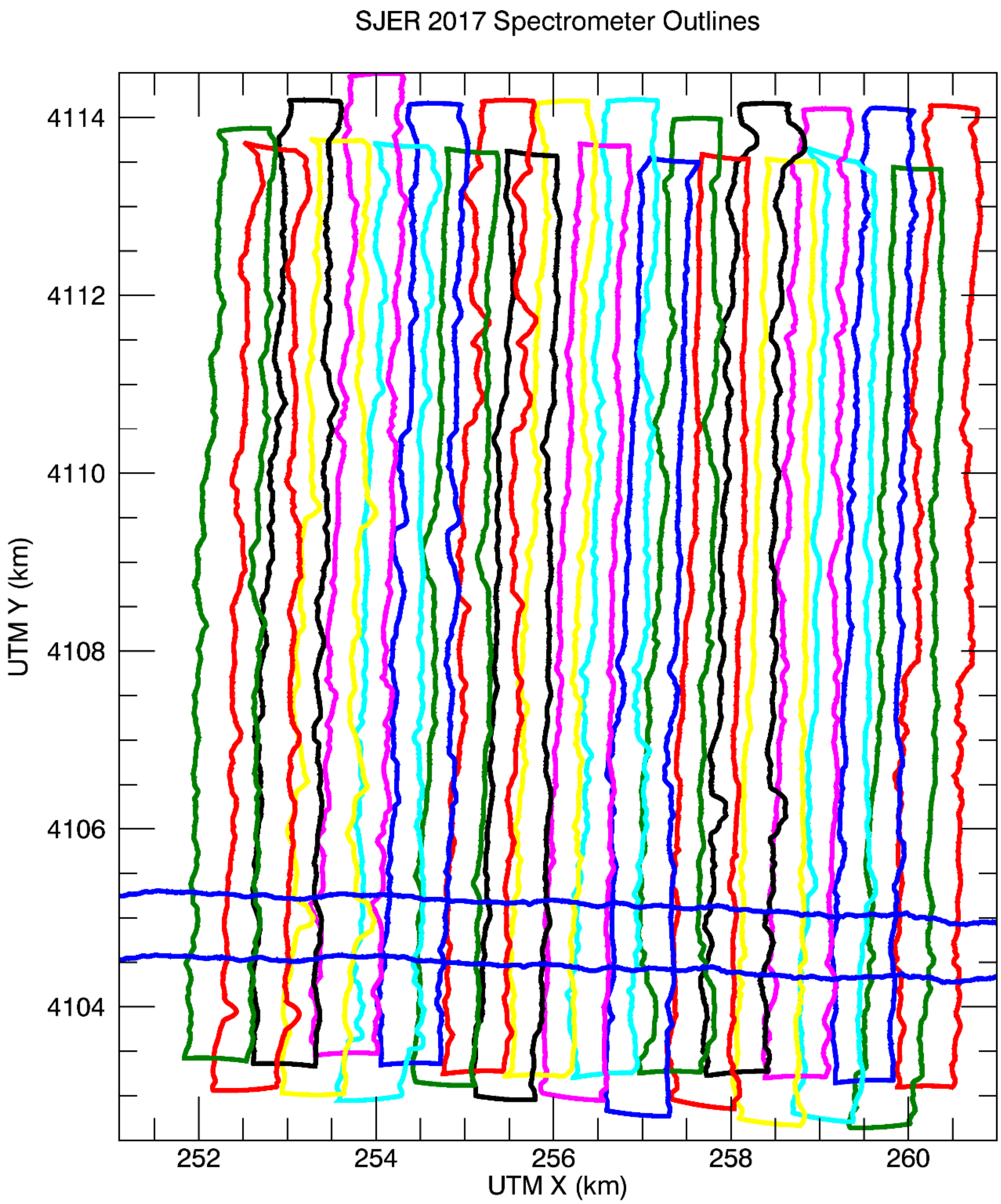

Figure 1. Outlines of the NIS images collected for SJER on 03/28/2017.

Figure 2 shows the reflectance for band 34 (548.8 micrometers) for a single image (the right-most image in **Figure 2**).

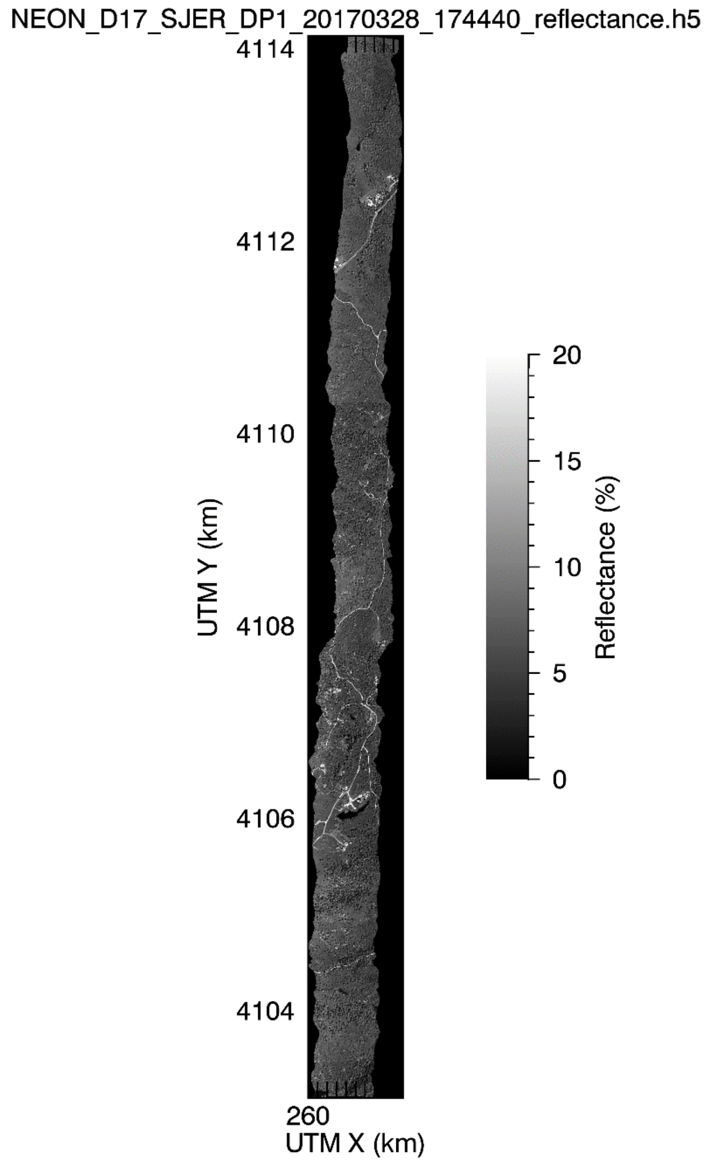

Figure 2. Reflectance for band 34 for the image NEON_D17_SJER_DP1_20170328_174440_reflectance.h5.

Mosaicking is the process of combining the individual overlapping images to form a single seamless image. The mosaicking process selects pixels from the different overlapping images that meet some criteria. Currently, the criteria is to select the pixel with the smallest LOS zenith angle at the ground. This criteria minimizes the distortion caused by high incidence angles (see Section 10). **Figure 3** shows the zenith angle for a single image. The white border around the image represents no data.

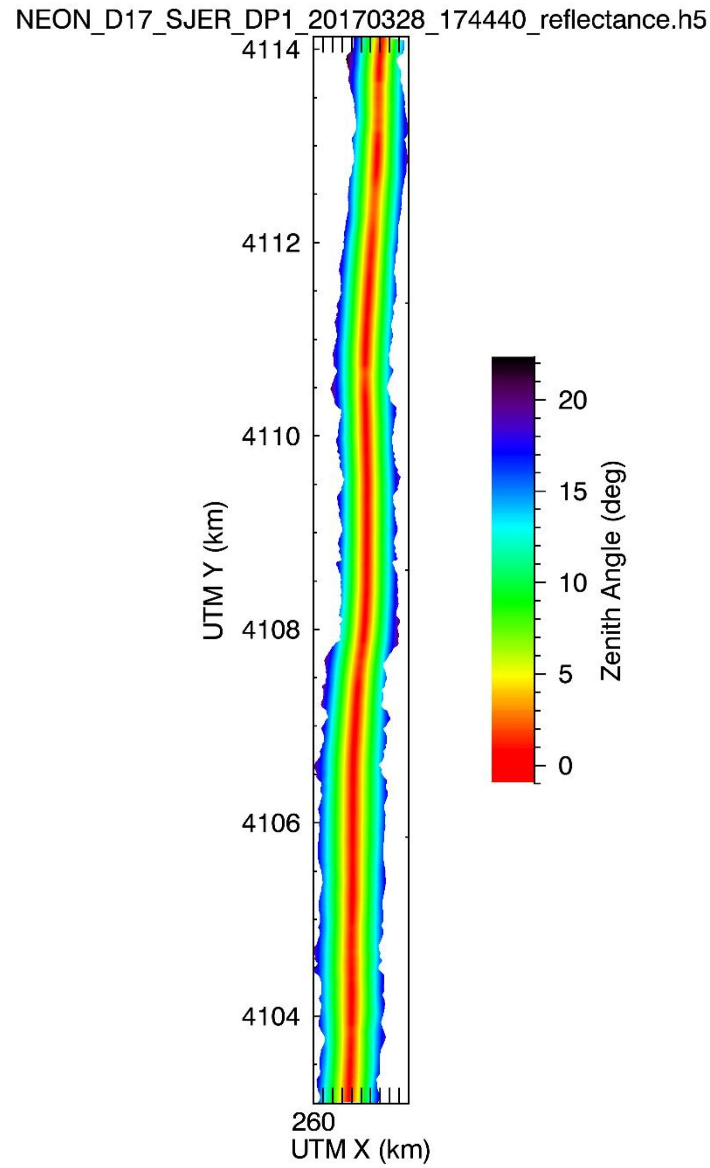

Figure 3. False color image of the LOS zenith angle at the ground for the image NEON_D17_SJER_DP1_20170328_174440_reflectance.h5.

Figure 4 shows a false color image of the LOS zenith angle at the ground for all the pixels in the SJER 2017 mosaic. The pixels near the center of a flight line have a zenith angle near zero while those at the junction between overlapping images are about 12 degrees. At the outside boundary where there is no overlap, the zenith angle may be as large as 25 degrees. **Figure 5** shows the regions of the mosaic populated by each image.

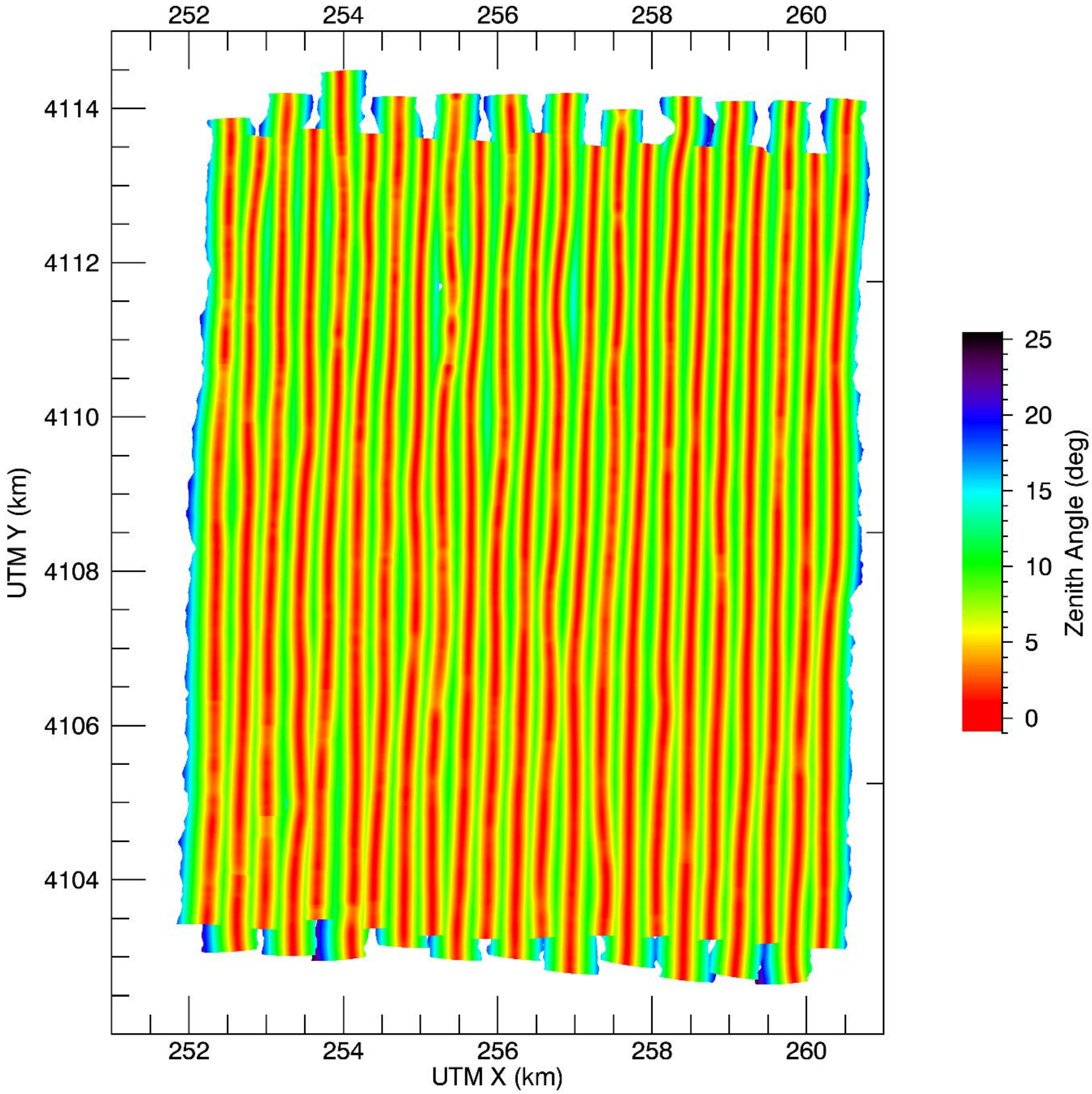

Figure 4. False color image of the zenith angle for each pixel of the mosaic. For the mosaic, the pixel with the smallest zenith angle from the overlapping images is selected.

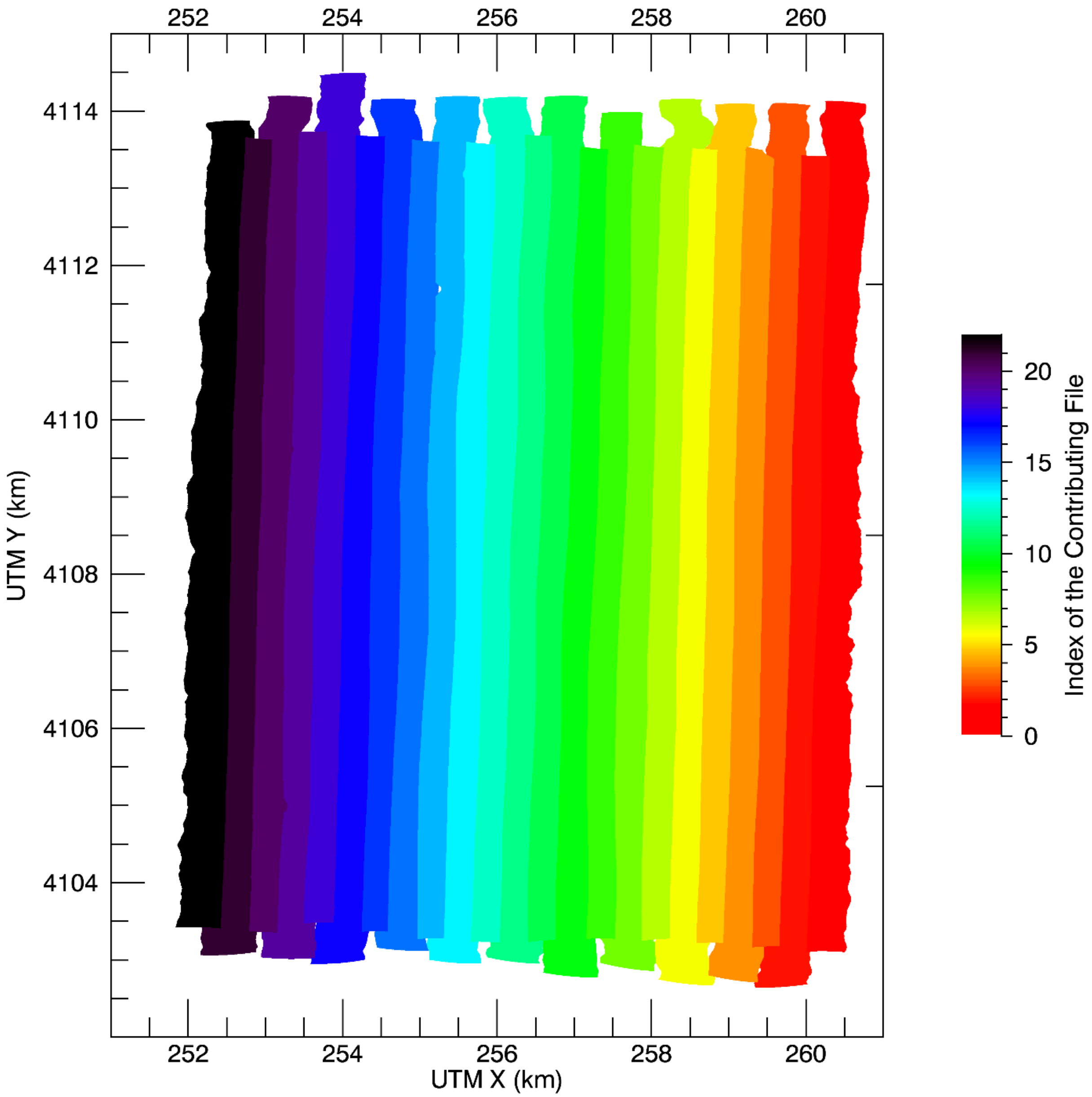

Figure 5. Plot of the regions of the mosaic populated by different images. Each colored area represents the region covered by a different image.

However, the full mosaic image containing all 426 bands may be greater than 100 GB and is typically too large to view conveniently. Tiling is the process of dividing a mosaicked image into smaller adjacent images, typically 1 km by 1 km tiles. **Figure 6** shows a low-resolution (5-meter) version of the full mosaic for SJER plus the boundaries in red of the tiles making up the mosaic. The bright white areas are clouds in the image. Note that the tile in the upper left corner has no data: no file is created for this tile.

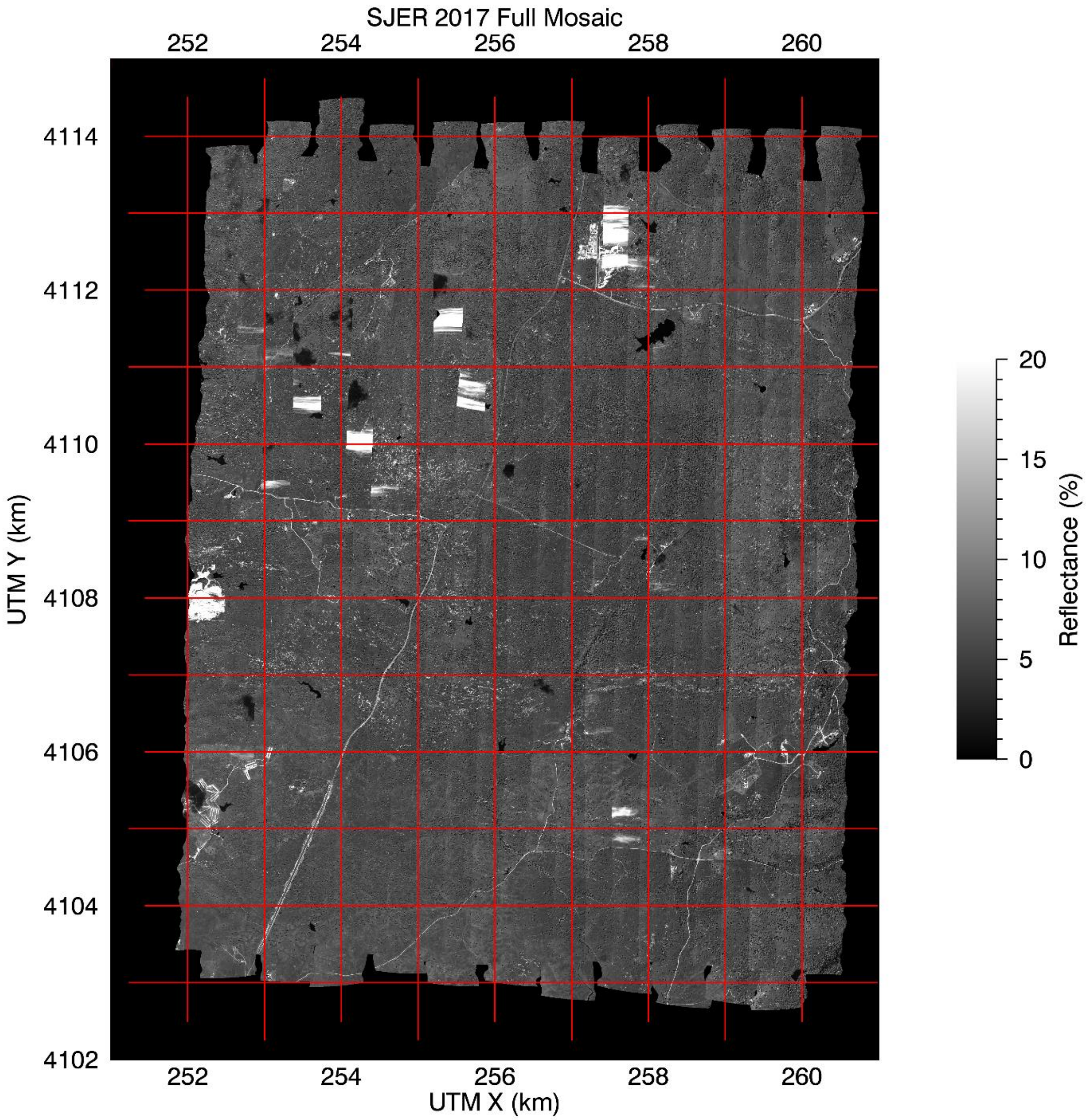

Figure 6. A low-resolution mosaic of the reflectance for band 34 (548.8 micrometers) for the site SJER.

Figure 7 shows one mosaic tile from SJER. The values in the filename (250000, 4109000) indicate the UTM X and Y locations in meters of the lower left corner of the tile.

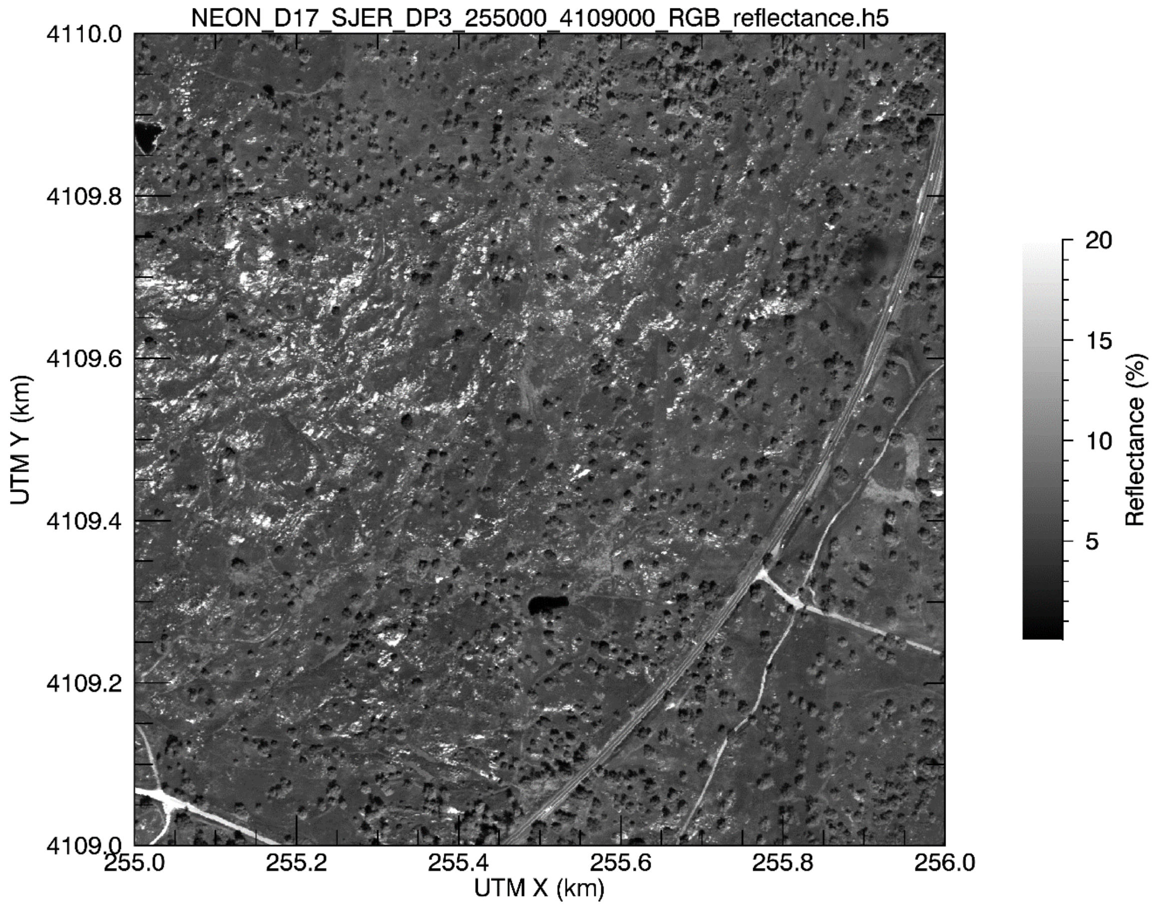

Figure 7. A 1-km-by-1-km mosaic tile from the site SJER.

5 THEORY OF MEASUREMENT

The measurements here are the individual orthorectified reflectance images, one for each flight line. The process of orthorectification is described in the spectrometer orthorectification ATBD (RD[03]).

6 THEORY OF ALGORITHM

6.1 Overview

The process of creating the mosaic is broken down into the following steps:

1. Select the images to be included in the mosaic
2. Determine the overall extent of the mosaic, i.e., the minimum extent that includes the individual images, rounded out to the nearest 1 km.
3. Create a file matching the extent and resolution of the mosaic, called the index file. Each element of the index file maps to the image file that will fill that element of the mosaic with data. For each element, select the pixel from the overlapping images with the smallest LOS zenith angle.
4. Create a set of 1 by km tile boundaries covering the mosaic
5. Fill in the tiles with the pixels from the overlapping images with the smallest zenith angle.
6. Create a kmz for the display of the mosaic properties in Google Earth

6.2 Detailed Steps

6.2.1 Select the Images

For the mosaic, it is preferable to use only images that fall along the N-S flight lines and avoid images on diagonal or E-W flight lines. These later lines contain mostly redundant information and have characteristics (reflectance angle, illumination) inconsistent with the N-S lines. See **Figure 1** for the flight lines for SJER. For SJER, 24 images (flight lines) are included in the mosaic.

Each image file is in H5 format and along with the reflectance images contains a variety of metadata including an array containing the LOS zenith angle at the ground for each pixel. The pixel with the smallest zenith angle of all the overlapping images will be used to populate the mosaic.

6.2.2 Determine the overall extent of the mosaic

The extent of the mosaic is maximum extent of all the images, rounded out to the nearest 1 km. Let the size of the mosaic by x by y km. The resolution of the mosaic is 1.0 meters so that the size of the mosaic in pixels is nx =1000*x by ny = 1000*y. The complete mosaic is a nx by ny by nband array, where nband is the number of bands, currently 426.

6.2.3 Create the zenith_angle and file_pointer arrays.

Create two arrays, each nx by ny: zenith_angle_array and file_pointer_array, initialized to a "missing" value. Each element in these arrays correspond to a pixel in the mosaic. When finished, the zenith_angle_array will contain the minimum zenith angle from all the image files for that pixel and the file_pointer_array will contain a pointer to the corresponding image file.

To generate these arrays, loop over the image files. For each image file:

1. Compare each pixel in the image file with the corresponding pixel in the zenith array.

2. If the zenith angle from the image is less than that in the zenith array:
   a. Replace the zenith angle in the zenith array with that from the image file
   b. Replace the value in the file_pointer array with a pointer to the current image file.

When finished, the values in zenith array that correspond to "missing" indicate pixels for which there is no data.

6.2.4 Create and fill in the tiles

Divide the full mosaic into a set of 1 km square tiles. For each tile:

1. Create an nx by ny by nband array (tile_data_array) that will contain the image data for the tile.
2. Cut out that portion of the file_pointer_array that corresponds to the tile (tile_pointer_array).
3. From this slice, extract the set of unique pointers for the current tile.
4. For each pointer from this set, open the corresponding image file.
   a. Cutout the slice of the image corresponding to the tile
   b. Fill in the pixels in the image_data_array with the pixels from the image
5. Write the completed image array into a H5 file with the relevant ancillary data and metadata.

7 ALGORITHM IMPLEMENTATION

7.1 Algorithm Program

The mosaicking algorithm is coded in the IDL (ED[02]) program run_neon_aig_vswir_mosaic. The instructions for obtaining and running this program are given in the comments at the beginning of the program.

7.2 Filenames

The mosaic tile names are of the form:

NEON_D*dd*_*site*_DP3_*xxxxxx*_*yyyyyyy*_reflectance.h5

where:

dd is the domain number

site is the 4-character site code

xxxxxx is UTM X (easting) coordinate in m of the lower right corner of the image

yyyyyyyy is UTM Y (northing) coordinate in m of the lower right corner of the image

For example, a tile from SJER 2017 has the file name:

NEON_D17_SJER_DP3_252000_4103000_reflectance.h5

7.3 File format

The mosaic tile files are in HDF5 format(ED[03]). A plugin for the program ENVI (ED[02]), is available to allow users to conveniently view the images and metadata (RD[05]).

8 UNCERTAINTY

Not applicable.

9 VALIDATION AND VERIFICATION

Verification has been achieved by comparing portions of the mosaic with the original images over the applicable regions. The results are identical.

10 FUTURE PLANS AND MODIFICATIONS

Currently the rule used to select pixels for the mosaic from the individual flight lines uses only the zenith angle. However, the individual flight lines are also graded according to the cloud cover during the acquisition time:

- green: cloud cover < 10 %,
- yellow: 10 % < cloud cover < 50 %
- red: cloud cover > 50 %

In the future, we may revise the selection rule to incorporate the cloud coverage as well as the zenith angle.