

<i>Title:</i> AOP Level 0 Data Quality Checks		<i>Date:</i> 12/01/2017
<i>NEON Doc. #:</i> NEON.DOC.002890	<i>Author:</i> T. Goulden, W. Gallery, D. Hulslander, K. Krause, N. Leisso	<i>Revision:</i> D

## AOP LEVEL 0 DATA QUALITY CHECKS

<b>PREPARED BY</b>	<b>ORGANIZATION</b>	<b>DATE</b>
Tristan Goulden	AOP	06/05/2015
William Gallery	AOP	06/05/2015
David Hulslander	AOP	06/05/2015
Keith Krause	AOP	06/05/2015
Nathan Leisso	AOP	06/05/2015
Ian Crocker	AOP	08/25/2016
Tristan Goulden	AOP	11/16/2017

<b>APPROVALS</b>	<b>ORGANIZATION</b>	<b>APPROVAL DATE</b>
Nathan Leisso	AOP	11/28/2017
Mike Stewart	SYS	11/27/2017

<b>RELEASED BY</b>	<b>ORGANIZATION</b>	<b>RELEASE DATE</b>
Judy Salazar	CM	12/01/2017

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## Change Record

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A	07/28/2015	ECO-03045	Initial release
B	07/31/2015	ECO-03172	Formatting changes only, no content changes
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D	12/01/2017	ECO-05275	Broken references fixed for Payload 3 IOCR.

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## 1 DESCRIPTION

This document describes in-house quality checks of NEON AOP L0 data developed to verify 1) the spatial coverage of data and 2) whether L0 data is within a tolerable range. L0 data observed by AOP is acquired through sensors mounted on an airborne platform and include a POS system (GPS / IMU), imaging spectrometer, high resolution RGB camera, and a full waveform LiDAR. This document describes the tolerance limits of an L0 measurement, which determines whether the measurement is ‘in-range’, and the algorithmic details on testing the tolerance criteria. Additionally, the document describes the spatial coverage criteria that must be met by in-range data for the airshed boundary (100% coverage) and the priority 1 flight box (80% coverage) along with an algorithm to determine the total spatial coverage.

### 1.1 Purpose

The purpose of this document is to describe the L0 raw quality assurance and quality checks to be performed for each sensor on the NEON AOP. The quality checks determine, to the extent possible, that the raw data is within range and acceptable for producing higher-level data products. The document also guides AOP personnel through the procedure of implementing the code used to perform these checks.

### 1.2 Scope

This document covers the processing required to produce level one LiDAR, imaging spectrometer, and camera data products.

## 2 RELATED DOCUMENTS AND ACRONYMS

### 2.1 Applicable Documents

Applicable documents contain information that shall be applied in the current document. Examples are higher level requirements documents, standards, rules and regulations.

AD [01]	
AD [02]	
AD [03]	
AD [04]	

### 2.2 Reference Documents

Reference documents contain information complementing, explaining, detailing, or otherwise supporting the information included in the current document.

RD [01]	NEON.DOC.000008	NEON Acronym List
RD [02]	NEON.DOC.000243	NEON Glossary of Terms
RD [03]	NEON.DOC.015013	AOP Imaging Spectrometer Specifications

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RD [04]	NEON.DOC.015073	AOP Imaging Spectrometer Statement of Work
RD [05]	NEON.DOC.001517	AOP Imaging Spectrometer Calibration Plan
RD [06]	NEON.DOC.001548	AOP Payload Data Time Stamping
RD [07]	NEON.DOC.001557	AOP Flight Planning Standards and Configurations
RD [08]	NEON.DOC.002652	NEON Level 1, Level 2, and Level 3 Data Products
RD [09]	NEON.DOC.001989	AOP Payload Imaging Spectrometer System
RD [05]	NEON.DOC.001517	AOP Imaging Spectrometer Calibration Plan
RD [06]	NEON.DOC.001277	AOP directory and file name conventions

### 2.3 External References

External references contain information pertinent to this document, but are not NEON configuration-controlled. Examples include manuals, brochures, technical notes, and external websites.

ER [01]	
ER [02]	
ER [03]	

### 2.4 Acronyms

AGL	Above Ground Level
BDE	Bad Detector Element
COTS	Commercial off the shelf
DN	Digital Number
GPS	Global Positioning System
GSD	Ground Sampling Distance
IMU	Inertial Measurement Unit
POS	Positioning and orientation system
RGB	Red Blue Green
SOBC	Spectral On-Board Calibrator

## 3 INTRODUCTION

The NEON AOP (Airborne Observatory Platform) contains a suite of remote sensing instrumentation on an airborne platform. The sensors on the AOP include a GPS / IMU, used to provide the position and orientation of the aircraft, a full waveform LiDAR which captures three-dimensional information about the topography and structure of surface features such as vegetation, a high resolution RGB digital camera which provides information on land-use, and a visible and shortwave infrared spectrometer which provides enhanced information on surface features, especially vegetation. According to NEON.MGMT.DPS.005004.REQ any raw information collected by the AOP sensors is considered Level-0

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(L0) data, and must be checked for quality and completeness. The fidelity of the L0 data is paramount because all subsequent data products (L1 through L4) are developed from the L0 data.

The AOP is tasked with acquiring L0 data at the NEON sites for a given year. A typical site for an AOP survey is contained within a 10 x 10 km box, which can be flown in a single mission. However, some areas will require multiple missions to complete. Several restrictions are placed on the timing for acquisition of L0 AOP data including plant photosynthetic activity (peak greenness), sun conditions (high solar angles) and weather (no inclement weather). Given the high cost and time sensitive nature of the flights it is imperative to gain a prompt estimate (< 12 hrs) of the quality and coverage of the L0 data to allow development of higher level data products of sufficient quality to perform scientific analyses. Once assurance of data quality is ascertained, the aircraft can depart the current site for the subsequent survey location. If the criteria have not been met, it indicates that another flight will be required prior to proceeding to the subsequent survey site. This document describes checks, which have been designed to ascertain the quality of L0 data. Table 1 lists the requirements, which must be met in order to achieve success on the L0 quality checks and allow departure of the aircraft to a subsequent survey site.

**Table 1: Requirements for Successful L0 Quality Check**

Criteria	Requirement
<b>Site coverage</b>	80% of the data AOP collects within the official site boundary shall be within range as defined in NEON.DOC.002890
<b>Airshed coverage</b>	95% of the data AOP collects within the TIS-defined site airshed shall be within range as defined in NEON.DOC.002890

The in-range criteria identified in Table 1 is described within the following sections which highlight the individual sensors including 1) GPS / IMU, 2) waveform LiDAR, 3) imaging spectrometer and 4) RGB camera. The design of the checks and their associated tolerance criteria considered both robustness of checks and their execution time. For example, processing the data to an L1 product provides the most robust assurance that the data is suitable for further product development; however, the volume of information collected in a single flight precludes processing to an L1 product due to time constraints. Therefore, deliberate effort was placed in avoiding processing data to an L1 product in order to maintain processing efficiency and allow a compromise between robustness and execution time.

In the field, the data must be extracted from the sensor systems prior to the implementation of L0 quality checks. Currently, this is performed through the Hotel Kit, with an in-house algorithm. In an operational scenario, the airborne sensor operators (ASOs) will extract the L0 data and perform the quality checks in-field at the end of each day of acquisition. The extraction of L0 data and associated



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quality checks must be completed prior to the beginning of the following day’s acquisition, imposing a maximum time for data extraction and execution of quality checks of 12 hrs.

The document is hereafter divided into five sections which discuss the quality checks for each individual sensor systems including 1) the GPS / IMU, 2) the spectrometer, 3) the waveform LIDAR, 4) the digital camera, followed by a section 5) assessment of spatial coverage for the LiDAR, camera and spectrometer. Within each section, the in-range criteria imposed for success, raw data required for verification, algorithm design, and if required; potential limitations and future improvements.

## 4 GPS / IMU

### 4.1 Raw Data Required

The GPS / IMU information is obtained with POS AV 510 sensor or 610 sensor, a commercial-off-the-shelf (COTS) product produced by Applanix (Applanix, 2012). The POS AV sensor records GPS information at 1 Hz and IMU data at 200 Hz. The raw GPS and IMU measurements are recorded into several files in a proprietary format designed by Applanix. Each file has a maximum size of ~12.8 MB, and several of these files are required to record the data for an entire flight. For a flight which maximizes the aircraft flight time, over 30 files may be required. The files are organized with an extension that begins with \*.000 and ends with number of files recorded (i.e. \*.033 as the last file of 34 total files) (Figure 1). As identified in Table 2, the L0 quality check for the GPS/IMU consists of ensuring the data is not corrupt.

**Table 2: Verification Criteria for the POS System**

<b>Verification</b>	<b>Criteria for fail</b>
POS data has not been corrupted	Files unsuccessfully open in POSpac MMS and unable to create smoothed best estimated trajectory (SBET)

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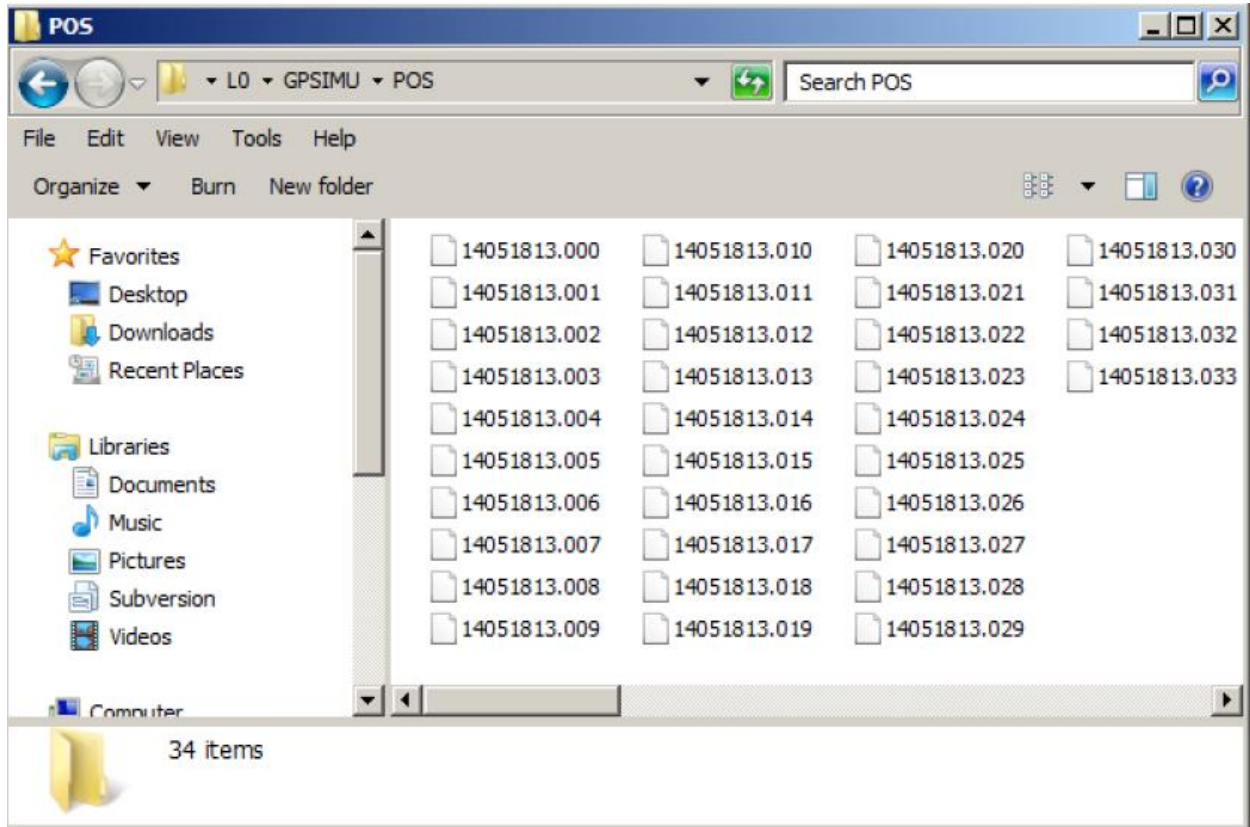


Figure 1: Listing of Raw POS Data for a Flight of DSNY in D03

## 4.2 Verification Procedure

As the file format of the data is in a binary and proprietary format, there is no possibility of developing in-house algorithm / code to verify the quality of the data. To read the proprietary format of the raw data the files must be opened in PosPAC MMS, a software package provided by Applanix. Opening the raw files PosPAC MMS automatically prompts an internal quality check on the continuity of the data. If the data can be successfully opened in the software, assurance is ascertained that the data has not been corrupted and an acceptable trajectory can be successfully produced. The importation of the raw files can be automated within a Window's DOS prompt with the following command (Applanix, 2014)

```
>> pospac.exe -b input_parameters.posbat
```

where the input\_parameters.posbat is an xml file organized as follows:

```
1 <?xml version="1.0"?>
```

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```

2      <Batch xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
3      xmlns:xsd="http://www.w3.org/2001/XMLSchema">
4      <Project>
5      <Name>L0_check</Name>
6      <Kernel />
7      <Extract>
8      <FirstPosFile>D:\tristan\POSTest_batch\POS\14101317.000</FirstPosFile>
9      <LastPosFile>D:\tristan\POSTest_batch\POS\14101317.013</LastPosFile>
10     <StartTimeTotalSec>0</StartTimeTotalSec>
11     <StopTimeTotalSec>999999</StopTimeTotalSec>
12     </Extract>
13     <Process>
14     <GnssMode>PriGNSSNav</GnssMode>
15     <GnssNavType>None</GnssNavType>
16     <SingleBaseList />
17     <AutoSelectDownload>>false</AutoSelectDownload>
18     </Process>
19     <TemplateFile />
20     <Status>Completed</Status>
21     <Stage>
22     <Name>POSDataImport</Name>
23     <Status>Completed</Status>
24     </Stage>
25     <Stage>

```

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```

26 <Name>GNSSInertial</Name>
27 <Status>Completed</Status>
28 </Stage>
29 </Project>
30 <Version>3.0</Version>
31 </Batch>

```

On line 8 of the XML file the first POS file intended for processing must be entered, and on line 9 the last POS file intended for processing must be entered. Line 5 contains the name of the project, which has been set at 'LO\_check.' The file is then run from the command line in a DOS prompt (Figure 2). Once executed POSpac MMS will open and extract the raw data (Figure 3) and perform a continuity QA check on the IMU data (Figure 4). Following this, the program does a coarse forward processing on the trajectory (Figure 5). For scientific data, the forward processing will be done with CORS and local basestation to improve the accuracy of the trajectory, however, execution of a coarse trajectory at this stage proves that it will be possible to create the desired trajectory at a later date. POSpac MMS will write the trajectory (Figure 6) to a folder that is located with the POS data.

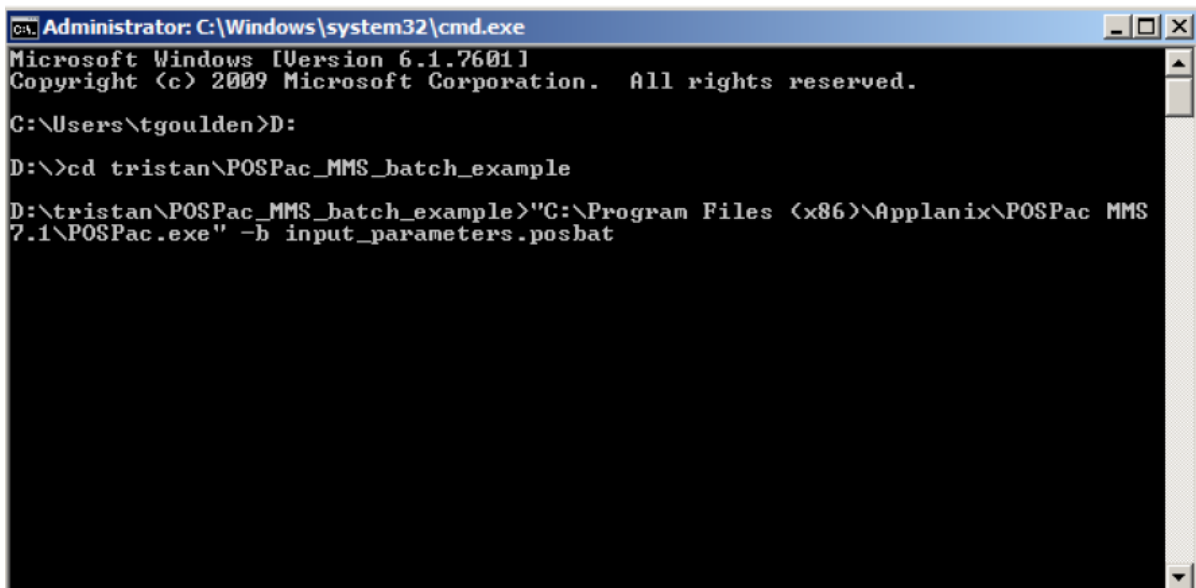


Figure 2: Running POSpac MMS from the command line in a DOS prompt

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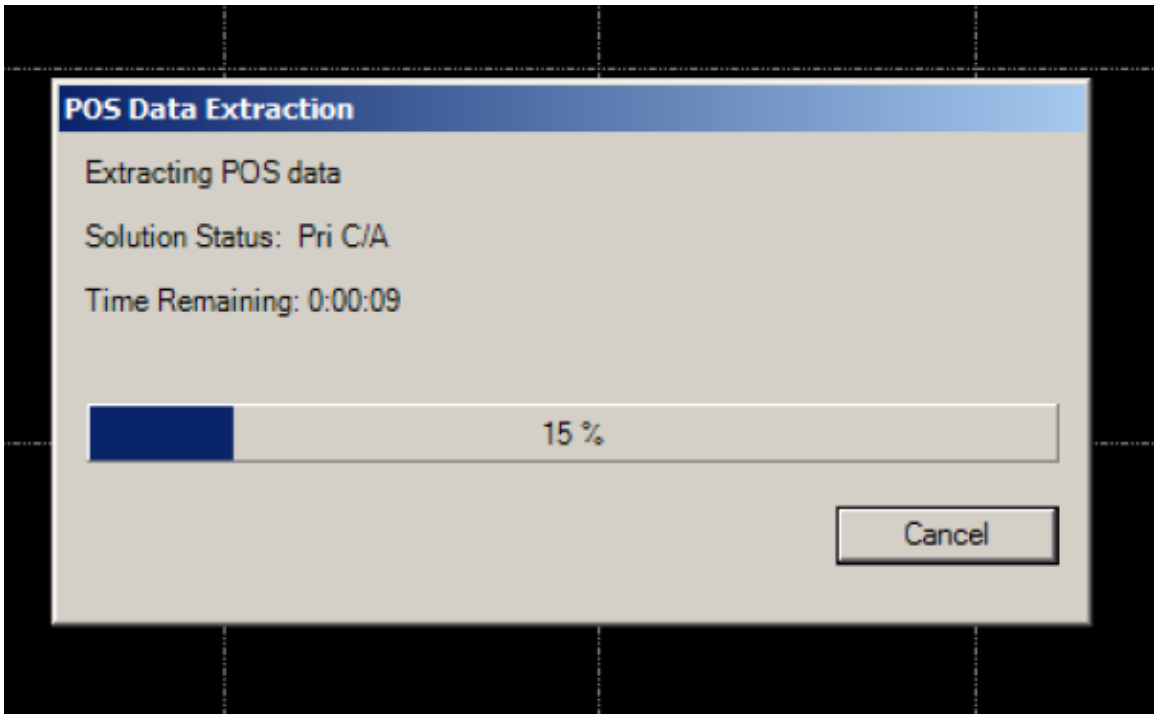


Figure 3: Extraction of raw data from the proprietary files

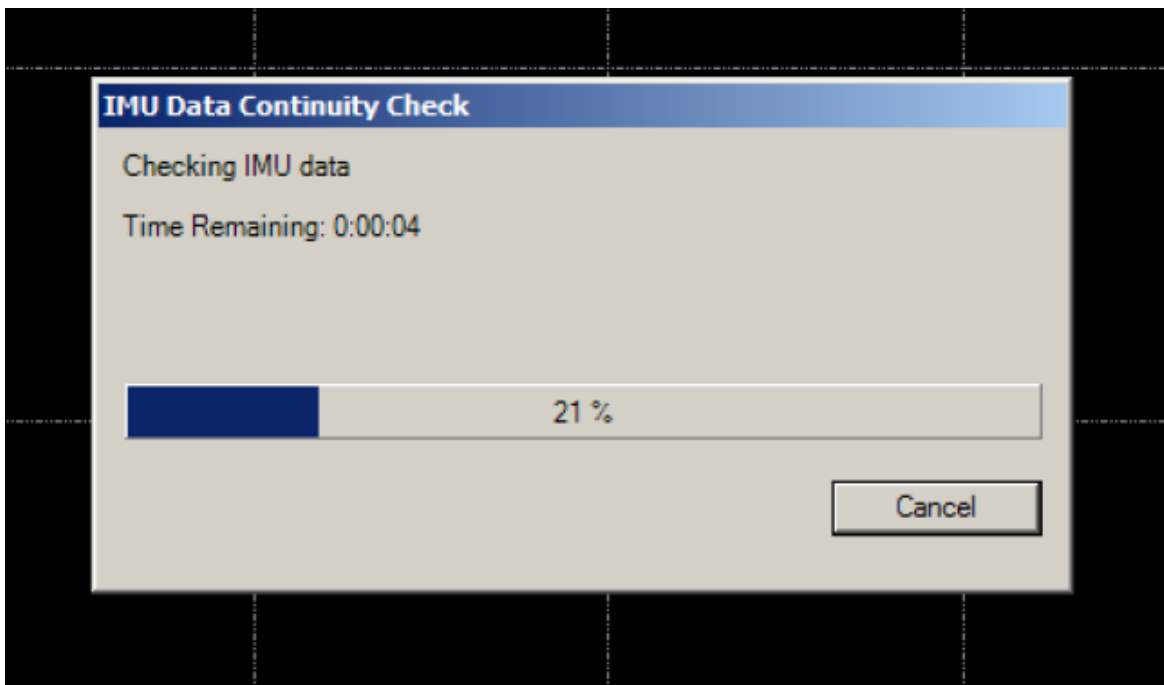


Figure 4: Internal quality check on the continuity of the IMU data

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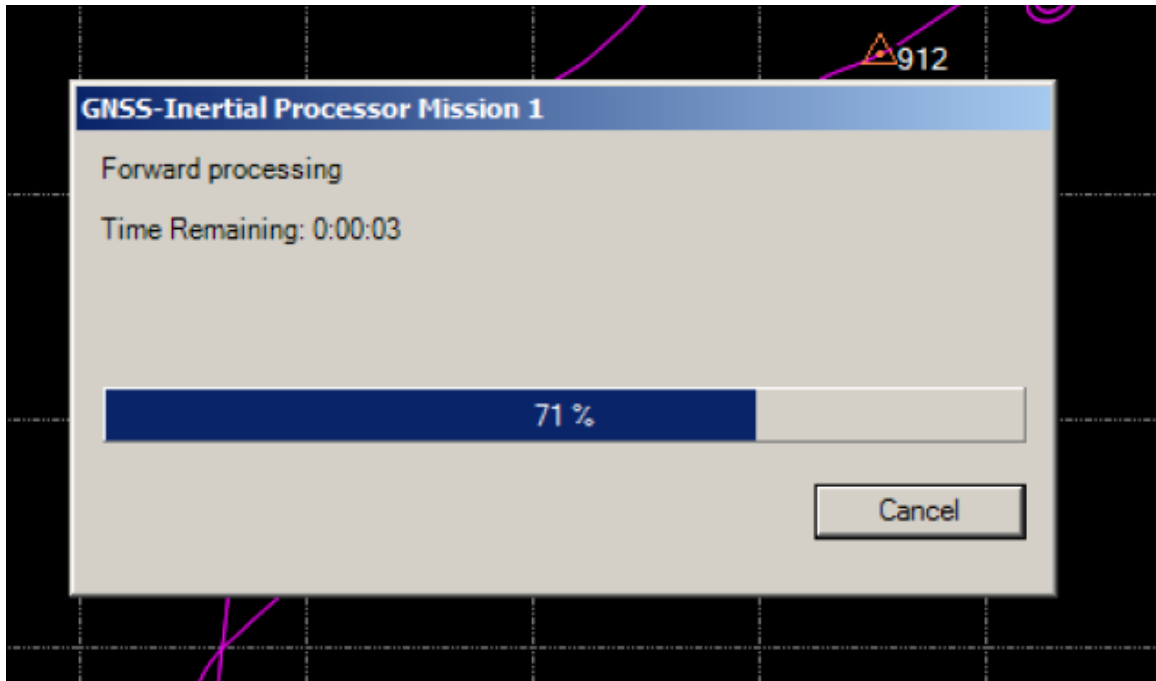


Figure 5: Processing of the POS data into a trajectory

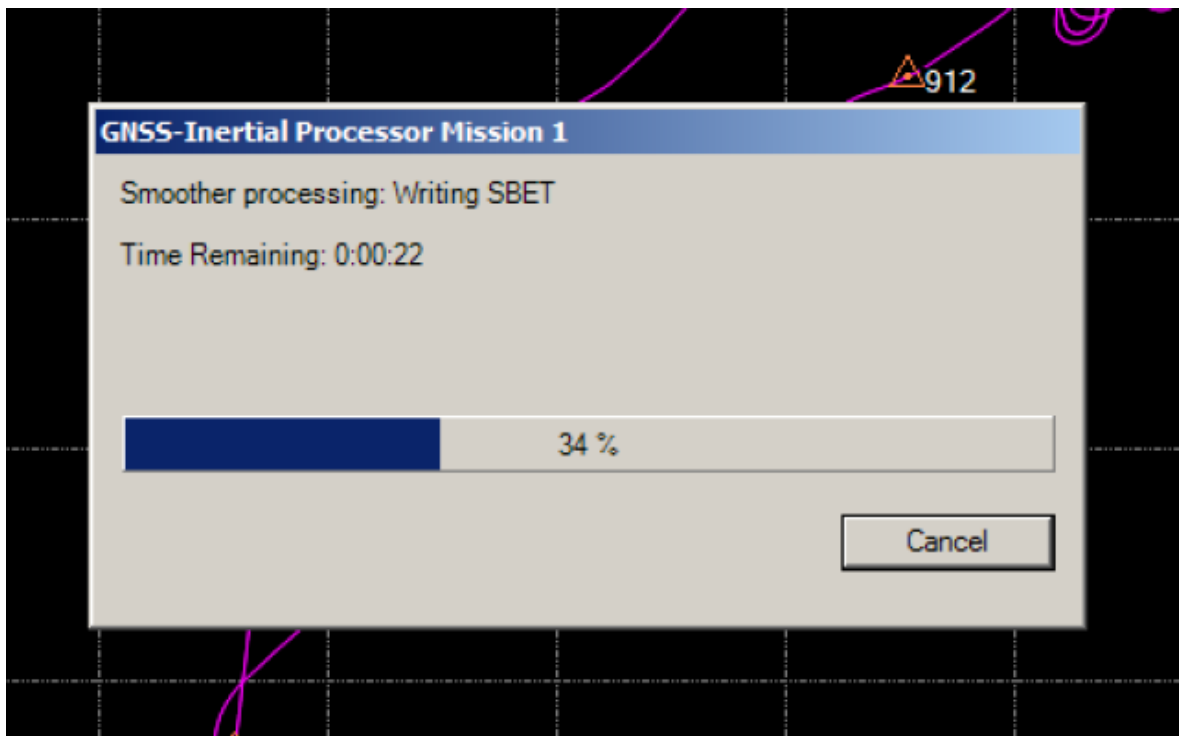


Figure 6: Writing out a processed smoothed best estimated trajectory (SBET)

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Once forward processing is complete, the trajectory will turn green, indicating the GPS and IMU data has been successfully processed into an airborne trajectory (Figure 7). The final SBET will be named **'sbet\_Mission 1.out'** and will be located in the folder where the executable was run in the DOS prompt. In this example, it was created in the folder **'\POSPac\_MMS\_batch\_example\'**. Within that folder, the final trajectory will be contained in

**'L0\_check \ Mission1 \ Proc'**



**Figure 7: Processed trajectory which shows successful combination of GPS and IMU data**

The successful creation of the SBET file provides the final verification that the GPS / IMU data is capable of producing a trajectory that will contribute to the within range verification of the remaining sensors. For the example flight presented here, less than five minutes was required for processing indicating it is sufficient for the time constraints imposed by the L0 quality check criteria.

### 4.3 Potential Limitations

It is possible during data collection that a power interruption (intended or not intended) will cause the POS data to stop recording. If a flight is continued after a power interruption there will be a large gap in the trajectory that occurred during the power outage. In this circumstance, the L0 quality check for the

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trajectory will have to be executed multiple times. A separate input file for execution in the DOS window will have to be created for the POS files associated with each unique portion of the trajectory. In this circumstance, the Name one line 5 of the input file will also have to be changed for each section. Following the NEON.DOC.001277, a letter, starting with 'A' should be appended to the end of the name for each section of the trajectory.

#### 4.4 Future Improvements

This process may be further automated in the future through automated population of the required fields in the XML input file for the project name, and the first and last input POS file. The execution of the DOS command prompt can also be automated, reducing any need for human interaction into the system. Such a system could also automate the processing of separate trajectories if unique naming was applied to each individual section. Further tests can also be performed on the SBET and associated QA files once it is produced, such as analysis of the errors, number of GPS satellites tracked during data acquisition, the PDOP during data acquisition.

### 5 NEON IMAGING SPECTROMETER

The Neon Imaging Spectrometer (NIS) is a custom instrument developed by NASA's Jet Propulsion Laboratory (JPL) specifically for use in ecological studies. Details about the design and operation of the instrument may be found in applicable reference documents listed above, see RD [03], RD [04], and RD [05].

The calibration is based on extensive work done in the NEON Sensor Test Facility. This calibration is operationally monitored through the use of an on-board calibration (OBC) system (see RD [05]). Typical flight lines consist of collection of OBC data, the desired science collect, and concluding with a second collection of OBC data. The OBC sequence consists of a 10-second collect of shuttered darks, a medium intensity broadband radiance, a high-intensity broadband radiance, and ending with a spectral source (HeNe laser at 632.8-nm).

#### 5.1 Raw Data

During flight operations, the NIS collects data along previously planned flight lines. The collected data consists of the desired raw science data collected over the site but also includes On-Board Calibration (OBC) data collected before and after each flight line (Figure 8, Table 3). These are stored as separate files beneath a common individual directory for each flight line.



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**Table 3: NIS Operating Sequence during a typical Flight**

<b>Flight Leg</b>	<b>NIS status</b>	<b>Spatial lines (Frames)</b>
Fly from forward operating base (FBO) to survey area	NIS not recording although a test collect is collected on the tarmac prior to taxi	
Conduct flight line	OBC dark shutter	1000
	OBC mid-level source	1000
	OBC high-level source	1000
	OBC dark shutter (Dark offset)	1000
	OBC HeNe laser	500
	Science flight line	variable, 50000 typical
	OBC dark shutter (Dark Offset)	1000
	OBC mid-level source	1000
	OBC high-level source	1000
	OBC HeNe laser	500
Turn around for next flight line	NIS not recording	Not recording
Conduct next flight line	...	...
Conduct next flight line	...	...
Return to FOB	NIS not recording	

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**Figure 8:** Example of a NIS OBC collect. In this figure, time is increasing from the top down. Each of the OBC collects have been temporally shortened for illustration. The OBC data is used for verification of the NIS behavior during the science collect.

The structure of each individual flight line directory (ex: NISX\_YYYYMMDD\_HHMMSS) consists of multiple sub-directories. A single sub-directory labeled ‘raw’ contains the OBC and science data collected. Each of the collects in Figure 8 consists of an individual ENVI format file consisting of the binary image and an associated header file of ASCII format. Other directories contain navigation data, calibration data, timing and geolocation data, and resulting shape of the collected flight line.

## 5.2 Verification Procedure

The operational behavior of the NIS is monitored through the use of the On-board Calibration (OBC) system in addition to environmental health telemetry collected by the image acquisition computer (DCC) and the monitor NIS laptop. This is required due to the size of the science portion of the acquisitions rendering the time required for analysis to be extensively long. In addition, monitoring the OBC data enables a better ability to monitor parameters that would be washed out due to the science signal in the actual imagery.

The plan laid out here is based on comparison of the operational OBC data to OBC data collected in the NEON sensor test facility during the calibration of the NIS. In addition, the focal plane temperature and

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vacuum vessel pressure from the environmental health telemetry is monitored to verify the behavior is within typical operating constraints.

The parameters used in the quality assurance are based on previously encountered issues during NEON engineering flights. While it is hoped that we may catch every conceivable failure mode this is not realistic for a starting point. As we continue to gain understanding of the operational behavior of the NIS, it is expected that the quality assurance verification algorithm will continue to improve. Table 4 summarizes the following performance metrics listed below and describes the within range criteria.

### 5.2.1 NIS Level-0 performance metrics and acceptable ranges

1. The FPA temperature is monitored for variances from the operational set point (nominal) defined by JPL for a particular NIS prior to delivery. If cooling to the NIS is lost, the FPA temperature will quickly drop below nominal then warm over a longer period. Temperature gradations throughout the NIS result in spectral calibration changes that lead to unacceptable data quality. In addition, as the temperature of the FPA warms, the noise level of the FPA increases leading to degraded quality of the LO data.
2. High Chamber pressure levels indicate that either the Non-Evaporable Getter pumps needs reactivation or the chamber is leaking at a higher than expected rate. This could lead to icing of the instrument and poor data quality.
3. The positive bias of the Focal Plane Array output (DN) while the NIS is shuttered is monitored for changes from the laboratory calibration. Variation in the dark offset is acceptable within a range of conditions. However, it is important that this value is not too low or too high. If the value is too low, it results in pixels that are floored meaning that they report zero when the NIS is shuttered. If the dark offset value is too high, the available dynamic range is reduced along with the resulting data quality. Variation in the dark offset should be minimal on the temporal scales of a flight line.
4. The dark offset data collected before and after the science collect is also used to monitor the noise levels of the FPA. This is monitored by looking at the RMS of the 1000 frames of shuttered data collected before and after each science collect.
5. The On-Board Calibration (OBC) is monitored to verify that the radiometric calibration has not shifted from the laboratory. Typically the NIS is more stable than OBC system in terms of absolute accuracy. However, the OBC may be used for trending the NIS behavior. The OBC illuminates the entire used area of the FPA with varying light levels depending on the spectral/spatial position. The results of the 1000 frame bright OBC collects are averaged and compared with the laboratory collect to look for gross changes in the NIS behavior. The range listed in Table 4 is the mean of the percent difference of the operation OBC from the lab OBC across the entire FPA.

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6. The number of determined Bad Detector Element (BDE's). This is determined through the analysis of the OBC and SOBC data collected operationally. A BDE mask is determined in the laboratory, typically the total number of BDE is around 200 (out of a total number of approximately 250,000 used pixels). Some of the BDE's are 'Blinkers'. These are pixels that operate for some light levels or just occasionally work. The algorithm for determining the number of BDE's is still in the early stages. Currently it is preferential to over count BDEs than to undercount due to the correction algorithm implemented in the Level-1 processing.
7. The spectral calibration is monitored through use of the Spectral On-Board Calibration (SOBC) system. The SOBC injects laser light into the NIS and onto a diffuser in the optical path. However, only portions of the FPA are illuminated. The first method examines the difference in spectral pixel location illuminated between the operational collects and Laboratory calibration.
8. The variation of in spectral pixel location illuminated by the laser source is also examined across the FPA, this variation is typically referred to as spectral clocking. The range listed in Table 4 equates to an allowable spectral range of approximately 0.30-nm across the FPA for the fit of a linear equation through the determined band-centers of the spatial columns illuminated by the SOBC.

**Table 4: NIS Quality Control Metrics tested by the NIS QC algorithm associated with nominal values and the acceptable ranges.**

Performance metric (calculated w/o BDE*)	Nominal	Low	High
1. Difference in FPA Temperature (Kelvin) from JPL setpoint (NIS-1 = 134K, NIS-2 = 140K).	NIS JPL setpoint	Setpoint – 0.5°	Setpoint + 0.5°
2. NIS Chamber Pressure (Values below 5.0E-4 Torr are acceptable).	< 5.0E-4 Torr	Not Applicable	> 5.0E-4 Torr
3. Focal Plane Array Dark Offset Positive Bias. Mean value for each pixel is calculated independently and the average determined for the used area of the FPA neglecting BDEs.	Nominal FPA dark offset value is about 1000 DN	10% < Nominal	10% > Nominal
4. Dark Offset RMS over 1000 frames. RMS for each pixel is calculated independently and the average determined for the used area of the FPA neglecting BDEs.	Nominal Dark Offset RMS is about 2.4 DN	2 DN	3 DN

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5. Difference in Bright OBC from Lab. Value each pixel is calculated independently and the average determined for the used area of the FPA neglecting BDEs.	Nominal FPA response to OBC determined in Lab	5% < Nominal	5% > Nominal
6. Number of BDEs in used area of FPA.	Nominal BDE determined in Lab	< 25 BDE	> 500 BDE
7. Fractional pixel location of the illumination from a SOBC HeNe laser at 632.8-nm.	Nominal determined from Lab Calibration	Nominal – 0.5	Nominal + 0.5
8. Absolute value of the SOBC Clocking of given as the slope in Pixel Space (zero is perfect spectral clocking).	Lab ~1E-5)	0	> 1E-4

\*BDE = Bad detector elements

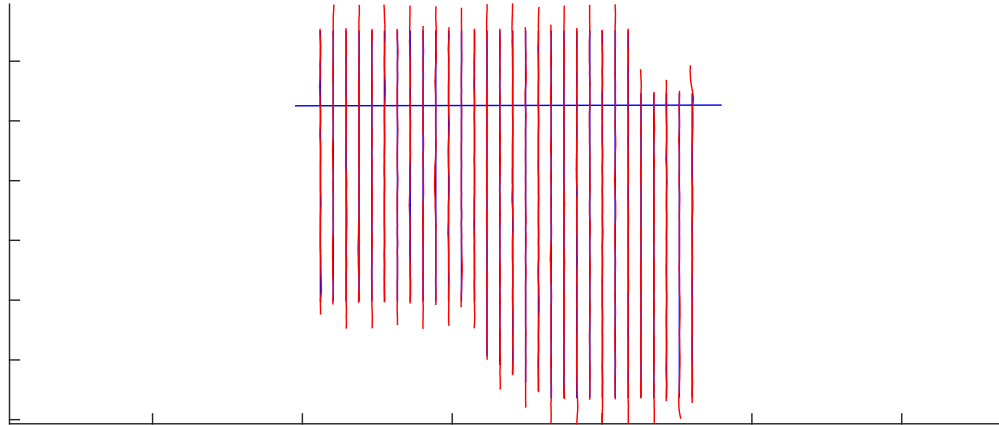
The performance metrics that will be monitored are based on the previously encountered failure modes as well as identified potential issues that could be detrimental to the NIS data. For each of these performance indices, there is the establish range of acceptable behavior listed above. Beyond this range the NIS Level-0 quality assurance algorithm will return an out-of-range response. The out-of-range response will result in either a warning or status of ‘fail’ for the NIS flight line of interest.

### 5.2.2 NIS preliminary flight line mapping utility

The NIS QC algorithm also attempts to determine the planned flight line number for each of the collected NIS datasets. This algorithm is in a very preliminary state and does not differentiate between flight lines flown at different altitudes along the same planned line. The flight logs collected by the Airborne Sensor Operators should be utilized as the definitive answer for matching the NIS collect with the planned flight line.

The computed mapping between planned flight line number and NIS collect is displayed via two methods. The first is graphically in a plot at the top of the QC output as shown in (Figure 9**Error! Reference source not found.**). In this plot the planned lines are in blue while the position information recorded from the NIS GPS/IMU (see RD [06]) is displayed in red. In addition, the assigned flight line number is printed at the start of QC output for each NIS collect. The plot is a useful diagnostic tool if the computed flight line number does not match the planned flight line or the recorded line number in the ASO logs.

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**Figure 9: Flight lines collected 2014-05-18 by NIS-1 over the NEON DSNY site in Florida. The blue lines are the planned flight lines while the red lines are the actual flight path for each of the NIS datasets.**

The algorithm for assigning flight line numbers to NIS datasets computes the distance between decimated values of the GPS/IMU data and the straight-line planned flight line. Averaging GPS/IMU data from 100 frames to a single value decimates the GPS/IMU data. This results in GPS/IMU data at 1-second intervals, which is sufficient for this work. The distance is then found between each of the GPS/IMU data points and the planned flight lines and the smallest difference below a threshold value is selected as the planned flight line number for that particular NIS dataset.

### 5.2.3 Procedure for Installing the NIS QAQC on the Hotel Kit

1. Checkout the NIS Level-0 Quality Assurance Algorithm from SVN. The algorithm is written in Matlab and makes use of a variety of included Matlab functions. For this reason, the entire NIS Matlab folder structure (the NIS\_test\_code folder and subdirectories) should be checked-out of SVN. The main NIS Matlab directory is located at:

**[https://svn.eco.neoninternal.org/svn/AOP/CommonTools/MATLAB/NIS\\_test\\_code/](https://svn.eco.neoninternal.org/svn/AOP/CommonTools/MATLAB/NIS_test_code/)**

2. Matlab will be installed on the Hotel Kits, if not, I will create an executable that may be run without Matlab being installed. Doing so, however, requires the Matlab Runtime Compiler, which we do not currently have.
3. The next step is editing the default path the script initially takes the user. To edit this, the variable `baseP='D:\nleisso\;` should be changed to the location the data to be tested will be on the Hotel Kit.

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- The final step is to edit the emailto variable to include the correct recipients (Figure 10). This should at a minimum include the relevant Airborne Sensor Operator’s email (fltops1@neoninc.org associated with NIS1, fltops2@neoninc.org associated NIS2, etc) and Nathan Leisso (nleisso@neoninc.org). Additional recipients may be added as needed.

```

43 - emailto = {'fltops1@neoninc.org', ...
44          'nleisso@neoninc.org'};

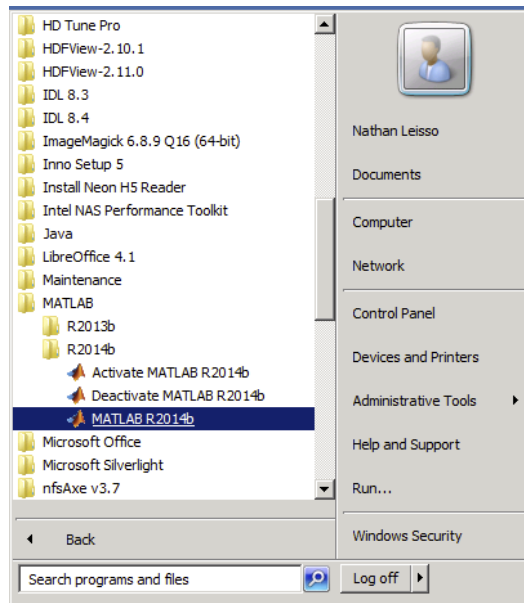
```

**Figure 10: Email recipients of NIS L0 quality check results**

- Verify the algorithm operates correctly including emailing the resulting PDF report to the desired recipients. The Matlab code uses the aopnis1@gmail.com email account for sending the results. This should be updated to a NEON account in the future.

### 5.2.4 Procedure for operating the NIS Level-0 Quality Assurance Algorithm

- Open Matlab from the Hotel Kit start menu (Figure 11), I have used 2013b for development but 2014 is acceptable as well.



**Figure 11: Opening Matlab on a Windows machine.**

- After Matlab has opened, click the open folder button, navigate to the nisDataChk.m file located several directories under the NIS\_test\_code directory checked out from SVN \NIS\_test\_code\statusChk\nisDataChk.m (Figure 12).

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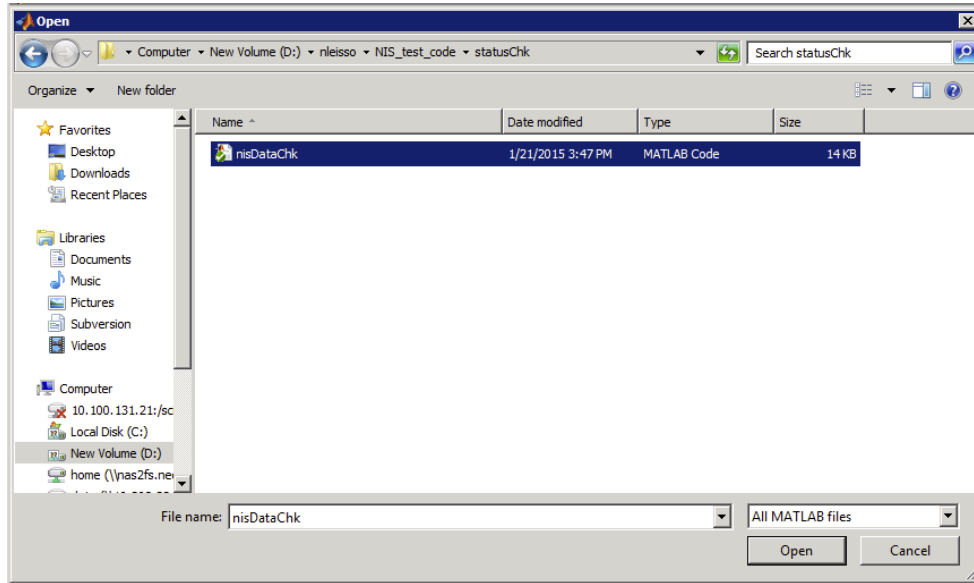


Figure 12: Opening the NIS QAQC algorithm in Matlab.

If Matlab is closed with the nisDataChk.m file still open in the editor, Matlab will reopen with the file already loaded.

- To run the script, click the green run button in the Matlab GUI header (Figure 13).

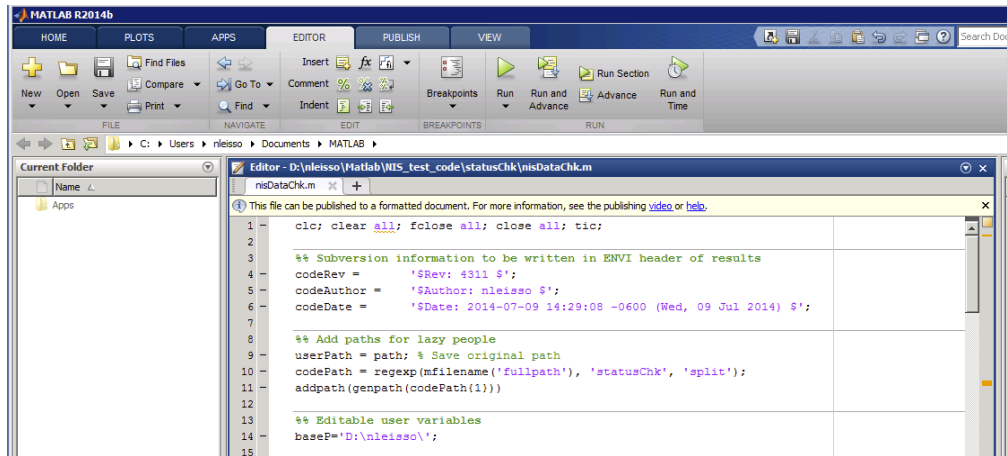


Figure 13: Start the scrip by click the green run button.

Clicking the Green run button will bring up a small gray dialog box asking whether the code should be added to the Matlab path. Click the 'Add to Path' button (Figure 14).



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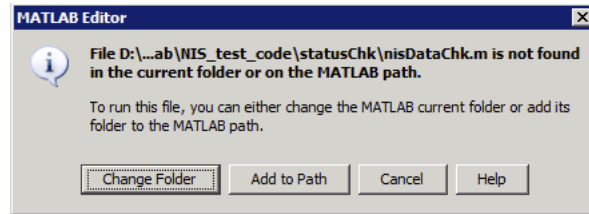


Figure 14: Click the 'Add to Path' button to point Matlab to all of the ancillary functions required to process the NIS data.

- The user is then prompted to select the main flight directory for quality checking. Navigate to the desired folder, highlight the directory, and proceed by clicking the 'Select Folder' button (Figure 15).

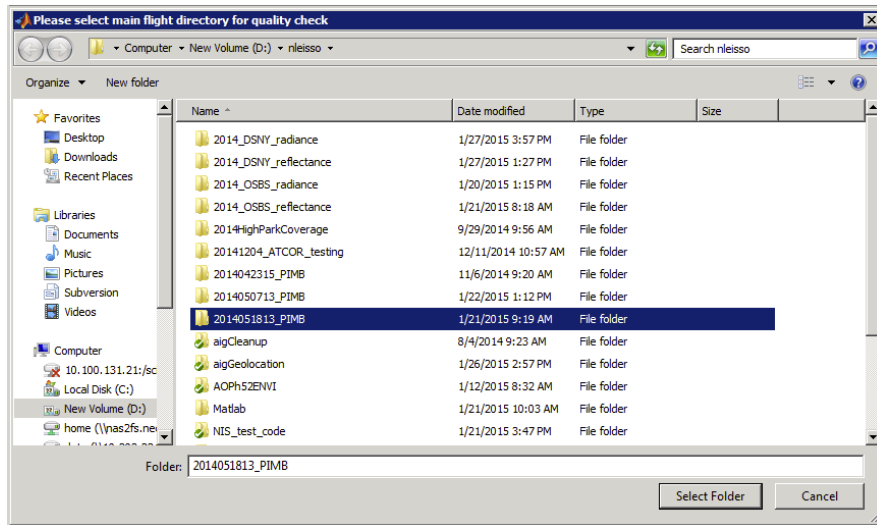


Figure 15: The user here has selected the 2014051813\_PIMB top-level directory for processing.

- The user is then prompted to select the \*.kml file associated with the flight plan that was flown. This is typically located `...\2014051813_PIMB\L0\Ancillary\FlightPlans\KMLs\` under the L0 ancillary folder. Please select the `*_fltlines.kml` file, NOT the `*_swath.kml` file (Figure 16).

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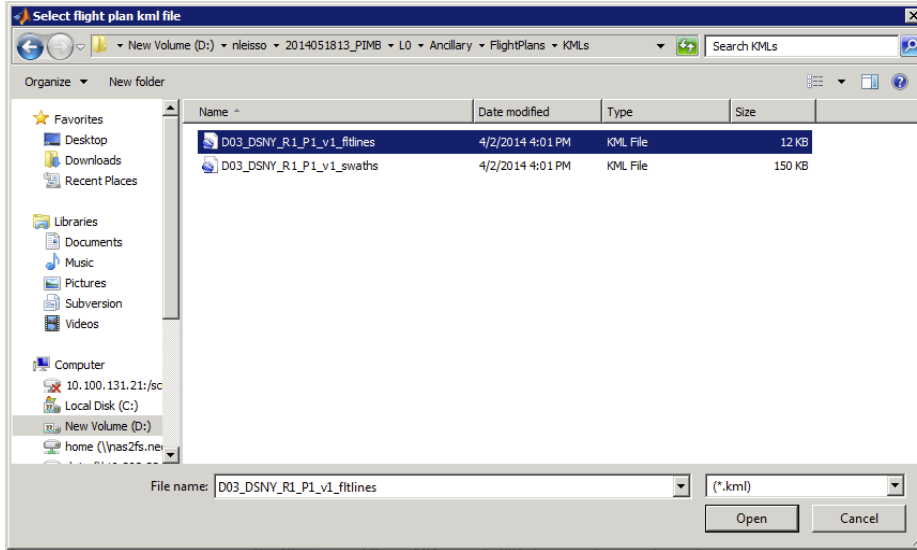


Figure 16: Select the \*.kml file associated with the flight plan that was flown.

- The script will then proceed to process the flightlines included in the selected directory. The status will be displayed in the Matlab Command Window (Figure 17).

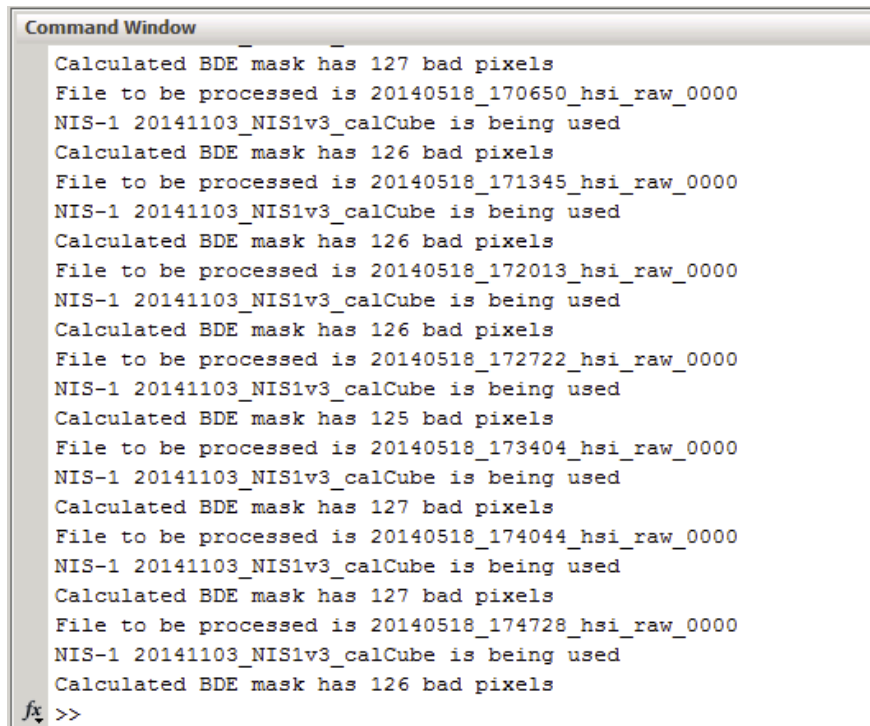
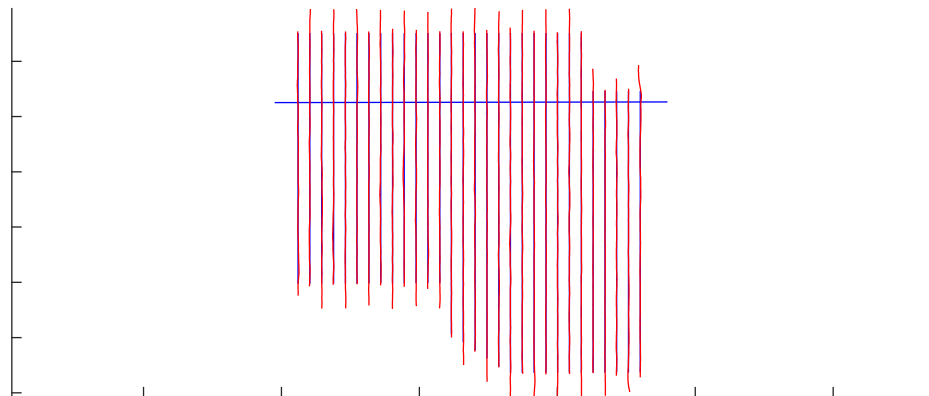


Figure 17: Updates from the NIS L0 quality check process are displayed in the Matlab command window. Upon completion, the Matlab command prompt (>>) returns to the command window.

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7. After the Matlab script has finished, a report will be emailed to the recipients included in the setup of the code. In addition, the report file is also saved to the Ancillary folder under L0 (Currently disable due to read/write access).
8. The user should then examine the status of the lines collected (**Error! Reference source not found.**).



Line	NIS Filename	FPA	Torr	Dark and RMS	% Dif OBC	# BDE	SOBC Px#	Clocking	Status
-	Lab Calibration			937.26 2.44		122	74.84	1.8e-05	-
2	20140518_141407	134.00	1.0e-06	951.04 2.39	-0.79	126	74.84	1.1e-05	Pass
3	20140518_142206	134.00	9.4e-07	954.43 2.39	-0.70	125	74.84	1.8e-05	Pass
4	20140518_142901	134.00	9.5e-07	958.72 2.39	-0.77	126	74.83	3.1e-05	Pass
5	20140518_143618	134.00	8.5e-07	963.78 2.39	-0.74	126	74.83	2.6e-05	Pass
6	20140518_144307	134.00	8.5e-07	967.44 2.39	-0.74	126	74.85	9.4e-06	Pass
7	20140518_145053	134.00	1.1e-06	969.07 2.39	-0.76	127	74.86	3.4e-05	Pass
8	20140518_145903	134.00	9.0e-07	969.51 2.39	-0.76	125	74.85	1.5e-05	Pass
9	20140518_150727	134.00	8.1e-07	969.82 2.39	-0.80	125	74.84	1.8e-05	Pass
10	20140518_151526	134.00	8.0e-07	970.16 2.39	-0.83	125	74.82	1.5e-05	Pass
11	20140518_152352	134.00	7.3e-07	970.43 2.38	-0.82	125	74.82	2.3e-05	Pass
12	20140518_153158	134.00	7.4e-07	970.60 2.38	-0.84	126	74.83	1.5e-07	Pass
13	20140518_154007	134.00	7.0e-07	970.78 2.38	-0.83	125	74.83	1.3e-05	Pass
14	20140518_154800	134.00	7.2e-07	970.69 2.38	-0.85	126	74.83	1.2e-05	Pass
15	20140518_155536	134.00	7.0e-07	970.89 2.38	-0.87	127	74.84	2.1e-05	Pass
16	20140518_160327	134.00	7.1e-07	971.13 2.39	-0.84	125	74.85	2.1e-05	Pass
17	20140518_161140	134.00	7.0e-07	971.01 2.38	-0.84	127	74.86	2.2e-05	Pass
18	20140518_161915	134.00	7.2e-07	971.12 2.38	-0.85	126	74.83	1.7e-05	Pass
19	20140518_162704	134.00	7.0e-07	971.09 2.38	-0.87	125	74.84	1.2e-05	Pass
20	20140518_163335	134.00	7.2e-07	971.02 2.38	-0.76	126	74.82	2.0e-05	Pass
21	20140518_164057	134.00	7.1e-07	971.19 2.38	-0.83	125	74.83	3.1e-05	Pass
22	20140518_164736	134.00	7.3e-07	971.18 2.38	-0.88	126	74.84	2.4e-05	Pass
23	20140518_165351	134.00	7.1e-07	971.22 2.39	-0.90	125	74.86	1.8e-05	Pass
24	20140518_170019	134.00	7.4e-07	971.17 2.38	-0.81	127	74.83	1.3e-05	Pass
25	20140518_170650	134.00	7.2e-07	971.02 2.38	-0.79	126	74.84	2.6e-06	Pass
26	20140518_171345	134.00	7.5e-07	970.94 2.38	-0.88	126	74.86	9.4e-06	Pass
27	20140518_172013	134.00	7.3e-07	971.08 2.38	-0.88	126	74.84	2.4e-05	Pass
28	20140518_172722	134.00	7.6e-07	970.90 2.39	-0.85	125	74.83	6.0e-06	Pass
29	20140518_173404	134.00	7.4e-07	971.04 2.38	-0.80	127	74.83	1.9e-05	Pass
30	20140518_174044	134.00	7.7e-07	970.94 2.38	-0.87	127	74.82	2.1e-05	Pass
31	20140518_174728	134.00	7.6e-07	970.86 2.39	-0.83	126	74.83	2.1e-05	Pass

Figure 18: Example of a QA report file from 2014-05-18 NIS dataset collected over the D3 Disney site.

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9. If a line does not pass inspection, the offending variable will be flagged in red and the status will report 'Fail' instead of 'Pass'.
  
10. If any of the quality checked flight lines do not pass inspection, the default option is to reply that particular flight line. However, if there is a systematic reason for the failure the root cause should be corrected prior to the second collection of the failed flight lines. A potential example is cooling to the NIS being lost during the flight and the focal plane temperature warming beyond the acceptable range.

### 5.3 Limitations

The current NIS Level-0 algorithm does not look at the actual science data collected. This is currently by design as this is not a controlled input. However, it would be useful to verify that the collected science data does not consist entirely of zeros or of saturated data. This is currently out of scope due to the size of the collected data and the expected turn-around time.

### 5.4 Future Improvements

Future additions to this algorithm will incorporate a method to check random subsets of the science collect. While the input is unknown, this will be used to verify the external shutter is not closed and data is collected above the Focal Plane Array's nominal background output yet remains below saturation levels for the collect.

## 6 WAVEFORM LIDAR

The waveform LiDAR sensor is a COTS system, manufactured at Optech. The LiDAR sensor produces both discrete LiDAR results and waveform LiDAR results. The discrete results can be thought of as a derivative of the waveform LiDAR, however the implementation of this difference within the Optech system is important. When a laser pulse is returned to the system, the signal is split between two receivers. One receiver records an analog signal and determines the discrete LiDAR directly from the analog signal. The second receiver performs an analog to digital conversion of the signal at time bins of 1 ns and an 11-bit dynamic range to produce the waveform. In our experience with the Optech system, the waveform signal is prone to hardware malfunctions, resulting in data gaps. However, the discrete return results have been robust, and no hardware malfunctions have been observed. The discrete LIDAR is saved into a proprietary format with a '.range' extension that cannot be read by code developed in-house. Optech provides software which can read this data, however, it does not perform an appropriate quality check to determine if the results are within an acceptable range. To provide the L0 quality check on the LiDAR data, it is being assumed that if waveform data was successfully observed, the same is true for the discrete LiDAR. This allows quality checks to be performed only on the waveform data, avoiding the issue of the inability to parse the proprietary format of the '.range' file. If the unusual circumstance occurred in which the discrete LiDAR were not taken, and the waveform did exist, the discrete LiDAR can

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be recreated in-house from the waveform LiDAR. Table 5 lists the criteria for testing the waveform LiDAR.

**Table 5: Waveform LiDAR verification criteria**

Parameter assessed	What data stream it is measured from	Within range value
PRF	Measured from returns	+/- 5% of expected
Dark offset	T0 pulse	Within a predefined range
Peak signal	T0 pulse	+/- 20% of expected
FWHM	T0 pulse	Within a predefined range
Number of missing shots	T0 pulses	< 0.01% of shots
Number of saturated shots	T0 pulses	< 5% of shots
Number of 'invalid' shots	T0 pulses	< 5% of shots
Number of missing return shots	Returned signal	< 25% of shots
Number of saturated returns	Returned signal	< 20% of shots
Valid signal range	Returned signal	< 5% of shots
Range values too small	Returned signal	< 5% of shots

## 6.1 Raw Data

The raw data required for the waveform verification is the binary waveform packets recorded during the flight as well as a log file which contains information about the flight parameters. The structure of the binary waveform packets is described by Optech, allowing in-house code to read their contents. The waveform packets contain waveform data in sections. The log file is in an ASCII format and contains information about the laser parameters used to acquire the data such as the PRF (pulse repetition frequency).

## 6.2 Verification Procedure

For each flight line processed and each subset frame the code runs stats on all laser pulses within that frame. A subset of frames processed to reduce analysis time. The subset fraction value is configured by an input parameter file. For each flight line, the code verifies that raw data is within range for the following parameters as listed in **Error! Reference source not found.:**

- Measured PRF
- T0 dark offset
- T0 Peak Signal
- T0 FWHM
- Missing T0 shots

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- Saturated T0 shots
- Invalid T0 shots
- Missing return shots
- Saturated return shots
- Low signal return shots
- Short range returns

### 6.2.1 Measured PRF

The PRF (Pulse repetition frequency) determines the rate at which LiDAR pulses are transmitted. The Optech system allows settings of 33, 50, 70, 100, 142 and 166 kHz. The purpose of this test is to verify that the instrument is operating nominally. The test compares the mean PRF (number of shots in frame divided by the time difference to the next frame) to the expected value. The expected values were determined through in house testing of the instrument as shown in Table 6.

**Table 6: Expected value and acceptable range of PRF values**

PRF Setting	Expected Value	Expected Range
33	33.3326 kHz	± 5%
50	49.9989 kHz	± 5%
70	71.4270 kHz	± 5%
100	99.9978 kHz	± 5%
125	124.9973 kHz	± 5%
142	142.8 kHz	± 5%
166	166.0 kHz	± 5%

### 6.2.2 T0 Dark Offset

The T0 dark offset represents the level of signal the receiver interprets in the absence of real signal. The T0 is assessed because a high dark offset value could be indicative of a data truncation issue, indicating that some actual signal was removed from the waveform. To verify, the mean T0 dark offset is compared to an expected value determined from in-house experimentation as shown in Table 7.

**Table 7: Expected T0 dark offset values**

PRF Setting	Expected Value	Expected Range
33	210.00 DN	150-250 DN
50	210.00 DN	150-250 DN
70	210.00 DN	150-250 DN
100	210.00 DN	150-250 DN

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125	210.00 DN	150-250 DN
142	210.00 DN	150-250 DN
166	210.00 DN	150-250 DN

### 6.2.3 T0 Peak Signal

The T0 peak signal corresponds to the maximum amplitude of the transmitted signal waveform. A low signal can be indicative of an optical misalignment in the receiving optics or an issue with the sensitivity of the receiving hardware. To verify, the mean T0 peak signal is compared to an expected value. Table 8 summarizes the expected value of the T0 peak signal with an associated PRF.

**Table 8: Expected value and range for T0 peak signal**

PRF Setting	Expected Value	Expected Range
33	2676.76 DN	± 20%
50	1719.55 DN	± 20%
70	1045.53 DN	± 20%
100	651.00 DN	± 20%
125	462.36 DN	± 20%
142	407.01 DN	± 20%
166	348.16 DN	± 20%

### 6.2.4 T0 Full Width Half Maximum

The FWHM (full width half max) of the T0 pulse describes its shape. The FWHM is based on the total transmission time of the pulse. If the T0 FWHM is outside of range it represents an issue in the laser transmission hardware. Table 6-5 lists the verification criteria for assessing the T0 FWHM, with the expected values being derived from in-house experimentation as shown in Table 9.

**Table 9: Expected values for the T0 FWHM**

PRF Setting	Expected Value	Expected Range
33	8.96 ns	2-20 ns
50	10.48 ns	2-20 ns
70	12.31 ns	2-20 ns
100	14.52 ns	2-20 ns
125	17.64 ns	2-20 ns
142	TBD	2-20 ns
166	TBD	2-20 ns

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In addition to the above components, which vary with PRF, several additional tests which are independent of PRF must be checked. The total number of missing T0 shots should be less than 0.01% of the total number of expected shots. The number of saturated T0 shots should be less than 5% of shots, a higher percentage represents a potential issue with insecure cabling. The total number of invalid T0 shots should be less than 5% of shots. The total number of missing return shots should be less than 25% of the total shots. If a high value of missing shots is noted, confirmations that this is not simply due to a surface feature such as a water body as water features will tend to absorb energy in the 1064 nm wavelength of the laser. The total number of saturated returns should be less than 20% of shots. If the number of saturated returns is higher, confirmation is required that surface features which result in strong returns, such as snow were not present. The returns are inspected for a valid signal range, which is considered to be 100 DN through in-house experimentation. The signal range is calculated as the difference between the maximum signal and the minimum signal. In total, less than 5% of shots should have a low signal. A basic range calculation is also performed to determine if shots were being returned from surface features and not some reflective particles in the atmosphere such as dust. Given the aircraft flies at 1000 m above ground level (AGL), a threshold of 400 m from the aircraft was set as the criteria for a short range. Less than 5% of shots should be less than the 400 m.

### 6.3 Limitations

The waveform L0 quality check has the ability to produce false positives in terms of rejecting returning waveforms due to missing shots or high signal strength as shown in Table 5. The criteria for the number of missing shots allows 25%. Waterbodies will typically absorb some portion of the 1064 nm laser, as well as cause a specular reflection at incidence angles above zero resulting in very few returns. Therefore, if a line contains a large body of water it may fail the L0 quality check, but this is not a result of a malfunction in the hardware system. A similar situation is true for the saturated signal, which allows 20% of shots according to Table 5. If there is a target within the swath which reflects the 1064 nm laser energy well (such as dry snow), it is possible that the L0 quality check will fail. In these circumstances, the landscape within the failed swath will have to be interpreted by a human operator.

## 7 DIGITAL CAMERA

The digital camera hardware is supplied by Optech in a package with the LiDAR, however the camera is manufactured by Phase One. The camera records RGB images at 8 cm resolution under nominal altitude conditions (1000 m) and each image has dimensions of 8,984 x 6,732 pixels. Images are captured in a snapshot mode, and assuming a nominal flight altitude of 1000 m AGL, each image encompasses an area of 770 m cross-track by 577 m along-track (44 deg x 33 deg). Images are collected at a rate designed to 50 percent overlap between adjacent images. At an altitude of 1000 meters and a ground speed of 100 knots, an image is collected about every 5.7 seconds. Table 10 lists the tested parameters and their failure criteria for the digital camera.



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**Table 10: Verification criteria for the digital camera**

Parameter	Criteria for fail
Corrupt	Cannot be read in
Black image	All pixel values = 0
White image	All pixel values = 255
Image underexposed	90% of pixels have counts <= 40
Image overexposed	90% of pixels have counts >= 230
Reduced dynamic range within image	Standard deviation of pixel values is <= 10

## 7.1 Raw data

The raw camera images are recorded in the proprietary IIQ format but have a .tiff extension (see <http://help.phaseone.com/en/CO7/Output/File-formats/Capture-One-and-RAW.aspx#item3>). The file includes a 561 by 420 rgb thumbnail, as described in '[.TIF vs .IIQ](#)'

*“Basically the final file is a valid TIFF of a very small preview of the image, with a “note” at the end of the file with the entire raw data. When opened in a program that does not support the Phase One Raw file format that program would see the TIFF-compliant preview and, at least, be able to show what the picture was of (although it would not be able to actually view the raw data).”*

This thumbnail can be viewed by any Windows picture viewer that supports tif files, including Windows Explorer and Microsoft Office<sup>1</sup>. Most image processing software, notably IDL and ENVI, can read these files but can access only the thumbnails.

Accessing the full 8,984 by 6,732 image requires software that recognizes the IIQ format, such as:

- [Capture One Pro 7 - photo editing software: http://www.phaseone.com/en/Imaging-Software/Capture-One-Pro-7.aspx](http://www.phaseone.com/en/Imaging-Software/Capture-One-Pro-7.aspx)
- [Raw Therapee: http://rawtherapee.com/blog/features](http://rawtherapee.com/blog/features)

Capture One is the software provided with the camera and is free to use with files in IIQ format. RawTherapee is open source software. Currently, AOP uses Capture One to process the raw images. The output from Capture One is a regular 8,984 by 6,732 tiff image that can be read by most software.

---

<sup>1</sup> However, Microsoft Photo Viewer displays a 2246 by 1683 image that appears similar to the uncorrected raw data. Apparently, it is accessing a portion of the raw data and not the thumbnail.

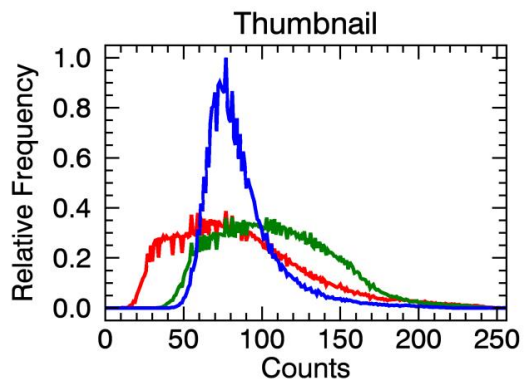
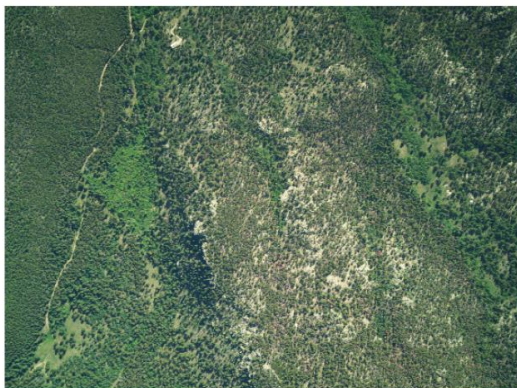
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However, processing the raw images requires, for example, several hours for 1000 images on a computer with 24 cores and 256 GB memory (all 24 cores are utilized.) For a ‘quick look’ of the images, processing the raw data is not feasible. Rather we must rely on the thumbnail images.

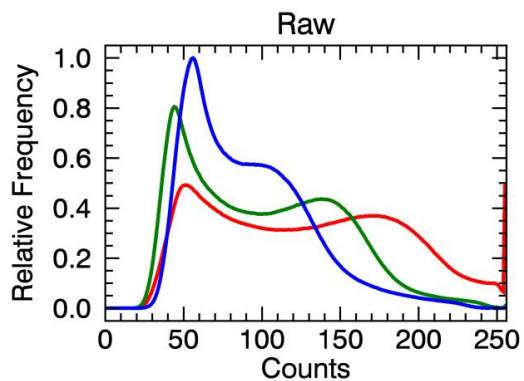
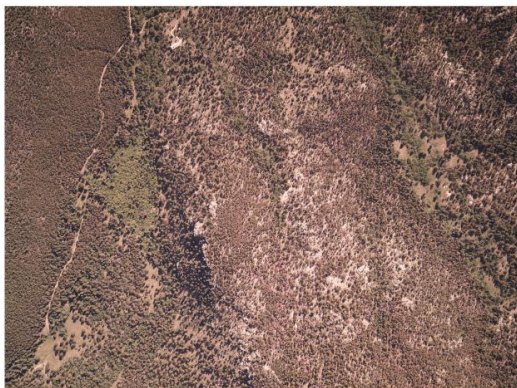
In creating the thumbnail images from the raw image data, the data collection software applies some (unknown) stretch to make the images more realistic, as shown in (Figure 19). In this figure, the left side shows the thumbnail image, the full resolution, raw uncorrected image, and the full resolution image after correcting for white balance and exposure. The right side shows the histograms of the *rgb* channels.

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Thumbnail



Raw



Processed

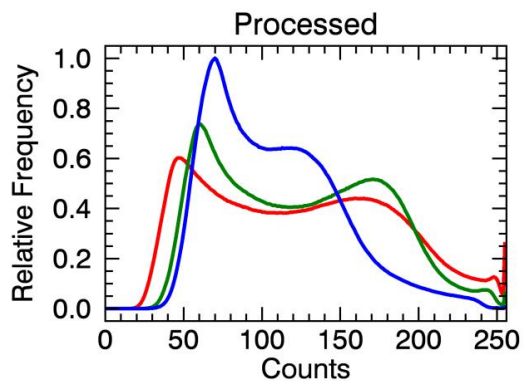
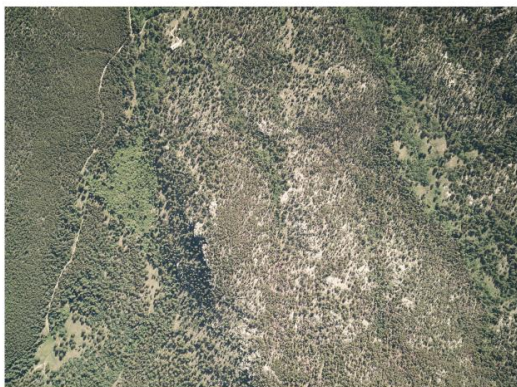


Figure 19: Image 130626A\_EH021537(20130626055958)-0001.tiff: left- images, right-histograms of the rgb channels.

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## 7.2 Verification Procedure

The possible failure modes identified through experience so are:

1. The camera is not turned on before the flight line
2. The data collection process fails and data is not collected
3. The image file is corrupt and cannot be read
4. The exposure is set incorrectly or the lighting conditions change significantly during the flight and the operator does not adjust the exposure.
5. The recorded image is readable but is corrupted or has significant artifacts.
6. The camera lens is obscured (lens cap on or there is dirt/water on the lens)
7. The image suffers from smearing due to excessive aircraft motion or incorrect forward motion compensation

The first two failure modes occur when data is not collected and will be covered by the LiDAR verification plan. The modes 3 and 4 occur when data is collected but is corrupted or out of range and will be covered here. Modes 5 through 7 may require that an operator visually review the images. It is more convenient to describe the out-of-range criteria than the within-range criteria. Failure modes 4 and 5 relate to the data values (exposure) and can be detected programmatically. Failure modes 5 through 7 will probably require an operator to view some or all of the images.

### 7.2.1 Exposure Test

The following conditions are identified as out-of-range:

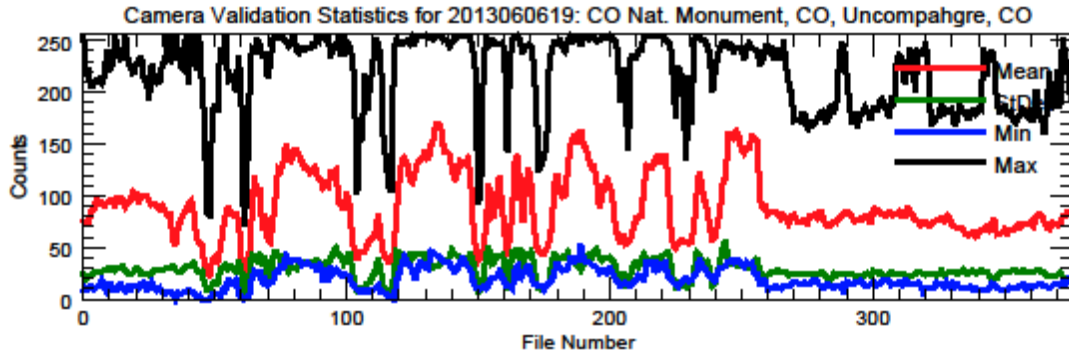
1. The image is all black: all the counts for all bands are 0
2. The image is all white: all the counts for all bands are 255
3. The image is very dark (underexposed) : the histograms of the image counts are shifted too far to the left
4. The image is very bright (overexposed): the histograms of the image counts are shifted too far to the right.
5. The histograms of the image counts are too narrow, i.e., the image appears uniform.

The IDL routine `verify_camera_validation_stats.pro` is designed to detect corrupt and out-of-range images. It reads each image and collects the following statistics:

6. Whether the file is corrupt, i.e., not readable
7. The mean, minimum, maximum and standard deviation of each band
8. The histogram and cumulative histogram of each band

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The routine then applies the five exposure tests listed above and plots the results. The results for one case, for 2013060619 over the Colorado National Monument Park and Uncompahgre, are shown in Figure 20. Note that four images fail the “Very dark” and thirteen images fail the “Very uniform” tests.



Number of failures by test:

- 1. Image is corrupt: 0
- 2. Black Image: All the pixels are 0: 0
- 3. White image: All the pixels are 255: 0
- 4. Very dark image: 90 percent of pixels have counts  $\leq 40$ : 4
- 5. Very bright image: 90 percent of pixels have counts  $\geq 230$ : 0
- 6. Very uniform image: the standard deviation of the image counts is  $\leq 10$ : 13

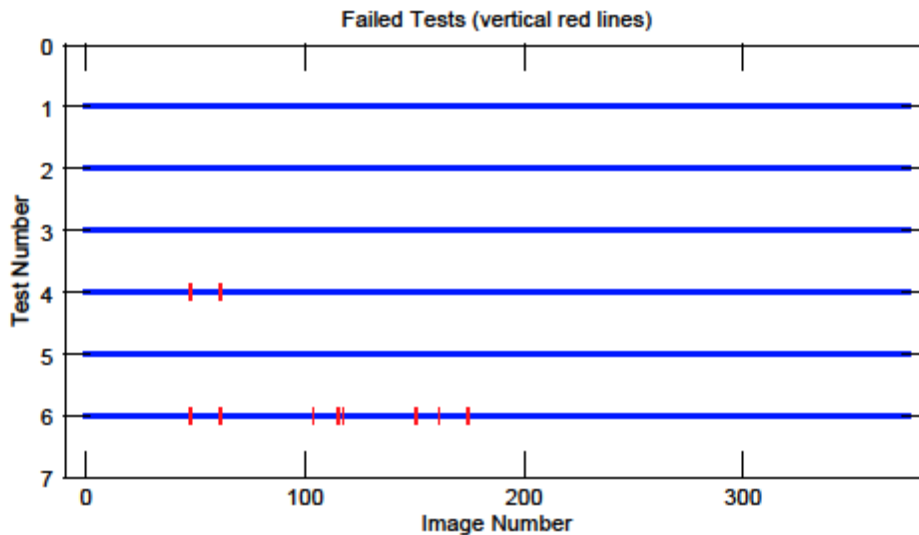


Figure 20: Summary statistics for 2013060619



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For each image that fails an exposure test, the image plus histograms of the band counts are plotted, as shown in Figure 21. In this case, the area within the image was in a deep cloud shadow. Other images that fail the “Very dark” test include views of water.

Failure results for image 20130606B\_EH021537(20130606110328)-0048.tiff  
 Failed tests:

- 4. Very dark image: 90 percent of pixels have counts  $\leq 40$
- 6. Very uniform image: the standard deviation of the image counts is  $\leq 10$

Statistics:

Band	Mean	StDev	Min	Max	# Black	# White
Red	19.0	10.3	0.0	97.0	10633	0
Green	30.0	6.7	0.0	81.0	5	0
Blue	24.7	7.9	0.0	75.0	2551	0

20130606B\_EH021537(20130606110328)-0048.tiff

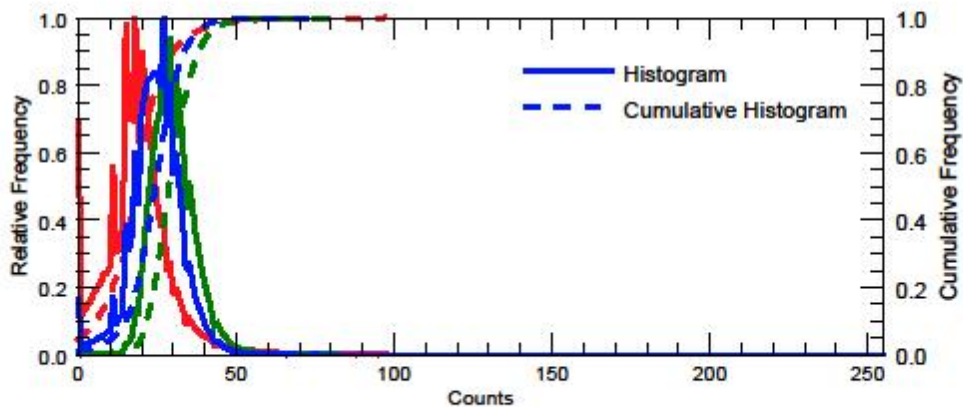


Figure 21: atistics, image and histograms for an image that failed both the “Very dark” and “Very uniform” tests.

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An image that fails the “Very bright” and “Very uniform” tests is shown in **Error! Reference source not found..** This image was taken over Railroad Valley, NV where the background is bright desert. It does not represent a “failure” rather just a natural background.

Failure results for image 20130608\_RRV\_EH021537(20130608074404)-0013.tiff  
 Failed tests:

- 5. Very bright image: 90 percent of pixels have counts ge 230
- 6. Very uniform image: the standard deviation of the image counts is le 10

Statistics:

Band	Mean	StDev	Min	Max	# Black	# White
Red	251.2	4.4	219.0	255.0	0	53108
Green	252.6	3.3	228.0	255.0	0	94270
Blue	237.7	9.9	178.0	252.0	0	0

20130608\_RRV\_EH021537(20130608074404)-0013.tiff

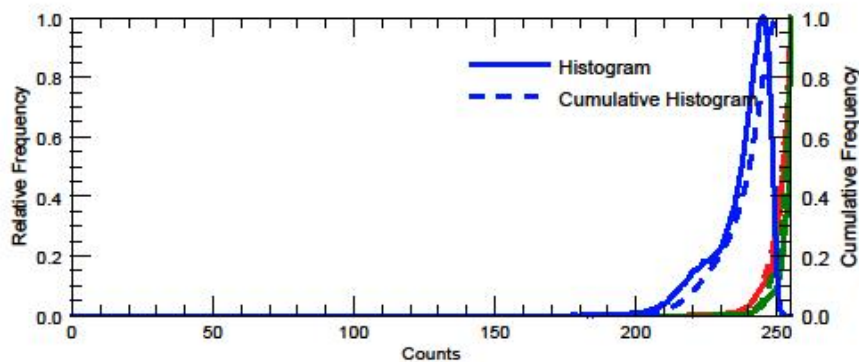
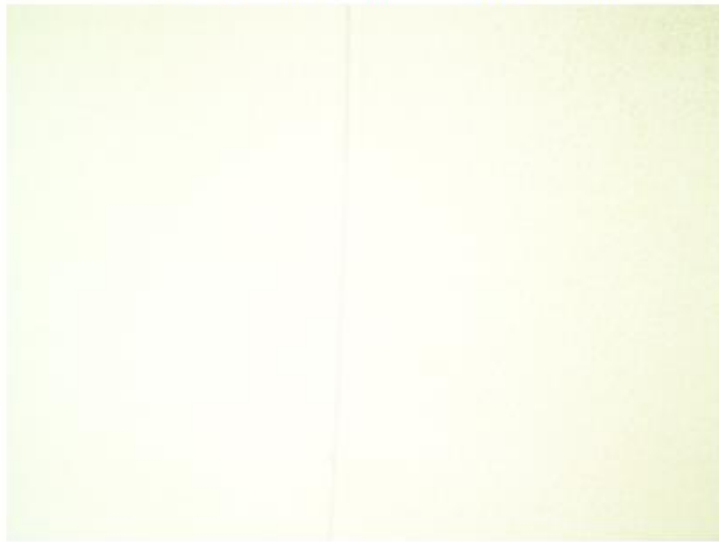


Figure 22: Statistics, image and histograms for an image that failed both the “Very bright” and “Very uniform” tests. This image was taken over Railroad Valley, NV. The background is desert

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### 7.2.2 Corrupt Images

Some images show obvious corruption and/or artifacts that are not revealed by the exposure tests. **Error! Reference source not found.** Figure 23 shows two consecutive images taken on 2-12-8-8 over Harvard Forest, Massachusetts. The second image shows obvious corruption. The source of this corruption is not known. Currently there is no known programmatic test to detect this kind of image failure. Until one is devised, this kind of failure can only be detected by an operator viewing the images.



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20120808\_D\_EH021656(20120808123644)-0210.tiff



20120808\_D\_EH021656(20120808123851)-0211.tiff

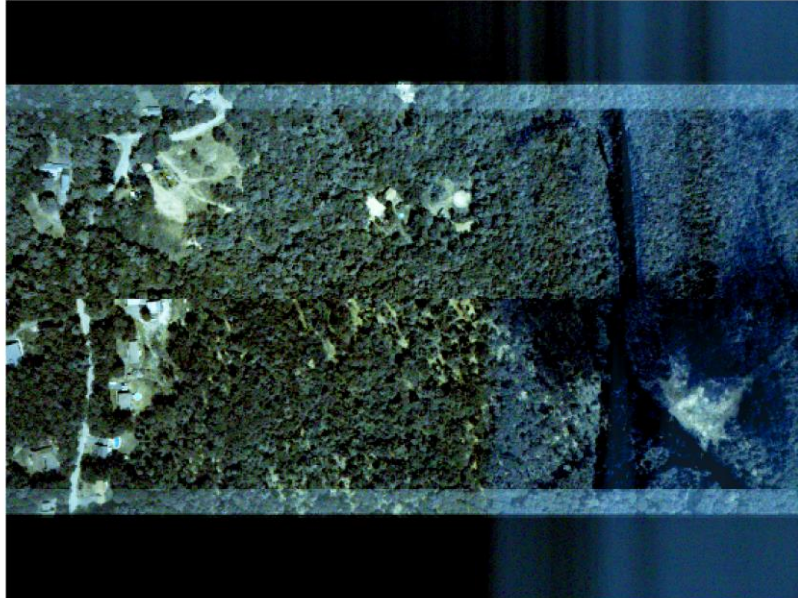


Figure 23: Two consecutive images taken on 20120808 over Harvard Forest showing corruption in the second image.

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### 7.3 Limitations

Similar to the waveform LiDAR, the camera L0 quality checks are capable of producing false positive failures. For instance, a deep water body will fail the ‘very uniform’ and ‘very dark’ tests. Additionally, if a bright area is flown, such as the desert landscape in Railroad Valley (Figure 22), the ‘Very uniform’ and ‘Very bright’ tests can potentially fail. This will require interaction by a human operator to assess the failures to determine if the failures are legitimate.

### 7.4 Future Improvements

The out-of-range tests described here are initial attempts at catching invalid data. Both the test parameters and the tests themselves are subject to revision based on experience. In particular, the too dark or too bright tests may flag images that are still useful, especially if in the future, 16-bit images are collected. In addition, some scenes are naturally uniform, e.g., smooth lake surfaces and dense hardwood forest. Further experience is needed to determine the optimum thresholds for these tests, or whether to keep these tests at all.

Note that the analysis shown here is based on the 561 by 420 pixel “thumbnail” images extracted from the full 8,984 by 6,732 images: it is not possible to read the full images in a timely fashion (see Section 3). The assumption is that the statistics for the thumbnails and the full resolution images are similar enough that the thumbnail histograms can be used as proxies for the full image histograms. As seen in Figure 19, the thumbnail and the full image histograms are significantly different. However, for the purpose of these tests, I feel that they are similar enough. Specifically, an all-black thumbnail should indicate an all-black full resolution image, and a too dark or bright thumbnail should indicate a too dark or bright full resolution image.

## 8 COVERAGE

### 8.1 Raw Data

The payload, as described in Section 3, produces sensor data (described elsewhere) and a large amount of ancillary data. The ancillary data produced includes two sets of KML files which can be used for L0 coverage checks. The KML files are generated in real-time and can be extracted immediately after flight. One set of KML files has polygons for the digital camera coverage and polygons for the LiDAR on-ground footprint per flight line. Within a single KML of a swath there is one polygon per acquired digital photograph, and one polygon per LiDAR swath. The second set of KML files contains polygons for the on-ground footprint of the NIS acquisition. These are also stored as complex polygon swaths with one KML per flight line. These sets of KML files are stored in two separate directories as described in the sensor data acquisition documents. An example of the polygons collected for one flight line is shown in Figure 24 **Error! Reference source not found..**

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It is important to note that these KML files and the polygons contained therein are first-order coverage polygons and are not exactly the same as those produced by downstream high-precision geolocation processing. They are sufficient for immediate coverage checks and have the added benefit of not requiring extensive processing time for accurate geolocation.



Figure 24: Photo (light blue), LiDAR (green), and spectrometer (red) coverage polygons for a single flight line over DSNY from 2014

AOP data acquisition is required to provide at least 80% coverage for all three instruments for the area described by the AOP priority 1 flight box and 952% coverage for the area described by the Airshed boundary as specified in Table 1. Flight plans to cover these areas are developed within AOP using considerations of platform capabilities, cloud cover, growing season and maximum greenness, system logistics and more. Flight plans, the Priority 1 Flight Box boundary, and the Airshed boundary are stored on the portable AOP systems (aka “Hotel Kit”) for immediate post-flight processing and L0 data checks.



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## 8.2 Verification Procedure

The AOP L0 coverage check code is written entirely in Python 2.7.9 using the open and freely available GDAL, os, pykml and tkinter modules. The program prompts the user to select the directory for the photograph and LiDAR input KMLs, the directory for the spectrometer input KMLs, the Priority 1 Flight Box boundary shapefile, the Airshed boundary shapefile, and lookup files for each of the three instruments (spectrometer, LiDAR, and digital camera) indicating any data footprint polygons which should be excluded from coverage consideration from failing earlier data range validity testing.

All photograph polygons are Unioned in to a large, complex, multipart polygon preserving any holes or separate pieces (Figure 25). Polygon Union operations produce a result where any area included in one or more of the input areas is included in the output area. All LiDAR swath polygons are Unioned similarly, as are all spectrometer polygons. LiDAR and spectrometer polygons are also topologically validated prior to Unioning to eliminate any self-crossing boundaries or other vector invalid conditions possible with active swath coverage spatial data. Photograph footprints do not require this validation as they are simple quadrilaterals by definition.

The photograph, LiDAR and spectrometer Union polygons are converted from their input native Geographic projection to the UTM map projection of the Priority 1 Flight Box and Airshed boundaries. This allows coverage areas to be expressed and tested in square meters and produces much more reliable percentage coverage results.

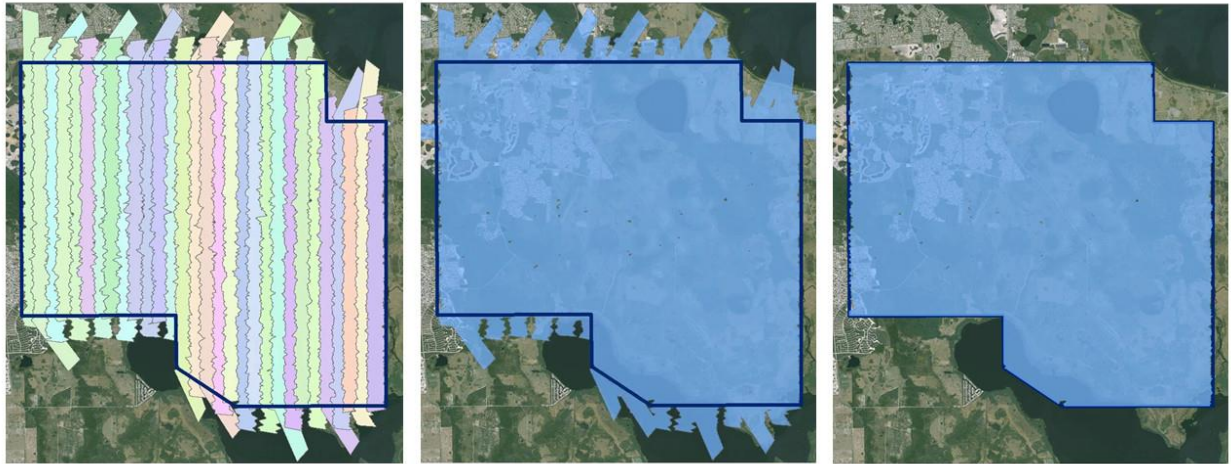
The photograph, LiDAR and spectrometer Union polygons are each individually Intersected with the Priority 1 Flight Box boundary and individually Intersected with the Airshed Boundary (Figure 25) Polygon Intersection produces an output area that includes only those areas covered by all input areas. Coverage percentage results are then calculated as:

$$\frac{\cup(\text{All Individual Sensor Polygons}) \cap (\text{Required Area Polygon})}{(\text{Required Area Polygon})} \tag{1}$$

This produces six percentage coverage values:

- 1) Percentage coverage of Priority 1 Flight Box by digital photographs
- 2) Percentage coverage of Priority 1 Flight Box by LiDAR
- 3) Percentage coverage of Priority 1 Flight Box by spectrometer
- 4) Percentage coverage of Airshed by digital photographs
- 5) Percentage coverage of Airshed by LiDAR and
- 6) Percentage coverage of Airshed by spectrometer.

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Original flightlines

Unioned flightlines

Intesected with flightbox

Figure 25: Calculation of coverage from flight swaths

### 8.2.1 Procedure for operating the AOP Level-0 Coverage check

1. Checkout the AOP Level-0 Coverage Check from SVN. The algorithm is written in Python and makes use of the GDAL, os, pykml and tkinter modules. These modules must be available on the machine on which the code is to be run.
2. Python will be installed on the Hotel Kits along with the required modeuls. If they are not, AOP scientists can create a Python app distribution that includes them with the code.
3. At a system command prompt, change directories to where the Level-0 Coverage Check code has been installed.
4. At the command prompt, type:

```
python PolygonTest
```

5. The user will be prompted to select the directory containing the KML files for the digital photograph and LiDAR flight line coverage polygons (Figure 26):

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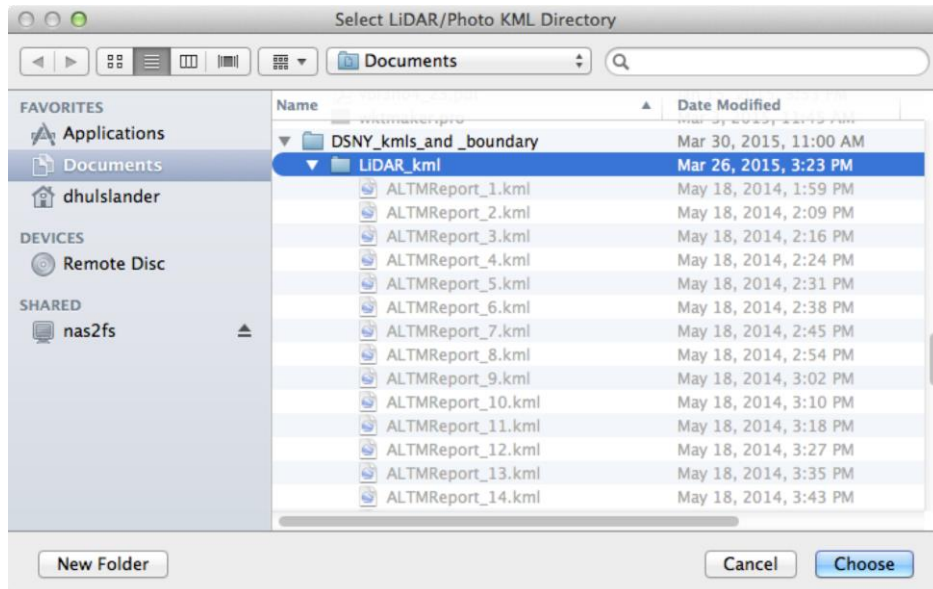


Figure 26: Prompt for directory containing photo and LiDAR KML files

- After clicking Choose/OK, the user will be prompted to select the directory containing the spectrometer coverage KML files (Figure 27):

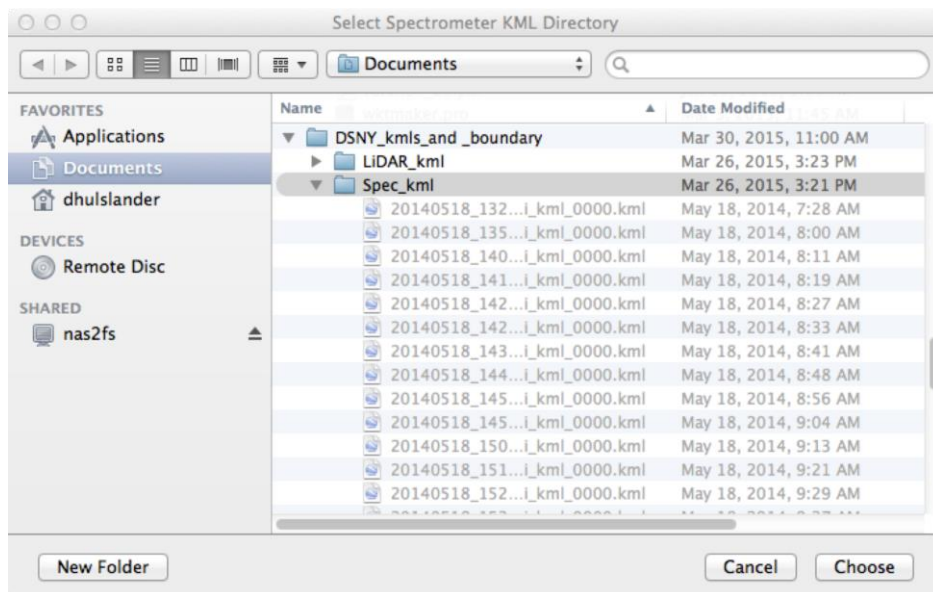


Figure 27: Prompt for selecting spectrometer coverage KML files

- After clicking Choose/OK, the user will be prompted to select the Priority 1 Flight Box boundary shapefile (Figure 28):

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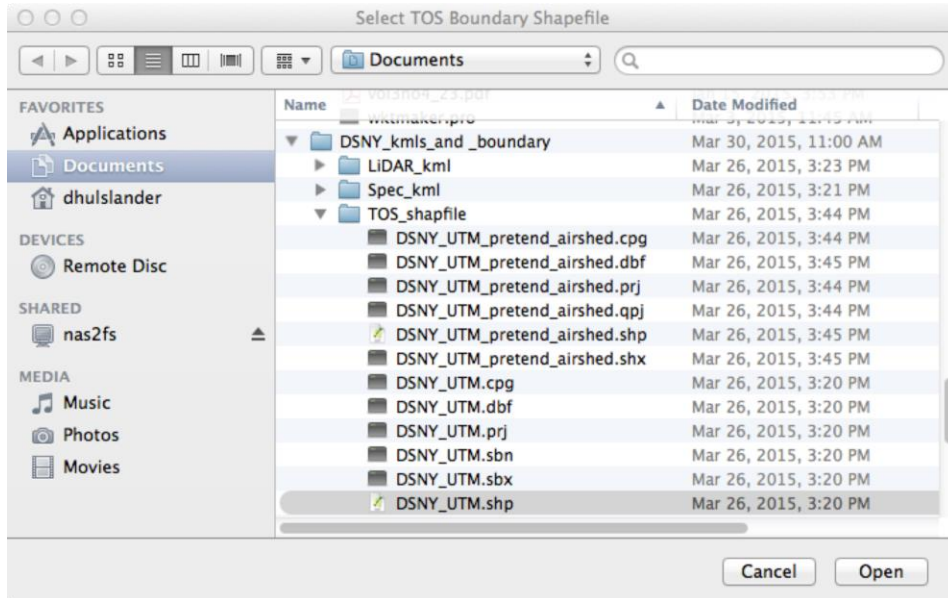


Figure 28: Prompt for selecting TOS boundary shapefile

- After clicking Choose/OK, the user will be prompted to select the Airshed boundary shapefile (Figure 29).

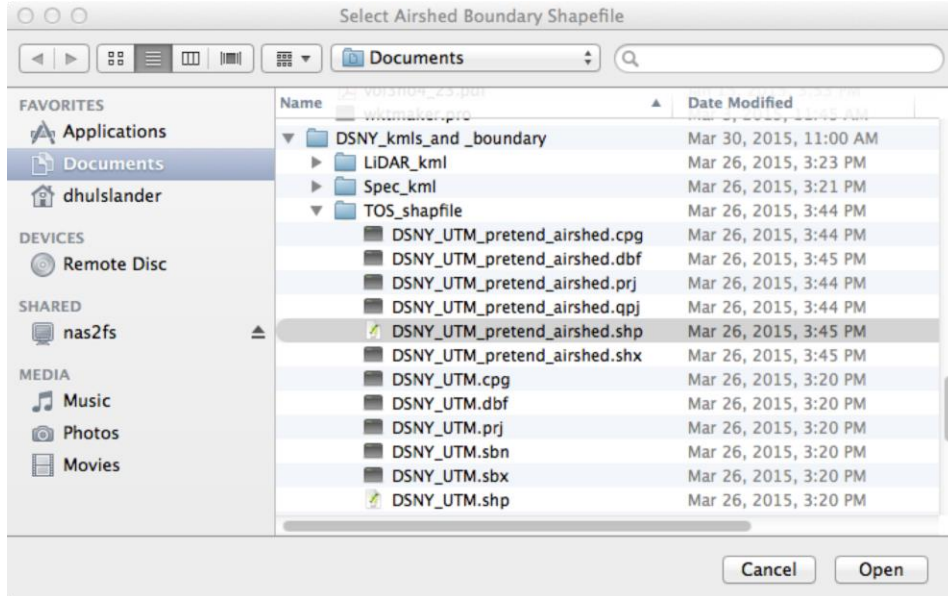


Figure 29: Prompt for selecting airshed boundary shapefile

- After clicking Choose/OK, the user will be prompted to select the valid spectrometer lookup file.
- After clicking Choose/OK, the user will be prompted to select the valid digital photo lookup file.

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11. After clicking Choose/OK, the user will be prompted to select the valid LiDAR lookup file.
12. After clicking Choose/OK, the user will be presented with a L0 Coverage Check Results dialog containing the results of all six required coverage checks (Figure 30).

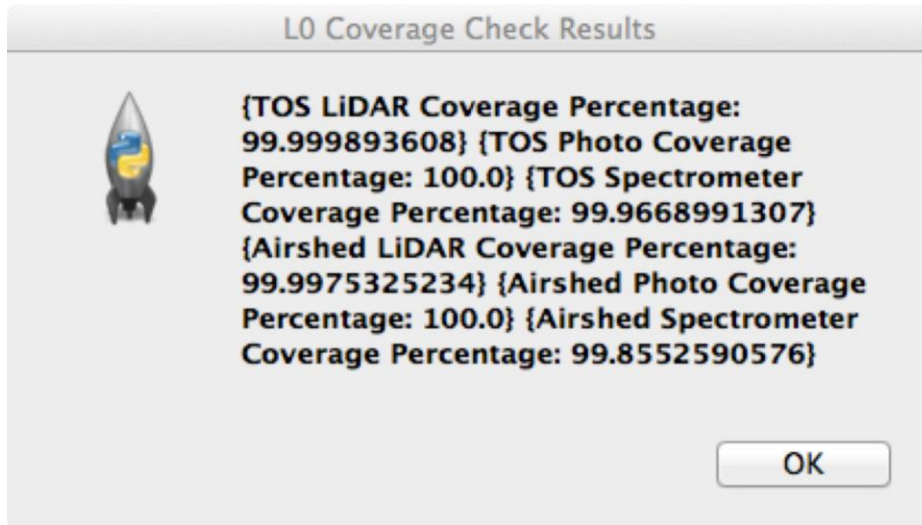


Figure 30: Results of the coverage check

### 8.3 Limitations

The coverage check utilizes KML files which are produced in real time by the sensors. The real-time results are not as accurate as results generated from a rigorous geolocation with appropriate calibration parameters and finalized aircraft trajectory. As a result the KML files of the swaths can contain geolocation errors of several tens of meters. It is possible that false positive and false negative gaps will occur in the data that will not become evident until L1 processing is complete.

### 8.4 Future Improvements

Future development of the L0 Coverage Check application includes:

- Integration with automated Hotel Kit processing, eliminating operator interaction/selection.

Creation of KML files containing any gaps in coverage, optionally displayable in Google Earth by operators with individual layers and symbology for each of the sensor systems.



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<i>NEON Doc. #:</i> NEON.DOC.002890	<i>Author:</i> T. Goulden, W. Gallery, D. Hulslander, K. Krause, N. Leisso	<i>Revision:</i> D

## 9 REFERENCES

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