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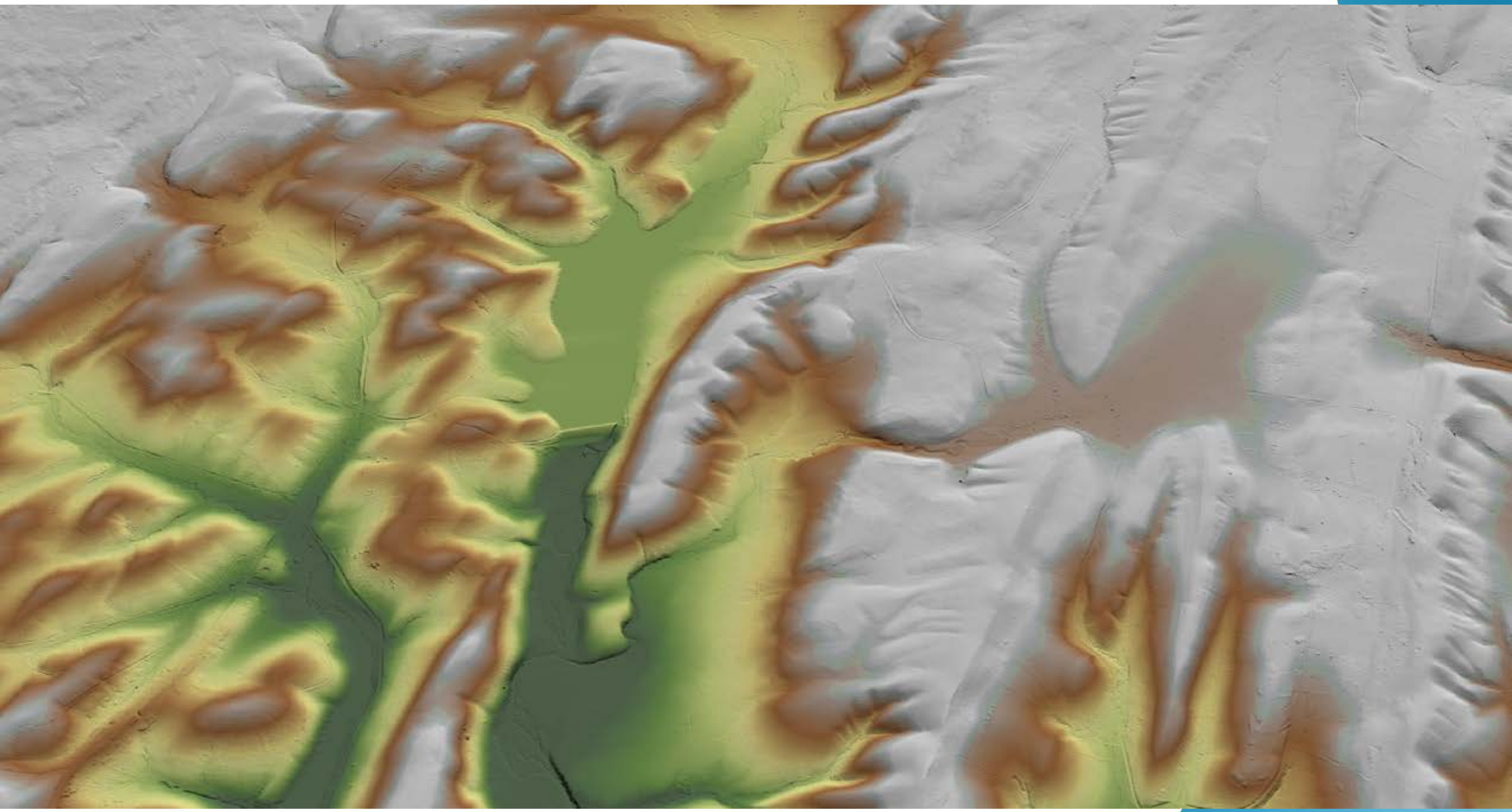

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THE PENNSYLVANIA STATE UNIVERSITY LIDAR, HYPERSPECTRAL IMAGERY, AND ORTHOIMAGERY PROCESSING REPORT

2020

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1. Summary / Scope

1.1. Summary

NV5 Geospatial, powered by Quantum Spatial, was contracted by The Pennsylvania State University for lidar, hyperspectral imagery, and orthoimagery acquisition and processing under RFP #RXF-PRCH-RFP-2383-M, dated March 3, 2020.

This report accompanies the delivered lidar, hyperspectral imagery, and orthoimagery data for the project and documents contract specifications, data acquisition procedures, processing methods, and analysis of the final dataset.

1.2. Scope

Aerial topographic lidar was acquired using state of the art technology along with the necessary surveyed ground control points (GCPs) and airborne GPS and inertial navigation systems. The aerial data collection was designed with the following specifications listed in Table 1 below.

Table 1. Originally Planned Lidar Specifications

Average Point Density	Flight Altitude (AGL)	Field of View	Minimum Side Overlap	RMSEz
≥ 30 pts / m²	950 m - 1036 m	≤ 60°	≥ 50%	≤ 10 cm

High resolution 3-inch, 8-bit 4-band (RGB-IR) digital imagery was acquired and used for digital orthophoto production. Imagery data collection was planned using the specifications listed below in Table 2.

Table 2. Originally Planned Orthoimagery Specifications

GSD	Flight Altitude (AGL)	Side Overlap	Front Overlap
0.3 m	~17,000 ft	30%	60%

High resolution 0.5-meter, 14-bit 48-band hyperspectral imagery was acquired and used for digital orthophoto production. Imagery data collection was planned using the specifications listed below in Table 3.

Table 3. Originally Planned Hyperspectral Imagery Specifications

GSD	Flight Altitude (AGL)	Min. Sun Angle	Side Overlap
0.5-meter	1030 m	55°	40%

1.3. Coverage

The project boundary covers approximately 28 square miles over Penn State Experimental Forest Lands (PSEFL). Project extents are shown in Figure 1.

1.4. Duration

Leaf-off lidar data was collected on March 22, 2020 in one lift. Leaf-on lidar data was collected on July 2, 2020 in one lift.

Leaf-on hyperspectral imagery was collected on July 18, 2020 in one lift.

Leaf-off orthoimagery data was collected on March 22, 2020 in one lift. Leaf-on orthoimagery data was collected on July 14, 2020 in one lift.

See “Section: 2.6. Time Period” for more details.

1.5. Issues

There are no issues to report.

PSU Experimental Forest
Project Boundary

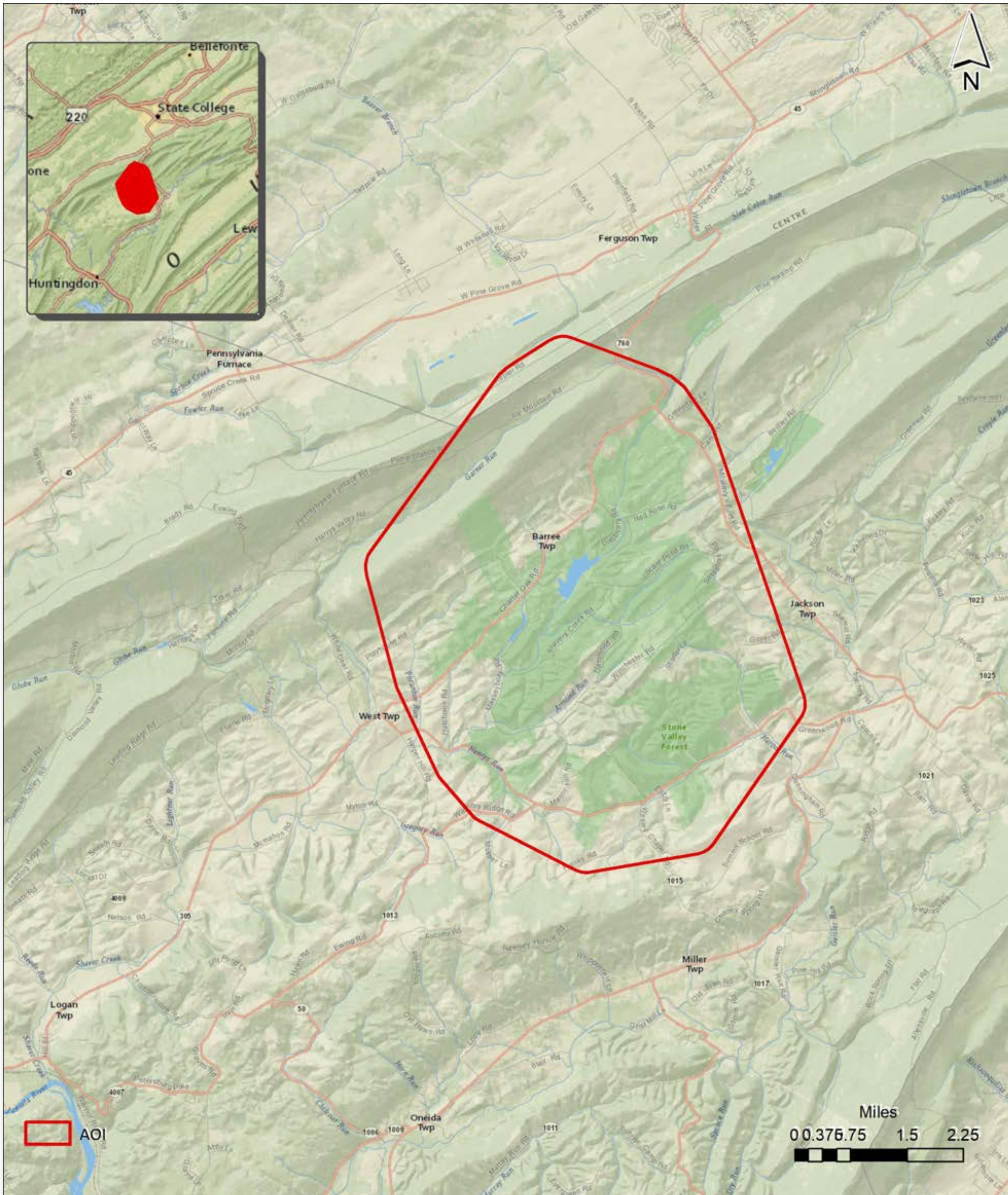

Figure 1. Project Boundary

2. Planning / Equipment

2.1. Flight Planning

Flight planning was based on the unique project requirements and characteristics of the project site. The basis of planning included: required accuracies, type of development, amount / type of vegetation within project area, required data posting, and potential altitude restrictions for flights in project vicinity.

Detailed project flight planning calculations were performed for the project using Leica MissionPro, RiPARAMETER, and Trackair snapPLAN planning software for lidar and imagery. The entire target area was comprised of 35 planned flight lines for the lidar acquisition (Figure 3), 3 planned flight lines for orthoimagery acquisition (Figure 4), and 26 planned flight lines for hyperspectral imagery (Figure 5)

2.2. Lidar Sensor

Quantum Spatial utilized a Riegl VQ1560i sensor (Figure 3), serial number 4040, for lidar acquisition.

The Riegl 1560i system has a laser pulse repetition rate of up to 2 MHz resulting in more than 1.3 million measurements per second. The system utilizes a Multi-Pulse in the Air option (MPIA). The sensor is also equipped with the ability to measure up to an unlimited number of targets per pulse from the laser.

A brief summary of the aerial acquisition parameters for the project are shown in the Lidar System Specifications in Table 4.

2.3. Imagery Cameras

Quantum Spatial also utilized an UltraCam Eagle M1 (817310) and UltraCam Falcon Prime (610270) (Figure 5), for orthoimagery acquisition, and a CASI-1500h (SN2607), for hyperspectral imagery acquisition (Figure 6).

This UltraCam system has 4 channel (RGB & NIR) multi-spectral capability. The combination of the camera's Forward Motion Compensation, along with the gyro stabilized mount, ensures the best possible image collection. A single full resolution image of the UCE M1 is 20,010 by 13,080 pixels in size. A single full resolution image of the UltraCam Falcon Prime is 17,310 by 11,310 pixels in size.

The CASI-1500h is a VNIR pushbroom sensor with a scientific CMOS sensor array. It has a spectral range of 380-1050nm and up to 288 spectral channels. The pixel size is 20x20 microns and it has a dynamic range of 14-bits. It has 1500 across-track pixels and a horizontal accuracy of +/- 3 pixels (1.5m).

A brief summary of the aerial acquisition parameters for the project are shown in the Camera System Specifications in Tables 5 and 6.

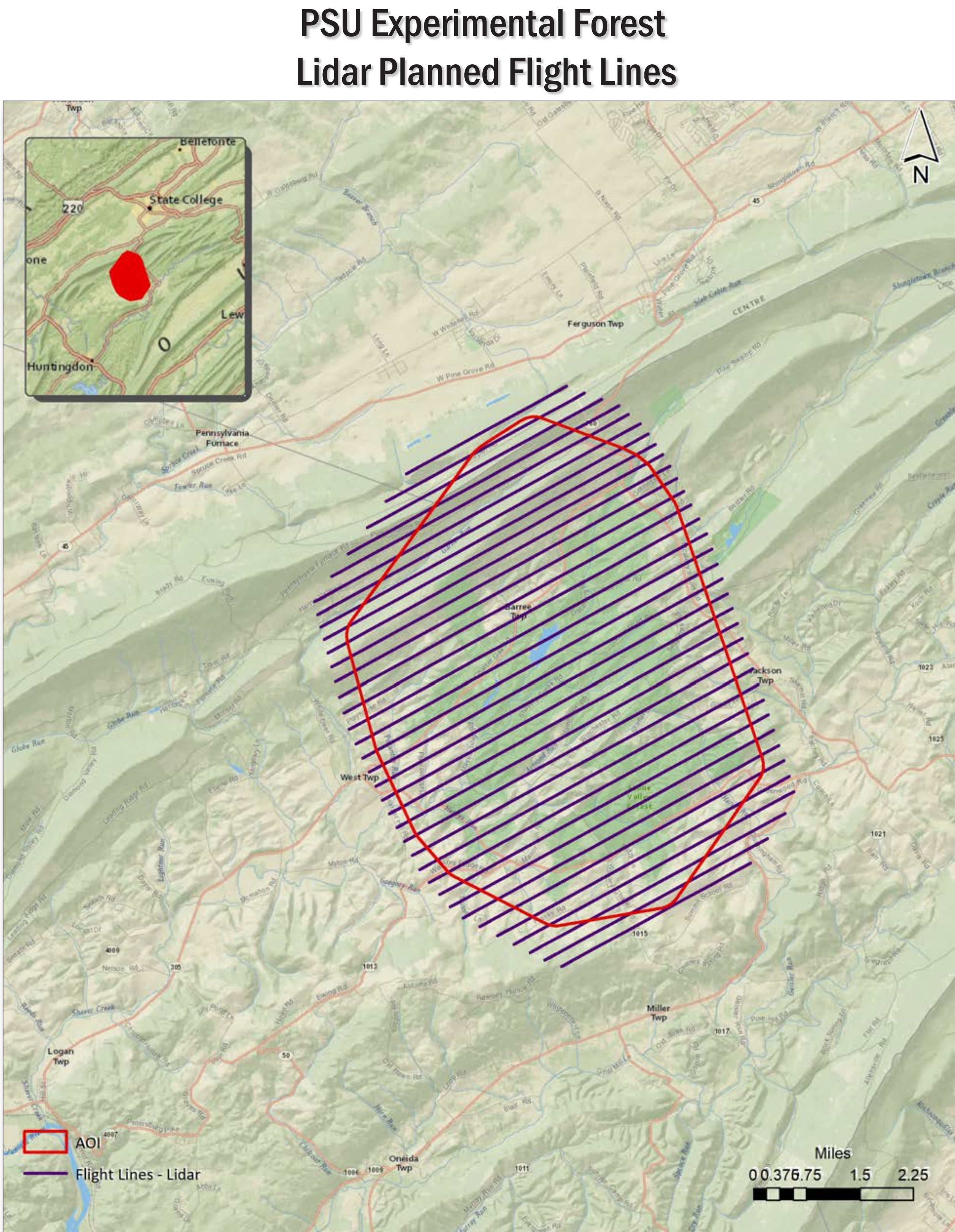

Figure 2. Planned Flight Lines Lidar

Table 4. Lidar System Specifications

		Riegl VQ1560i (leaf-off)	Riegl VQ1560i (leaf-on)
Terrain and Aircraft Scanner	Flying Height	950 m	1036 m
	Recommended Ground Speed	150 kts	120 kts
Scanner	Field of View	60°	58.52°
	Scan Rate Setting Used	422 Hz	2 x 183 lines per second
Laser	Laser Pulse Rate Used	2000 kHz	500 kHz per channel
	Multi Pulse in Air Mode	yes	yes
Coverage	Full Swath Width	1096 m	1161 m
	Line Spacing	548 m	522.45 m
Point Spacing and Density	Average Point Spacing	0.18 m	0.18 m
	Average Point Density	31.2 pts / m^2	30.8 pts / m^2

Figure 3. Riegl VQ1560i Lidar Sensor

PSU Experimental Forest
Orthoimagery Planned Flight Lines

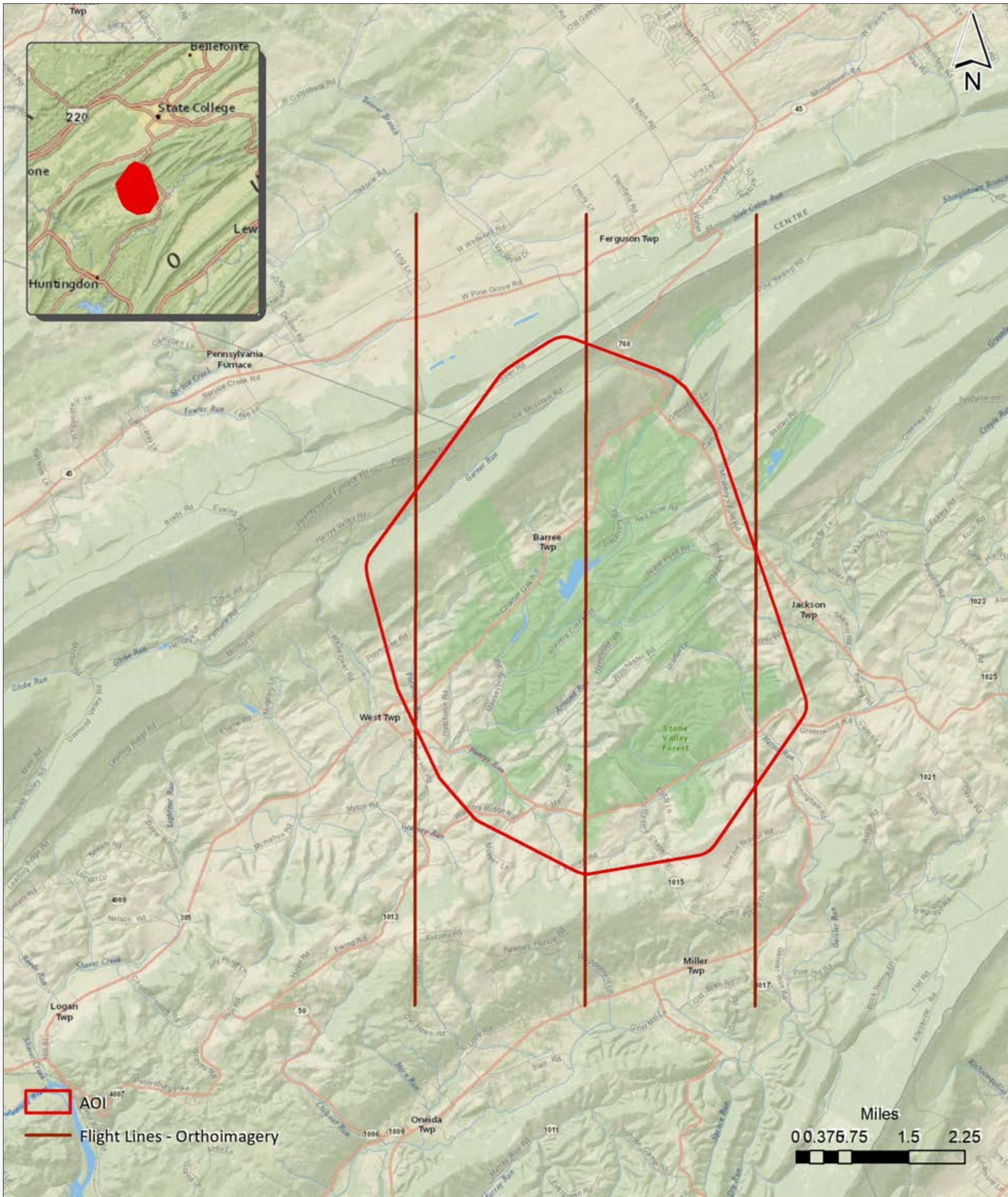

Figure 4. Planned Flight Lines Orthoimagery

Table 5. Imagery Camera System Specifications

		UCE M3 (Orthoimagery)
Terrain and Aircraft	Flying Height AGL	~17,000 ft
	Recommended Ground Speed (GS)	160 kts
Overlap	Forward Overlap	60%
	Side Overlap	30%
Coverage	Strip Width	5,100 m
Resolution	Ground Sample Distance	0.3 m

Figure 5. UltraCam Eagle **and** UltraCam Falcon **Cameras**

PSU Experimental Forest
Hyperspectral Imagery Planned Flight Lines

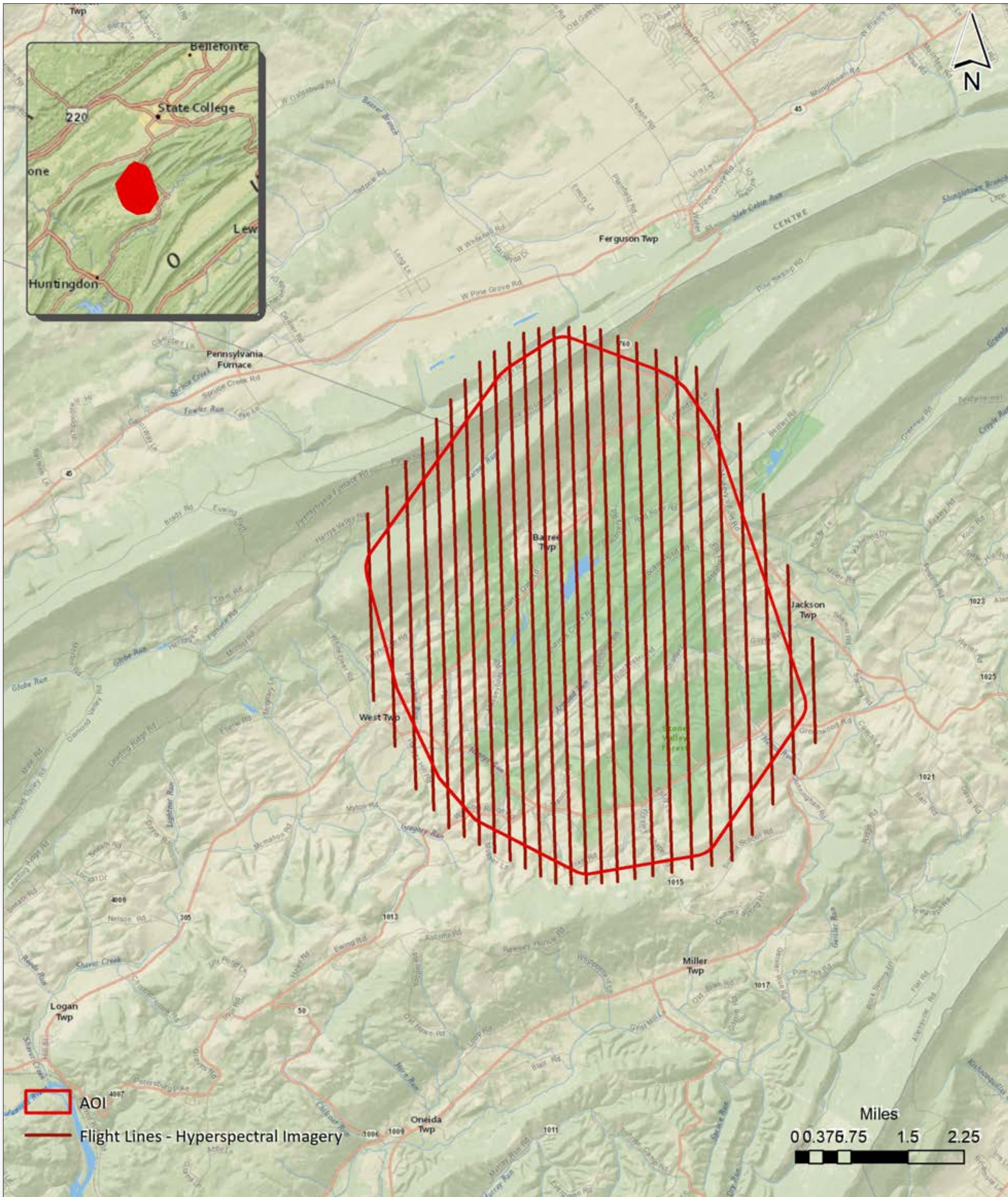

Figure 6. Planned Flight Lines Hyperspectral Imagery

Table 6. Imagery Camera System Specifications

		CASI-1500h (Hyperspectral Imagery)
Terrain and Aircraft	Flying Height AGL	1030 m
	Recommended Ground Speed (GS)	120 kts
	Side Overlap	40%
Resolution	Ground Sample Distance	0.5-meter

Figure 7. CASI-1500h Camera

2.4. Aircraft

All flights for the project were accomplished through the use of customized planes. Plane type and tail numbers are listed below.

Lidar Collection Planes
- Cessna Caravan (single-turboprop), Tail Number: N704MD

Imagery Collection Planes
- Piper Navajo (twin-piston), Tail Number: N812TB, N6GR
- Cessna Conquest 2 (twin-turboprop), Tail Number: N441MD
- Cessna 310 (twin-piston), Tail Number: N4948A

These aircraft provided an ideal, stable aerial base for lidar and imagery acquisition. These aerial platforms have relatively fast cruise speeds which are beneficial for project mobilization / demobilization while maintaining relatively slow stall speeds which proved ideal for collection of high-density, consistent data posting using state-of-the-art lidar and imagery systems. Some of the operating aircraft can be seen in Figure 8 below.

Figure 8. Quantum Spatial Planes

2.5. Time Period

Project specific flights were conducted in March and July 2020. See below for specific lift info.

Lidar Lifts

- 20200322 (SN4040, N704MD)
- 20200714 (SN4040, N704MD)

Orthoimagery Lifts

- 20200322 (SN817310, N441MD)
- 20200714 (SN610270, N4948A)

Hyperspectral Imagery Lifts

- 20200718 (SN2607, N6GR)

3. Processing Summary

3.1. Flight Logs

Flight logs were completed by LIDAR sensor technicians for each mission during acquisition. These logs depict a variety of information, including:

- Job / Project #
- Flight Date / Lift Number
- FOV (Field of View)
- Scan Rate (HZ)
- Pulse Rate Frequency (Hz)
- Ground Speed
- Altitude
- Base Station
- PDOP avoidance times
- Flight Line #
- Flight Line Start and Stop Times
- Flight Line Altitude (AMSL)
- Heading
- Speed
- Returns
- Crab

Similar information was also collected for imagery:

- Job / Project #
- System
- Flight Date / Lift Number
- Flight Line Number
- Flight Line Start Time
- Flight Line Stop Time
- Image Range
- F-Stop Setting
- Shutter Setting

Notes: (Visibility, winds, ride, weather, temperature, dew point, pressure, etc).

3.2. LiDAR Processing

Applanix + POSPac software was used for post-processing of airborne GPS and inertial data (IMU), which is critical to the positioning and orientation of the LiDAR sensor during all flights. Applanix POSPac combines aircraft raw trajectory data with stationary GPS base station data yielding a "Smoothed Best Estimate Trajectory" (SBET) necessary for additional post processing software to develop the resulting geo-referenced point cloud from the LiDAR missions.

During the sensor trajectory processing (combining GPS & IMU datasets) certain statistical graphs and tables are generated within the Applanix POSPac processing environment which are commonly used as indicators of processing stability and accuracy. This data for analysis include: max horizontal / vertical GPS variance, separation plot, altitude plot, PDOP plot, base station baseline length, processing mode, number of satellite vehicles, and mission trajectory.

Point clouds were created using the RiPROCESS software. The generated point cloud is the mathematical three dimensional composite of all returns from all laser pulses as determined from the aerial mission. The point cloud is imported into GeoCue distributive processing software. Imported data is tiled and then calibrated using TerraMatch and proprietary software. Using TerraScan, the vertical accuracy of the surveyed ground control is tested and any bias is removed from the data. TerraScan and TerraModeler software packages are then used for automated data classification and manual cleanup. The data are manually reviewed and any remaining artifacts removed using functionality provided by TerraScan and TerraModeler.

DEMs and Intensity Images are then generated using proprietary software. In the bare earth surface model, above-ground features are excluded from the data set. Global Mapper is used as a final check of the bare earth dataset.

Finally, proprietary software is used to perform statistical analysis of the LAS files.

The lidar tile layout is shown in Figure 9.

Software	Version
RiPROCESS	1.8.6
Applanix + POSPac	8.4
GeoCue	2017.1.14.1
Global Mapper	19.1;20.1
TerraModeler	20.004
TerraScan	20.011
TerraMatch	20.004

3.3. LAS Classification Scheme

The classification classes are determined by the USGS Version 2.1 specifications and are an industry standard for the classification of LIDAR point clouds. All data starts the process as Class 1 (Unclassified), and then through automated classification routines, the classifications are determined using TerraScan macro processing.

The classes used in the dataset are as follows and have the following descriptions:

Table 7. LAS Classifications

	Classification Name	Description
1	Processed, but Unclassified	Laser returns that are not included in the ground class, or any other project classification
2	Bare earth	Laser returns that are determined to be ground using automated and manual cleaning algorithms
5	High Vegetation	First return vegetation greater than 18” above ground
6	Buildings	Points falling on buildings, structures inside of water bodies, docks, and piers.
7	Low Noise	Laser returns that are often associated with scattering from reflective surfaces, or artificial points below the ground surface
14	Bridges	Laser returns falling on bridges

3.4. Classified LAS Processing

The bare earth surface is then manually reviewed to ensure correct classification on the Class 2 (Ground) points.

All overlap data was processed through automated functionality provided by TerraScan to classify the overlapping flight line data to approved classes by USGS. The overlap data was identified using the Overlap Flag, per LAS 1.4 specifications.

All data was manually reviewed and any remaining artifacts removed using functionality provided by TerraScan and TerraModeler. Global Mapper is used as a final check of the bare earth dataset. GeoCue was then used to create the deliverable industry-standard LAS files for all point cloud data. Quantum Spatial’s proprietary software was used to perform final statistical analysis of the classes in the LAS files, on a per tile level to verify final classification metrics and full LAS header information.

3.5. Hydro-Flattened Raster DEM Processing

Class 2 lidar in conjunction with the hydro-breaklines were used to create a 1.25-foot raster DEM. Using automated scripting routines within ArcMap, a GeoTIFF file was created for each tile.

Each surface is reviewed using Global Mapper to check for any surface anomalies or incorrect elevations found within the surface.

3.6. Intensity Image Processing

GeoCue software was used to create the deliverable intensity images. All overlap classes were ignored during this process. This helps to ensure a more aesthetically pleasing image. The GeoCue software was then used to verify full project coverage as well. TIF/TWF files with a cell size of 1.25-foot raster were then provided as the deliverable for this dataset requirement.

3.7. Contour Processing

Using automated scripting routines within ArcMap, a terrain surface was created using the ground (ASPRS Class 2) lidar data as well as the hydro-flattened breaklines. This surface was then used to generate the final 1-foot contour dataset in Esri File Geodatabase format.

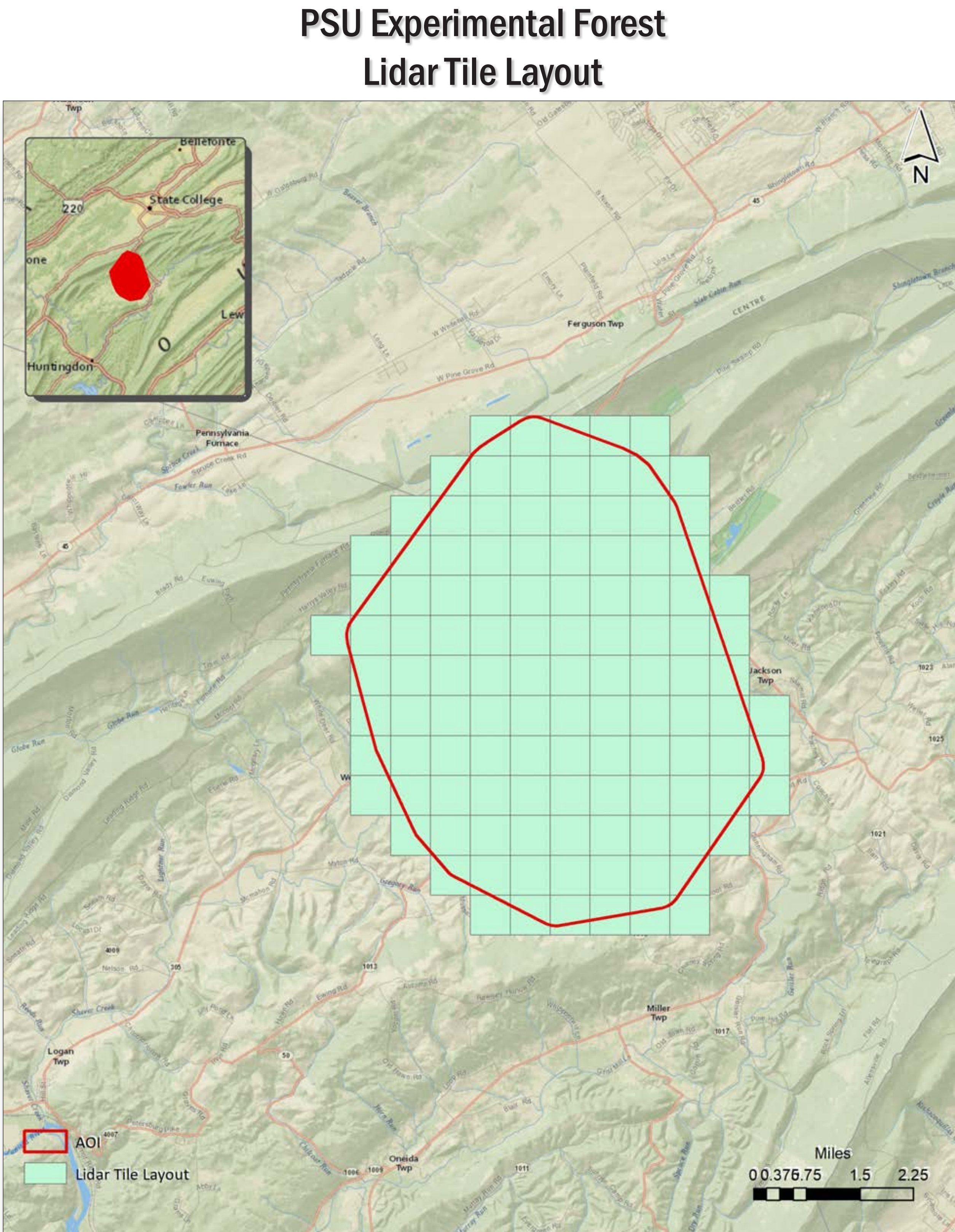

Figure 9. Lidar Tile Layout Lidar

3.8. Imagery Processing Summary

Within the UltraMap software suite, raw acquired images are radiometrically and geometrically corrected using the camera's calibration files and output as Level 2 images. The resulting radiometry is then manually edited to ensure each image has the appropriate tone, no pixels are clipped, and that each image is blended with the adjacent images. Once radiometry has been edited, separate RGBI and Panchromatic images are blended together to form single level 4-band TIFF images.

Image radiometric values were calibrated to specific gain and exposure settings associated with each capture using the UltraMap software suite. The calibrated images were saved in TIFF format for input to subsequent processes. Photo position and orientation were calculated by linking the time of image capture, the corresponding aircraft position and attitude, and the smoothed best estimate of trajectory (SBET) data in Applanix POSPac. Adjusted images were then draped upon a ground model and orthorectified. Individual orthorectified tiffs were blended together to remove seams and corrected for any remaining radiometric differences between images using ImageStation OrthoPro.

3.9. Raw Data Extraction

Data processing of UltraCam Eagle M3 imagery and metadata is a streamlined digital workflow process utilizing Quantum Spatial's proprietary software and commercial softcopy photogrammetric software including Ultramap, ImageStation Orientations, ImageStation Automatic Triangulation and ImageStation OrthoPro.

3.10. Airborne GPS and IMU Post Processing

During the sensor trajectory processing (combining GPS & IMU datasets) certain statistical graphs and tables are generated within the Applanix POSPac processing environment which are commonly used as indicators of processing stability and accuracy. This data for analysis include: Max horizontal / vertical GPS variance, separation plot, altitude plot, PDOP plot, base station baseline length, processing mode, number of satellite vehicles, and mission trajectory.

3.11. Aerotriangulation

Using RAW images, Airborne ABGPS/IMU external orientation parameters and ground control data, the imagery control solution was further extended and densified using analytical aerotriangulation adjustment techniques. This adjustment of the measurements was performed using a robust aerotriangulation software package, ImageStation Automatic Triangulation (ISAT) software, on softcopy photogrammetric workstations. Ten aerotriangulation blocks were developed for the project.

3.12. Orthophotography Creation

Digital orthophoto frames are created by using in-house lidar data, which were in turn combined with processed RAW imagery, aerotriangulation data, as well as government supplied airborne topographic lidar bare earth data sets of various vintages. This orthorectification process is done in ImageStation OrthoPro.

Manual seamlines were drawn in ArcMap on every frame. Then, using the grid created with in-house software a set of "base" mosaicked tiles were created in Intergraph OrthoPro using a bilinear interpolation method on the three data sources (rectified imagery, aerotriangulation data and surface data). At this stage a final color balancing is also done to ensure a superior balance across the entire dataset. The first step to the quality control process is to draw circles on areas of concern. Reviewers look for mismatches at seamlines, smears caused by elevation discrepancies (building lean, bridge warping) and radiometric distortions. Then, a different technician corrects the circles. There are a total of 127 tiles in GeoTIFF format.

Tile layout is shown in Figure 10 on the following page.

PSU Experimental Forest
Orthoimagery Tile Layout

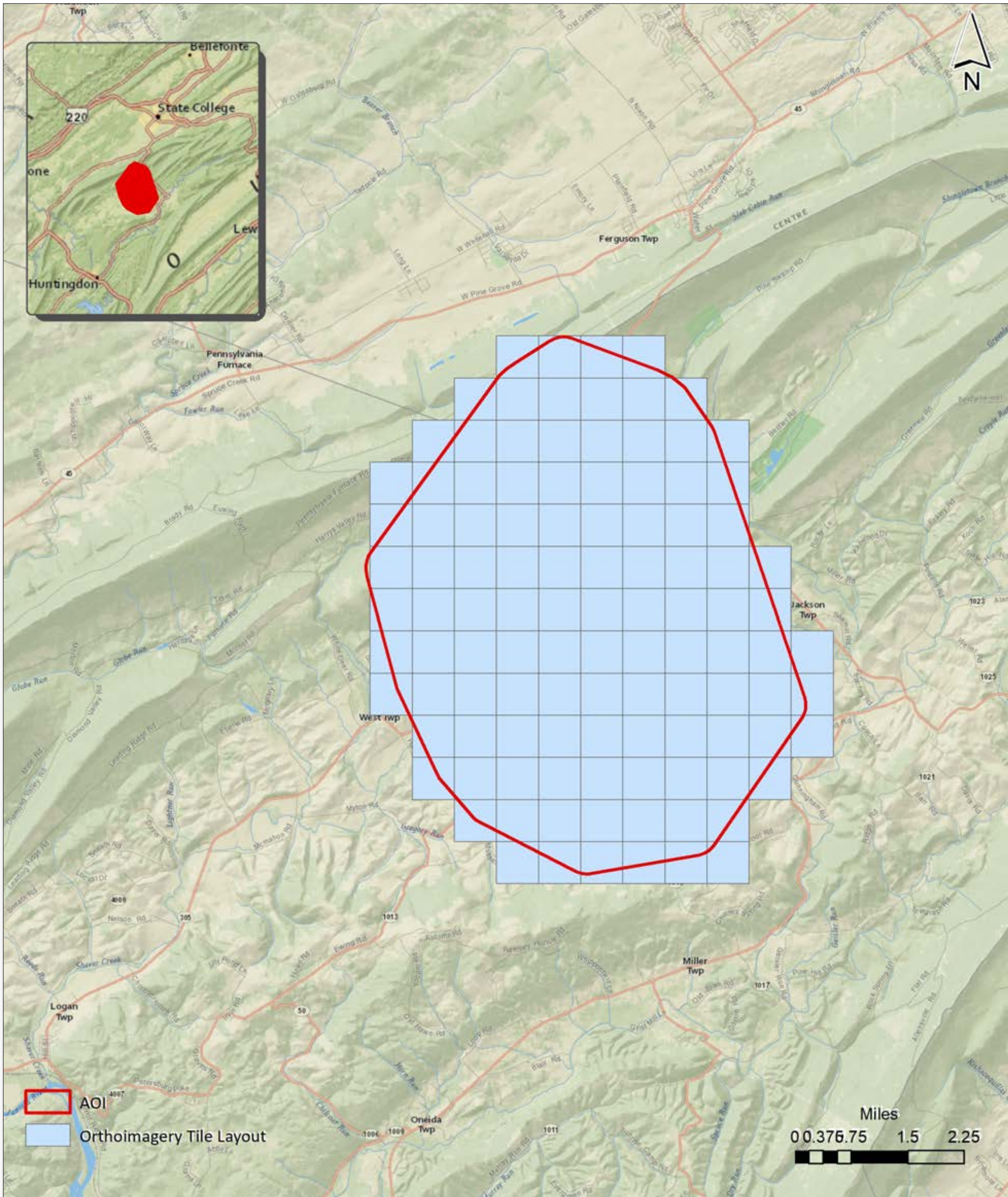

Figure 10. Tile Layout Orthoimagery

3.13. Hyperspectral Data

Hyperspectral imagery was also passed by QSI processing staff through a series of routines to convert from raw to orthorectified atmospherically corrected reflectance images for delivery. A summary of these steps and the software used to perform them is provided in Table 8, and descriptions follow below. The tile layout is show in Figure 11.

Table 8. Hyperspectral Data Processing Workflow

Hyperspectral Processing Step	Software Used
Convert Raw Imagery DNs to Radiance Values	ITRES RCX
Calculate Smooth Best Estimate of Trajectory	PosPac MMS v.8.3
Orthorectification	ITRES GeoCorrection Software
Atmospheric Correction	Atmospheric and Topographic Correction Software

3.14. Raw to Radiance

To convert raw data collected by the sensor to a usable format, QSI used the Radiometric Correction Xpress (RCX) software from ITRES Research Ltd. This program output *.pix (radiance images) and *.att (timing synchronization/attitude data) files for each flight line to be used in down-stream geometric processing.

To produce calibrated radiance data, RCX uses calibration coefficients, unique to each sensor, that are generated during laboratory calibrations using tools (integrating spheres, blackbodies, lamps, etc.) that are traceable to known standards. These coefficients are applied to the raw data in a three-subroutine process. The first subroutine accounts for environmental effects (spectral shifting of the data due to temperature/pressure shifts – not atmospheric corrections) and adjusts for any low/non-responsive pixels in the sensor array. The second subroutine applies a dark correction to account for electronic noise inherent to the sensor itself and applies the coefficients to map raw digital number (DN) to radiance (µW/cm2/ micron/sr^{-1} * 1000). The internal noise can come from a variety of sources including electrical and thermal energy generated by the sensor, as well as the reflection and diffraction of light energy off internal sensor components. The final subroutine resamples the spectral data to the desired output.

The output from this process is a 16-bit data cube, where pixel units are µW/cm2/ micron/ sr^{-1} scaled by 1000 so the data can be stored as integer type. The file format used is Band Interleaved by Pixel (BIP) in an ENVI Standard Type file (binary file + text header sidecar file).

3.15. Boresight Overview

Quantum Spatial also performed a boresighting routine for the set of hyperspectral imagery acquisitions completed for this project. Boresighting is a process by which positional and angular offsets of the sensor from the IMU are calculated. Calculating these offsets allows the very precise measurements of the IMU/GPS to be mapped to the head of the sensor unit, making accurate orthorectification possible.

This process was completed using ITRES's PBSBUND (Push Broom Scanner BUNDle adjustment) program. First a six flight-line cross hatch pattern was flown over an area with existing lidar data, so spatially accurate DEM's and Ground Control Points could be marked. The flight lines were flown in alternating, perpendicular cardinal directions. This allowed for a variety of sensor orientations to be used during positional and angular offset calculations. The locations of the Ground Control Points were translated from a coordinate reference system to sensor geometry image array coordinates. The pairs of coordinates were then used to solve a set of linear equations that produce the angular and positional offsets of the sensor with reference to the GPS/IMU system. These angles and positional offsets were used during the orthorectification process to calculate spatially and angularly accurate positional information for each frame of each flight-line.

3.16. Orthorectification (Hyperspectral)

The next step in processing the hyperspectral imagery for the PSU Experimental Forest area of interest (AOI) was orthorectification of radiance images for each flight line. Orthorectification is the process of removing image perspective (angle of sensor with respect to imaging surface) and terrain effects to create a planimetrically correct image. This allows the user to accurately measure distances, angles and area of features in a given image.

To orthorectify data from the ITRES CASI 1500h sensor, a series of four proprietary executables was used. First, positional information was extracted from the SBET to create the location of the aircraft in 3-dimensional earth-centric space. Next, timing and angular orientation data were taken from the attitude files (*.att) and cross-referenced with the timestamps from the SBET to create a file with timestamp, positional location, and sensor orientation. Then, the angular offsets from the boresight calculation were applied at each timestamp, resulting in a file with the precise position and angular orientation of the sensor for every frame in a flight-line. This information was used to project each pixel to the location where it intersects the earth surface, accounting for terrain, to create an image that is free from perspective and terrain-based distortions. During the orthorectification process the nearest neighbor resampling algorithm was used to ensure radiometric fidelity of the data. Next, a grid of the AOI was created in ITRES' GeoCorrection software and filled in with each orthorectified pixel. In areas of overlap between flight line images, the pixel with the lowest off-nadir look angle was preferentially selected. The output was a mosaic of all flight line images covering the entire AOI using the pixels with the shortest path distance to the sensor. Applying this nadir mosaicking method reduces sensor effects in the imagery and increase the accuracy of the atmospheric correction process. Finally, the nadir radiance mosaic was divided into 49 1520 m by 1520 m tiles, with an overlap of 20 m, using the Geospatial Data Abstraction Library. The output of this process was georeferenced 16-bit radiance images in the projected coordinate system used to process the data.

3.17. Atmospheric Correction

The final step in processing the hyperspectral imagery for the PSU Experimental Forest area of interest (AOI) was applying an atmospheric correction to the radiance images for each flight line. Atmospheric correction is the process of removing from the imagery the effects of solar geometry, viewing geometry, and altitude, as well as the scattering and absorption of light in the atmosphere due to water vapor and aerosols. To correct for these artifacts, we used the Atmospheric and Topographic Correction software (ATCOR-4) developed by ReSe Applications LLC. The output of ATCOR-4 was a *.hdr and *.bsq image file with pixel values of atmospherically corrected reflectance. Reflectance is the ratio of the radiance reflected off a material (exitance) to the radiance striking the material (irradiance), and a reflectance spectrum should be unique for a given material. Therefore, these atmospherically corrected reflectance images will allow the user to accurately perform material analysis and feature classification across the AOI.

To produce atmospherically corrected reflectance images, a hybrid approach to atmospheric correction was employed using ATCOR-4. This approach involved applying the ATCOR4r Rugged Terrain radiative transfer model to the input radiance imagery, as well as an In-Flight Calibration (IFC) process to help further correct the model. The ATCOR4r radiative transfer model estimates the composition of the atmosphere at different altitudes and models how light moves from the top of the atmosphere to the ground and back up to the sensor. For this model to be accurate it needs a variety of inputs regarding the sensor's position and the position of the sun at each frame of the image. These inputs were extracted from each flight line's trajectory file (see Orthorectification) and an auxiliary data file (*nad.bsq) output by the ITRES GeoCorrection Software. Another important parameter, the water absorption region (between 930 to 960 nm), was identified in the radiance spectra. To measure the relative magnitude of water vapor absorption, the bands corresponding to the start, end, and trough (lowest value) of the impacted region of the spectra (usually between ~876 to 1011 nm) were recorded and used as inputs for the model.

IFC was applied to the radiative transfer model using four reflective tarps placed throughout the AOI. A linear regression model of known reflectance to observed radiance was calculated for each tarp before being deployed in the field. The difference between the radiance values of a tarp measured in-flight vs expected was calculated using the tarp's regression model, and this correction was applied to the radiative transfer model. To maintain the consistency of reflectance values throughout the AOI, only one tarp was used for the final atmospheric correction. However, testing was performed on all four tarps to determine which tarp produced corrected reflectance values that best matched the same tarp's known reflectance profile. Furthermore, water vapor content and aerosol type were determined by applying different values iteratively and identifying the output reflectance spectra that best matched the known reflectance profile of the tarps in the AOI. Once the best atmospheric and IFC parameters for ATCOR-4 were identified they were then applied to all flight lines in the area of interest.

The output from this process was a 16-bit data cube for each flight line image, with pixel values as a unitless ratio of reflectance scaled by 10,000 so that the data can be stored as an integer type. The file format used is Band Sequential (BSQ) in an ENVI Standard Type file (binary file + text header sidecar file). These reflectance images were mapped from sensor geometry to projected space using the nadir radiance mosaic's *nad.bsq file and a similar auxiliary file (*.glu) created for each reflectance image.

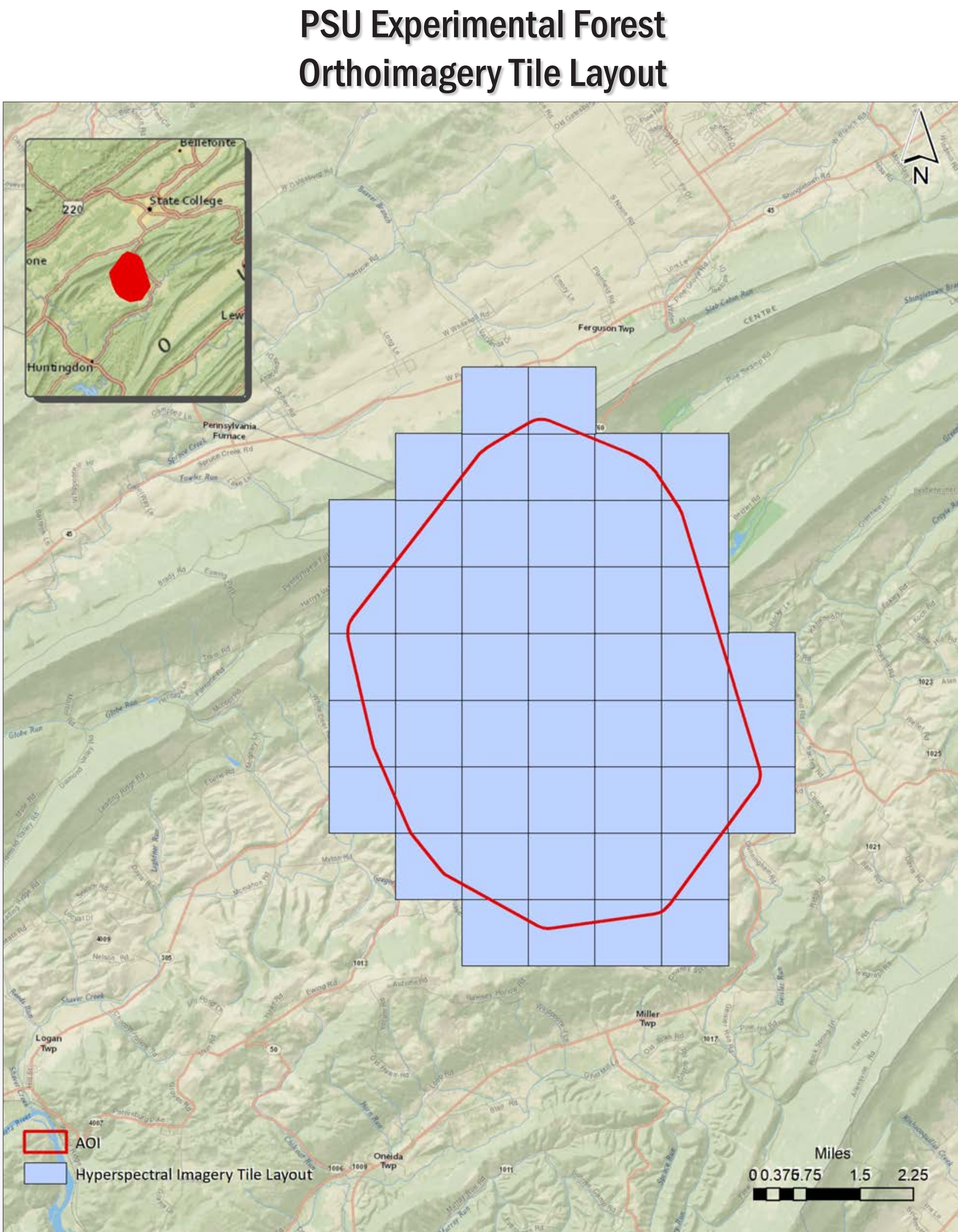

Figure 11. Tile Layout Orthoimagery

4. Project Coverage Verification

Coverage verification was performed by comparing coverage of processed .LAS files captured during project collection to generate project shape files depicting boundaries of specified project areas. Please refer to Figures 12 and 13.

Imagery coverage (see Figure 14) and content verification was performed and validated by visual review. This action was performed in the field by flight crew during the acquisition phase as well as by imagery QA technicians at our processing center. The ABGPS/IMU and base station data was uploaded to the company FTP site after each flight for the INS processing team in Lexington, Kentucky to verify accuracy of data collected.

PSU Experimental Forest
Lidar Coverage

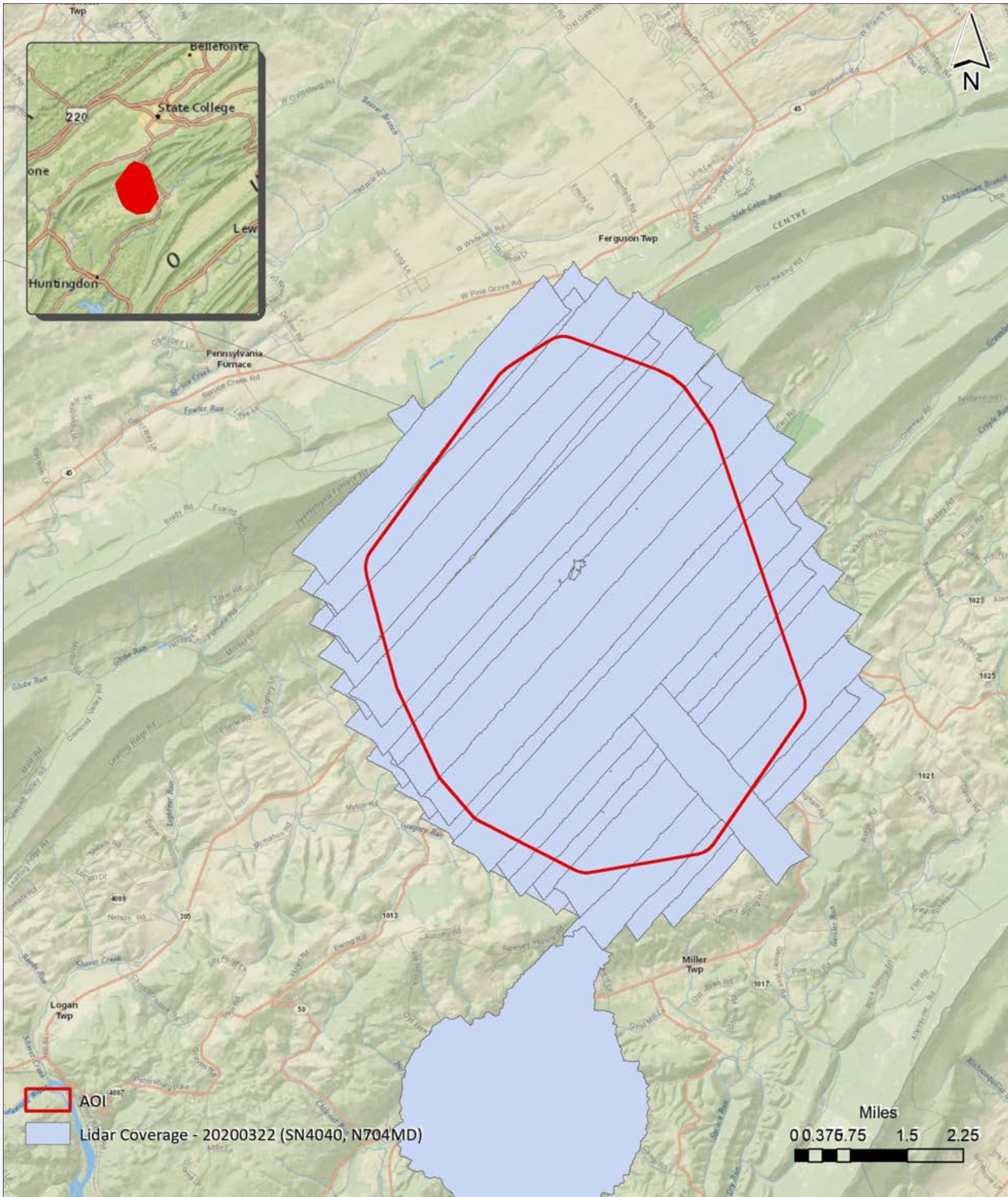

Figure 12. Lidar Coverage

PSU Experimental Forest
Lidar Coverage

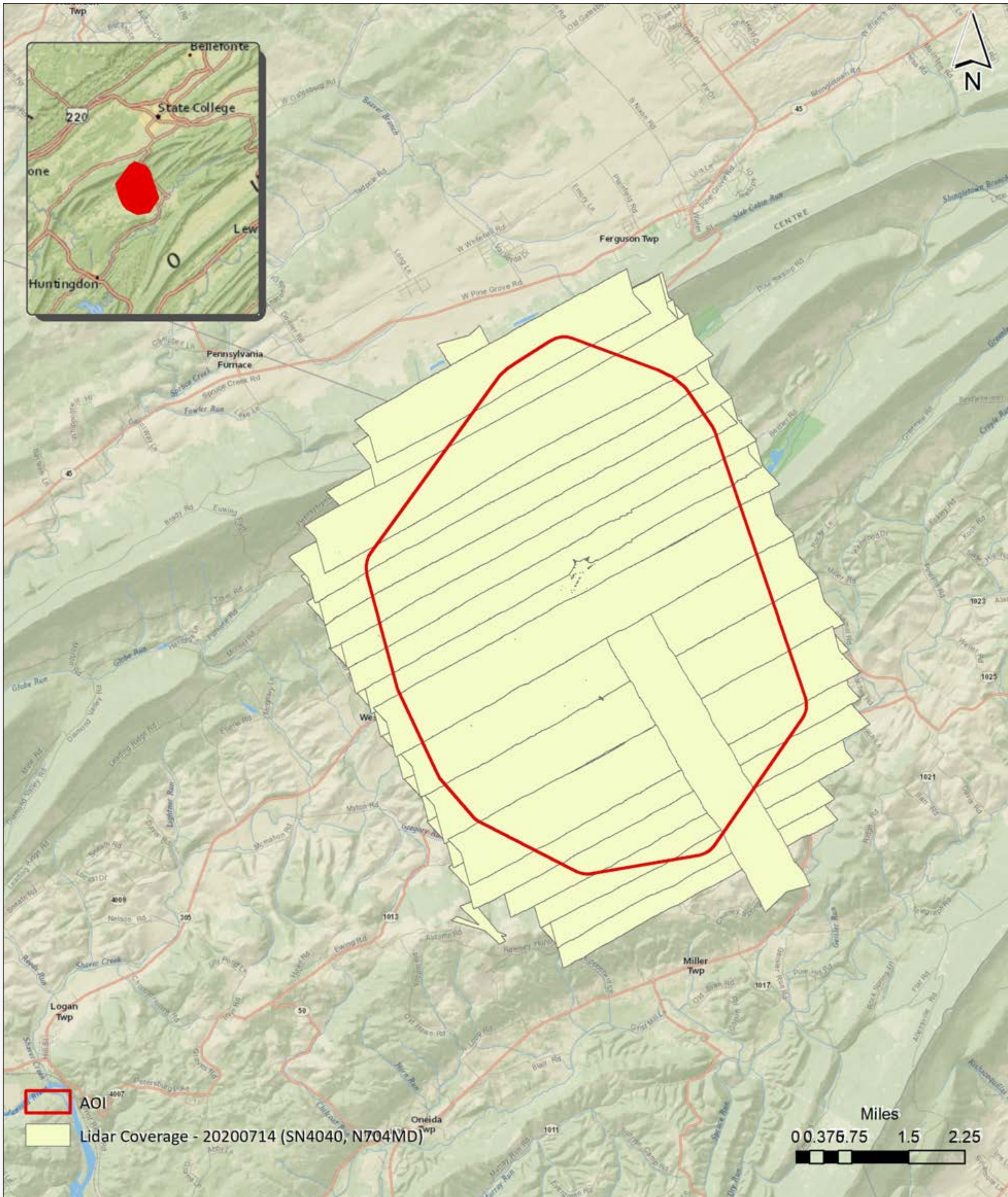

Figure 13. Lidar Coverage

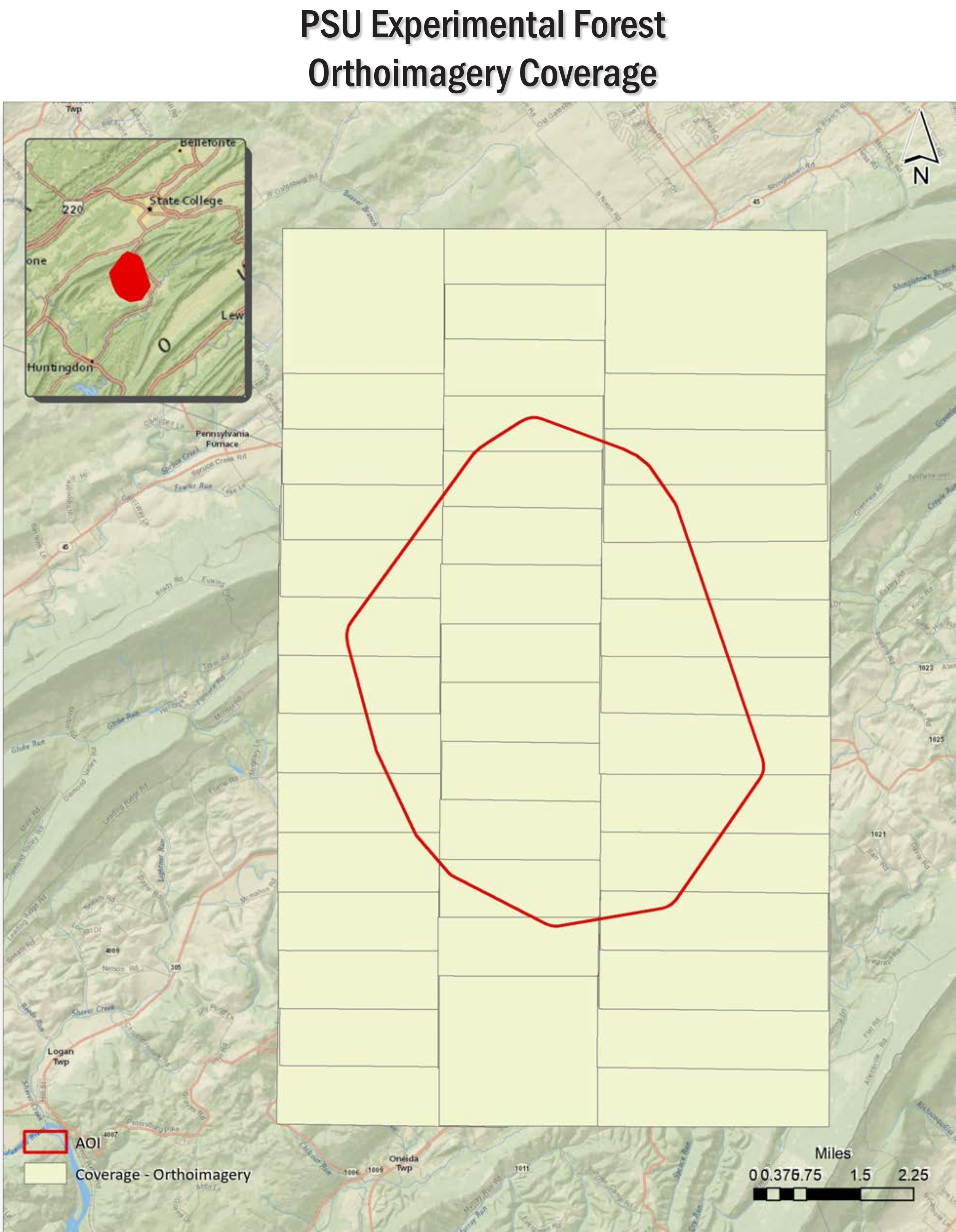

Figure 14. Orthoimagery Coverage

5. Ground Control and Check Point Collection

On behalf of NV5 Geospatial, Platinum Geomatics completed a field survey of 22 points.

A combination of precise GPS surveying methods, including static and RTK observations were used to establish the 3D position of ground calibration points and QA points for the point classes above. GPS was not an appropriate methodology for surveying in the forested areas during the leaf-on conditions for the actual field survey (which was accomplished after the lidar acquisition). Therefore the 3D positions for the forested points were acquired using a GPS-derived offset point located out in the open near the forested area, and using precise offset surveying techniques to derive the 3D position of the forested point from the open control point.

5.1. Calibration Control Point Testing

Figure 15 shows the location of each bare earth calibration point for the project area. TerraScan was used to perform a quality assurance check using the lidar bare earth calibration points. The results of the surface calibration are not an independent assessment of the accuracy of these project deliverables, but the statistical results do provide additional feedback as to the overall quality of the elevation surface.

PSU Experimental Forest
Calibration Points

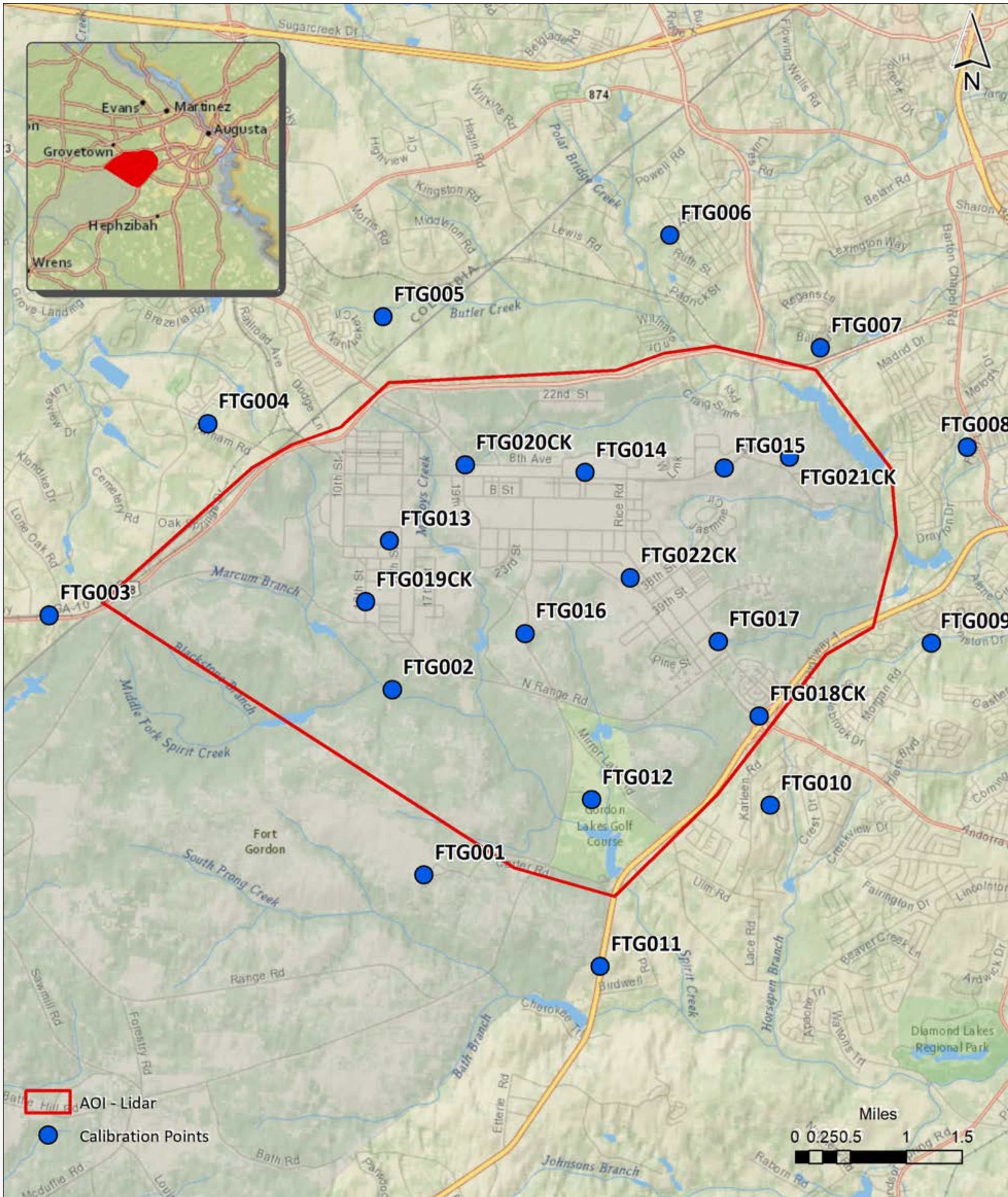

Figure 15. Calibration Control Point Locations

5.2. Orthoimagery Testing

Upon completion of all production activities and prior to delivery of the final orthophoto dataset, Quantum Spatial used Accuracy Analyst QC software to compute the overall accuracy of the orthophoto data set. A total of 5 points were used.

Figure 16 shows the location of each photo ID for the project area. A brief summary of the accuracy testing results is listed below. Please see the Ortho Accuracy Analyst report in Appendix D for more information.

Orthoimagery Accuracy			
	Target	Measured	Point Count
RMSEx	0.35 ft	0.205 ft	5
RMSEy	0.35 ft	0.121 ft	5
RMSEr	0.50 ft	0.238 ft	5

5.3. Hyperspectral Imagery Accuracy Assessment

Due to the high density of easily-identifiable ground features, the boresight location (Sheboygan County Memorial Airport) was chosen to perform the accuracy assessment.

Image accuracy was measured using ground control points (GCPs), located on hard, permanent surfaces which were identified using LiDAR intensity images in areas of clear visibility. Once the GCPs were identified in the intensity images, the same location was identified in the orthorectified hyperspectral imagery for each GCP, and the displacement was recorded for further statistical analysis. To support all desired user goals, Horizontal accuracy is reported based on Lidar-derived GCPs alone.

The NSSDA standard horizontal accuracy (ACCr) at 95% confidence level for the study area was 1.461 m.

Hyperspectral Imagery Accuracy	
GCP Count	**N=24**
Root Mean Square Error (RMSE); $RMSE_r = \sqrt{(RMSEx^2 + RMSEy^2)}$	
$RMSE_r$	**0.845 m**
Circular Standard Error (CSE); CSE = 0.5*(RMSEx + RMSEy)	
CSE	**0.597 meters**
Horizontal Accuracy (ACC); ACCr = 2.4477*0.5*(RMSEx + RMSEy)	
ACC_r	**1.461 meters**

PSU Experimental Forest
Orthoimagery QC Check Points

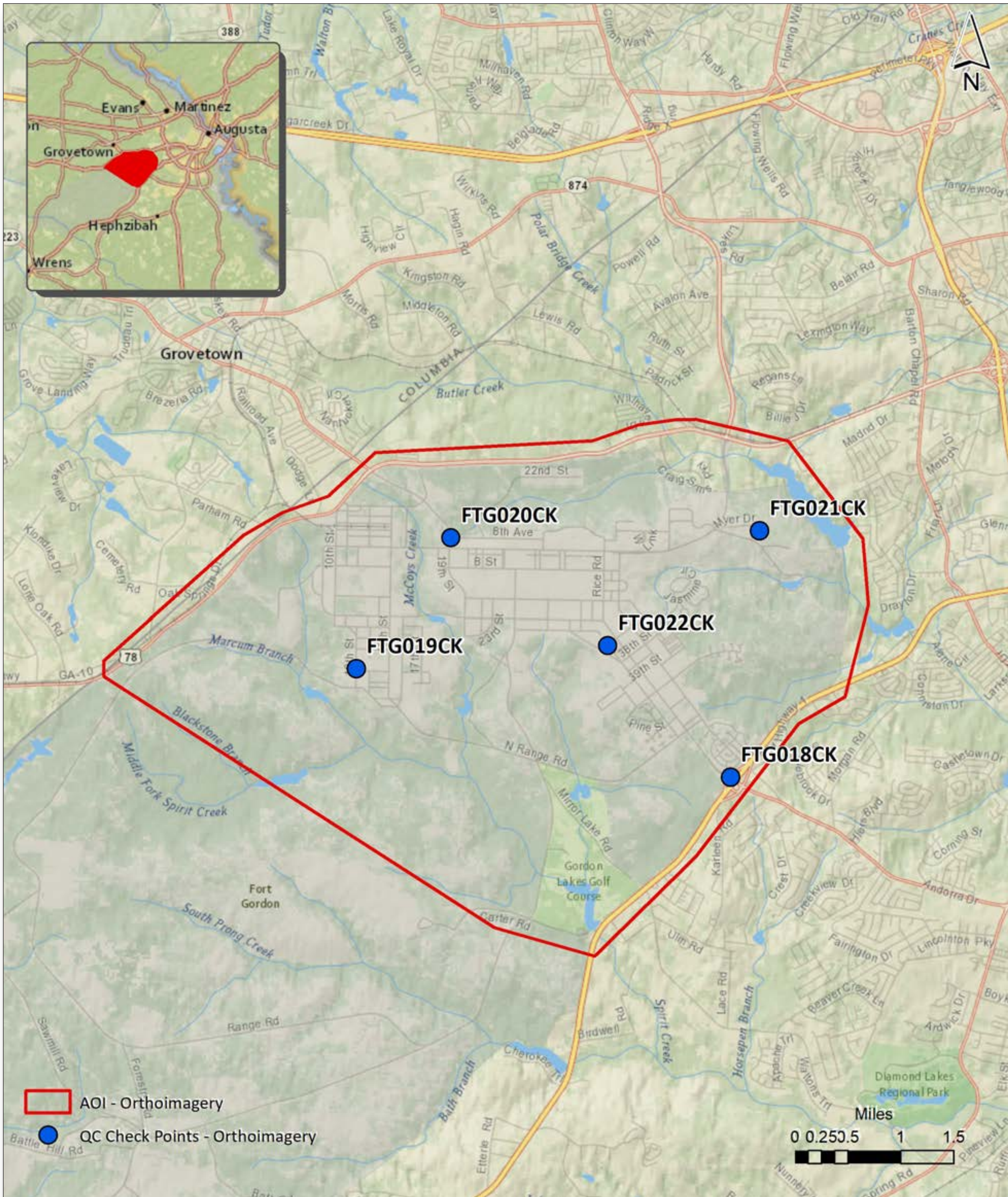

Figure 16. Orthoimagery Checkpoint Locations

XY Deviation of GCP in Orthorectified Hyperspectral Imagery Compared to Lidar Intensity Images

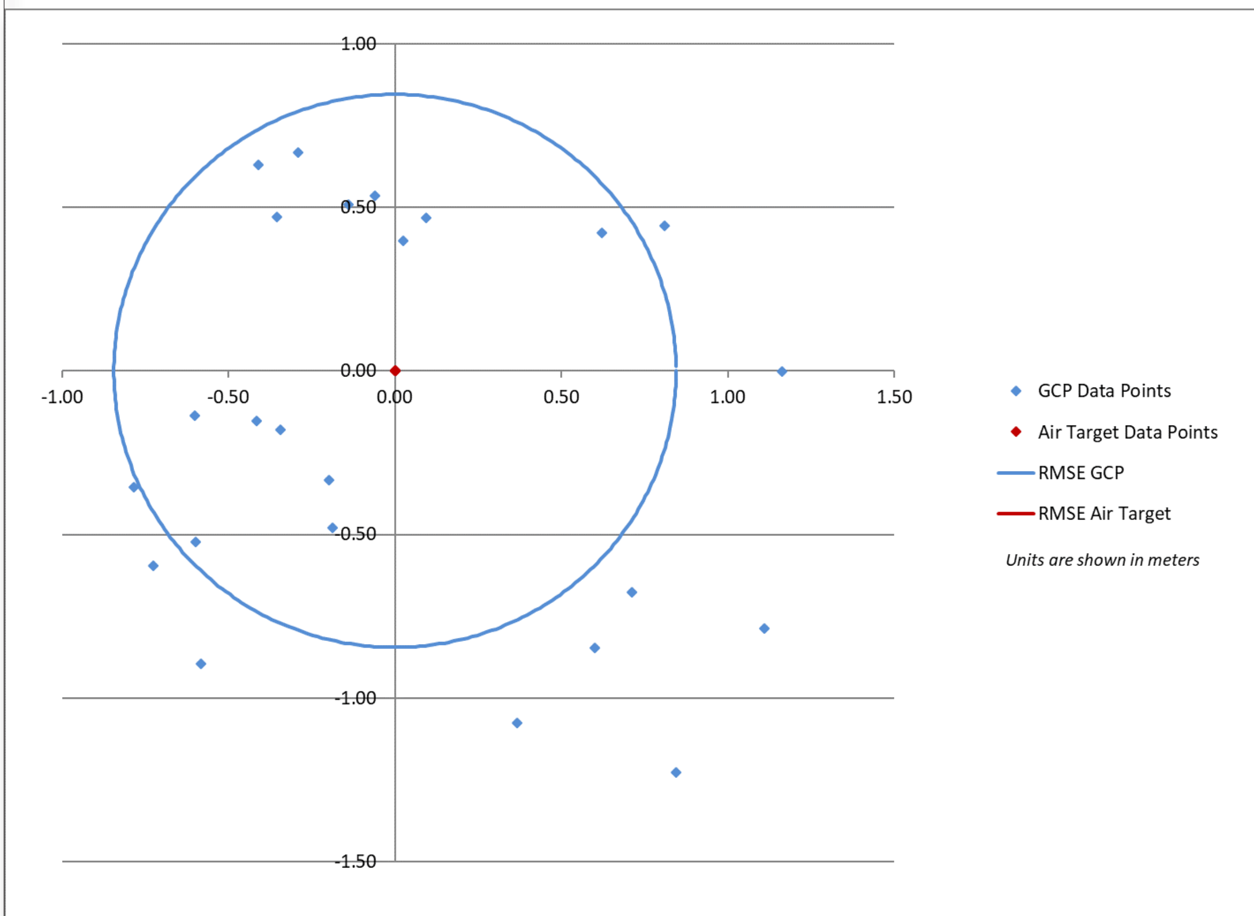

Figure 17. XY Deviation Scatterplot