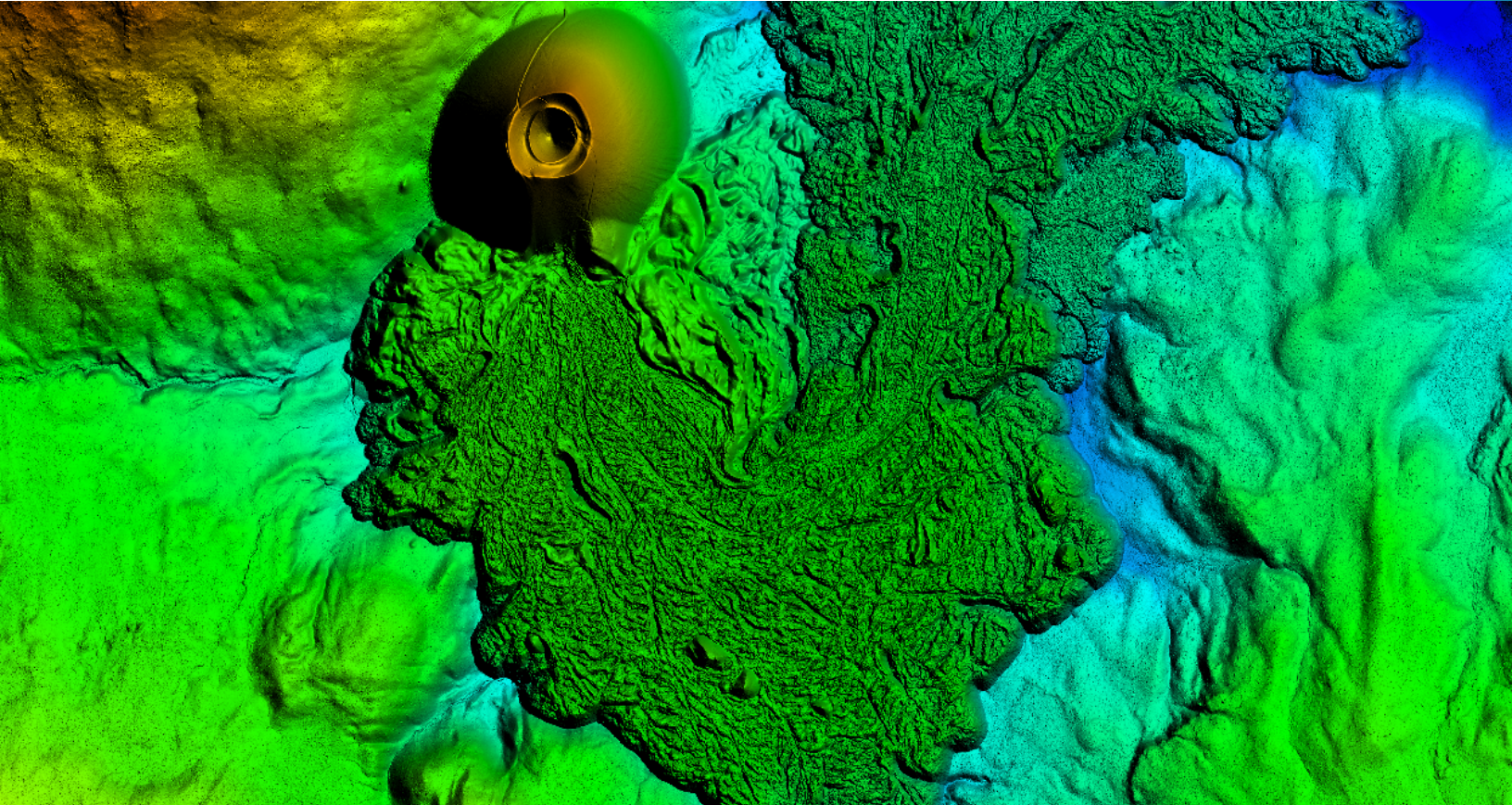


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CA_LOWERBEARCREEK_2020 QL2 LIDAR PROCESSING REPORT

Work Package: 198556
Work Unit: 214870

2021

Submitted: July 14, 2021

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Appendix A: Flight Logs

1. Summary / Scope

1.1. Summary

This report contains a summary of the CA_LowerBearCreek_2020 QL2, Work Unit 214870 lidar acquisition task order 140G0220F0297, issued by USGS under their Contract G16PC00016 on September 23, 2020. The task order yielded a project area covering approximately 236 square miles over California. The intent of this document is only to provide specific validation information for the data acquisition/collection, processing, and production of deliverables completed as specified in the task order.

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
2.4 pts / m ²	2305 m	58.5°	20%	≤ 10 cm

1.3. Coverage

The project boundary covers approximately 236 square miles over Lower Bear Creek in California. Project extents are shown in Figure 1.

1.4. Duration

LiDAR data was acquired on December 11, 2020 in one lift. See “Section: 2.4. Time Period” for more details.

1.5. Issues

There were no major issues to report for this project.

CA_LowerBearCreek_2020 QL2 Work Unit 214870 Projected Coordinate System: UTM Zone 10N Horizontal Datum: NAD 1983(2011) Vertical Datum: NAVD88 (GEOID 18) Units: Meters	
Lidar Point Cloud	Classified Point Cloud in .LAS 1.4 format
Rasters	<ul style="list-style-type: none"> • 1-meter Hydro-flattened Bare Earth Digital Elevation Model (DEM) in GeoTIFF format • 1-meter Intensity images in GeoTIFF format
Vectors	Shapefiles (*.shp) <ul style="list-style-type: none"> • Project Boundary • LiDAR Tile Index • Calibration and QC Checkpoints (NVA/VVA) Geodatabase (*.gdb) <ul style="list-style-type: none"> • Continuous Hydro-flattened Breaklines
Reports	Reports in PDF format <ul style="list-style-type: none"> • Focus on Delivery • Focus on Accuracy • Survey Report • Processing Report
Metadata	XML Files (*.xml) <ul style="list-style-type: none"> • Breaklines • Classified Point Cloud • DEM • Intensity Imagery

CA_LowerBearCreek_2020 QL2 Work Unit 214870 Boundary

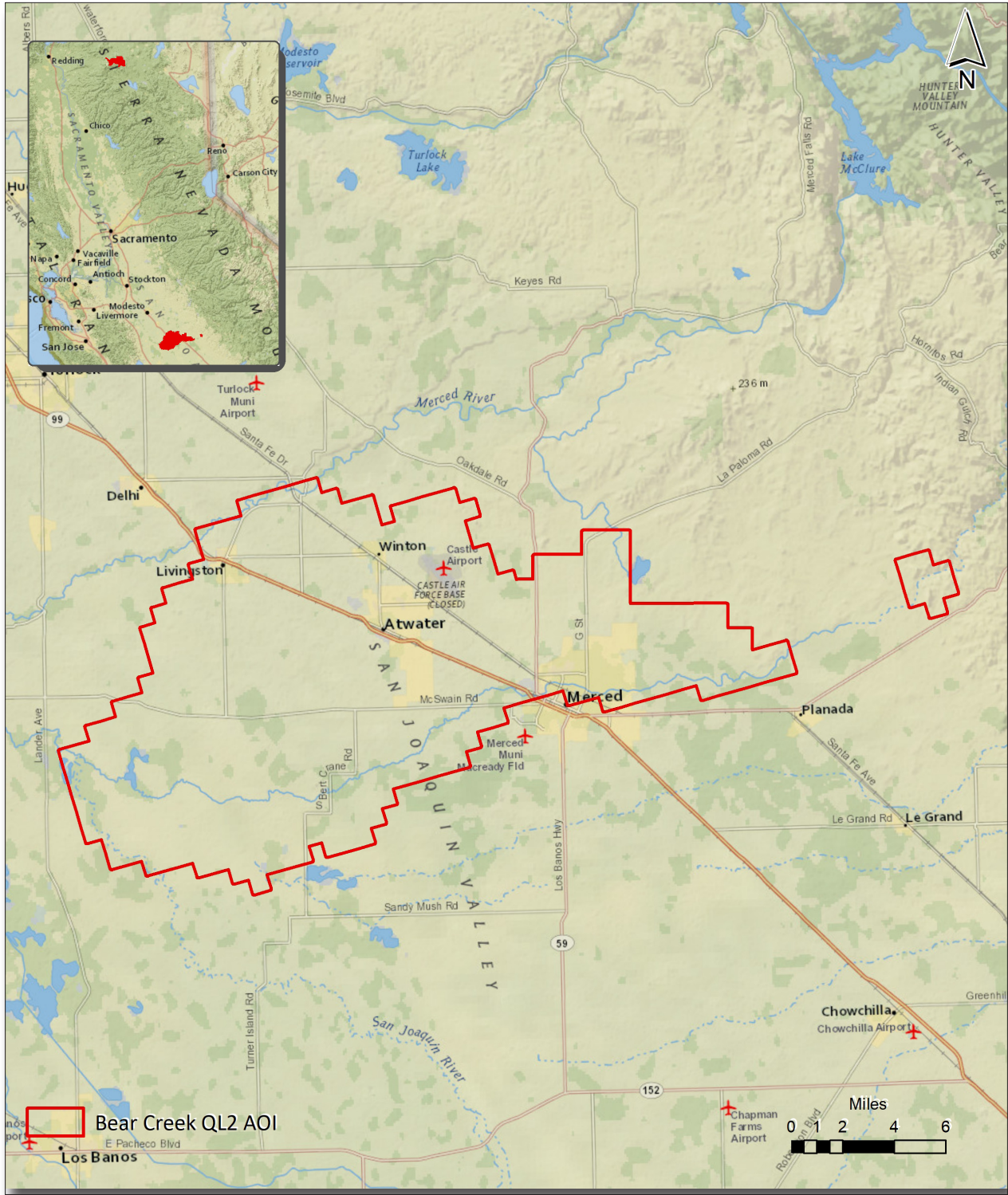


Figure 1. Work Unit Boundary

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 RiPARAMETER planning software. Planned flight lines are shown in Figure 2.

2.2. LiDAR Sensor

Quantum Spatial utilized a Riegl VQ1560i lidar sensor (Figure 3), serial number 3061, for lidar data 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 2.

CA_LowerBearCreek_2020 QL2 Work Unit 214870 Planned Flight Lines

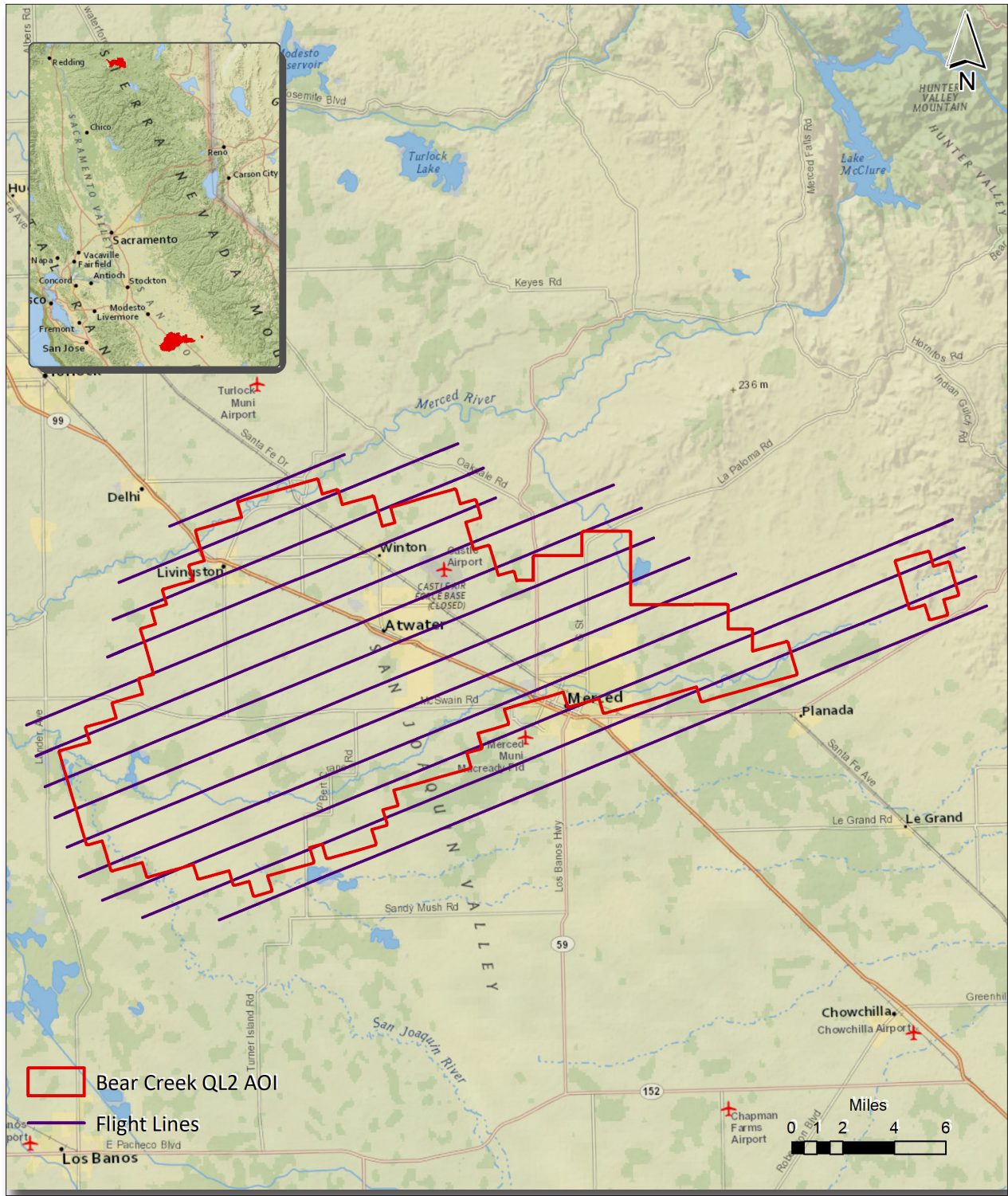


Figure 2. Planned Flight Lines

Table 2. LiDAR System Specifications

		Riegl VQ1560i
Terrain and Aircraft Scanner	Flying Height	2305 m
	Recommended Ground Speed	150 kts
Scanner	Field of View	58.5°
	Scan Rate Setting Used	75 lines/second
Laser	Laser Pulse Rate Used	350 x 2 kHz
	Multi Pulse in Air Mode	Multi-Time Around (MTA)
Coverage	Full Swath Width	2586 m
	Line Spacing	517 m
Pulse Spacing and Density	Average Pulse Spacing	0.65 m
	Average Point Density	2.4 pts / m ²

Figure 3. Riegl VQ1560i Lidar Sensor



2.3. 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 Conquest, Tail Number: N441CJ

These aircraft provided an ideal, stable aerial base for LiDAR acquisition. These aerial platforms have relatively fast cruise speeds, which are beneficial for project mobilization / demobilization while maintaining relatively slow stall speeds, proving ideal for collection of high-density, consistent data posting using a state-of-the-art Riegl lidar system. Some of Quantum Spatial's operating aircraft can be seen in Figure 4 below.

Figure 4. Some of Quantum Spatial's Planes



2.4. Time Period

Project specific flights were conducted on December 11, 2020. One aircraft lift was completed. The accomplished lift is listed below.

- 12112020A (SN3061, N441CJ)

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

Notes: (Visibility, winds, ride, weather, temperature, dew point, pressure, etc). Project specific flight logs for each sortie are available in Appendix A.

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 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.

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 3. 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
7	Low Noise	Laser returns that are often associated with scattering from reflective surfaces, or artificial points below the ground surface
9	Water	Laser returns that are found inside of hydro features
17	Bridge Deck	Laser returns falling on bridge decks
18	High Noise	Laser returns that are often associated with birds or artificial points above the ground surface
20	Ignored Ground	Ground points that fall within the given threshold of a collected hydro feature.

3.4. Classified LAS Processing

The bare earth surface is then manually reviewed to ensure correct classification on the Class 2 (Ground) points. After the bare- earth surface is finalized; it is then used to generate all hydro-breaklines through heads-up digitization.

All ground (ASPRS Class 2) LiDAR data inside of the Lake Pond and Double Line Drain hydro flattening breaklines were then classified to water (ASPRS Class 9) using TerraScan macro functionality. A buffer of 3 feet was also used around each hydro flattened feature to classify these ground (ASPRS Class 2) points to Ignored ground (ASPRS Class 20). All Lake Pond Island and Double Line Drain Island features were checked to ensure that the ground (ASPRS Class 2) points were reclassified to the correct classification after the automated classification was completed.

Any noise that was identified either through manual review or automated routines was classified to the appropriate class (ASPRS Class 7 and/or ASPRS Class 18) followed by flagging with the withheld bit.

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 Breakline Processing

Class 2 LiDAR was used to create a bare earth surface model. The surface model was then used to heads-up digitize 2D breaklines of Inland Streams and Rivers with a 100 foot nominal width and Inland Ponds and Lakes of 2 acres or greater surface area.

Elevation values were assigned to all Inland streams and rivers using proprietary software.

All ground (ASPRS Class 2) LiDAR data inside of the collected inland breaklines were then classified to water (ASPRS Class 9) using TerraScan macro functionality. A buffer of 3 feet was also used around each hydro flattened feature. These points were moved from ground (ASPRS Class 2) to Ignored Ground (ASPRS Class 20).

The breakline files were then translated to Esri file geodatabase format using Esri conversion tools.

Breaklines are reviewed against lidar intensity imagery to verify completeness of capture. All breaklines are then compared to TINs (triangular irregular networks) created from ground only points prior to water classification. The horizontal placement of breaklines is compared to terrain features and the breakline elevations are compared to lidar elevations to ensure all breaklines match the lidar within acceptable tolerances. Some deviation is expected between breakline and lidar elevations due to monotonicity, connectivity, and flattening rules that are enforced on the breaklines. Once completeness, horizontal placement, and vertical variance is reviewed, all breaklines are reviewed for topological consistency and data integrity using a combination of Esri Data Reviewer tools and proprietary tools.

3.6. Hydro-Flattened Raster DEM Processing

Class 2 LiDAR in conjunction with the hydro breaklines were used to create a 1-meter Raster DEM. Using automated scripting routines within proprietary software, 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.

3.7. Intensity Image Processing

GeoCue software was used to create the deliverable intensity images. All withheld points 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. GeoTIFF files with a cell size of 1-meter were then provided as the deliverable for this dataset requirement.

CA_LowerBearCreek_2020 QL2 Work Unit 214870 Tile Layout

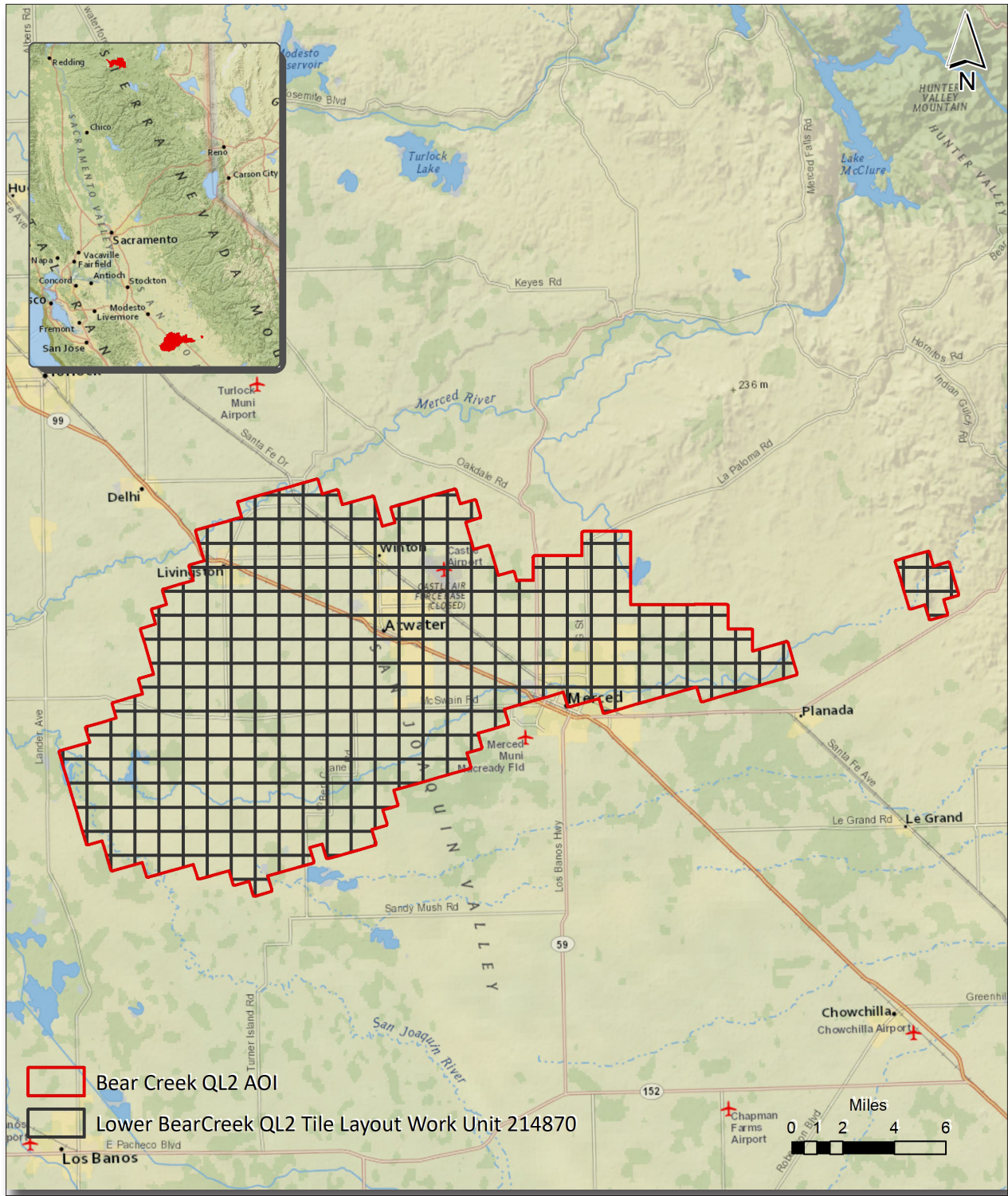


Figure 5. Lidar Tile Layout

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 Figure 6.

CA_LowerBearCreek_2020 QL2 Work Unit 214870 Lidar Coverage

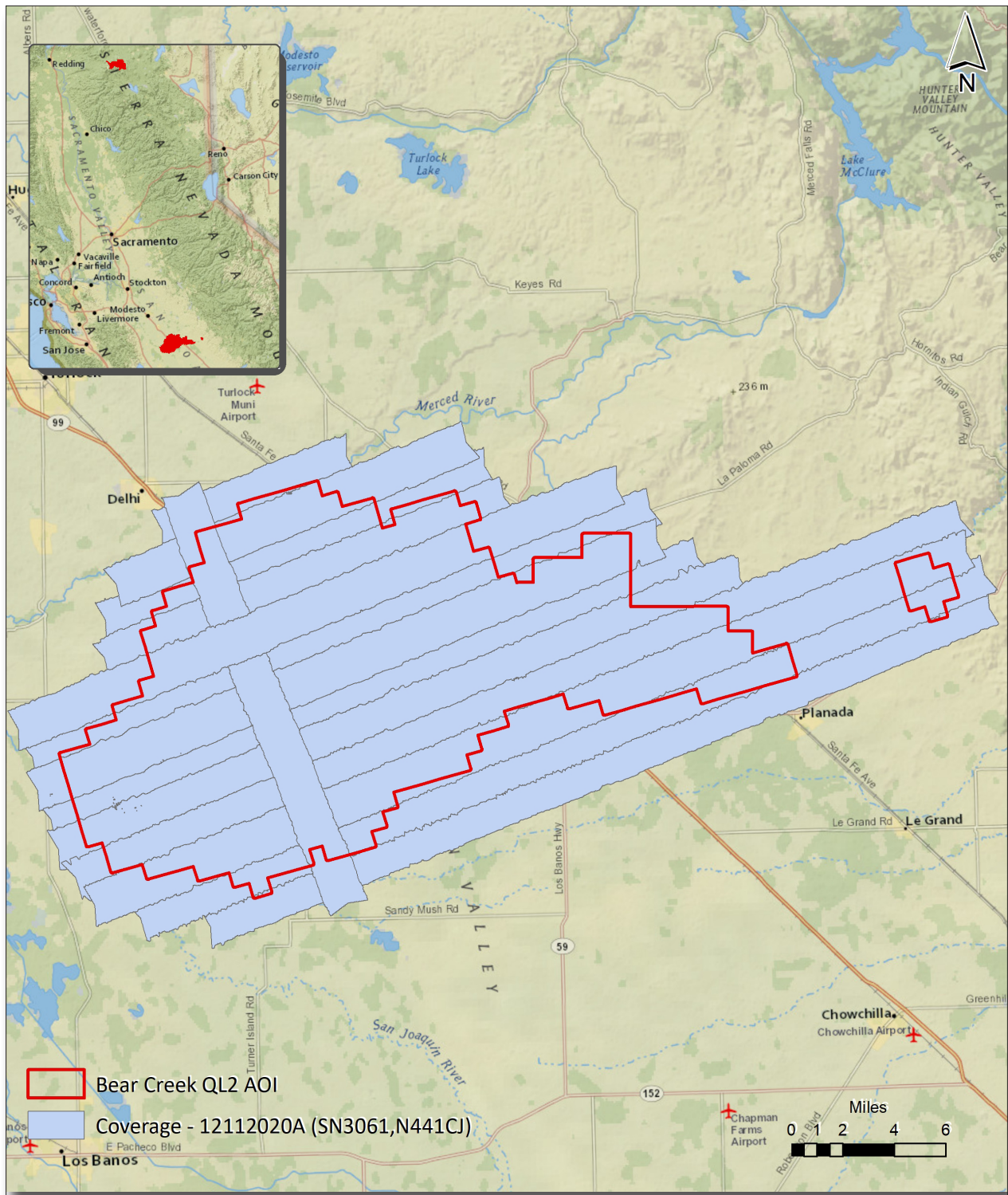


Figure 6. Lidar Coverage

5. Ground Control and Check Point Collection

NV5 Geospatial utilized 14 ground control (calibration) points along with 71 blind QA points (46 NVA points and 25 VVA points). These NVA and VVA points were used as an independent test of the accuracy of this project.

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. The explicit goal for these surveys was to develop 3D positions that were three times greater than the accuracy requirement for the elevation surface. In this case of the blind QA points the goal was a positional accuracy of 5 cm in terms of the RMSE.

The required accuracy testing was performed on the LiDAR dataset (both the LiDAR point cloud and derived DEM's) according to the USGS LiDAR Base Specification Version 2.1.

5.1. Calibration Control Point Testing

Figure 7 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.

5.2. Point Cloud Testing

The project specifications require that only Non-Vegetated Vertical Accuracy (NVA) be computed for raw lidar point cloud swath files. The required accuracy (ACCz) is: 19.6 cm at a 95% confidence level, derived according to NSSDA, i.e., based on RMSE of 10 cm in the "bare earth" and "urban" land cover classes. The NVA was tested with 46 checkpoints located in bare earth and urban (non-vegetated) areas. These check points were not used in the calibration or post processing of the lidar point cloud data. The checkpoints were distributed throughout the project area and were surveyed using GPS techniques. See survey report for additional survey methodologies.

Elevations from the unclassified lidar surface were measured for the x,y location of each check point. Elevations interpolated from the lidar surface were then compared to the elevation values of the surveyed control points. AccuracyZ has been tested to meet 19.6 cm or better Non-Vegetated Vertical Accuracy at 95% confidence level using $RMSE(z) \times 1.9600$ as defined by the National Standards for Spatial Data Accuracy (NSSDA); assessed and reported using National Digital Elevation Program (NDEP)/ASPRS Guidelines.

5.3. Digital Elevation Model (DEM) Testing

The project specifications require the accuracy (ACCz) of the derived DEM be calculated and reported in two ways:

1. The required NVA is: 19.6 cm at a 95% confidence level, derived according to NSSDA, i.e., based on RMSE of 10 cm in the “bare earth” and “urban” land cover classes. This is a required accuracy. The NVA was tested with 46 checkpoints located in bare earth and urban (non-vegetated) areas. See Figure 8.

2. Vegetated Vertical Accuracy (VVA): VVA shall be reported for “brushlands/low trees” and “tall weeds/crops” land cover classes. The target VVA is: 29.4 cm at the 95th percentile, derived according to ASPRS Guidelines, Vertical Accuracy Reporting for Lidar Data, i.e., based on the 95th percentile error in all vegetated land cover classes combined. This is a target accuracy. The VVA was tested with 25 checkpoints located in tall weeds/crops and brushlands/low trees (vegetated) areas. The checkpoints were distributed throughout the project area and were surveyed using GPS techniques. See Figure 9.

AccuracyZ has been tested to meet 19.6 cm or better Non-Vegetated Vertical Accuracy at 95% confidence level using $RMSE(z) \times 1.9600$ as defined by the National Standards for Spatial Data Accuracy (NSSDA); assessed and reported using National Digital Elevation Program (NDEP)/ ASPRS Guidelines.

A brief summary of results are listed below.

	Target	Measured	Point Count
Raw NVA	0.196 m	0.0914 m	46
NVA	0.196 m	0.0904 m	46
VVA	0.294 m	0.2300 m	25

CA_LowerBearCreek_2020 QL2 Calibration Points

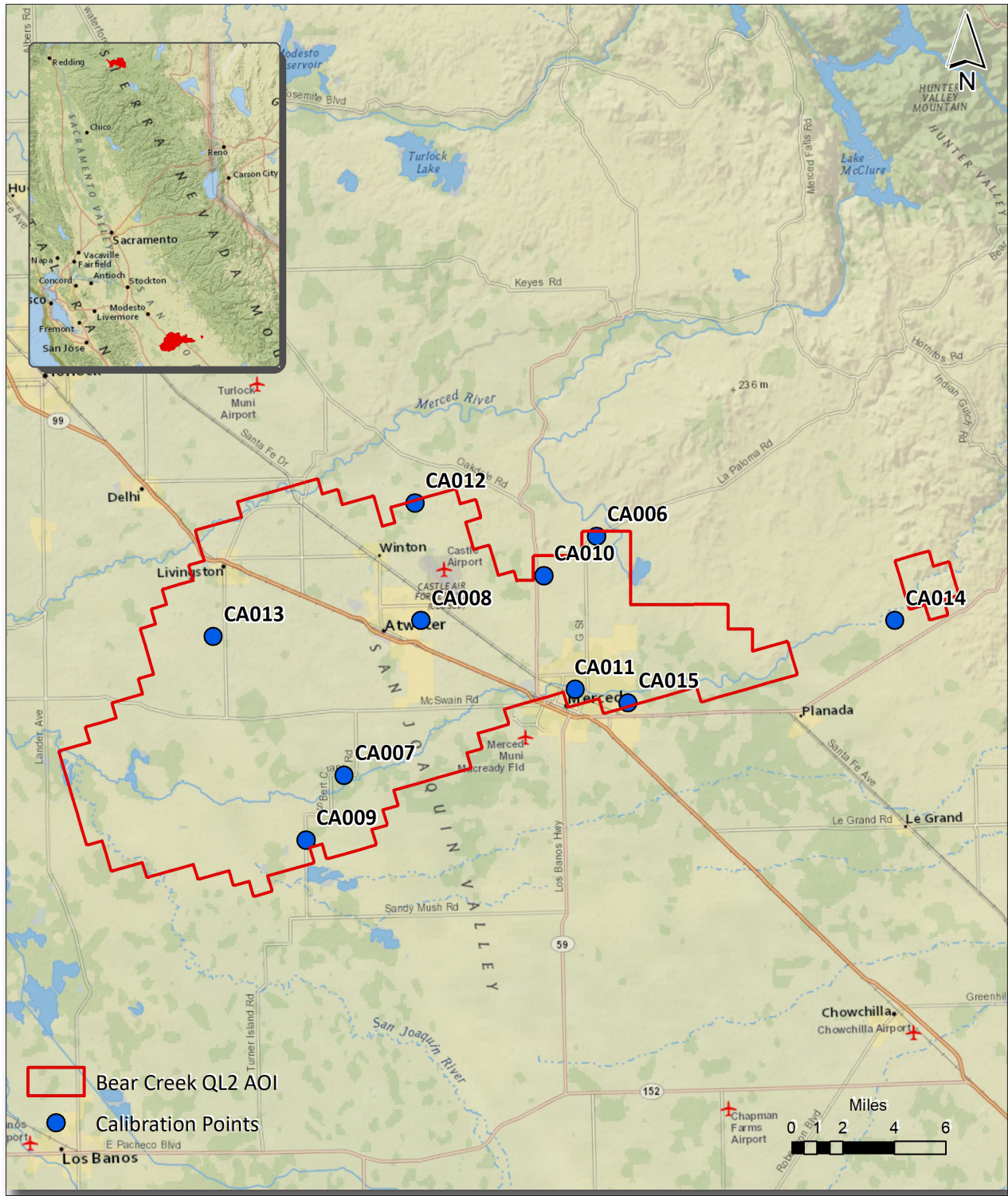


Figure 7. Calibration Control Point Locations

CA_LowerBearCreek_2020 QL2 NVA Points

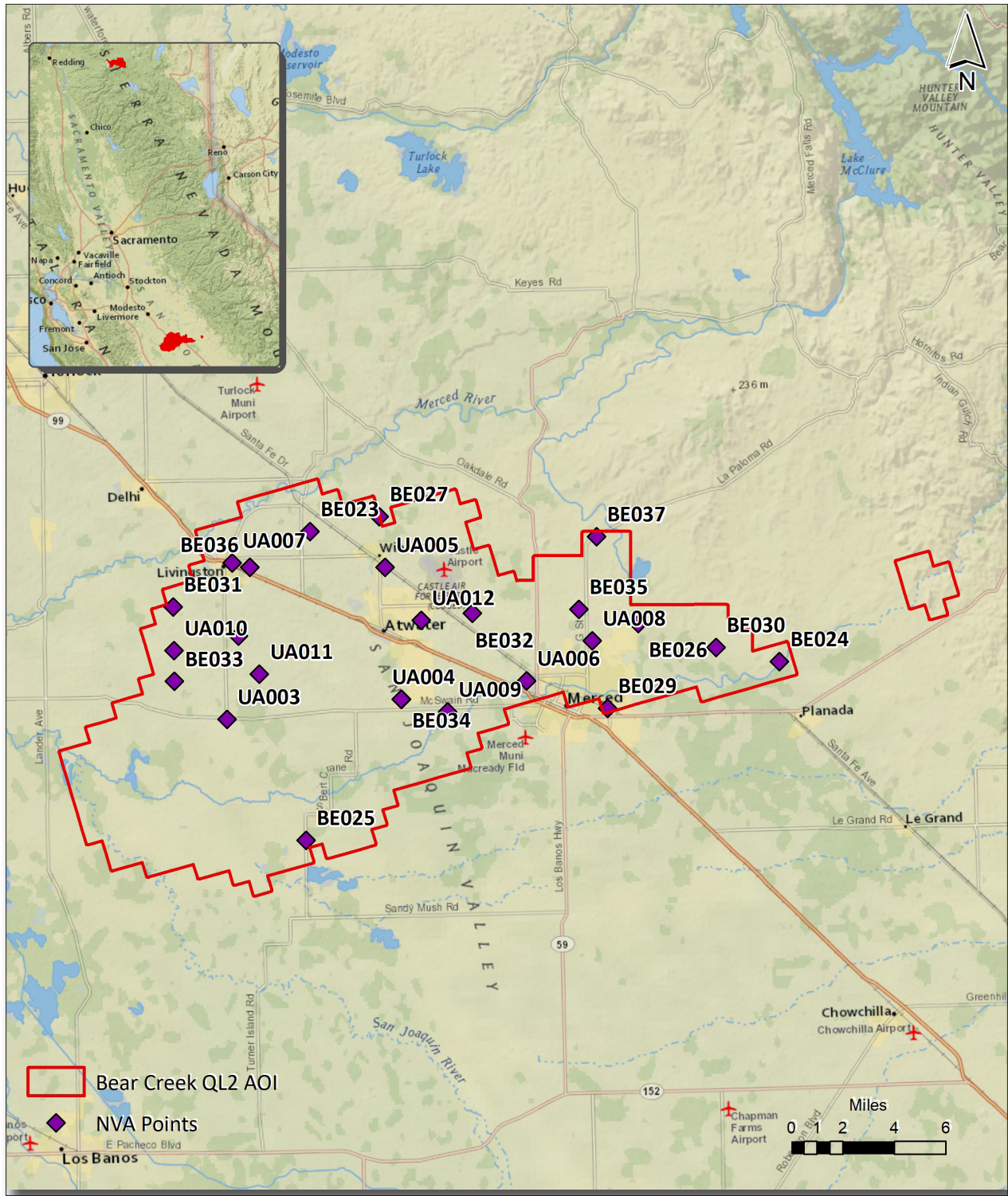


Figure 8. QC Checkpoint Locations - NVA

CA_LowerBearCreek_2020 QL2 VVA Points

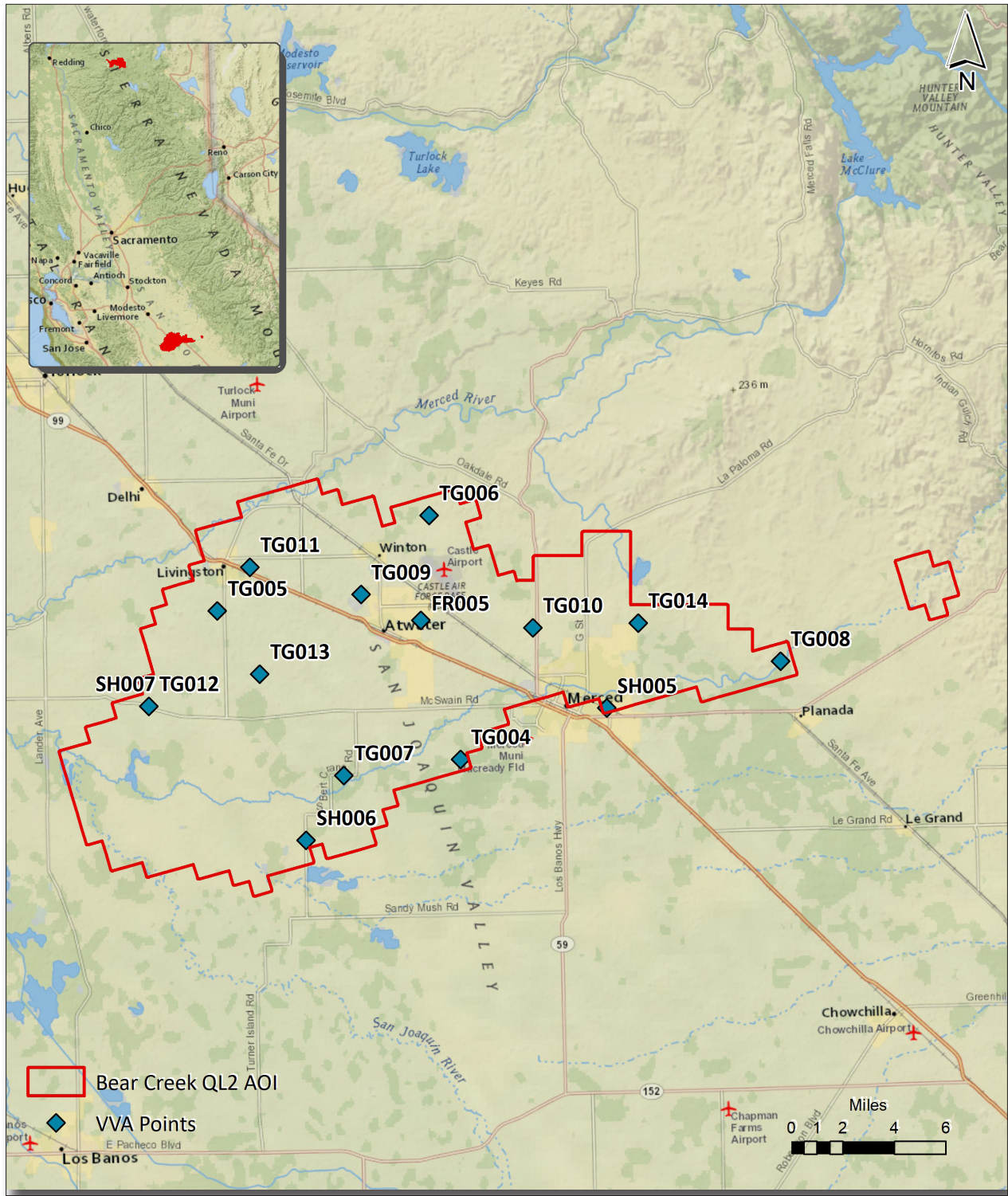


Figure 9. QC Checkpoint Locations - VVA

6. Geometric Accuracy

6.1. Horizontal Accuracy

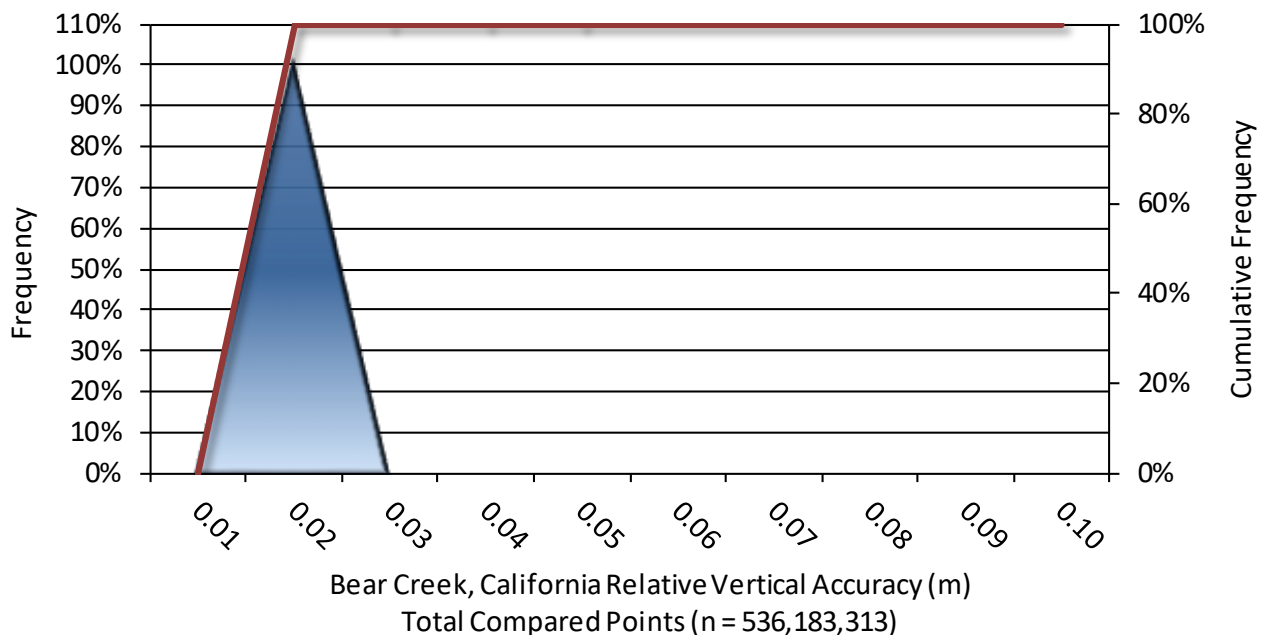
Lidar horizontal accuracy is a function of Global Navigation Satellite System (GNSS) derived positional error, flying altitude, and INS derived attitude error. The obtained $RMSE_r$ value is multiplied by a conversion factor of 1.7308 to yield the horizontal component of the National Standards for Spatial Data Accuracy (NSSDA) reporting standard where a theoretical point will fall within the obtained radius 95% of the time. Based on a flying altitude of 2305 meters, an IMU error of 0.002 decimal degrees, and a GNSS positional error of 0.015 meters, this project was compiled to meet 0.25 meter horizontal accuracy at the 95% confidence level. A summary is shown below.

Horizontal Accuracy	
$RMSE_r$	0.47 ft
	0.14 m
ACC_r	0.82 ft
	0.25 m

6.2. Relative Vertical Accuracy

Relative vertical accuracy refers to the internal consistency of the data set as a whole: the ability to place an object in the same location given multiple flight lines, GPS conditions, and aircraft attitudes. When the lidar system is well calibrated, the swath-to-swath vertical divergence is low (<0.10 meters). The relative vertical accuracy was computed by comparing the ground surface model of each individual flight line with its neighbors in overlapping regions. The average (mean) line to line relative vertical accuracy for the Project Name Lidar project was 0.042 feet (0.013 meters). A summary is shown below.

Relative Vertical Accuracy	
Sample	13 flight line surfaces
Average	0.042 ft
	0.013 m
Median	0.042 ft
	0.013 m
RMSE	0.042 ft
	0.013 m
Standard Deviation (1σ)	0.001 ft
	0.000 m
1.96 σ	0.002 ft
	0.001 m



Project Report Appendices

The following section contains the appendices as listed in the CA_LowerBearCreek_2020 QL2 LiDAR Project Report.

Appendix A

Flight Logs

USGS Lassen & Lower Bear Creek Lidar

Project Name:

Date	Mission ID	Sensor	Aircraft Make/Model	Aircraft Number	Flight Plan	Lines Flown	# Reflites	Flight 1 Wheels Up (PDT)	Flight 1 Wheels Down (PDT)	Flight 1 Begin Hobbs	Flight 1 End Hobbs	Flight 1 Total Hobbs	Operator 1	Pilot 1	Base of Operations (airport, KXXX)	Notes	System Error(s)	Action Taken
10/12/2020	20201012_SN3061	Riegl VQ1560i S2223061	Cessna Caravan	N840JA	Lassen QL1	1-24	0	8:05:00 AM	12:52:00 PM	2345.5	2350.2	4.7	J Maxey	C Griffin	KSVE	Flew and completed Lassen QL1	None	N/A
12/11/2020	20201211_SN3061	Riegl VQ-1560i SN3061	Cessna Conquest	N441CJ	Bear Creek QL2	1-13	0	8:43:00 AM	12:55:00 PM	6577.7	6581.6	3.9	S. White	C. Christopher	KFAT	We were able to sneak in under the cloud deck to acquire Bear Creek.	None	N/A

USGS_LowerBearCreek_QL2

USGS_LowerBearCreek_QL2								
Line Name	Line Length [nmi]	Flying Alt. [ft MSL]	Date	Mission #	Sensor SN#	Op	Time Stamp	Notes (Direction, Atmos. Conditions, Speed, PR, Errors)
1	7.3	7552	20201211	A	SN3061	SW	FLOWN	
2	14.2	7546	20201211	A	SN3061	SW	FLOWN	
3	15.5	7562	20201211	A	SN3061	SW	FLOWN	
4	16.3	7556	20201211	A	SN3061	SW	FLOWN	
5	24.6	7530	20201211	A	SN3061	SW	FLOWN	
6	25.4	7530	20201211	A	SN3061	SW	FLOWN	
7	25.5	7526	20201211	A	SN3061	SW	FLOWN	
8	26.6	7513	20201211	A	SN3061	SW	FLOWN	
9	28	7523	20201211	A	SN3061	SW	FLOWN	
10	36.6	7533	20201211	A	SN3061	SW	FLOWN	
11	36.1	7533	20201211	A	SN3061	SW	FLOWN	
12	34.9	7530	20201211	A	SN3061	SW	FLOWN	
13	32.2	7526	20201211	A	SN3061	SW	FLOWN	