MINIMUM TECHNICAL STANDARDS, VOL. 2
FINAL REPORT OF LIDAR MAPPING

INDIAN RIVER COUNTY, FLORIDA

STATE OF FLORIDA
DIVISION OF EMERGENCY MANAGEMENT

TASK ORDER NO. 20070525-492718A
TASK ORDER NO. 20070525-492718C
CONTRACT NO. 07-HS-34-14-00-22-469
PRIVITY AGREEMENT

DECEMBER 23, 2008
REVISED

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PREPARED BY:
WOOLPERT, INC.
LAUREL BUILDING
3504 LAKE LYNDA DRIVE, SUITE 400
ORLANDO, FLORIDA 32817-1484
TEL 407.381.2192 / FAX 407.384.1185
FLORIDA CERTIFICATE OF AUTHORIZATION LB 0006777

DECEMBER 23, 2008
REVISED

QUALITY

At Woolpert, quality is the cornerstone of our business. We invite your comments and suggestions for improving this document.

TRADEMARKS

NOTICE OF PROPRIETARY INFORMATION

MINIMUM TECHNICAL STANDARDS REPORT
REPORT OF TOPOGRAPHIC SURVEY

Task Order No. 20070525-492718a
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Contract No. 07-HS-34-14-00-22-469
Privity Agreement

INDIAN RIVER COUNTY

For:
State of Florida, Division of Emergency Management
"State Emergency Response Team"
2555 Shumard Oak Boulevard
Tallahassee, Florida 32399-2100

By:
WOOLPERT, Inc.
Laurel Building
3504 Lake Lynda Drive, Suite 400
Orlando, FL 32817-1484
Tel 407.381.2192 / Fax 407.384.1185
Florida Certificate of Authorization LB 6777

Prepared by:
Richard R. Hudson, PE, PSM
Florida Professional Surveyor and Mapper PSM 5473

SUMMARY OF CONTENTS

REPORT OF TOPOGRAPHIC SURVEY
INDIAN RIVER COUNTY: LIDAR TOPOGRAPHIC MAPPING FOR THE
FLORIDA DIVISION OF EMERGENCY MANAGEMENT

Purpose

This data set is one component of a digital terrain model (DTM) for the Florida Division of Emergency Management's (FDEM) Project Management and Technical Services for Mapping within Coastal Florida (Contract 07-HS-34-14-00-22-469), encompassing the entire coastline of Florida.

This survey was performed according to Baseline Specifications v 1.2. These specifications were developed by a coalition of GIS practitioners, including the Florida Division of Emergency Management, Florida Water Management Districts, Florida Fish and Wildlife Conservation Commission, Florida Department of Environmental Protection, Army Corp of Engineers Jacksonville District, and other state and federal agencies as the model requirements for orthophotography and LiDAR data collection for publicly funded projects within Florida.

The LiDAR topographic mapping survey is to support the Florida Division of Emergency Management (FDEM) development and maintenance of Regional Evacuation Studies (Study), which include vulnerability assessments and assist disaster response personnel in understanding threats to Florida's citizens and visitors. Additionally-intended uses for this survey are growth management, map modernization/floodplain mapping, natural lands stewardship, and homeland security planning.

Type of Survey

Topographic Survey – Line-Drawn (Vector) Topographic Features by LiDAR and Photogrammetric Methods.

Sensor Description

All data was acquired using Leica ALS50-II LiDAR sensor number 59. The ALS50 has a laser pulse rate of up to 150 kilohertz, records up to 4 returns per pulse, and records return intensities for 3 laser returns per pulse. The Indian River County LiDAR data was collected at 4,000' above ground level, at an average airspeed of 110 knots. Sensor Field of View was set to 29 degrees. Bore-sight calibration was performed at the beginning and at the end of the overall project. A description of that calibration may be found in Appendix D.

Dates of Survey

The LiDAR data was acquired August 24-28, 2007. The GPS ground control and QA/QC observations occurred from January 8-10 and March 5, 2008.

Survey Area

The survey encompassed approximately +/-255 square miles within Indian River County, Florida.

Map Reference

There are no printed maps for this survey. All map data was delivered to the Florida Division of Emergency Management in digital form only.

Name of Responsible Surveyor

Richard R. Hudson, PE, PSM
Woolpert, Inc.
Laurel Building
3504 Lake Lynda Drive
Suite 400
Orlando, Florida 32817-1484
Professional Surveyor and Mapper Number LS-0005473

Name of Company

Woolpert, Inc.
Laurel Building
3504 Lake Lynda Drive
Suite 400
Orlando, Florida 32817-1484
Florida Certificate of Authorization No. LB-0006777

Abbreviations

2D – Two-Dimensional
3D – Three-Dimensional
ABGPS – Airborne GPS
AGL – Above Ground Level
AT – Aerial Triangulation
CI – Confidence Interval
DEM – Digital Elevation Model
DTM – Digital Terrain Model
FDEM – Florida Division or Emergency Management
FGCC – Federal Geodetic Control Committee
GeoTIFF – Georeferenced Tag(ged) Image File Format
GPS – Global Positioning System
GSD – Ground Sample Distance
ID – Identification
IMU – Inertial Measurement Unit
Inc. – Incorporated
IPAS – Inertial Positioning and Attitude System
LAS – LASer File Format Exchange

LiDAR – Light Detection And Ranging
NAD 83-HARN – North American Datum 1983 High Accuracy Reference Network adjustment
NAVD 88 – North American Vertical Datum of 1988
NGS – National Geodetic Survey
NMAS – National Map Accuracy Standards
NOAA – National Oceanic and Atmospheric Administration
NSSDA – National Standards for Spatial Data Accuracy
PSM – Professional Surveyor and Mapper
QA/QC – Quality Assurance/Quality Control
RGB – Red, Green and Blue Bands
RMSE – Root Mean Square Error
RTK – Real Time Kinematic
STD – Standard
TIFF – Tag(ged) Image File Format
TIN – Triangulated Irregular Network
USGS – United States Geological Survey
Vx – Residual Horizontal Error in the X Direction
Vy – Residual Horizontal Error in the Y Direction
Vxy – Residual Horizontal Error in the XY Direction (Resultant)
XYZ – Easting, Northing and elevation grid coordinates (ASCII format)

Definitions

Orthophoto: A digital image (raster) map produced from a series of aerial photographs and/or image strips that have been rectified to correct for aircraft tilt, terrain relief, and camera lens distortion. The resulting image has a consistent scale throughout, allowing the user to take direct measurements such as distances, angles, positions, and areas. The digital raster image is comprised of a digital grid of pixels, or picture elements. Each pixel has a row and column "address" (an X,Y coordinate) and an intensity value ranging from 0 to 255. Each pixel within an RGB image, will have an intensity value for the red, green, and blue bands. Orthophotos may be produced as a natural color image using natural color bands (red, green, blue) or as a false-color infrared image using the red, green, near-infrared bands.

Map Data Accuracy

Horizontal Feature Accuracy: Per contract specifications, the horizontal accuracy requirement is to meet or exceed a 3.8-foot horizontal accuracy at the 95% confidence level using RMSE(r) x 1.7308 as defined by the FGDC Geospatial Positioning Accuracy Standards, Part 3: NSSDA.

Vertical Feature Accuracy: Per contract specifications, the vertical accuracy requirement of the digital terrain model (DTM) is 0.6 foot at 95% confidence level using RMSE(z) x 1.9600 as defined by the National Standard for Spatial Data Accuracy (NSSDA).

For the following landcover point classifications,

1. Bare-earth and low grass
2. Brush lands and low trees
3. Forested areas fully covered by trees
4. Urban areas

Vertical accuracy guidelines are as follows from FEMA's Appendix A:

In category 1, the RMSEz must be < .30 ft (Accuracy$_z$ < .60 feet)
In category 2, the RMSEz should be < .61 ft (Accuracy$_z$ < 1.19 feet)
In category 3, the RMSEz should be < .61 ft (Accuracy$_z$ < 1.19 feet)
In category 4, the RMSEz should be < .61 ft (Accuracy$_z$< 1.19 feet)
In all categories combined, the RMSEz should be < .61 ft (Accuracy$_z$ < 1.19 feet)

Additionally, two-foot contours in unobscured areas are certified to meet or exceed National Map Accuracy Standards (NMAS). These standards state that not more than 10 percent of the elevations tested shall be in error by more than one-half the contour interval, and none will be in error by more than the full contour interval. Therefore, for a 2-foot contour interval, not more than 10 percent of the elevations tested shall be in error of more than 1 foot, and none will be in error by more that 2 feet. Two-foot contours within low confidence (obscured) areas are attributed as such and are not required to meet NMAS. Additionally, 1-foot contours are delivered for graphical purposes, and are not required to meet these accuracy standards.

The accuracy assessment was performed using a standard method to compute the root mean square error (RMSE) based on a comparison of ground control points and filtered LiDAR data points. Filtered LiDAR data has had vegetation and cultural features removed and by analysis represents bare earth elevations. The RMSE figure was used to compute the vertical National Standard for Spatial Data Accuracy (NSSDA).

The results of Woolpert's accuracy analysis are included in Appendix B, LiDAR Accuracy Checks.

Datums/Coordinate Systems

The LiDAR data and breaklines are in reference to the State Plane Coordinate System, Florida East Zone (0901), in units of US Survey Feet. The horizontal datum is NAD83-HARN, and the vertical datum is NAVD88.

Data Sources

Original Control Point Coordinates: NGS Information Services
NOAA, N/NGS12 National Geodetic Survey SSMC-3, #9202 1315 East-West Highway Silver Spring, Maryland 20910-3282
Phone: (301) 713-3242 Fax: (301) 713-4172
Email: info_center@ngs.noaa.gov
http://www.ngs.noaa.gov/

Methodology

A digital terrain model (DTM) was developed from a combination of newly-flown LiDAR point data and existing orthophoto imagery. Stereo imagery was created from the LiDAR surface and orthophoto imagery using GeoCue software, generating the stereo view from the 3D LiDAR data.

Terrain breakline data was photogrammetrically collected to improve the digital elevation model within this stereo view.

The project area encompasses approximately 255 square miles Indian River County, Florida (see Appendix A: Mapping Area and QC Checkpoint Locations). The LiDAR data was collected at a maximum post spacing of 4 feet in unobscured areas for random point data. The end product complies with the Florida Administrative Code 61G17, Minimum Technical Standards for Surveying and Mapping.

A minimum of one hundred and twenty (120) ground survey quality control (QC) checkpoints are required for per 500 square miles of project area. These were surveyed by Woolpert throughout the project area and were used to confirm the accuracy of the LiDAR data. The accuracy analysis was based on methods outlined in the Geospatial Positioning Accuracy Standards, Part 3: National Standards for Spatial Data Accuracy (NSSDA) developed by the Federal Geodetic Data Committee (FGDC-STD-007.3-1998).

LiDAR Ground Control Survey

The ground control network to support the LiDAR survey was comprised of 19 control points located by rapid static GPS methods to second-order horizontal and third-order vertical accuracies in Indian River County. For a detailed overview of the ground control survey, refer to Volume 1 of this report.

QA/QC Checkpoint Survey

To support the accuracy analysis of the topographic mapping, Woolpert acquired 76 new field-surveyed QC checkpoints using rapid static GPS ground surveys, along with conventional surveying methods to locate points within dense tree cover. Again, a detailed overview of the QA/QC checkpoint survey may be found in Volume 1 of this report.

LiDAR Acquisition and Processing

The LiDAR data was acquired using a Leica ALS50-II LiDAR sensor, on August 24-28, 2007. The LiDAR data was collected at a maximum post spacing of 4 feet in unobscured areas for random point data. The ABGPS base station used during acquisition was VRB A at Vero Beach Airport (KVRB).

The ABGPS data was reduced using the GrafNav software package by Waypoint Consulting, Incorporated.

The IMU data for Sensor 59 was reduced using Leica's IPAS Pro software to process the IMU data, with Leica's IPAS sensor embedded.

The initial LiDAR "point cloud" was derived through the ALS Post Processor software package by Leica Geosystems. The ground base stations were placed at no more than a 20-mile radius from the flight survey area.

Once the initial LiDAR "point cloud" was derived, the data was reviewed to look for any systematic error within the LiDAR flights using proprietary software. After systematic errors were identified and removed, above-ground features were classified and removed using proprietary software to produce the bare-earth coverage. The overlap area between flight lines was maintained in order that potentially usable data is available.

LiDAR QC/Photogrammetric Compilation

To collect the breaklines, the LiDAR data was used as the main source data set in addition to orthophotography. Orthophoto imagery was from new imagery collected and developed by the Woolpert Team. All imagery for Indian River County is dated 2007 with a 0.5 foot pixel resolution.

Stereo imagery was created from the LiDAR surface and orthophoto imagery using GeoCue software. From these stereo images, or LiDARgrammetry, breakline features were collected along linear topographic features as required. Breakline elevations were linearly ramped between identified critical elevation points.

In accordance with the Baseline Specifications v 1.2, the following breakline features were collected:

- Closed water bodies (lakes, reservoirs, etc) as 2-D or 3-D polygons
- Linear hydrographic features (streams, shorelines, canals, swales, embankments, etc) as 3-D breaklines
- Coastal shorelines as 2-D or 3-D linear features
- Edge of pavement road features as 3-D breaklines
- Soft features (ridges, valleys, etc.) as 3-D breaklines
- Low confidence areas as 2-D polygons; island features as 2-D or 2D polygons
- Overpasses and bridges as 3-D breaklines

The Coastal Shoreline breaklines were collected at varying elevations at the land-water interface, with elevations linearly ramped between identified critical elevation points. Breakline features were captured to develop a hydrologically correct DTM.

Automated QC processes were run on the breaklines and LiDAR elevation points to check for outlying elevations not probable within the mapping area. Additional visual QC was performed to verify the automated processes.

Breakline features were compiled in the softcopy environment using ImageStation SSK software on Pentium IV, quad processor, 3GHz photogrammetric workstations. Intergraph Corporation of Huntsville, Alabama, distributes the ImageStation SSK software.

The DTM was delivered as LiDAR mass points in LAS version 1.1 and the breaklines were delivered as an ArcGIS geodatabase. A list of the 284 LAS files delivered for Indian River County may be found in Appendix C.

Contours were generated from a 30-foot gridded DEM: 2-foot contours meet NMAS, with 1-foot contours for visualization purposes. The LiDAR masspoints are delivered in the LAS 1.1 file format based on FDEM’s 5,000' by 5,000' grid. Contours were generated using TerraScan software, distributed by TerraScan, Inc., of Lincoln, Nebraska.

The dataset is comprised of an ESRI ArcGIS geodatabase containing the mass points (ground only), 2-D and 3-D breakline features, 1-foot and 2-foot contours, ground control, vertical test points, and a footprint of the data set; and LAS 1.1 binary files of the classified LiDAR points.

The LiDAR point classification codes for LAS 1.1 files are as follows:

- Class 1 = Unclassified
- Class 2 = Ground
- Class 7 = Noise
- Class 9 = Water
- Class 12 = Overlap

Classes 1, 2, 7, and 9 include LiDAR points in the overlap area between flight lines.

Class 1 is used for all features that do not fit into the Classes 2, 7, 9, or 12, including vegetation, buildings, etc.

Class 7 represents artifacts not representing the earth's surface (cell towers, birds, etc.) – Noise as defined above.

Shorelines of water bodies are captured as breaklines and LiDAR points inside of water bodies are classified as Class 9 = Water in the LAS deliverable.

Class 12 LiDAR points are in areas of overlapping flight lines, which have been deliberately deleted and removed from all other classes because of their reduced accuracy, for example, due to their off-nadir position.

Accuracy Checks

The vertical accuracy of the final LiDAR DTM/Mass-Point Data mapping was verified using the field-surveyed QC checkpoints. Results of those field verifications are included in Appendix B.

References

Florida GIS
Baseline Specifications for Orthophotography and LiDAR, v 1.2
http://www.floridadisaster.org/GIS/specifications/Documents/BaselineSpecifications_1.2.pdf

UGSG Internet Site for National Map Accuracy Standards.
http://erg.usgs.gov/isb/pubs/factsheets/fs17199.html#Map%20Accuracy

General Notes

1. **THIS REPORT IS NOT COMPLETE WITHOUT THE PORTABLE HARD DRIVE OF THE DIGITAL MAPPING, AND VICE VERSA.**

2. **INTENDED DISPLAY SCALE – THIS MAPPING IS INTENDED TO BE DISPLAYED AT A SCALE OF 1:1,200 (1"=100') OR SMALLER.**

3. **THIS MAP COMPLIES WITH NATIONAL STANDARDS FOR SPATIAL DATA ACCURACY.**

4. **THIS MAP COMPLIES WITH THE FEDERAL EMERGENCY MANAGEMENT AGENCY (FEMA) "GUIDELINES AND SPECIFICATIONS FOR FLOOD HAZARD MAPPING PARTNERS, APPENDIX A: GUIDANCE FOR AERIAL MAPPING AND SURVEYING."**

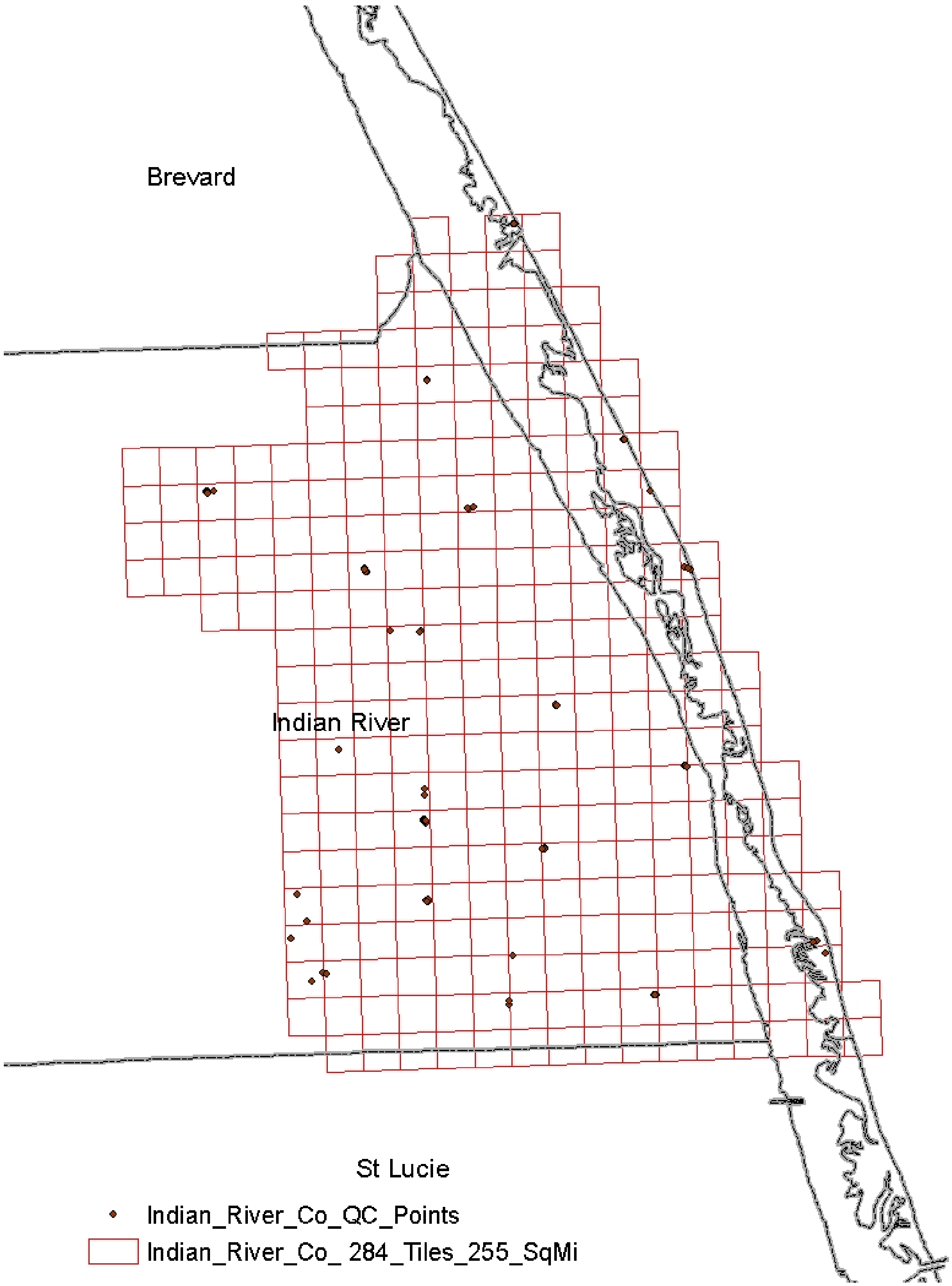
THIS REPORT IS NOT VALID WITHOUT THE SIGNATURE AND RAISED SEAL OF A FLORIDA LICENSED SURVEYOR AND MAPPER IN RESPONSIBLE CHARGE.

Surveyor and Mapper in Responsible Charge
Richard R. Hudson, PE, PSM
Professional Surveyor and Mapper
License Number: PSM 5473

Signed: Richard R. Hudson 12-23-08
Date

Seal: RICHARD R. HUDSON CERTIFICATE NO.5473 STATE OF FLORIDA Registered Surveyor & Mapper

Appendix A: Mapping Area and QC Checkpoint Locations



APPENDIX B: LIDAR ACCURACY CHECKS

The vertical accuracy of the LiDAR DTM was verified by comparison of the DTM/TIN against the field-surveyed QC checkpoints. The requirements are to acquire a minimum of one-hundred twenty (120) three-dimensional LiDAR QA/QC checkpoints per 500 square miles of project area. To the extent allowed by the terrain, the LiDAR control points and checkpoints are distributed so that points were spaced at intervals of at least 10% of the diagonal distance across the dataset and at least 20% of the points were located in each quadrant of the project area.

For this 255 square-mile area, 61 checkpoints are required – a total of 76 checkpoints were captured across the delivery area. Woolpert field crews observed and established 3-dimensional coordinates on four different types of landcover:

1. Bare-earth and low grass
2. Brush lands and low trees
3. Forested areas fully covered by trees
4. Urban areas

Woolpert acquired the QC checkpoints using rapid static GPS ground surveys, along with conventional surveying methods to locate points within dense tree cover. A detailed overview of the QA/QC checkpoint survey may be found in Volume 1 of this report.

The accuracy analysis was based on methods outlined in the Geospatial Positioning Accuracy Standards, Part 3: National Standards for Spatial Data Accuracy (NSSDA) developed by the Federal Geodetic Data Committee (FGDC-STD-007.3-1998). The first step was to generate a TIN from the DTM. Each QC checkpoint was then compared against its corresponding TIN elevation. The difference between field-surveyed QC checkpoint and DTM/TIN elevation represents the residual error (Vz) at that point. A statistical analysis was then performed on the residual errors.

Per contract specifications, the vertical accuracy requirement of the digital terrain model (DTM) is 0.6 foot at 95% confidence level using RMSE(z) x 1.9600 as defined by the National Standard for Spatial Data Accuracy (NSSDA).

Vertical accuracy guidelines are as follows from FEMA's Appendix A:

In category 1, the RMSEz must be < .30 ft ($Accuracy_z$ < .60 feet)
In category 2, the RMSEz should be < .61 ft ($Accuracy_z$ < 1.19 feet)
In category 3, the RMSEz should be < .61 ft ($Accuracy_z$ < 1.19 feet)
In category 4, the RMSEz should be < .61 ft ($Accuracy_z$< 1.19 feet)
In all categories combined, the RMSEz should be < .61 ft ($Accuracy_z$ < 1.19 feet)

Additionally, two-foot contours in unobscured areas are certified to meet or exceed National Map Accuracy Standards (NMAS). These standards state that not more than 10 percent of the elevations tested shall be in error by more than one-half the contour interval, and none will be in error by more than the full contour interval. Therefore, for a 2-foot contour interval, not more than 10 percent of the elevations tested shall be in error of more than 1 foot, and none will be in error by more that 2 feet. Two-foot contours within low confidence (obscured) areas are attributed as such and are not required to meet NMAS. Additionally, 1-foot contours are delivered for graphical purposes, and are not required to meet these accuracy standards.

The following table summarizes the statistical tests for the four landcover classifications, for the overall accuracy at all checkpoints, and NMAS within unobscured areas:

Statistical Summary By LANDCOVER					
Bare Earth and Low Grass			**Brush Lands and Low Trees**		
Calculated RMSEz	0.27	ft	Calculated RMSEz	0.68	ft
Target RMSEz	0.30	ft	Target RMSEz	0.61	ft
Calculated 95% CI	0.54	ft	Calculated 95% CI	1.33	ft
Target 95% CI	0.60		Target 95% CI	1.19	
Min	0.02	ft	Min	0.02	ft
Max	0.75	ft	Max	1.56	ft
Average	0.22	ft	Average	0.50	ft
Count	22		Count	19	
Forested Areas Fully Covered by Trees			**Urban Areas**		
Calculated RMSEz	0.92	ft	Calculated RMSEz	0.19	ft
Target RMSEz	0.61	ft	Target RMSEz	0.61	ft
Calculated 95% CI	1.80	ft	Calculated 95% CI	0.37	ft
Target 95% CI	1.19		Target 95% CI	1.19	
Min	0.10	ft	Min	0.03	ft
Max	1.79	ft	Max	0.49	ft
Average	0.77	ft	Average	0.14	ft
Count	19		Count	36	
Overall at All Checkpoints			**Unobscured LANDCOVER NMAS**		
Calculated RMSEz	0.60	ft	Calculated 90^{th} Percentile	0.38	ft
Target RMSEz	0.61	ft	Target 90^{th} Percentile	1.0	ft
Calculated 95% CI	1.17	ft	Calculated Max	0.75	ft
Target 95% CI	1.19		Target Max	2.0	ft
Min	0.0	ft	Count	38	ft
Max	1.79	ft			
Average	0.44	ft			
Count	76				

The calculated RMSEz and 95% confidence interval (CI) are shown for each of the four landcover types, and for all landcover types combined. To calculate the correlation to NMAS, only the Bare

Earth and Low Grass, and the Urban Areas landcover types were considered, because these are the only "unobscured" landcover types. To calculate "not more than 10 percent" of the values, the 90th Percentile was determined for the combined Bare Earth and Low Grass, and the Urban Areas landcover measurements.

The Brush Lands and Low Trees, and the Forested Areas Fully Covered by Trees Landcover types exceed the recommended maximum values for RMSEz and 95% CI. Brush Lands and Low Trees exceed the recommended accuracies by 0.07 foot and 0.14 foot, respectively. Forested Areas Fully Covered by Trees exceed the recommended accuracies by 0.31 foot and 0.61 foot, respectively. This indicates that there is a greater degree of misclassification of LiDAR points within these Landcover types than within the other two Landcover types. The LiDAR DTM does meet the accuracy requirements of the Baseline Specifications (RMSEz *should* be < .61 ft ($Accuracy_z$< 1.19 feet), but it's important that users of the data be aware of the potential accuracy limitations within the Forested Areas Fully Covered by Trees, and to a lesser degree for the Brush Lands and Low Trees.

The following table lists the test results for all checkpoints:

Accuracy Analysis
Indian River County
Map Projection: State Plane Coordinate System, Florida East Zone
Horizontal Datum: NAD 83/HARN
Vertical Datum: NAVD 88
Units: U.S. Survey Feet
Date: October, 2008

Image Tile	QC Point	Field Truth (US SV FT)			DTM Measurement (US SV FT)	Residual Error (US SV FT)	LANDCOVER
CELLNUM	ID	Northing	Easting	Elevation	Elevation	Vz	
075225_E	501	1248796.53	791384.90	24.73	24.83	0.097	BARE EARTH AND LOW GRASS
075829_E	506	1237354.56	812487.11	19.51	19.48	-0.022	BARE EARTH AND LOW GRASS
077930_E	511	1203514.61	819324.67	20.10	20.12	0.015	BARE EARTH AND LOW GRASS
078530_E	516	1192532.42	819325.00	23.80	23.74	-0.057	BARE EARTH AND LOW GRASS
079432_E	521	1178821.78	829933.33	20.21	20.02	-0.184	BARE EARTH AND LOW GRASS
079436_E	526	1179018.16	849801.70	21.14	20.39	-0.751	BARE EARTH AND LOW GRASS
078234_E	531	1199142.48	835418.20	21.94	22.20	0.267	BARE EARTH AND LOW GRASS
077034_E	536	1218728.96	837544.59	21.72	21.53	-0.188	BARE EARTH AND LOW GRASS
075232_E	541	1245501.65	826485.77	21.69	21.32	-0.376	BARE EARTH AND LOW GRASS

074331_E	546	1262985.94	821526.70	19.75	19.81	0.057	BARE EARTH AND LOW GRASS
073133_E	551	1283732.80	834012.92	9.31	9.23	-0.089	BARE EARTH AND LOW GRASS
074936_E	556	1254154.04	847778.21	8.62	8.80	0.188	BARE EARTH AND LOW GRASS
074936_E	561	1236586.06	855550.29	8.68	9.06	0.381	BARE EARTH AND LOW GRASS
077637_E	566	1209827.90	854762.52	2.68	2.95	0.276	BARE EARTH AND LOW GRASS
078841_E	571	1185603.37	871814.87	4.69	4.57	-0.123	BARE EARTH AND LOW GRASS
078527_E	IRX01	1190402.85	802960.17	22.04	22.40	0.359	BARE EARTH AND LOW GRASS
078527_E	IRX03	1194036.47	801835.04	22.36	22.62	0.256	BARE EARTH AND LOW GRASS
077630_E	IRX12	1207854.86	819486.13	20.96	21.35	0.387	BARE EARTH AND LOW GRASS
079127_E	IRX20	1183314.55	804863.12	22.33	22.40	0.074	BARE EARTH AND LOW GRASS
079128_E	IRX21	1183269.05	805485.46	23.40	23.59	0.189	BARE EARTH AND LOW GRASS
076430_E	IRX25	1229246.56	815559.11	20.53	20.21	-0.313	BARE EARTH AND LOW GRASS
078234_E	IRX26	1229163.40	819554.97	21.26	21.44	0.179	BARE EARTH AND LOW GRASS
075225_E	500	1248662.20	791378.01	25.25	25.10	-0.152	URBAN AREAS
075829_E	505	1237724.28	812236.96	20.92	20.85	-0.076	URBAN AREAS
077930_E	510	1203506.58	819401.93	21.21	21.31	0.097	URBAN AREAS
078530_E	515	1192605.27	819308.69	23.97	23.92	-0.048	URBAN AREAS
079133_E	520	1184872.53	830655.60	20.23	20.36	0.127	URBAN AREAS
079436_E	525	1179024.24	849665.95	21.76	21.27	-0.489	URBAN AREAS
078234_E	530	1199186.90	835057.01	22.02	22.28	0.266	URBAN AREAS
077034_E	535	1218555.82	837644.87	20.92	20.89	-0.03	URBAN AREAS
075232_E	540	1245615.45	827307.09	19.90	19.52	-0.381	URBAN AREAS
074331_E	545	1262912.34	821564.61	19.25	19.40	0.143	URBAN AREAS
073133_E	550	1283672.34	833884.60	5.19	5.34	0.148	URBAN AREAS

075838_E	555	1254150.81	847847.46	8.68	8.65	-0.033	URBAN AREAS
075838_E	560	1236462.16	855893.05	10.83	10.78	-0.056	URBAN AREAS
077637_E	565	1209717.15	854977.27	7.22	7.18	-0.035	URBAN AREAS
078841_E	570	1185454.02	871359.81	4.82	4.85	0.032	URBAN AREAS
077630_E	IRX14	1206946.55	819463.58	21.79	21.91	0.121	URBAN AREAS
075225_E	502	1248906.96	792232.41	24.53	24.78	0.252	BRUSH LANDS AND LOW TREES
075829_E	507	1237250.54	812523.36	19.00	20.56	1.562	BRUSH LANDS AND LOW TREES
077930_E	512	1203094.05	819481.27	18.88	20.37	1.487	BRUSH LANDS AND LOW TREES
078530_E	517	1192691.82	819172.23	23.38	23.27	-0.117	BRUSH LANDS AND LOW TREES
079432_E	522	1178206.46	829958.02	20.35	20.56	0.212	BRUSH LANDS AND LOW TREES
079436_E	527	1179026.66	849585.01	21.58	20.81	-0.765	BRUSH LANDS AND LOW TREES
076430_E	532	1199263.64	835477.38	21.26	21.28	0.02	BRUSH LANDS AND LOW TREES
077034_E	537	1218481.68	837513.67	22.01	22.06	0.057	BRUSH LANDS AND LOW TREES
075232_E	542	1245412.63	826574.98	21.20	21.02	-0.181	BRUSH LANDS AND LOW TREES
074331_E	547	1262890.74	821482.64	21.32	22.65	1.33	BRUSH LANDS AND LOW TREES
073133_E	552	1283653.28	834134.72	16.50	16.91	0.407	BRUSH LANDS AND LOW TREES
075237_E	557	1247036.20	851171.57	14.14	14.58	0.434	BRUSH LANDS AND LOW TREES
075838_E	562	1236373.48	856279.09	14.49	14.98	0.494	BRUSH LANDS AND LOW TREES
077637_E	567	1209809.77	854702.10	5.07	5.45	0.385	BRUSH LANDS AND LOW TREES
079141_E	572	1183832.30	872948.35	9.63	9.81	0.18	BRUSH LANDS AND LOW TREES
078827_E	IRX02	1188078.58	800795.17	23.46	24.22	0.761	BRUSH LANDS AND LOW TREES
077328_E	IRX10	1213391.01	808052.26	29.08	29.34	0.256	BRUSH LANDS AND LOW TREES

079127_E	IRX23	1182203.87	803337.73	22.48	22.82	0.336	BRUSH LANDS AND LOW TREES
076430_E	IRX27	1228951.02	819426.42	21.29	21.02	-0.273	BRUSH LANDS AND LOW TREES
077637_E	6900	1209910.15	854590.62	0.92	2.50	1.584	FORESTED AREAS FULLY COVERED BY TREES
077637_E	6901	1209837.25	854591.16	1.18	1.84	0.663	FORESTED AREAS FULLY COVERED BY TREES
077637_E	6902	1209776.56	854607.90	0.89	1.45	0.556	FORESTED AREAS FULLY COVERED BY TREES
073133_E	6903	1283744.89	833800.44	2.64	3.44	0.796	FORESTED AREAS FULLY COVERED BY TREES
073133_E	6904	1283740.46	833859.11	3.97	4.90	0.926	FORESTED AREAS FULLY COVERED BY TREES
073133_E	6905	1283712.21	833912.13	5.09	5.67	0.575	FORESTED AREAS FULLY COVERED BY TREES
075829_E	6906	1237608.36	812275.56	19.63	21.09	1.458	FORESTED AREAS FULLY COVERED BY TREES
075829_E	6907	1237615.98	812320.79	20.72	22.23	1.513	FORESTED AREAS FULLY COVERED BY TREES
075829_E	6908	1237808.98	812341.09	19.14	20.10	0.968	FORESTED AREAS FULLY COVERED BY TREES
075225_E	6909	1248922.80	791413.57	24.91	26.70	1.791	FORESTED AREAS FULLY COVERED BY TREES
075225_E	6910	1248910.77	791251.44	24.73	25.55	0.821	FORESTED AREAS FULLY COVERED BY TREES
075225_E	6911	1248769.15	791231.68	24.97	25.89	0.918	FORESTED AREAS FULLY COVERED BY TREES
078530_E	6912	1203598.38	819077.91	20.36	20.84	0.481	FORESTED AREAS FULLY COVERED BY TREES
077930_E	6913	1203647.88	819247.20	19.89	20.02	0.132	FORESTED AREAS FULLY COVERED BY

							TREES
077930_E	6914	1203551.85	819183.55	20.97	20.27	-0.696	FORESTED AREAS FULLY COVERED BY TREES
077930_E	6915	1192590.10	819458.88	20.36	20.49	0.137	FORESTED AREAS FULLY COVERED BY TREES
078530_E	6916	1192660.58	819463.00	21.16	21.26	0.103	FORESTED AREAS FULLY COVERED BY TREES
078530_E	6917	1192787.44	819433.01	21.27	21.64	0.368	FORESTED AREAS FULLY COVERED BY TREES
077930_E	6914a	1203373.30	819296.86	21.15	21.31	0.166	FORESTED AREAS FULLY COVERED BY TREES

APPENDIX C: LAS FILES DELIVERED

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APPENDIX D: LIDAR CALIBRATION

Photo Science ALS50 LiDAR Calibrations

Introduction

Woolpert Team member Photo Science, Inc., performed all LiDAR acquisition and post processing. The following is the LiDAR system calibration report from Photo Science.

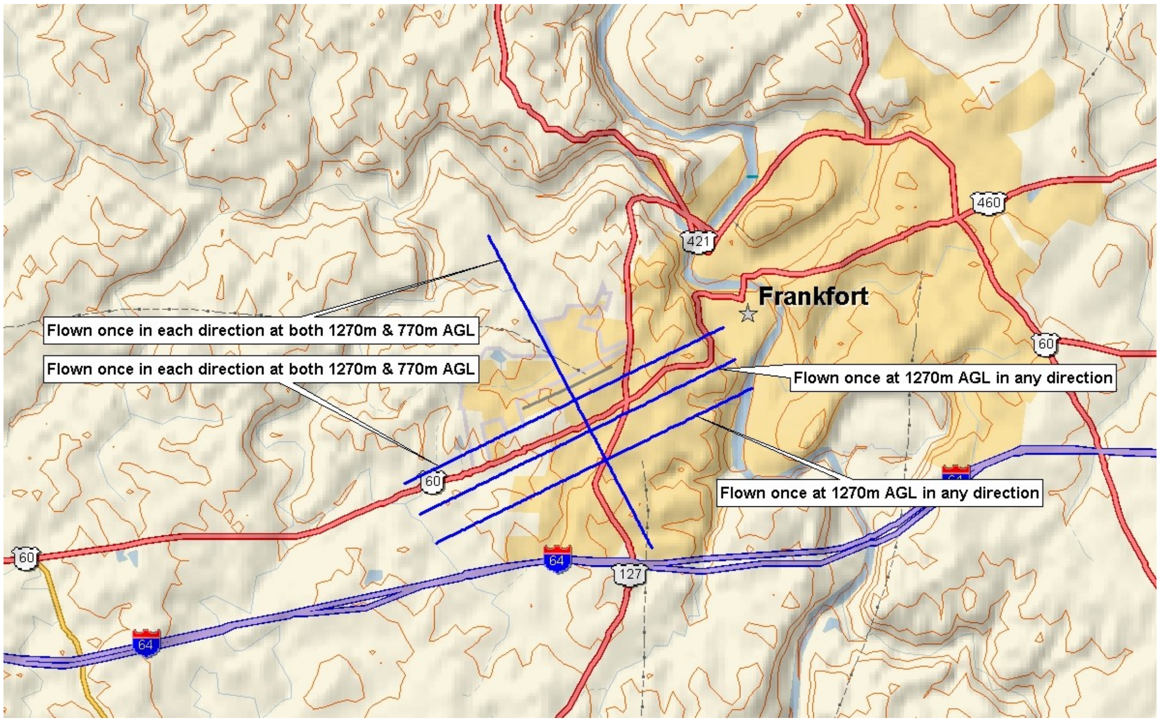
Overview

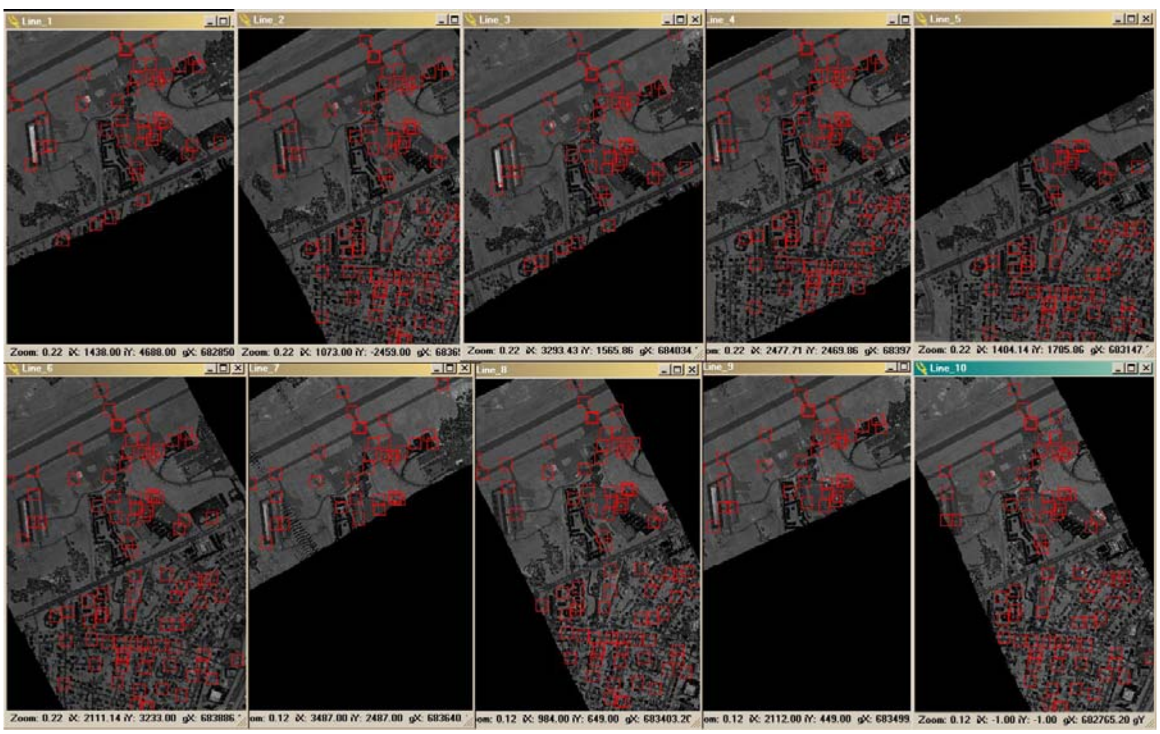
This Calibration Report shall be used to confirm LiDAR system specifications, performance, and requirements. The system functionality, elevation, and horizontal accuracy performance shall be demonstrated for calibration purposes. Photo Science completes calibration flights at regular intervals for ongoing monitoring of correction values, both at our home airport as well as in the field.

Once computed, the various derived values for correcting the inherent errors in the system should remain fairly constant, monitoring to ensure that no value starts to change more than expected. The sensors come from the factory with a set of values provided, measured by Leica, many of which will not change over the life of the system. Even moving a sensor in to and out of an aircraft should not appreciably change the correction values unless it experiences a hard bump or other trauma; the calibrated values are internal to the sensor.

Our main source of calibration data is collected in the form of Leica's prescribed Attune method. This involves collecting opposing passes at right angles to one another at 1270m above ground, and again at 770m above ground, centered over the same ground features, and using their proprietary calibration software for picking common tiepoints to determine roll, pitch, and heading correction values. They normally require 4 total passes at a minimum (2 high, 2 low) and have strong suggestions about types of features to use as tie-points.

We have slightly modified Leica's Attune flight procedure, with their guidance, wherein we fly 10 passes (4 high crisscross, 2 high offset, and 4 low crisscross) as seen below. This terrain includes not only the flat pavement of the airport and its surroundings, but a large amount of residential and commercial features in a gently rolling setting.





Periodically, roughly twice a year, we collect calibration data at 11000 feet above our home airport and have it analyzed by Leica with their higher-level calibration regimen. The increased flying height exaggerates the internal misalignments and makes them easier to measure, serving as tighter comparison benchmarks for the previous and subsequent Attune flights.

For this entire project we used the following sensors and aircraft:
Leica ALS50 Phase II Capable: serial number 019, mounted in N7320G
Leica ALS50 Phase II : serial number 059, mounted in N9471R and N2448G
Leica ALS50 Phase II : serial number 062, mounted in N2448G

Antenna Offsets

We mount our LiDAR systems exclusively in our fleet of Cessna 206 aircraft, removing them as little as possible to help maintain consistent system integrity. As such, our GPS antennas and the mounting plates for the sensor heads remain constant per plane. Once a new plane or sensor is incorporated in to our fleet and the initial sensor installation is completed, we have our ground survey team derive the offsets with a total station. That antenna offset value will not change unless the placement of a sensor's head within the aircraft changes.

N7320G, 1977 Cessna 206
X = -0.07
Y = 0.05
Z = -1.10

N9471R, 1985 Cessna 206
X = 0.875
Y = -0.125
Z = 1.012

N2448G, 2001 Cessna 206
X = -0.018
Y = -0.169
Z = -1.057

Leica provides their precisely measured internal IMU offsets, with respect to the focal point of the system's mirror, per each of the 2 types of IMU they use. These are embedded into the sensors' firmware for carrying forward into the subsequent trajectory-generating software, so these are not measured by us.

GPS Base Stationing

Whether calibration flights occur at our home airport (FFT – Capital City Airport in Frankfort, KY) or in the field on a project site, we strive to set up our GPS base station over the Primary Airport Control Station (PACS) as indicated by the National Geodetic Survey. If this is not possible, or the flight is only for purposes of resolving roll, pitch, and heading corrections, we can use almost any point because the software is solving the corrections for these parameters within the flight's data, not with respect to absolute positions on the ground.

Photo Science uses Trimble 5700 GPS data logging units paired with Trimble Zephyr Geodetic antennas. We log at a 2hz interval (every ½ second) and with a 5 degree elevation mask. We also use variable height tripods, measured and logged at the beginning and end of each session.

Ground Control Points / Vertical Bias

Due to electronic delay within the sensor, there is a constant element of vertical bias which must be corrected. We have surveyed many points along the length and width of the runway and taxiways of our home airport and reference this in to our calibration flights to monitor over time that the pertinent correction value is unchanging. In the case of an upgrade or repair to certain parts of the sensor, we recalculate this value.

Overall Calibration Results

The values below are a combination of constants provided by the manufacturer and variables derived from analysis of data collected over Photo Science's calibration site(s). These were the used throughout the Florida Gulf Coast 2007 project, with minor variations per individual aircraft sortie as needed.

June 23rd, 2007

	Parameter	Value
SN19	**Leica provided**	
	Encoder Latency	0.0 mcr sec
	Ticks Per Revolution	8388608 ticks
	Ranging Correction	-0.48m
	Scan Angle Correction	-19120 ticks
	Pitch Slope	0.0000185 rad/deg
	Attitude	
	Roll	0.00088397 rad
	Pitch	0.00966448 rad
	Heading	-0.00282358 rad
	Mechanical	
	Torsion	-19370 units

June 14th, 2007

SN59	Parameter	Value
	Leica provided	
	Encoder Latency	0.5 mcr sec
	Ticks Per Revolution	8388608 ticks
	Ranging Correction	1.258m
	Scan Angle Correction	8000 ticks
	Pitch Slope	0.000058 rad/deg
	Attitude	
	Roll	0.00170705 rad
	Pitch	0.01463471 rad
	Heading	-0.00165231 rad
	Mechanical	
	Torsion	-60000 units

Provided by Leica – their 'loaner' unit

SN62	Parameter	Value
	Leica provided	
	Encoder Latency	0.0 mcr sec
	Ticks Per Revolution	8388608 ticks
	Ranging Correction	2.425m
	Scan Angle Correction	23800 ticks
	Pitch Slope	0.00000011 rad/deg
	Attitude	
	Roll	0.004918 rad
	Pitch	0.00956337 rad
	Heading	0.0000545 rad
	Mechanical	
	Torsion	-35000 units

APPENDIX E: LIDAR FLIGHT DATES