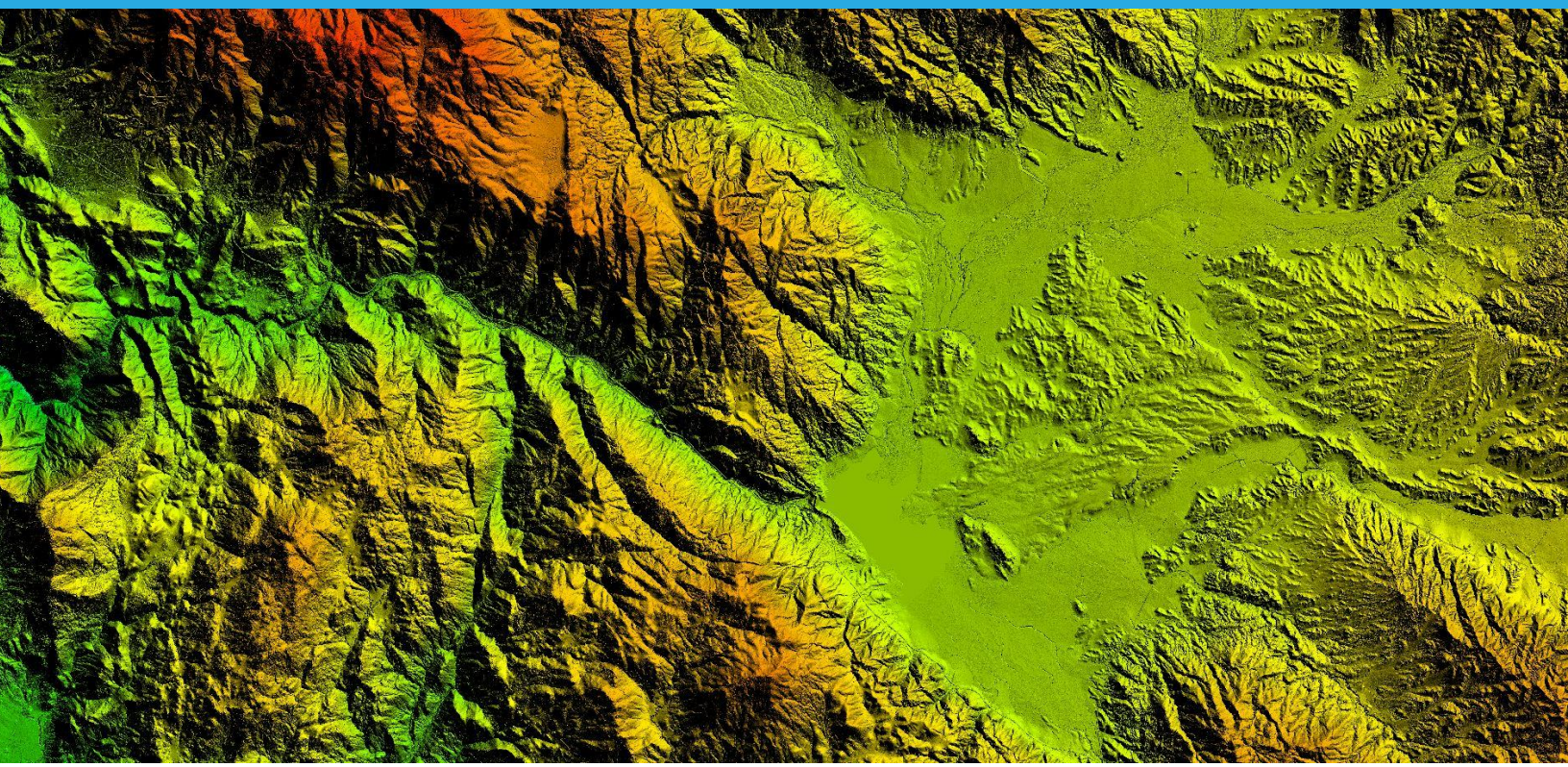
October 11, 2016

FEMA STARR II San Diego LiDAR



Relative Accuracy Validation Workflow

QUANTUM SPATIAL, INC.
523 Wellington Way,
Suite 375
Lexington KY 40503

www.quantumspatial.com

Quantum Spatial was contracted by STARR II to collect QL2 LiDAR for FEMA Region 9 in San Diego County, California under FEMA Task Order HSFE09-15-J-0001. All data collected and processed by Quantum Spatial under this task order adhered to all applicable FEMA Standards, USGS LiDAR Base Specification v1.2 (2014), ASPRS LAS Specification Version 1.4-R13 (2013), and ASPRS Positional Accuracy Standards for Digital Geospatial Data v1.0 (2014). The information in this document is meant to represent the tools and processes used to achieve the relative accuracy requirements of those specifications.

Quantum Spatial uses two main tools during the calibration phase to check and validate the relative accuracy of adjoining LiDAR flightlines. These tools are built into the overall workflow to ensure that the accuracy is sufficient to meet the project requirements before moving forward with any classification or product development.

The first check is done using the terrascan reports generated after each set of corrections are made to the data. As you can see in the following 3 images, the final average error continues to decreases each set of corrections are applied to the data.

First set of corrections (Applied on a per mission bases):

```
Used loaded tie lines
Trajectories: P:\Projects\26965_FEMA_STARR_San_Diego\Lidar\TMatch\Trajectory\
Solution for line groups
Combined solution for all scanners

Starting avg 3d mismat 0.18713
Starting avg xy mismat 0.00000
Starting avg z mismatc 0.18713

Final avg 3d mismatch: 0.07550
Final avg xy mismatch: 0.00000
Final avg z mismatch:  0.07550

Execution time: 201.1 sec
Number of iterations: 46

Group          Z shift H shift R shift P shift    Scale
103015A_8146    +0.034 -0.0054 +0.0051 -0.0075 +0.00021
103115A_8146    -0.089 -0.0051 +0.0066 -0.0083 +0.00018
103115C_8146    +0.073 -0.0057 -0.0003 -0.0078 +0.00018
103115B_8146    -0.041 -0.0048 +0.0043 -0.0080 +0.00017


Number of usable observations
Group                Z Heading    Roll   Pitch   Scale
103015A_8146    929614  641567  881789  641567  929614
103115A_8146    430935  302877  394608  302877  430935
103115C_8146    122485   78302  112998   78302  122485
103115B_8146     64257   47191   58544   47191   64257
```

Second set of corrections (Applied on a per flightline basis):

```
Used loaded tie lines
Trajectories: P:\Projects\26965_FEMA_STARR_San_Diego\Lidar\TMatch\Trajectory\
Solution for individual strips
Combined solution for all scanners

Starting avg 3d mismat 0.07309
Starting avg xy mismat 0.00000
Starting avg z mismatc 0.07309

Final avg 3d mismatch: 0.05494
Final avg xy mismatch: 0.00000
Final avg z mismatch:  0.05494

Execution time: 523.4 sec
Number of iterations: 101
```

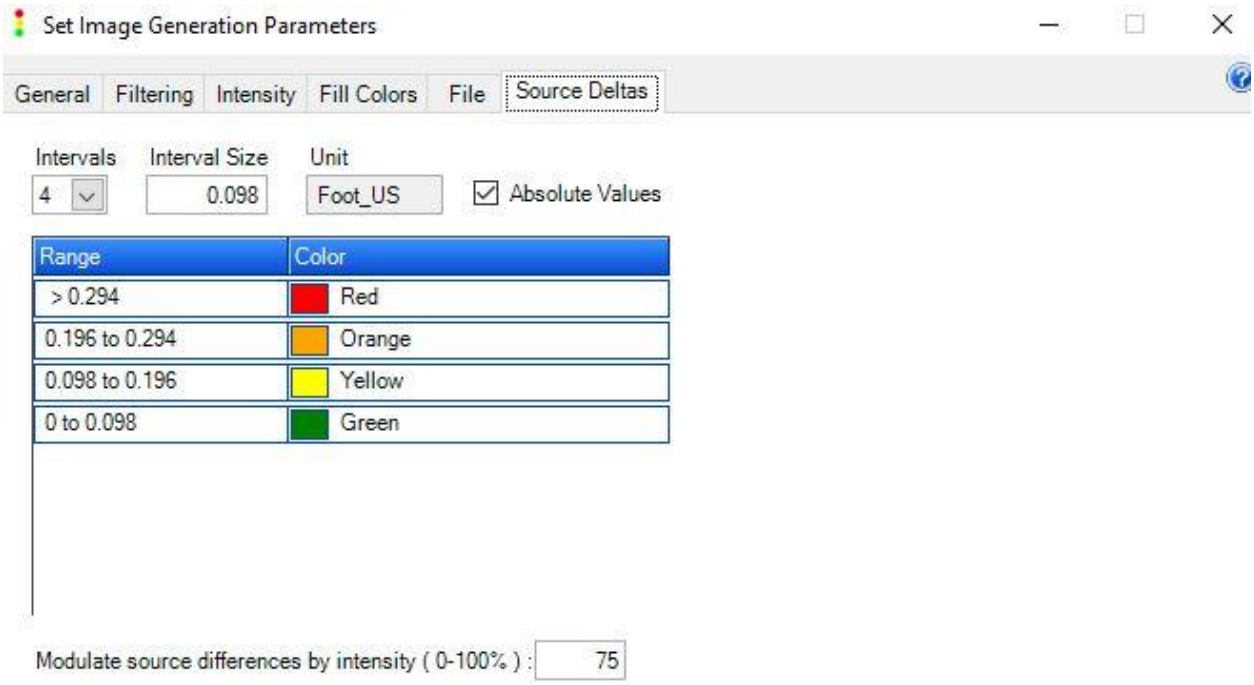
Flightline	E shift	N shift	Z shift	H shift	R shift	P shift	Scale
100	-0.117	+0.034	+0.006	-0.0025	+0.0014	+0.0015	-0.00006
101	+0.067	-0.013	-0.019	-0.0011	-0.0026	-0.0004	-0.00003
102	-0.036	-0.089	-0.031	+0.0011	+0.0032	+0.0014	-0.00002
103	+0.044	+0.046	+0.001	-0.0009	-0.0023	-0.0009	+0.00002
104	-0.057	+0.115	+0.050	+0.0006	+0.0016	+0.0011	+0.00005
106	+0.055	+0.149	-0.018	-0.0019	-0.0002	-0.0009	-0.00005
107	+0.003	+0.054	-0.002	+0.0003	+0.0019	+0.0006	-0.00003
108	+0.034	+0.076	-0.034	-0.0013	-0.0013	-0.0015	-0.00002
109	-0.050	+0.027	+0.023	+0.0026	+0.0018	+0.0008	+0.00000
111	+0.037	+0.249	-0.109	-0.0011	+0.0035	+0.0017	-0.00005
112	-0.020	+0.030	-0.033	-0.0026	+0.0017	+0.0015	-0.00004
113	-0.019	+0.001	-0.031	-0.0002	-0.0018	+0.0007	-0.00003
114	+0.020	-0.045	+0.008	+0.0009	+0.0037	+0.0007	+0.00002
115	+0.016	+0.039	-0.010	-0.0008	-0.0026	+0.0002	+0.00001
116	+0.012	+0.055	-0.039	+0.0011	+0.0007	+0.0017	+0.00003
117	+0.014	+0.031	-0.015	-0.0008	-0.0023	+0.0007	-0.00000
118	-0.039	-0.049	+0.008	+0.0023	+0.0015	+0.0018	-0.00001
119	+0.020	-0.003	-0.034	+0.0004	-0.0030	+0.0002	+0.00001

Third and final set of corrections (Applied on a per flightline basis):

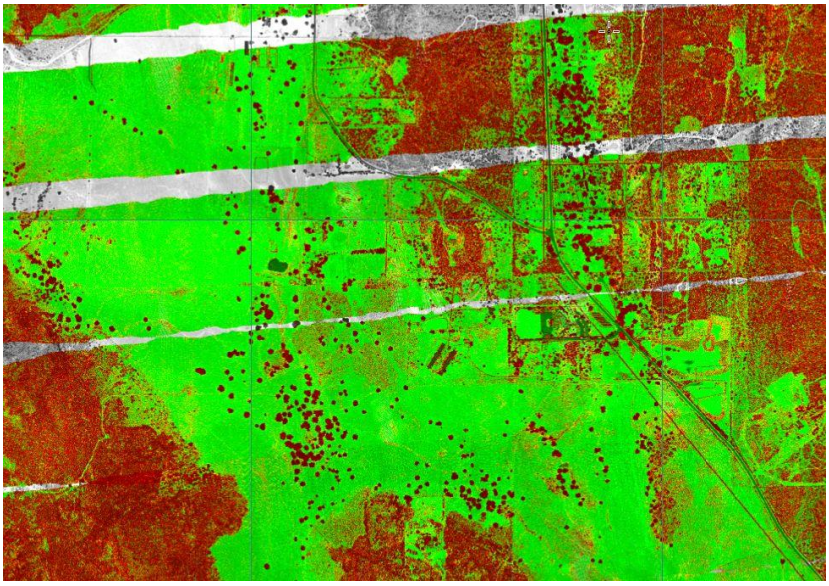
```
Used loaded tie lines
Trajectories: P:\Projects\26965_FEMA_STARR_San_Diego\Lidar\TMatch\Trajectory\
Solve xy: No
Solve z: Yes
Solve h: No
Solve r: No
Solve p: No

Starting avg 3d mismat  0.0548
Final avg 3d mismatch:  0.0481

Execution time: 356.7 sec
Number of iterations: 20
```

These values are all expressed in US Ft. So the starting error was 0.18713ft or 5.7cm. After all corrections are made the final error was 0.0481ft or 1.4cm. It is important to note that these measurements are made from the tielines used to identify errors that need to be corrected for. In order to validate the relative accuracy of the entire dataset Quantum Spatial uses DZ orthos to visualize the offset between flightlines.

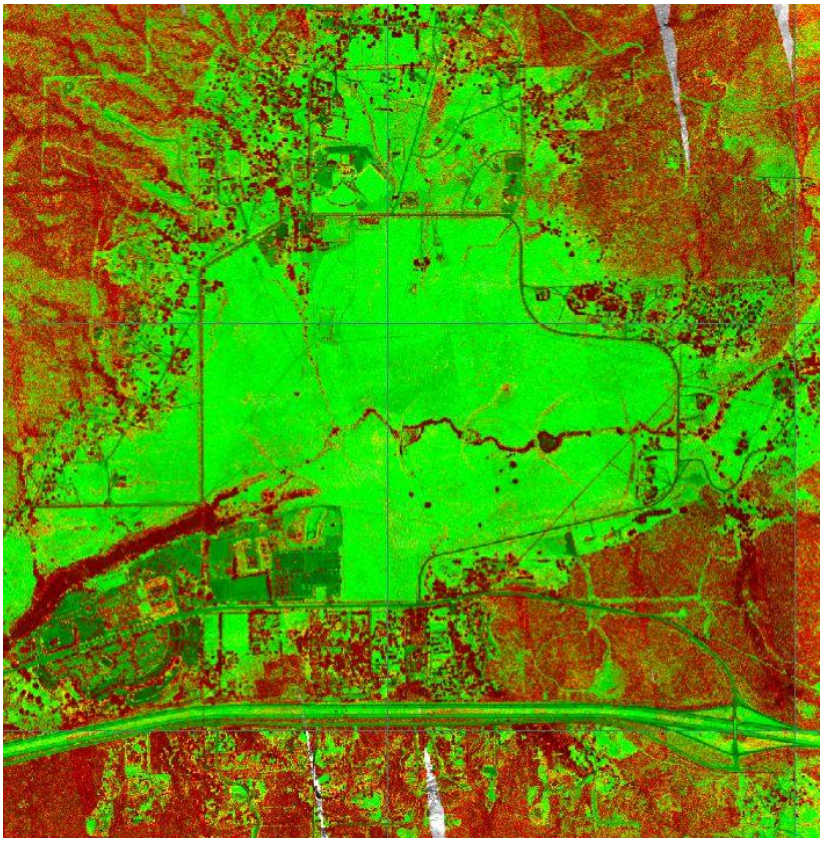
Dz Orthos provide us with a quick visual representation of flightline offset by taking standard intensity images and using parameters set by the analyst to color the difference in flightline by the magnitude of offset that exists. For a QL2 LiDAR project with working units in US Feet the color intervals are set as such:

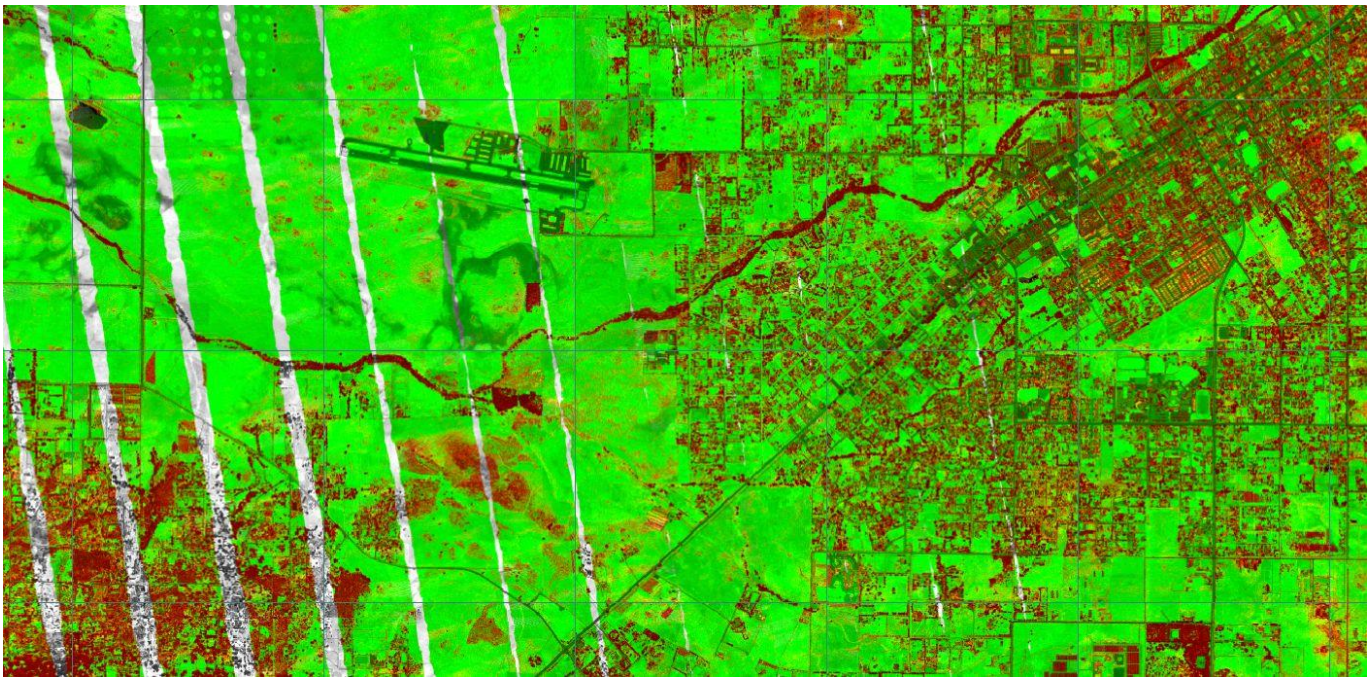


Creating the DZ Orthos with these color ranges allows us to quickly see any areas that would not meet the USGS LiDAR Base Specifications v1.2 swath overlap difference requirements for QL2 data of ≤8cm, because the areas would be colored in red.



In this image the areas of overlap are all within the spec for swath overlap relative accuracy. The areas of red are vegetation points. This testing is done against the full unclassified point cloud. Below are 2 more examples.





These tools allow Quantum Spatial to validate the relative accuracy of the dataset prior to moving forward with data classification and product generation.