Developing a program for using UAVs in undergraduate Geosciences program at Hamilton College: The Nuts & Bolts

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Abstract

Twelve plus years ago, in response to the growth of GIS in the geosciences, Hamilton Geosciences began to integrate GIS projects into our core classes, and the program has grown to the point where not only is GIS integrated into most of our core classes, we also offer a semester-long GIS for Geoscientists course. With the growth of UAV technology it seems like déjà vu all over again.

Unmanned Aerial Vehicles (UAVs) offer new ways to collect imagery and other data sets to enhance geological research and, like GIS, is technology that we should be offering our students access to and training with both the hardware and Structure from Motion (SfM) software. With this goal in mind, Hamilton Geosciences is developing Standard Operating Procedures for using UAVs for both classwork and senior project data collection that are in accordance with FAA Part 107 and Hamilton College's developing campus-wide UAV policy.

We have begun by collecting imagery and derived products of stream channel morphology for sections of the local Oriskany Creek, which is prone to high water events and flooding particularly due to entrainment and damming by woody debris. New York State flew one-foot, 4 band orthoimagery in April 2017. These data were collected before a major July flooding event and provides a perfect "before" set of images. Data collected with a Phantom 4 Pro in early December of two sections of Oriskany Creek provide high resolution "after" images. UAV images incorporate ground control points (GCPs) with associated coordinates to allow precise georeferencing of the imagery to the April NYS imagery. Orthoimagery shows dramatic changes in channel morphology in the two flown sections of the creek with marked erosion, deposition of point bar deposits and movement of large uprooted trees and associated debris. In the derived DSMs, terrace features that developed during high water flow are visible as well.

With the goal of expanding UAV use within the Geosciences Department, this initial work has put us on the right track. We are developing our program in full compliance with Part 107 rules, a well thought-out set of SOPs, and support from the local Highway Superintendent, Physical Plant Director of Grounds, and the College Administration.

This is really a progress report on where we stand 6 months into development of our UAS program.

Collecting data for your research is considered a commercial operation and requires an FAA certified Pilot in Command to be operating the UAV or supervising a designated operator.

What does CFR Part 107 entail ?

14 CFR Part 107 certification

Remote pilot Part 107 certification consists of:

- 16 years of age or older
- passing a 60 question multiple choice FAA exam at an authorized testing center, $150.00 test fee
- passing a TSA security background check
- if your have a Part 61 pilot certificate (other than student pilot) and a flight review within the past 24 months, you can apply for Part 107 certification online

- there is not a "flight test" associated with certification

- FAA exam focuses mainly on reading sectional charts, reading aviation weather reports, airspace classification, a bit of flight physics and the Part 107 rules

- multiple study guides are available online both from the FAA and commercial vendors

- Drone Pilot Ground School (www.dronepilotgroundschool.com/) online course was excellent and covered, in great detail, all material needed to pass the exam

Some Part 107 operational rules

- UAV must weigh less than 55 lbs (25 kg)
- maintain visual line of sight (VLOS) of UAV either by Pilot in Command (PIC) or Visual Observer (VO) without binoculars
- UAV may not operate over any persons not directly participating in the operation, who are not under a covered structure, or who are not inside a covered, stationary vehicle
- daylight operations only, 30 minutes before sunrise and 30 minutes after sunset (local time) allowed with anti-collision lighting on UAV
- yield right-of-way to manned aircraft
- maximum ground speed 100 mph (87 knots)
- maximum altitude 400 feet above ground level (AGL)
- can fly up to 400 feet above highest point of structure within 400 feet of the structure, up to floor of Class E air space
- minimum visibility 3 miles from control station
- must fly 500 feet below clouds
- no flights in controlled airspace without FAA waiver
- flight distance from airports depends on airport airspace classification.
- remote Pilot in Command or Visual Observer cannot act for more than one UAV at a time
- operation from moving vehicle only allowed over sparsely populated area

Equipment

Hardware

- DJI Phantom 3 standard — *FAA registered*
- DJI Phantom 4 Pro — *FAA registered*
- Go Professional Cases custom fitted for each DJI UAV
- Firehouse Technology 4X LED strobe lights
- Hoodman 5 foot folding landing pad
- Icom IC-A14 air band radio
- FLT Geosystems 48" x 48" aerial targets
- MicroAerial safety vests

Software

- DJI Go 4 app
- Map Pilot Pro app
- Agisoft PhotoScan Pro ($549 educational pricing)
- Cloud Compare

Stuff we already had

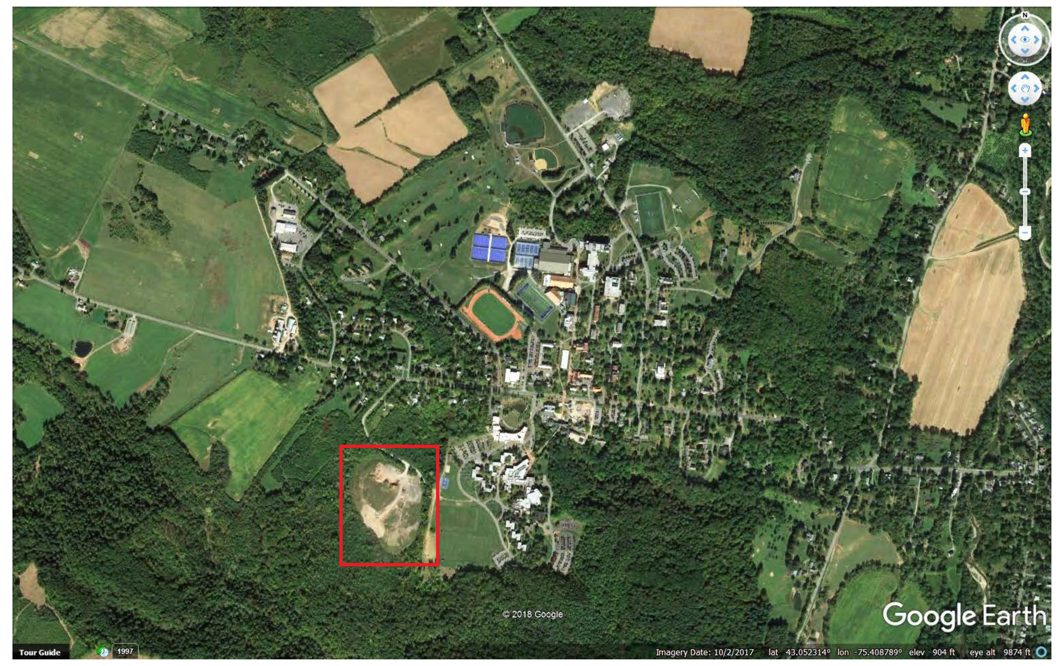
- Trimble Geo7X GPS
- Trimble Tornado antenna and range pole
- Trimble R1 bluetooth antenna
- Trimble GNSS app
- Trimble Pathfinder Office software
- ArcGIS
- Global Mapper
- PC desktop and laptop computers
- Epson large format printer
- iPad and iPhone
- usual field gear

Initial flight testing area

We did inital flight testing at a construction staging area on the west side of campus.

We chose the site because it is wide open, away from campus activities and, because of ongoing construction on campus, the site was constantly changing, with excavated soil being trucked to the site and bulldozers regularly moving and smoothing the piles.

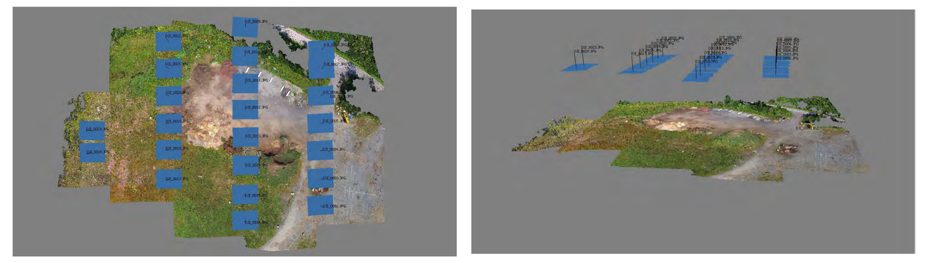
This was a perfect demonstration site, as parts of the site were changing on an almost daily basis, but there were also fixed objects that were not moving and could be used to compare repeatability of flights over the course of multiple weeks.



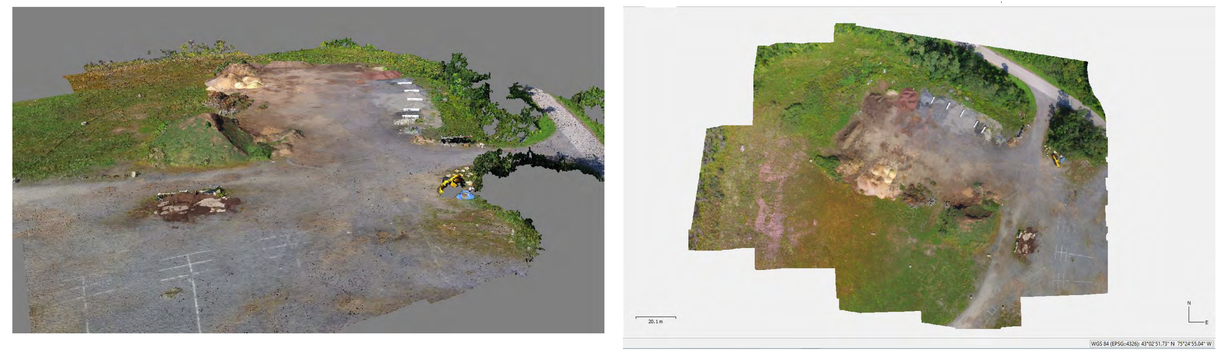
Collecting first imagery with UAV

Map Pilot Pro app flight plan to collect first aerial imagery for mapping with UAV. Orange dots and yellow lines define boundary of map area. Purple dot indicates launch/landing site. Green dot marks start of mapping flight and red dot marks end of mapping flight. White lines indicate flight path.

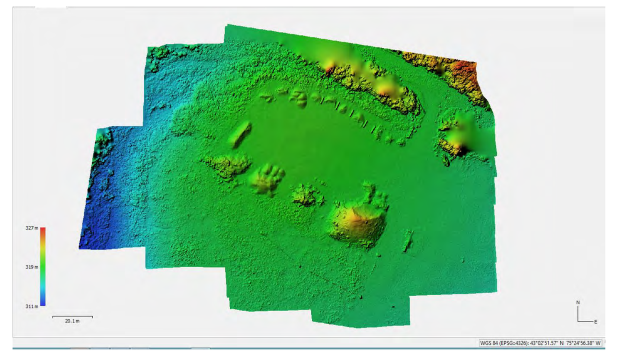
Imagery into Agisoft PhotoScan Structure from Motion (SfM)



GPS data in each image EXIF file is used by Agisoft PhotoScan Structure from Motion software (SfM) to roughly position the cameras in the scene before running point matching algorithm to build 3D point cloud.



Agisoft PhotoScan, SfM dense point cloud (upper left), orthophoto (upper right) and DSM (lower left) constructed from 24 images



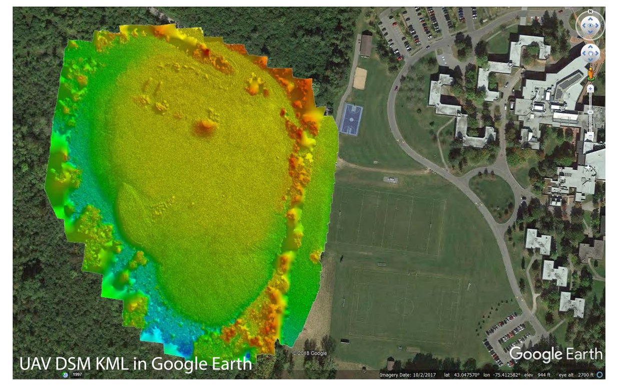
Pretty impressive results with the UAV and software basically straight out of the box

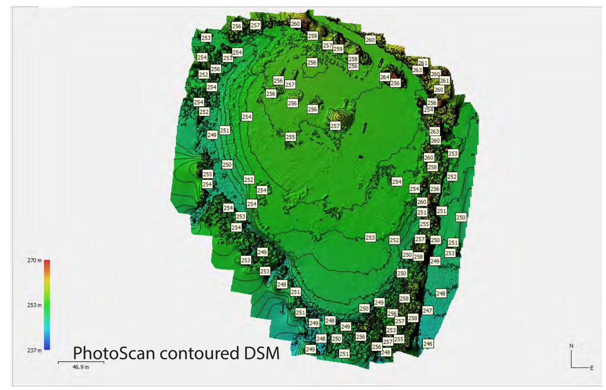
Expanding the flight area and testing additional functions in Agisoft PhotoScan

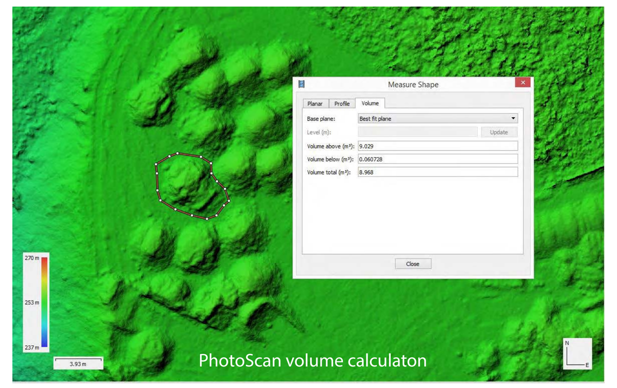
We expanded coverage to over 14. 5 acres, flight time to 19 .5 minutes, 324 images collected, totaling 1.61 GB of data.

We programmed the flight elevation to 42 m above ground level (AGL) for a finished resolution of 1.2 cm/pixel. Using the 10x rule, this suggests that, on the final image, objects 12 cm or larger can be resolved.

Results: orthophoto and DSM exported as KML files and viewed in Google Earth. Agisoft PhotoScan contouring and volume calculations. Note, a commercial dump truck holds 10 -14 yd^3 (7.64 - 10.7 m^3)



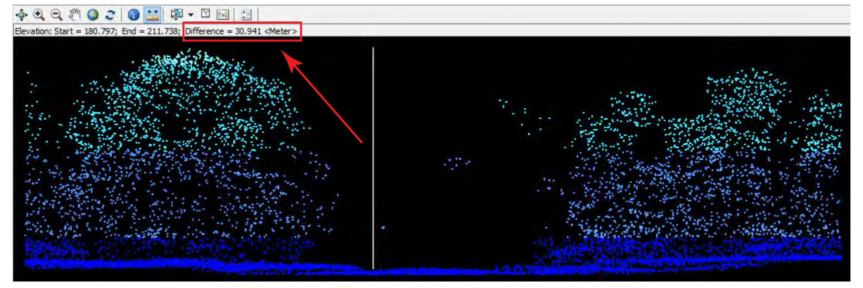




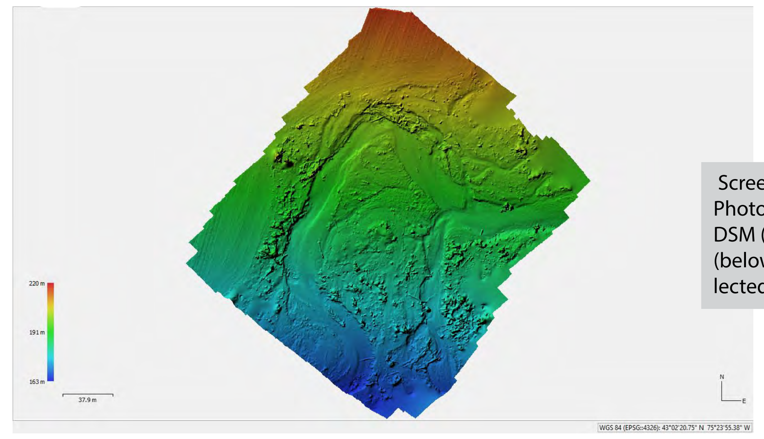
Flights with both the DJI Phantom 3 and Phantom 4 Pro over the course of multiple weeks using the same Map Pilot Pro flight plan resulted in data that, when exported as KML and overlain in Google Earth, showed a 0.5 m or less X, Y offset between data sets.

SfM-created data is NOT lidar. You cannot easily classify the dense point cloud ground points and create a DTM. Note the difference in the contoured DSM between the open area and the surrounding vegetated area.

Moving off campus - Oriskany Creek flight planning



We used 2008 lidar all returns data to get tree heights for the area. Sampled areas showed tree heights in the 31 m range, so we added 10-15 m to flying height (AGL) to avoid clearance issues and still retain good ground resolution.



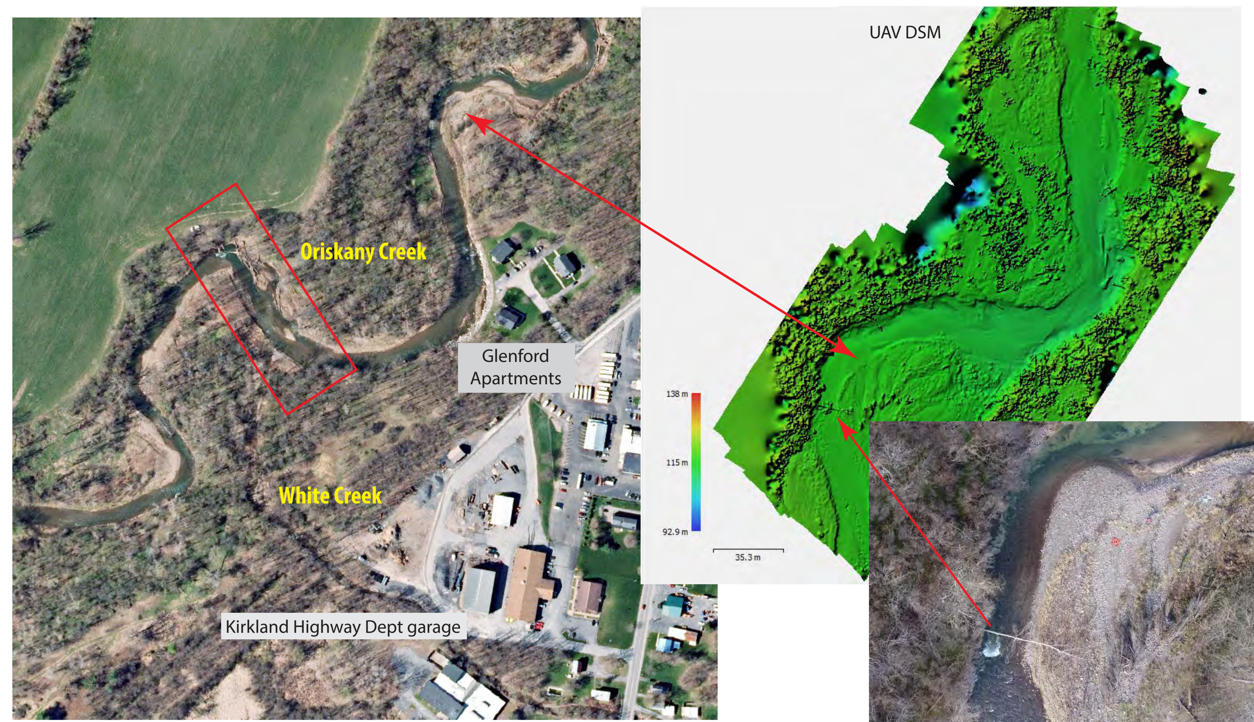
Screen shots of Agisoft PhotoScan Pro-processed DSM (left) and orthophoto (below) from images collected by UAV flight.

Flight path laid out in Map Pilot Pro

Green dot (arrow, lower left) is start point and red dot (arrow, upper left) is end point. Purple dot is launch site. Once UAV is set up and flight controls tested, flight path is uploaded to UAV and autonomous flight follows defined path. At end of flight, UAV returns to launch point for landing.

Alison headed out to observation point prior to flight

Oriskany Creek before and after flooding events

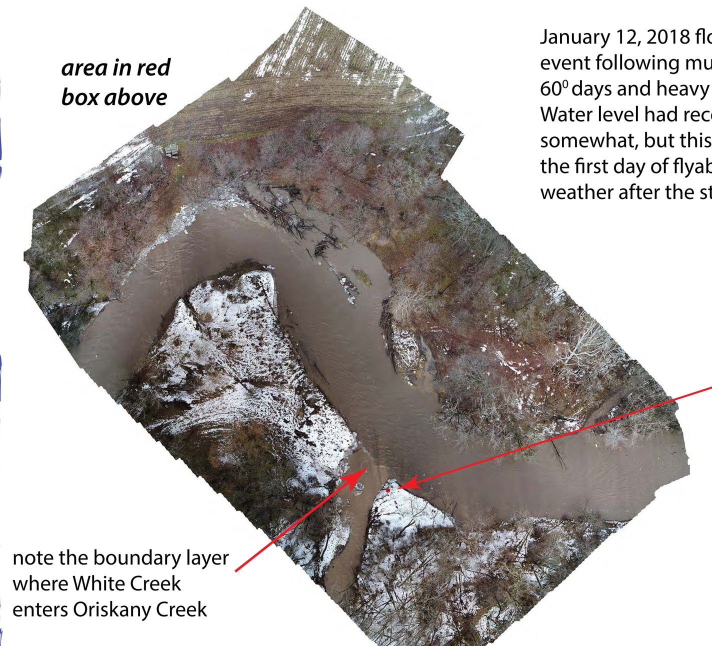


2017 4 band NYS orthophoto collected April 2017 prior to July flooding event, pixel size: 1 ft ground sample distance (GSD)

Flight on 11/30/17 over a point bar complex downstream from the Glenford Apartment complex.

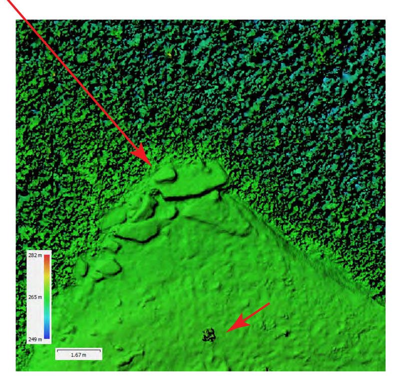
Note the flow channels visible in the DSM and swept vegetation visible in the UAV orthophoto resulting from the July 2017 flooding event.

area in red box above

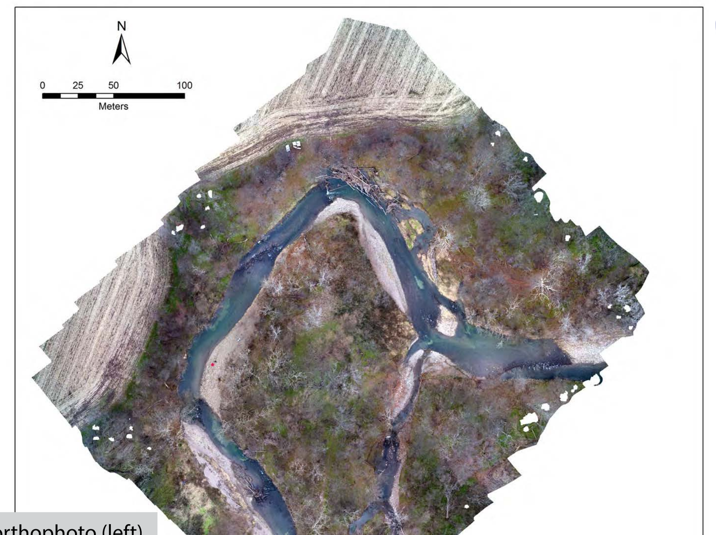


note the boundary layer where White Creek enters Oriskany Creek

January 12, 2018 flood event following multiple 60° days and heavy rain. Water level had receeded somewhat, but this was the first day of flyable weather after the storm.



Rafted ice blocks visible in DSM. Turbulent, fast flowing water results in noisy texture in the DSM. Arrow points to me as rendered in the DSM.



April 2017 NYS orthophoto (left) November 2017 UAV-derived orthophoto (right). Note the dramatic changes in point bar distribution and channel morphology resulting from the July 2017 major flooding event impacting both Oriskany and White Creeks.

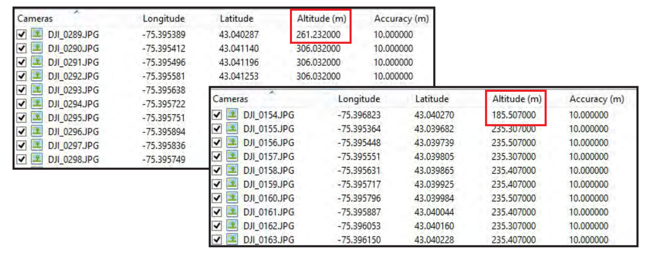
Improving spatial positioning of SfM orthophotos and DSMs with Ground Control Points (GCPs)

Orthophotos and DSMs generated from Phantom 3 & 4 imagery with SfM software appear correctly spatially located until viewed in detail. Multiple flights over the same area using the same autonomous flight path data show offsets of 0.5 to 1 m when fixed objects are compared. This is fine if the goal is simply visual comparison of datasets. Note the new dump truck loads of dirt in the 9/23 image (arrow).

Image (far right) shows semi-transparent 9/23 orthoimge overlain on 9/17 ortho image. Measured offset of fixed large concrete block between the two images is 0.54 m in a NE direction.

If the goal is to overlay data sets and do change detection, spatial positioning with 0.25-1.0 m offset is far from adequate. But the X & Y offset is actually minor in comparison to the Z offset that can be present between similar datasets.

X & Y positions for the camera are tagged in the image EXIF file from the GNSS chip in the UAV, but Z is calculated from the takeoff atmospheric pressure. A flight on one day had a calculated Z value of 261.232 m above mean sea level (MSL) for the launch point elevation. A flight on a different day covering the same area and launched from the same point had a Z value of 185.507 m MSL. Although the UAV was still flying 45-50 m AGL in both cases, the resulting orthophotos and DSMs have base elevations differing by 75.725 m.



Cameras	Longitude	Latitude	Altitude (m)	Accuracy (m)
DJI_0154.JPG	-75.396823	43.040270	185.507000	10.000000
DJI_0155.JPG	-75.395364	43.039682	235.307000	10.000000
DJI_0156.JPG	-75.395448	43.039739	235.507000	10.000000
DJI_0157.JPG	-75.395551	43.039805	235.307000	10.000000
DJI_0158.JPG	-75.395631	43.039865	235.407000	10.000000
DJI_0159.JPG	-75.395717	43.039925	235.407000	10.000000
DJI_0160.JPG	-75.395796	43.039984	235.507000	10.000000
DJI_0161.JPG	-75.395887	43.040044	235.407000	10.000000
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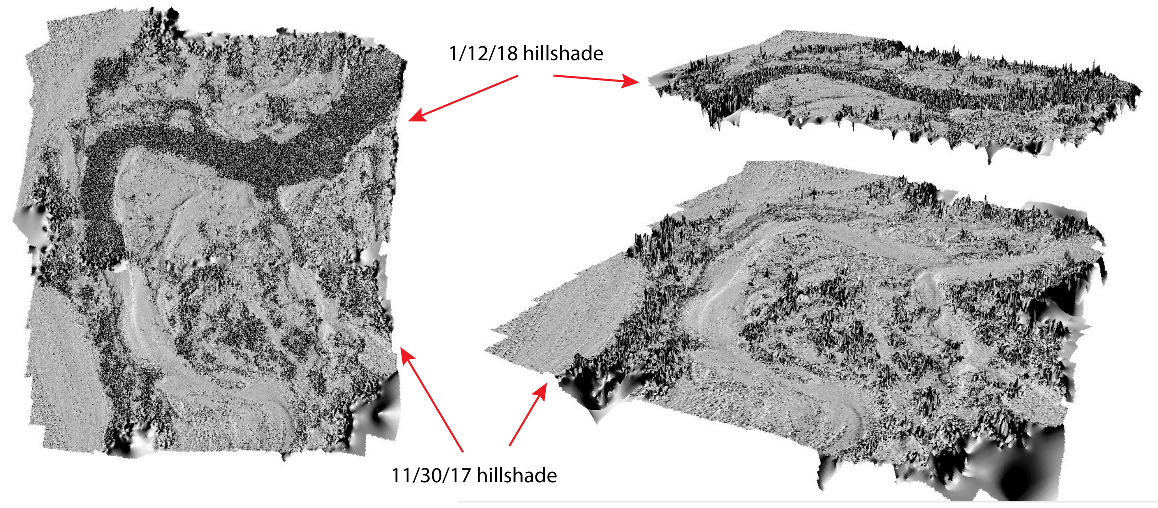


Hillshaded DSMs from two flights, one on 11/30/17 and a second on 1/12/18 during a flooding event, viewed in ArcScene shows the issue clearly. In map view, the two surfaces align quite well; however, viewed in perspective, the surface created from the 1/12/18 flight data is displaced vertically above the 11/30/17 surface.

An interesting math exercise:

Difference in calculated elevation of the launch points is: 261.232 m - 185.507m = 75.725 m

Barometric pressure data from a weather station approx 15 miles away on the date and time of each flight:

11/30/17 - 30.02 "Hg, 1/12/18 - 29.74 "Hg

30.02 - 29.74 = 0.28 "Hg

A 1 inHg change is equal to a change of 1000 feet so,

0.28 "Hg * 1000 = 280 ft or 85.344 m.

Ground Control Points (GCPs) are the key to good spatial control, but the accuracy of GCP location measurements governs just how useful they are

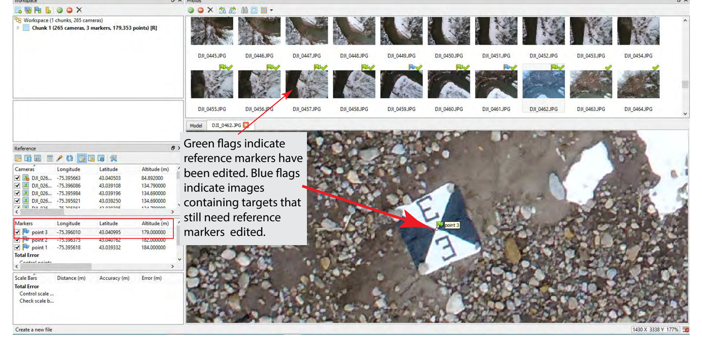
Quality location measurement (X, Y, Z) of the target center point is critical for achieving the best possible spatial positioning of the generated DSM and orthophoto. At a UNAVCO workshop I attended last fall, we were flying a $1500 Phantom 4 Pro and measuring GCPs with around $20,000 worth of differential GPS equipment. A current senior project at Hamilton involves testing the accuracy and repeatability of GPS measurements using a variety of different GPS receivers and antennas that we have.

GPS Z values are calculated from the XY location to derive a height above the ellipsoid (HAE) value for the land surface at that point. A calculation within the GPS unit subtracts the HAE value from a geoid height at that location to produce the land surface elevation (MSL). The precision of Z is dependent on the accuracy of the XY position and the quality of the geoid model used for the calculation, the default geoid used in Trimble units is the DMA10x10 (elevation averaged over a 10' by 10' area). For higher quality Z, higher resolution geoid models for a local area can be installed.

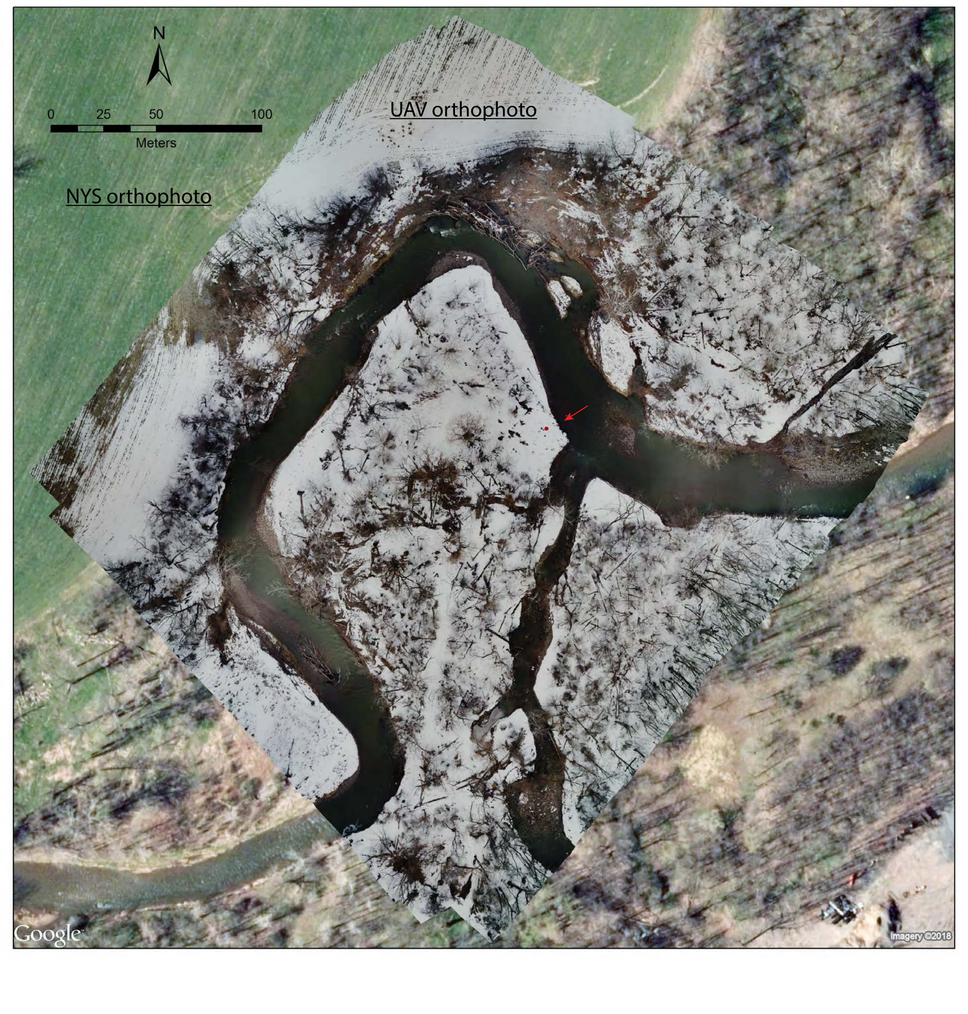
The Trimble R1 Bluetooth antenna outputs Z value as HAE, not elevation (MSL) and requires calculation of elevation as an additional step. UNAVCO has an on-line calculator to calculate elevation from HAE for a given XY location using the EMG96 geoid. (www.unavco.org/software/geodetic-utilities/geoid-height-calculator/geoid-height-calculator.html)

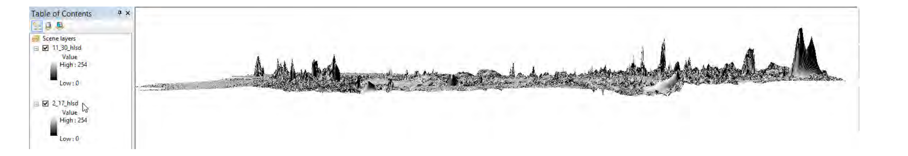
Placement of Ground Control Points (GCPs)

- 4' by 4' numbered aerial targets are evenly distributed throughout the survey area
- Care must be taken to place them where they can be seen by the UAV's camera on multiple passes
- Trees, branches, and other obstructions can obscure visibility of tragets when viewed from other than directly overhead
- To be effective, the targets must be visible in multiple images
- Quality X, Y, Z positions must be collected for each target for use in Agisoft PhotoScan to georeference target-containing images

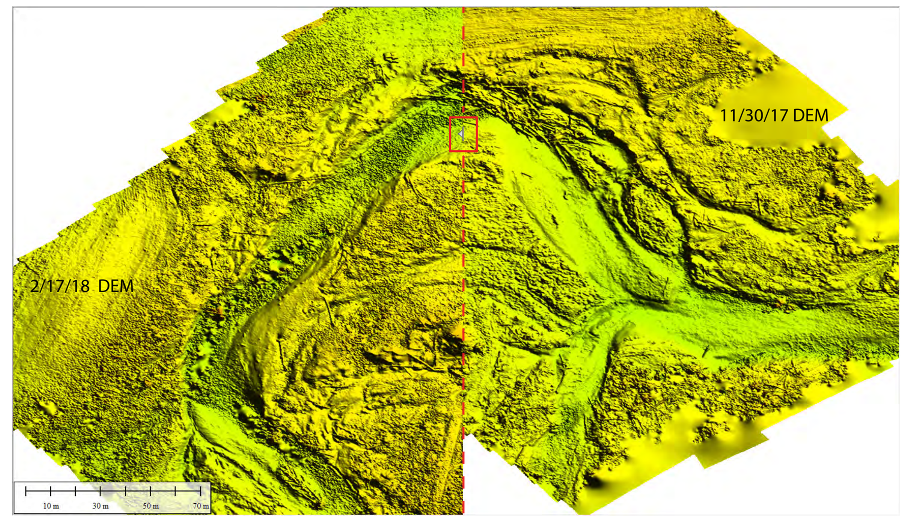


PhotoSoft processed UAV orthophoto from 2/17/18 imagery overlain on April 2017 NYS orthophoto. Note higher water conditions, and much higher resolution in the UAV orthophoto. Orange dot (arrow) is approx 1.5 m fabric launch pad.





Hillshades mapped to corresponding DSM heights from 11/30/17 and 2/17/18 flights viewed edge on in ArcScene. Use of good ground control for both flights resolves the Z issue associated with differing calculated launch elevations when processing images in Agisoft PhotoScan.



The Global Mapper swipe tool can be used to reveal 11/30/17 DSM below 2/17/18 DSM. Images have good registration between the two data sets from use of GCPs with both flights. 11/30/17 flight had low water conditions and no snow on the ground. 2/17/18 had high and rough water conditions with about 6" of snow on the ground.