Droning-On at NMSU: Exploring Geologic and UAS Workflows

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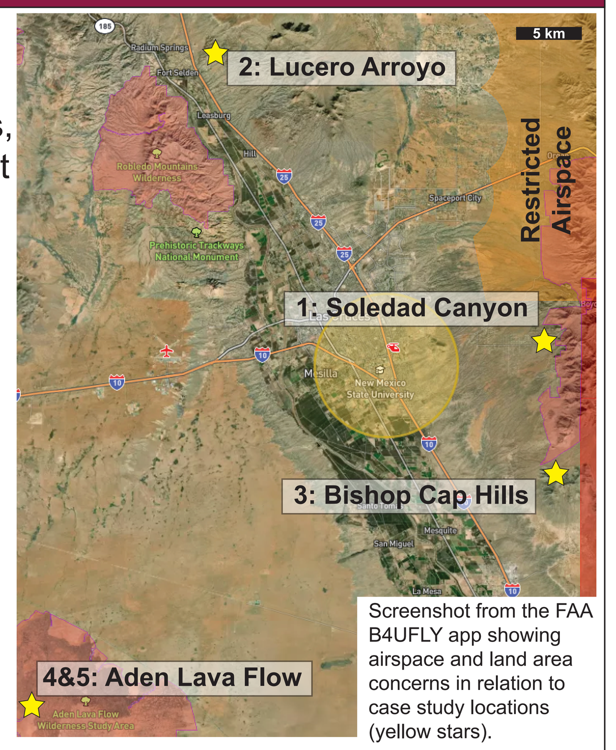
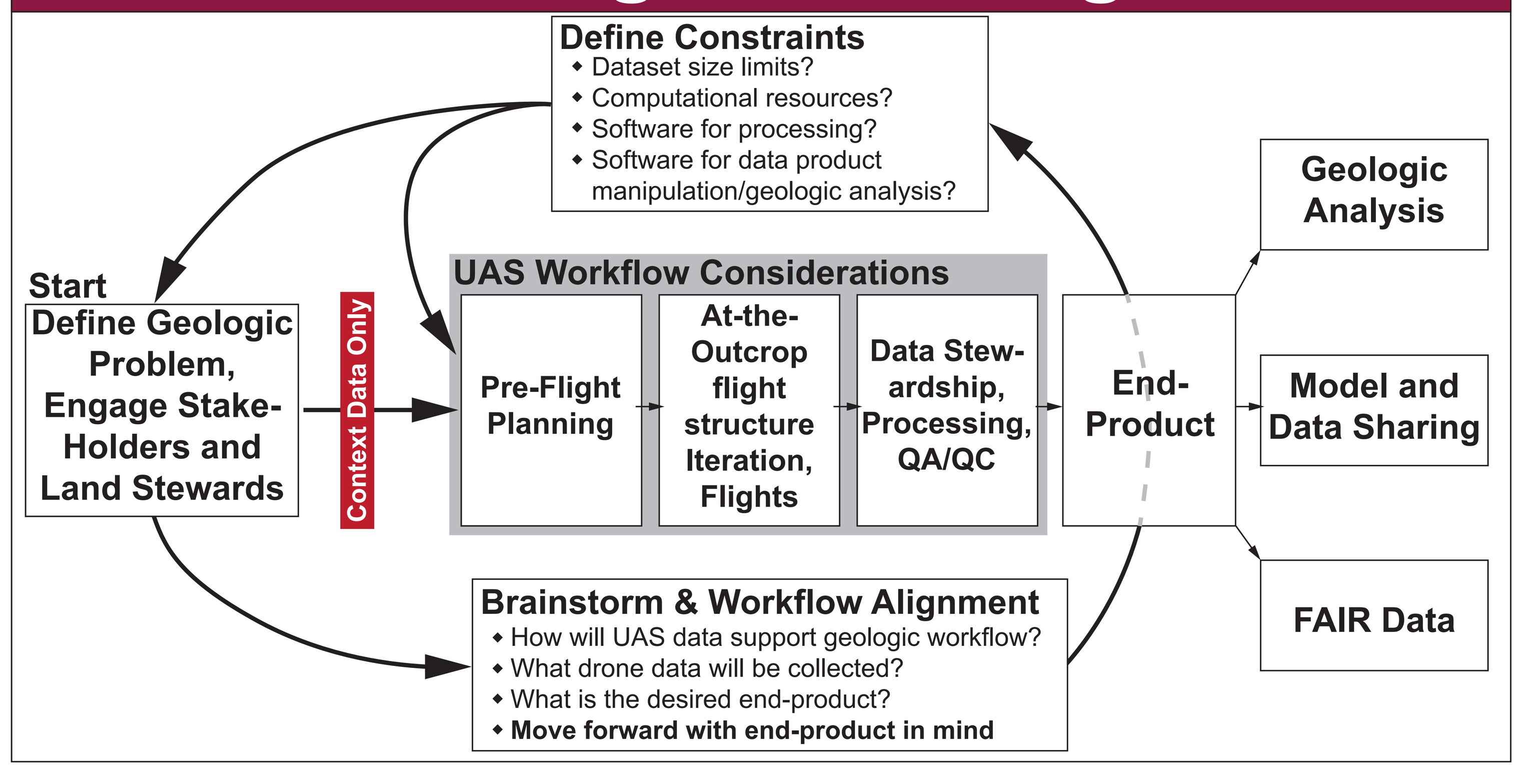
A. Introduction

As part of GEOL- 520 Drones in the Geosciences, graduate seminar course at NMSU, we explored the integration of Uncrewed Aircraft Systems (UAS) in field geology workflows. Through five case studies, we used UAS imagery to build digital products to supplement, not supplant, field observations of geologic features and outcrops near Las Cruces, New Mexico.

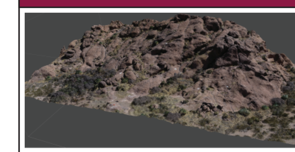


Screenshot from the FAA B4UFLY app showing airspace and land area concerns in relation to case study locations (yellow stars).

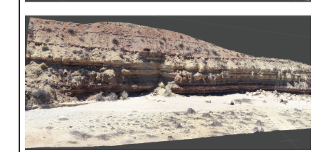
B. Flight Planning



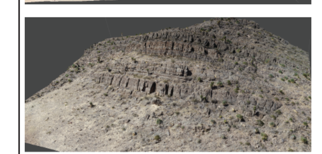
C. Case Study Summary



Case Study #1: Soledad Canyon Area
Purpose: Map orientation of mineralized faults, foliation
Issues: Precise pre-flight planning, determining flight distance



Case Study #2: Lucero Arroyo
Purpose: Document lateral stratigraphic architecture, structures
Issues: Dealing with shadows (north aspect), flight structure



Case Study #3: Bishop Cap Hills
Purpose: Document vertical stratigraphic changes/relationships
Issues: Precise pre-flight planning, determining flight altitudes

Case Study #4: Aden Lava Flow
Purpose: Document lava flow structure and surface texture
Issues: Surrounded by Wilderness study area, flight structure

Case Study #5: Aden Lava Flow
Purpose: Determine camera Ground Sampling Distance (GSD)
Issues: Surrounded by Wilderness study area, sufficient overlap

D. Conclusions

Through the exploration of integrating geologic and UAS workflows, the following primary conclusions can be drawn:

1. To truly *integrate* UAS with geologic workflows, flight planning must be iterative and go beyond simple logistical/regulatory planning
2. Geologic workflows necessarily dictate UAS implementation workflows, driven by resolution requirements, needed data types, and desired end-products, all relative to particular goals:
   a. If mapping workflow- Nadir imagery acquired at the proper altitude to ensure required GSD, with sufficient image overlap
   b. If 3D outcrop modeling workflow- Sufficient imagery at multiple angles and altitudes (normal to outcrop surfaces), collected at sufficient distance to ensure required GSD of features of interest
3. UAS-derived datasets are excellent for collecting additional data (e.g., measured sections, feature orientations, bed thickness or height), but should be ground-truthed due to resolution limitations inherent in the data

Acknowledgements: We would like to thank Prof. Michaela Buenemann for access to the UAS used in this class and flight activities, Jerry Fleming for safety training and support with NMSU flight approvals, and Colin Dunn for assistance with BLM regulations.

Case Study #1

Location: Sierra Vista Trail, off of Soledad Canyon Road

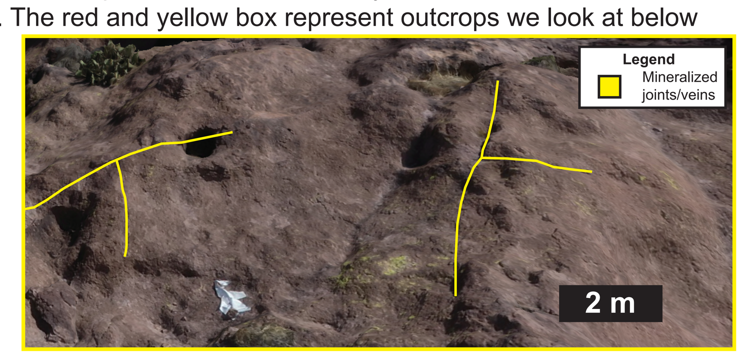
Statement of Purpose: Create a 3D outcrop model generation using UAS imagery for analysis of the structures of outcrops for field studies.

Flight Planning/Considerations: Check the weather, check the airspace regulations for the desired field area, and get approval from NMSU, calibrate the image capture distance to resolve cm-scale structures, calibrate the camera settings to collect optimal images, and finalize flight path.

Results:

Figure 1a: This is a digital outcrop model created to analyze structures on the three outcrops in this case study. The red and yellow box represent outcrops we look at below

Figure 1b: The yellow lines in the photo to the right show the orientations and size of the mineralized joints in the field area.



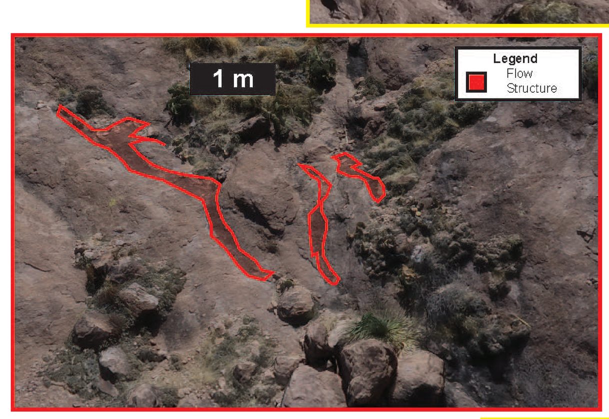
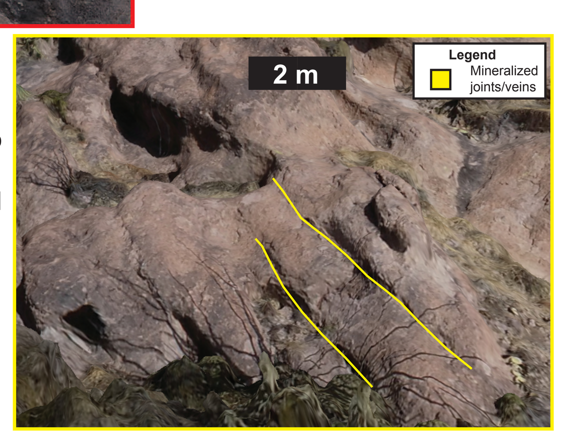


Figure 1c: The red shapes in thephoto to the left capture the morphology of a different flow in this outcrop.

Figure 1d: The yellow lines in the photo to the right show the orientations and size of the mineralized joints in the field area. This outcrop was in an area that was hard to access, so UAS imagery helped gather visuals that otherwise would be an inconvinience to get.



Conclusion: Integrating UAS imagery/modeling to complement field analysis of the morphology of mineralized veins and a flow helps visualize various perspectives of the frequency, orientation, and size of the structures.

Take-Away: UAS image collection can be used to supplement field observations for structural analysis and interpretations but must be based of first-hand observations.

Case Study #2

Location: Lucero Arroyo, New Mexico, USA

Statement of Purpose: Use UAS imagery to construct a 3D outcrop model to analyze lateral stratigraphic architecture

Introduction/Flight Overview: The Permian Abo Formation is a fluvial unit composed of siltstones, shales, sandstones, and packages of carbonates.To image lateral stratigraphic architecture of the Abo Formation in Lucero Arroyo, we used UAS to capture images from a working distance of 10-30 meters. Features of interest include tabular vs. lenticular beds, scour depth, and scale of lateral continuity. We collected nadir and oblique camera angles to resolve vertical features within the outcrop.

Flight Planning/Flight: The field area was in Class G airspace, so the UAS was allowed to fly within a visual line of sight under 400 feet. Before the flight, the weather was clear, with minimal wind. First, the drone was flown directly above the outcrop at a height of 30 meters, taking photos along the length of the formation. Multiple passes were made along the length of the outcrop from increasingly oblique angles and lower altitudes. Finally, the drone flew about 5 meters in front of the outcrop and imaged the formation face-on.

Results:

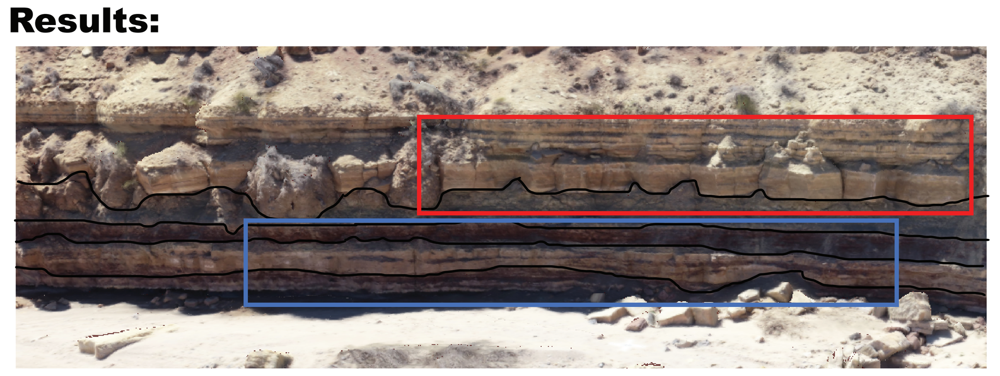


Figure 2a: The Abo Formation in Lucero Arroyo, New Mexico. Individual beds have been outlined in black. The lower beds exhibit a lenticular structure. The blocky bed above represents a tabular structure. The blue box represents the image in Figure 2b, and the red box represents the image in Figure 2c.

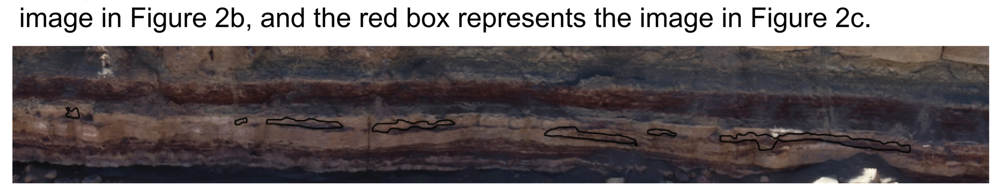


Figure 2b: Small structures within a lenticular bed showing where units are pinched out. This is representative of a fluvial system.

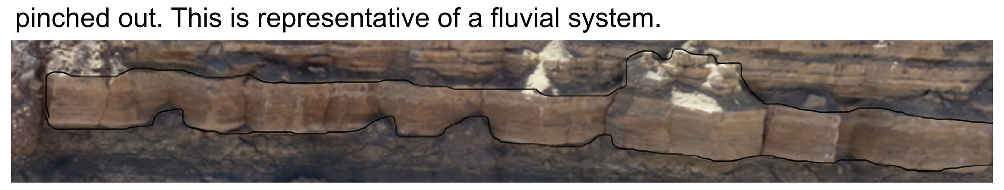


Figure 2c: Tabular sandstone beds above the lenticular beds. The curves in the bed represent places where rocks have fallen out of place.

Conclusions: The 3D model allowed us to see the outcrop clearly from several different angles. With the model, we can measure the length and widths of the beds, lithological changes throughout the section, and describe the scour amplitudes. This dataset can also be preserved for others to use in the future.

Take-Away: UAS imagery, when used appropriately, can be a powerful tool for exploring lateral stratigraphic architecture within units. In this case, UAS integration gave insight into hard-to-reach areas at the middle and top of the outcrop. Others can use this case study as an example to image their own stratigraphic relationships.

Case Study #3

In this case study we built a measured section from field observations and compared it to that of a measured section built from a UAS derived DOM. With this comparison we can begin to understand how well UAS imagery can supplement field-based measurements, and at what scale features can be resolved.

Figure 3a: (A) Broard view of DOM looking West. Red square denoting extent of figure b. (B) DOM with limestone bedding planes outlined. Blue square denoting extent of figure c. (C) Orange square denoting chert nodules resolved in DOM with ~5cm resolution.

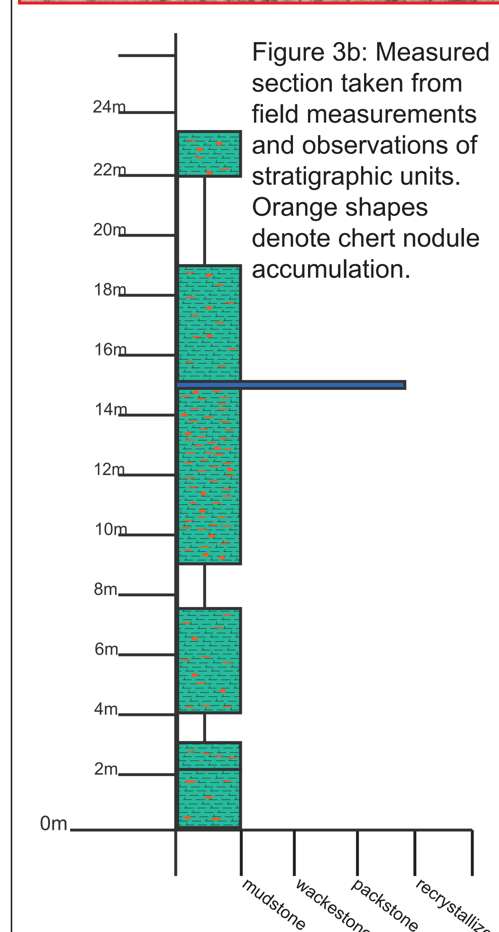


Figure 3b: Measured section taken from field measurements and observations of stratigraphic units. Orange shapes denote chert nodule accumulation.

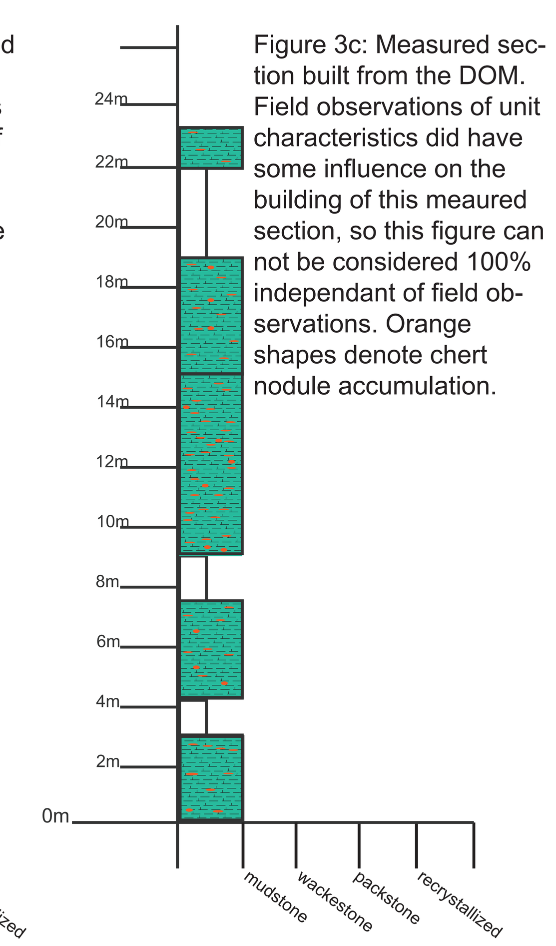


Figure 3c: Measured section built from the DOM. Field observations of unit characteristics did have some influence on the building of this meaured section, so this figure can not be considered 100% independant of field observations. Orange shapes denote chert nodule accumulation.

An UAS provides geologists with the ability to analyze sedimentary features down to a few centimeters in scale, but this does not remove the need for detailed field descriptions of rocks. For preliminary analysis of overall sedimentary packages and basic descriptions, a UAS derived DOM could be immensely useful. This workflow, while intriguing, could be a waste of time and resources, if UAS data is not essential to one's research goals.

Case Study #4

Resolving Lava Flow Morphology Using UAS at Aden Flow Wilderness, NM

Basaltic lava flow morphology is a complex fluid dynamic system. High viscosity liquids respond to temperature, landscapes, surrounding topography, etc. These factors influence lava flow morphology and are recorded as flow fabrics and textures on m to cm scales. In order to examine lava flow morphology on multiple scales, we utilized UAS imagery to construct a 3D outcrop model of one lobe of the Aden Crater Lava Flow. A UAS was used for image collection because the rough terrain and vegetation made it difficult to record flow fabrics and their relationship to surrounding features. To ensure that images were collected on cm scales, a test feature and scale markers were used to select a working height (15 m). Additionally, the flight was conducted with the UAS landing/take off and pilots standing outside the wilderness boundary with the UAS always remaining in visual line of sight. Images were collected by flying a "lawnmower" pattern cross the outcrop with the camera pointing straight down at 90° deg and then the flight was repeated with the camera at 45°. Images were compiled in Agisoft Metashape in order to build a 3D outcrop model (fig 4a).

Figure 4b (above). Large scale flow fabric across different terrain/vegetation is highlighted within this 3-D outcrop model.

Figure 4a (below). Model of one lobe of the Aden Lava Flow

Principal Results

Photographs	394
Model Faces	20,005,000
Resolution	3.23 mm/pixel
Model Area	50 x 150 m 750,000 m^2

Figure 4c. Changes in pahoehoe surface texture boundaries are highlighted in this model allowing for a more nuanced questioning of the factors impacting lava flow morphology (temperatures/viscosity/gas content) on a variety of scales.

This model allows for the exploration of large- (m) and small- (cm) scale flow fabrics across the lava flow (fig. 4b). This resolution shows large-scale flow structures, their relationships to inflation pits and the underlying terrain as well as subtle changes in flow morphology and direction (fig. 4c). The complexity and rugged nature of lava flows/morphology make it an ideal candidate for 3D outcrop modeling and an associated examination of texture changes on varying scales.

Case Study #5

In this case study, imagery of a relatively flat volcanic flow near Aden Cater, NM, was collected at an altitude of 100 meters, 50 meters and 10 meters to examine how to optimize flight planning using Ground Sampling Distance (GSD) to calculate flight elevation.

GSD measures the space between the center of two pixels in an image. If a pilot knows the desired GSD, the equation:

$$GSD=(H*Sw)/(Fr*imW),$$

where H is flight altitude, Sw is sensor width, Fr is real focal length, and imW is image width, can be used to calculate the altitude the UAS should collect imagery to create the necessary quality of data in an efficient manner.

A flight plan was written, an adequately flat area was located, and airspace and weather conditions were verified to be within the UAS operating limits. Using a standard mapping workflow, the UAS flew in a lawnmower-like path, moving up and down a field approximately 100 m by 100 m.

Figure 5a: Map created from 100 meter imagery.

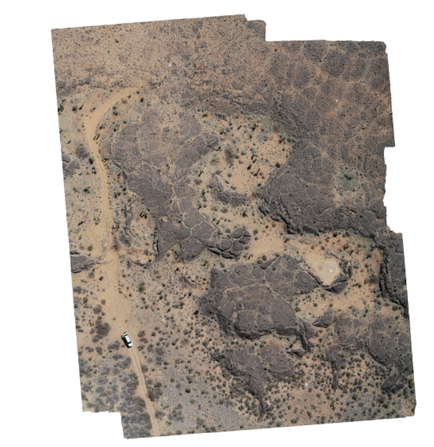


Figure 5b: Map created from 50 meter imagery.

Individual images taken from each flight altitude and each image's data was put into the GSD equation, resulting in GSD of 3.16cm/pixel, 1.58 cm/pixel, 0.32cm/pixel respectively. Two maps were created from 100 and 50 meters, and were processed in ArcGIS to again calculate GSD and how GSD changed in relation to altitude.

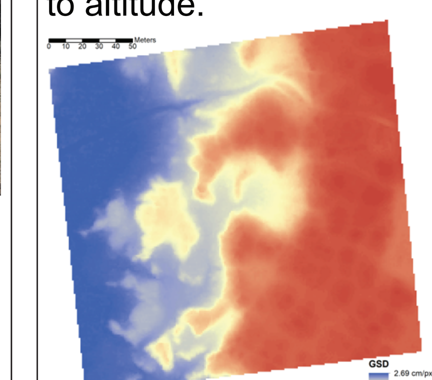


Figure 5c: Map of GSD at 100m as it changes based on terrain elevation

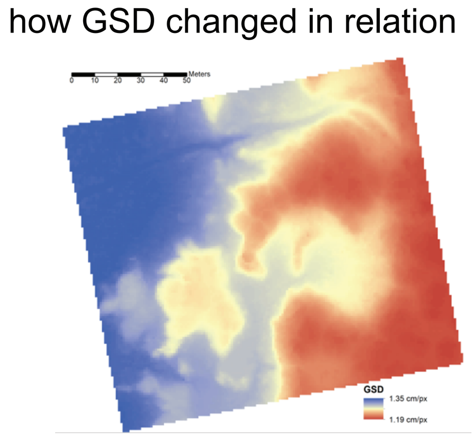


Figure 5d: Map of GSD at 50m as it changes based on terrain elevation

CONCLUSION

Using the GSD equation we can improve the flight planning process and fly more efficiently buy gathering as much data as possible while achieving the desired image resolution. We observed that actual imagery had a higher GSD than expected which allows flexibilty to handle terrain variations of a few degrees.