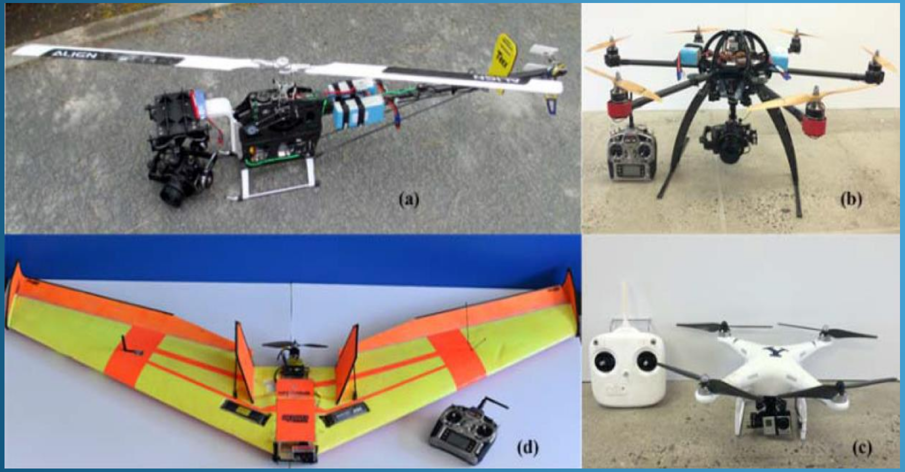
The Use of Small Unmanned Aerial Vehicles for Post-Disaster Geotechnical Reconnaissance



Webinar Given April 20, 2016
by
Kevin Franke, Ph.D., P.E.
Assistant Professor, CEEn
Brigham Young University
and
Dimitrios Zekkos, Ph.D., P.E.
Associate Professor, CEEn
University of Michigan

Webinar Outline

- Welcome
- Types of UAV Platforms
- Types of UAV Sensors
- Current UAV Regulations
- Potential Uses for UAVs
- Case Histories
- Lessons Learned
- Questions/Answers

TYPES OF UAV PLATFORMS

Types of UAV Platforms

- Many, MANY different types of small UAVs commercially available today
- These types can be generalized into three broad classifications:

1. Fixed Wing Platforms

Trimble UX5

Sensefly Ebee

3dr Aero Fixed

Customized Ritewing

Types of UAV Platforms

- Many, MANY different types of small UAVs commercially available today
- These types can be generalized into three broad classifications:

2. Multi-Rotor Platforms

DJI Phantom

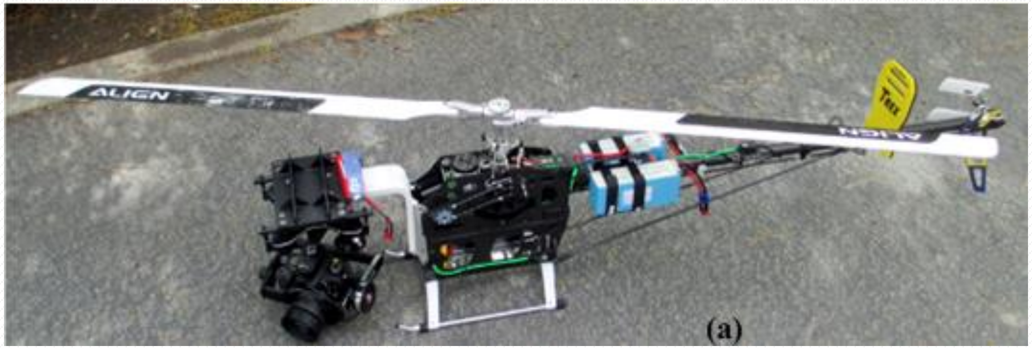
DJI S1000

Sensefly Exom

Types of UAV Platforms

- Many, MANY different types of small UAVs commercially available today
- These types can be generalized into three broad classifications:

3. Single-Rotor Platforms



Customized Align T-Rex 800

Types of UAV Platforms

- Fixed Wing Platforms

Pros: stable in wind, low vibrations, can carry large payload (…if large), typically longer flight endurance

Cons: Harder for amateur to fly, some need landing space, difficulty imaging vertical objects, difficulty navigating in cluttered terrain, can have pixel blur due to higher velocities

- Multi-Rotor Platforms

Pros: most stable flight (in no wind), can carry payloads up to about 7-10 lbs if large, easy to fly if includes stabilization/GPS technology, superior maneuverability, little space needed for takeoff/landing

Cons: unstable in winds >20mph, short (~10-15 min) flight endurance per battery, sometimes susceptible to extreme temps

- Single-Rotor Platforms

Pros: same as multi-rotor platform, but much more stable in windy and extreme temperature environments

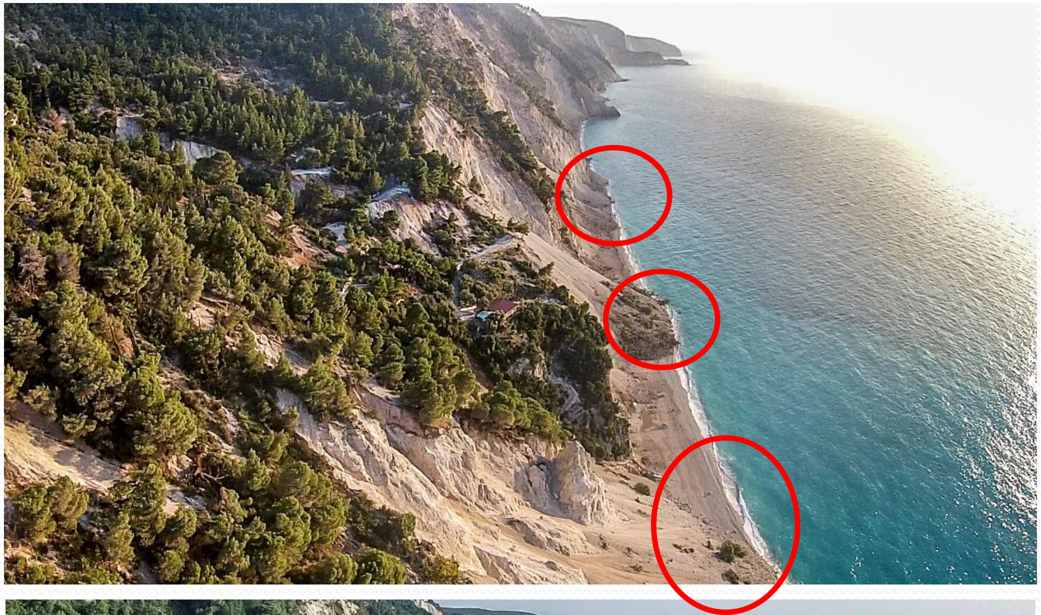
Cons: Generally same as multi-rotors, but more difficult to operate; high vibrations; can pose life-safety hazard

TYPES OF UAV SENSORS

UAV Sensors for Data Acquisition

- Number of sensors used for communication, flight control, and collision avoidance → not discussed today
- For field recon data acquisition, by far the most common are Vision-Based Sensors (e.g., cameras)
- Pictures (>12 MP) or Video(4k UHD video, i.e., higher resolution 3840 x 2160 pixels, better colors, higher video frame rate)
- Digital image processing can generate truly valuable data for geotechnical reconnaissance
- Key considerations for quality imagery data:
  - Weather (sunlight)
  - UAV viewpoint
  - Pixel Density for feature recognition (affected by camera characteristics and distance to target)

Mobility & Accessibility are key advantages of UAV-based imagery!



- November 17th 2015 Mw 6.4 Lefkada earthquake (Greece)

← November 19th 2015 (2 days later)

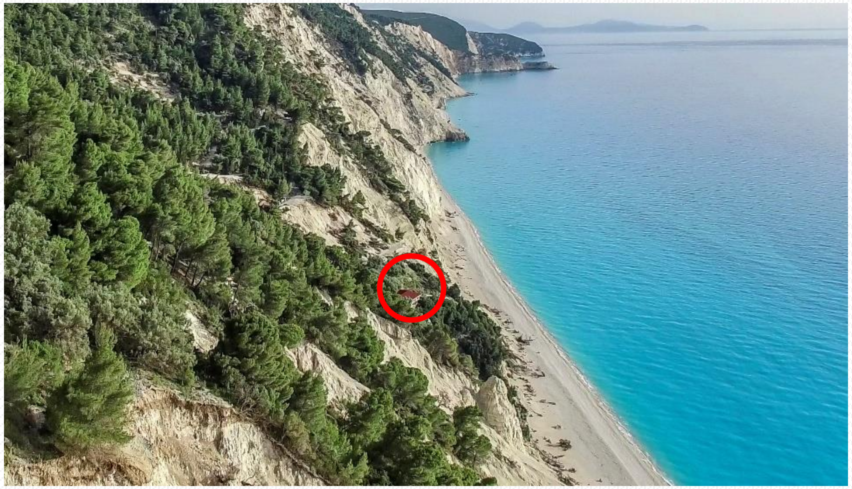
UAVs allow immediate access to field data that may be otherwise inaccessible by land or satellite

← April 12th 2016 (5 months later)

Also **viewpoint** is key advantage of UAV-based imagery!

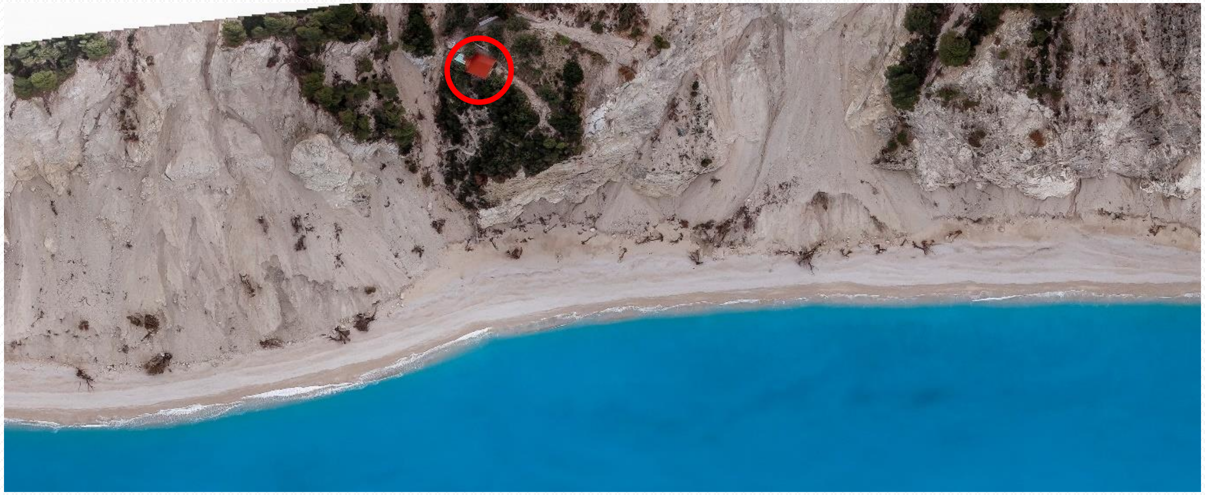
- April 12th 2016 imagery

Dataset developed in collaboration with John Manousakis



Side View

Front View



Plan View

UAV Sensors Beyond Visible Frequencies (RGB)

- LIDAR
- Near-Infrared → Esp. for vegetation
- Thermal
- Infrared

Esp. for inspections, resource management, surveillance, search and rescue

- Multi-Spectral → Combo of e.g., Visible, NIR, IR
- Hyper-Spectral

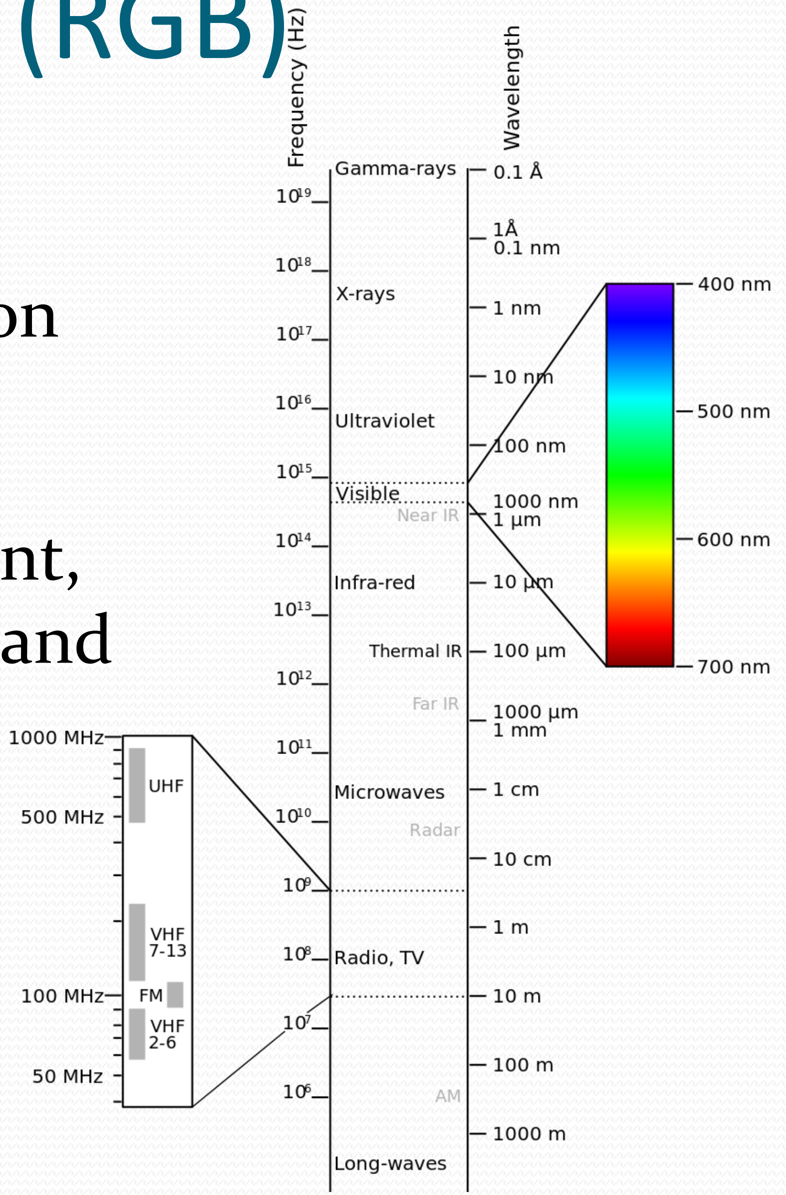


Fig. By Victor Blacus - Wikimedia

CURRENT UAV REGULATIONS

UAV Regulations

- Current Regulations in the U.S.
  - Messy! Can't fly commercially w/out explicit authorization from the FAA (requires at least certificate of authorization, air worthiness certificate, registered UAV, and a fully-licensed pilot)
  - FAA introduced the Section 333 Exemption in 2012 to expedite the certification process and allow commercial operation of small UAVs. To date, over 3,800 exemptions have been granted
  - The Section 333 Exemption petition process has become log-jammed, and can require several months for an application to be processed

UAV Regulations

- Pending Regulation Changes in the U.S.
  - U.S. Congress has mandated that the FAA develop a set of practical rules that will allow the safe commercial operation of UAVs in the U.S.
  - A draft set of regulations has been developed, and is awaiting approval and implementation (…possibly as early as summer 2016) (See the overview here: https://www.faa.gov/regulations_policies/rulemaking/media/021515_sUAS_Summary.pdf)
  - In general, UAVs will need:
    - FAA registration (simple, online, $25-$50 fee)
    - A licensed operator (…licensed by taking an online test)
    - To stay below a max altitude of 500 ft above the ground
    - Stay away from people not involved in the UAV operation, unless a special exemption (based on operator qualifications) is granted
    - Operate only in the daytime and ONLY in Class G airspace

UAV Regulations

- International Regulations
  - Not standardized! Varies from country to country
  - Some countries (e.g., Australia, New Zealand) are quite open and favorable to commercial UAV operation. Others (e.g., India) are not
  - Must be considered on a case-by-case basis. <u>It would be good for GEER to perform some preliminary "homework" regarding the current UAV regulations in various countries where reconnaissance work is frequently performed.</u> If possible, obtain necessary authorizations now before potential extreme events occur

POTENTIAL USES FOR UAV-BASED DATA

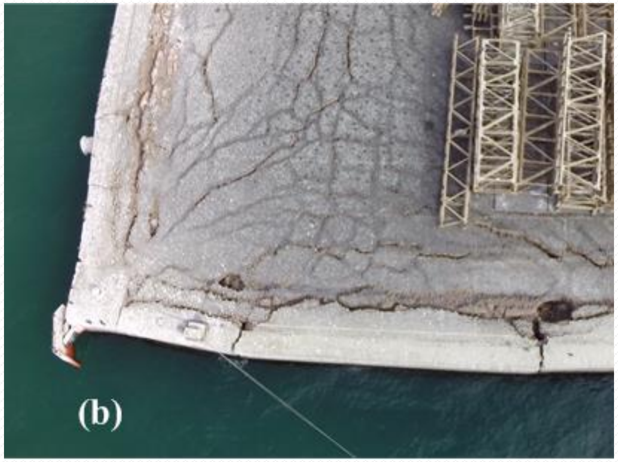
Potential Uses for UAV-based Data

Aerial Imagery and Video

Port of Iquique, Chile – April 2014

From the Ground…

From the Air…

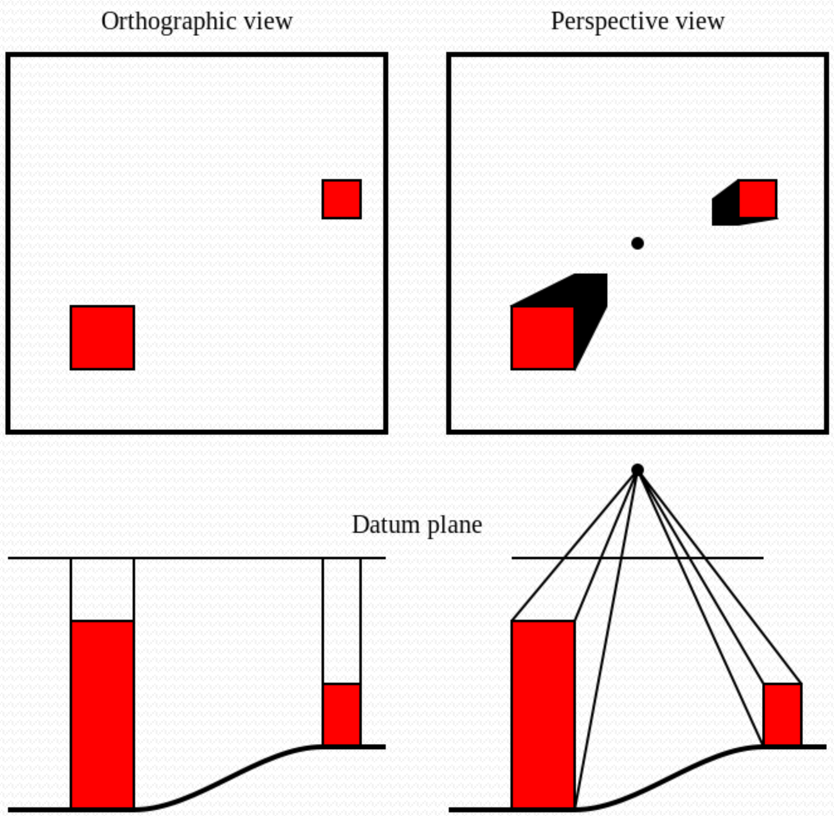


- See the "bigger picture" of the damage
- Avoid many occlusions
- Low altitude flight allows a unique combination of large field of view AND good image resolution

Potential Uses for UAV-based Data

Orthorectified Images and DEMs

What is an orthophoto?

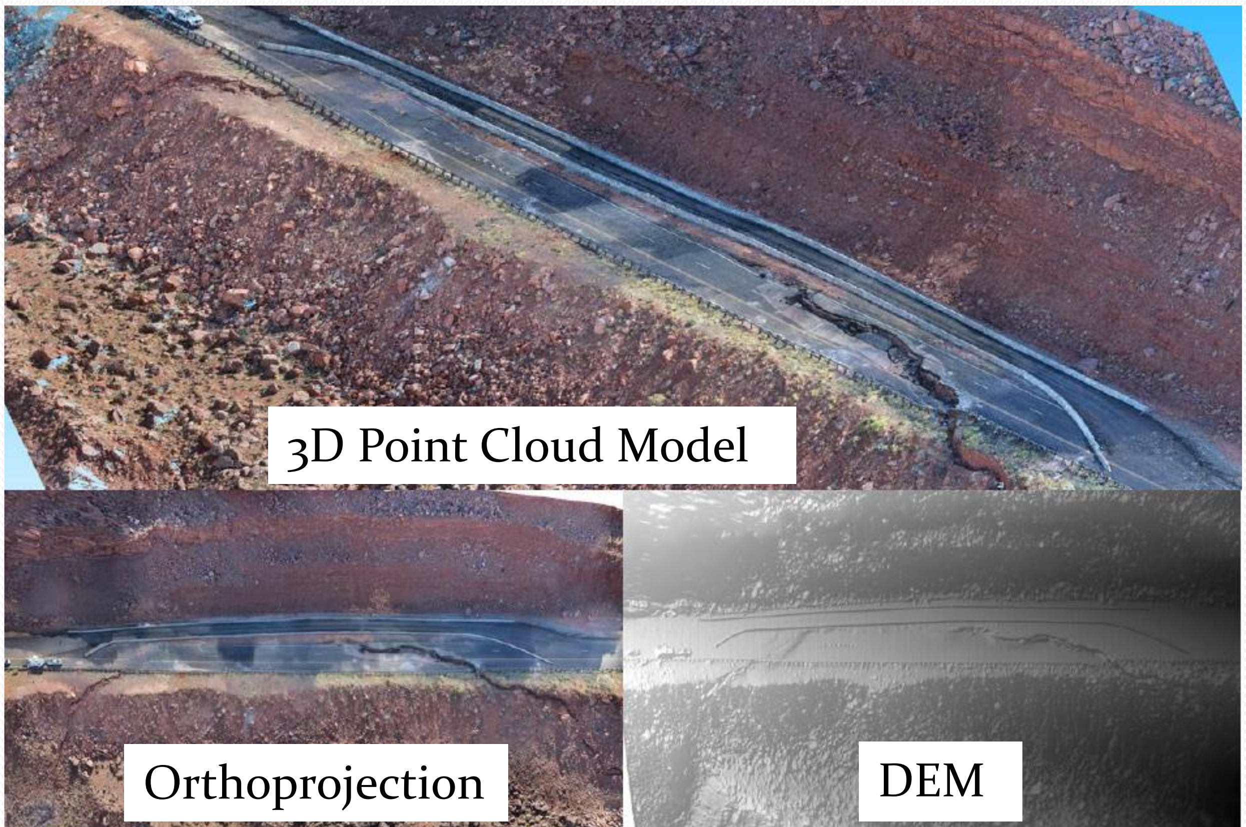


By SVG by User:Pieter Kuiper - Original w:Image:OrthoPerspective.JPG by w:User:Kymstar, which probably was from "GIS fundamentals" by Paul Bolstad., Public Domain, https://commons.wikimedia.org/w/index.php?curid=5252153

Potential Uses for UAV-based Data

Orthorectified Images and DEMs

US Highway 89 Landslide, near Page, AZ – July 2014

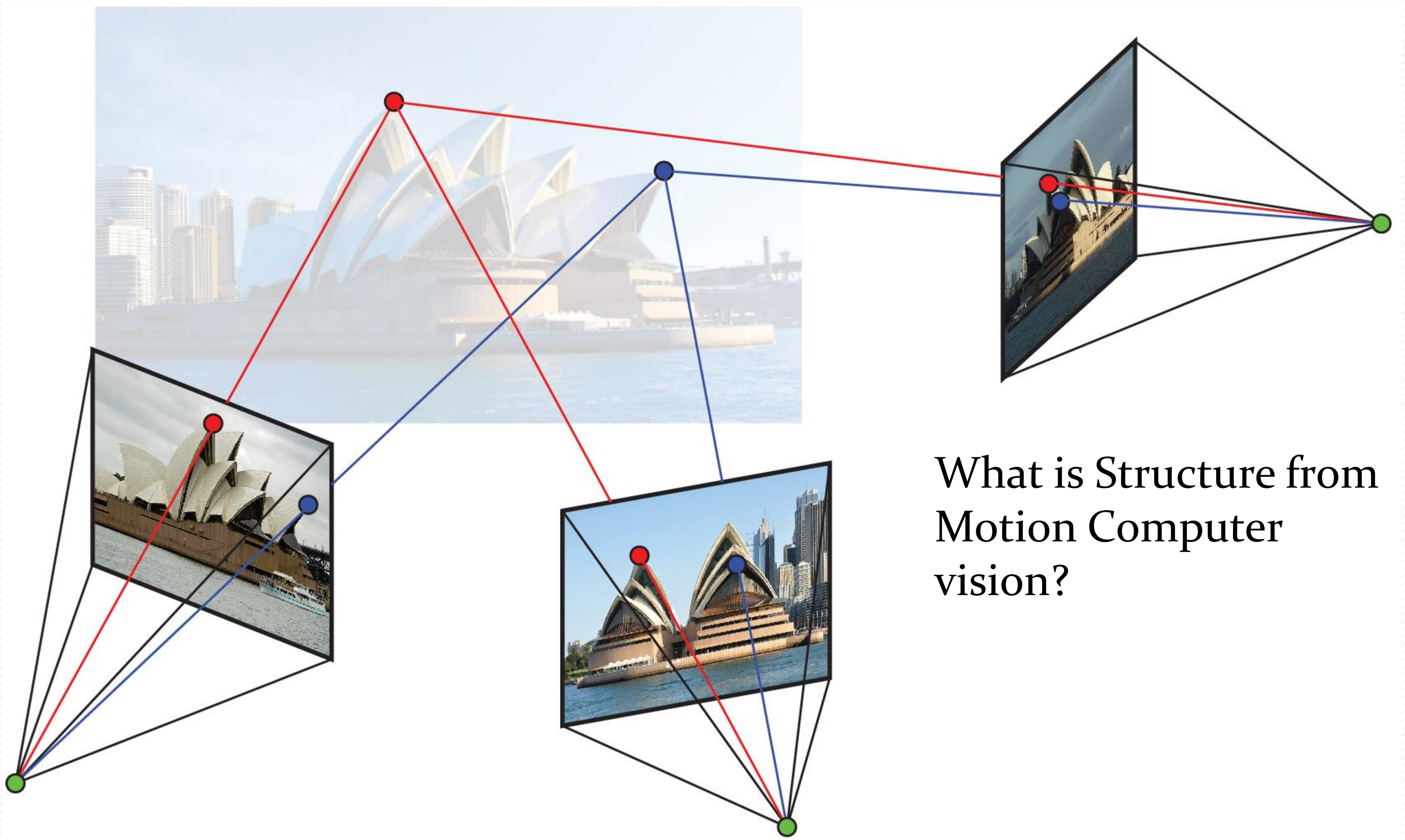


- Use LiDAR or computer vision 3D point clouds to produce orthoprojections and/or DEMs
- DEM requires geo-referencing of the point cloud
- Compatible with ArcGIS

*Rathje, E.M. and Franke, K.W. (forthcoming) “Remote Sensing for Geotechnical Earthquake Reconnaissance”, submitted to SDEE for review

Potential Uses for UAV-based Data

SfM 3D Point Clouds and Meshed Models



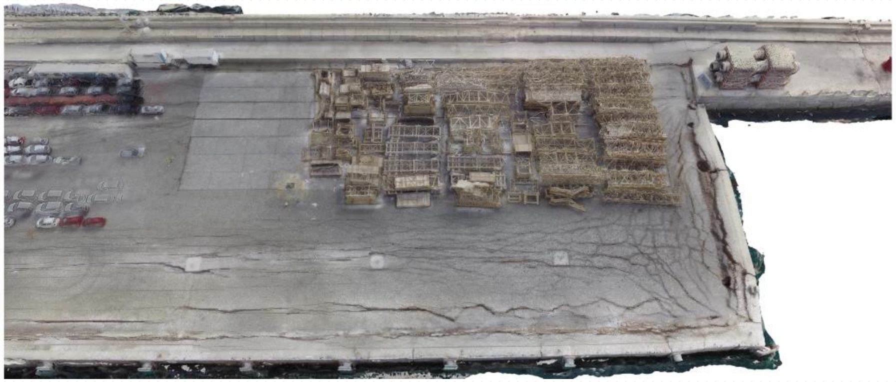
What is Structure from Motion Computer vision?

Images: CC - jdegenhardt, Bob Snyder, Jacques van Nierkerk, Kyle Wagaman, (Flickr)

Potential Uses for UAV-based Data

SfM 3D Point Clouds and Meshed Models

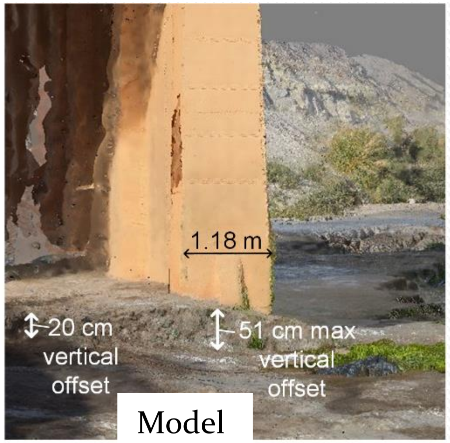
Molo Pier SfM 3D Model, Iquique, Chile – June 2014



- Developed from digital photographs
- Can require 48 hours+ to process a large model in-house
- Cloud computing requires 12-24 hours

Tana Bridge, North of Iquique, Chile – June 2014

Photograph



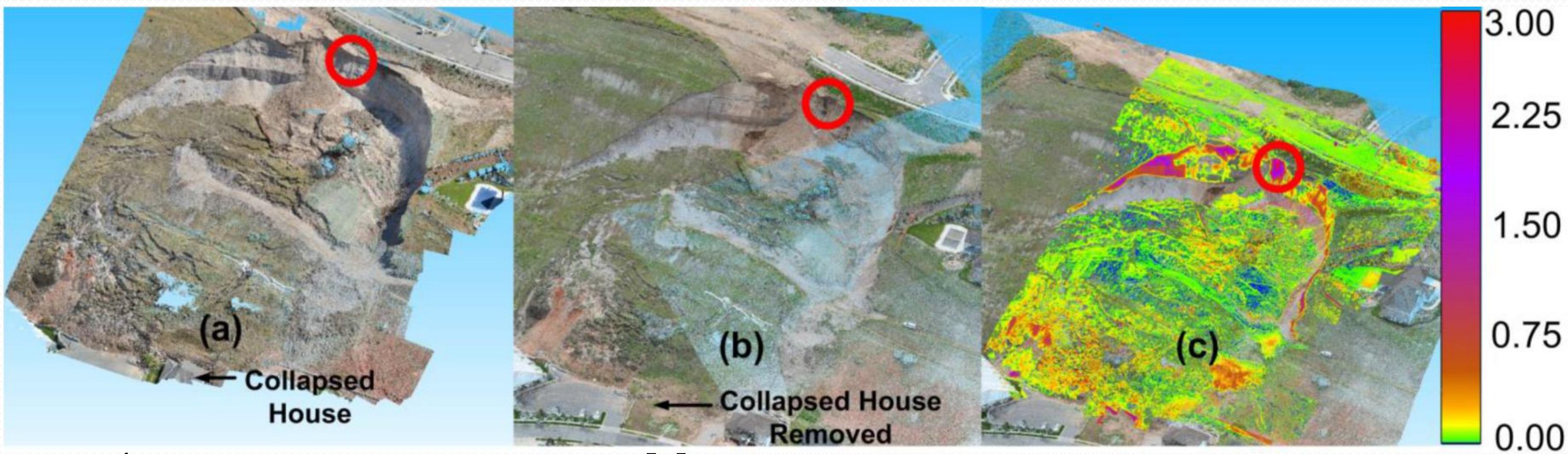
Model

*Franke, K.W. et al. (forthcoming) "Reconnaissance of Two Liquefaction Sites using Small Unmanned Aerial Vehicles and Structure from Motion Computer Vision Following the April 1, 2014 Chile Earthquake", submitted to ASCE JGGE for review

Potential Uses for UAV-based Data

Change Detection Analysis for Measurement of Ground Movement – 2D or 3D

North Salt Lake Landslide – August 2014



August 2014

May 2015

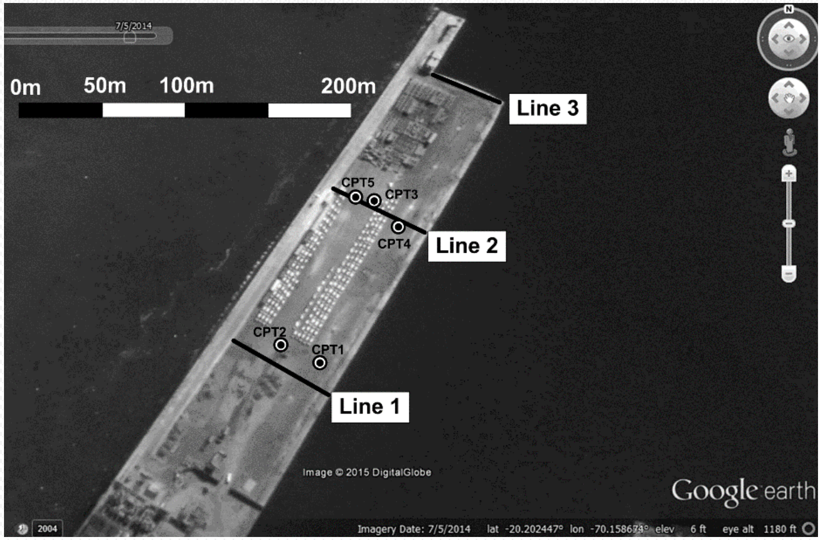
Average Detected Movement (meters)

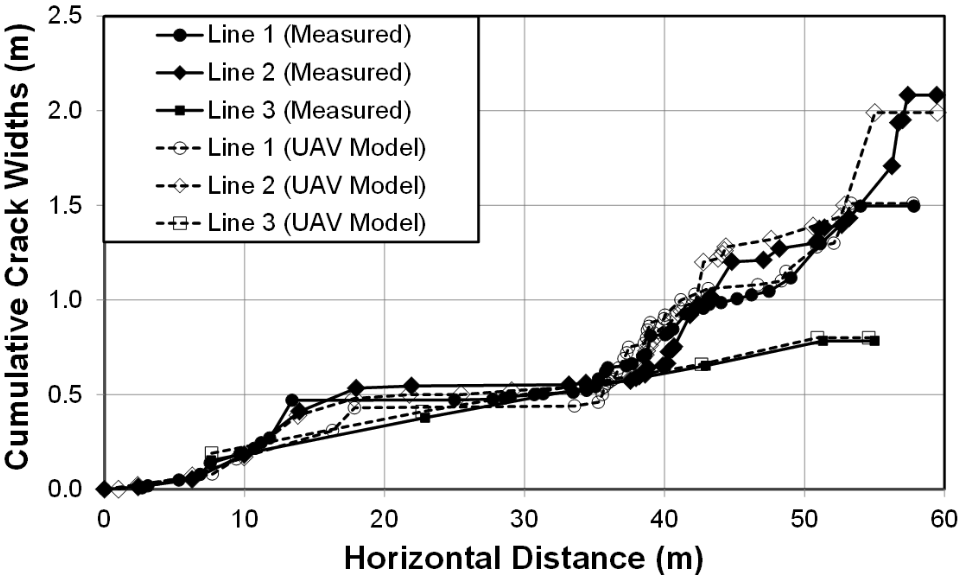
*Rathje, E.M. and Franke, K.W. (forthcoming) "Remote Sensing for Geotechnical Earthquake Reconnaissance", submitted to SDEE for review

Potential Uses for UAV-based Data

Manual Measurement of Ground Deformations or Other Objects of Interest

Molo Pier Liquefaction Site, Iquique, Chile – June 2014

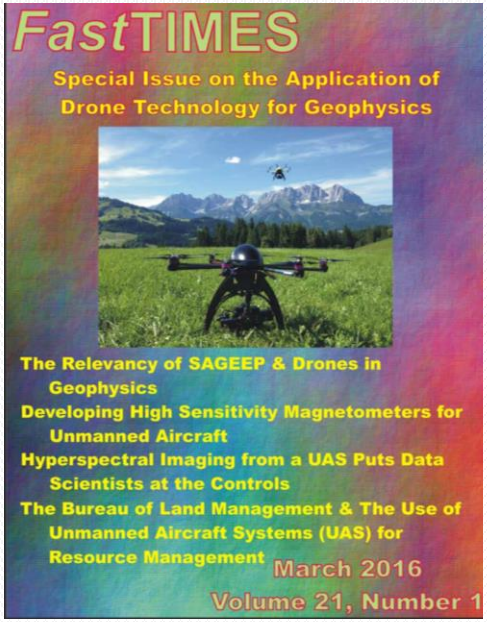


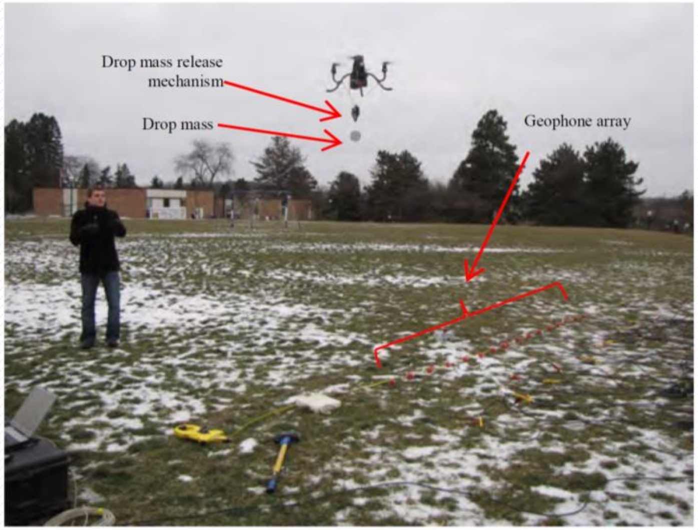


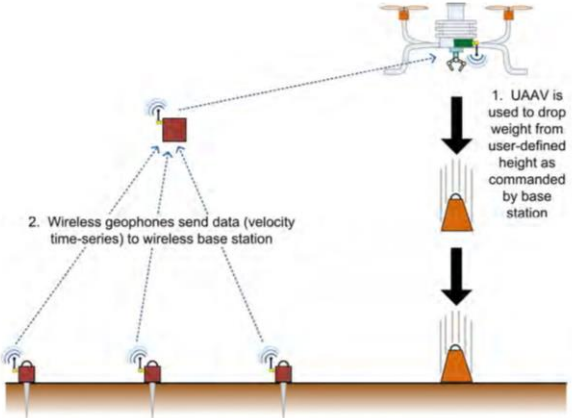
*Franke, K.W. et al. (forthcoming) "Reconnaissance of Two Liquefaction Sites using Small Unmanned Aerial Vehicles and Structure from Motion Computer Vision Following the April 1, 2014 Chile Earthquake", submitted to ASCE JGGE for review

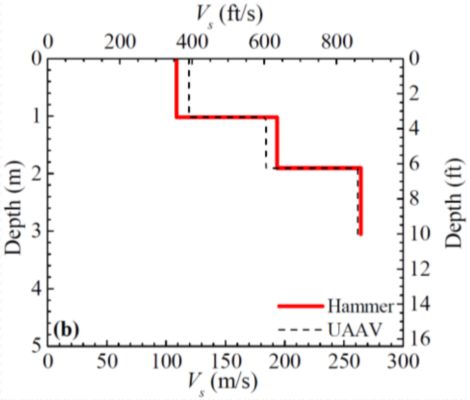
UAVs for Geophysics

- Many applications of UAVs in geophysics being considered, e.g.,
  EM, hyperspectral, Magnetics, Seismic
- UAVs have the potential to revolutionize non-contact sensing technologies not only as data acquisition, but also as computational platforms









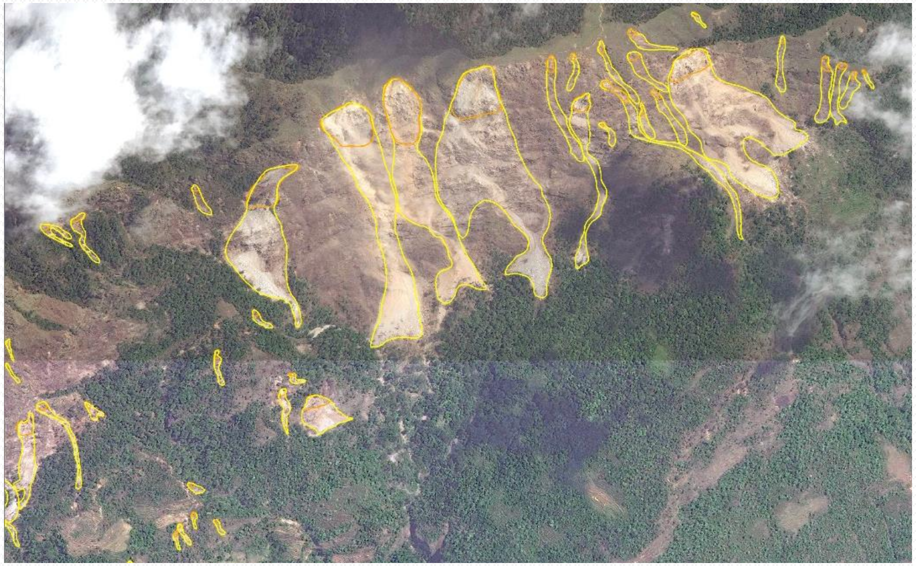
Zekkos, D. and Lynch, J., Sahadewa, A., Hiroshi, M. (2014). "Proof-of-Concept Shear Wave Velocity Measurements Using an Unmanned Autonomous Aerial Vehicle," Geocongress 2014, Atlanta, Georgia, February 23-26 2014, 953-962.

UAVs as Computational Platforms

- UAVs have already powerful on-board processors
- UAV processing capabilities currently used mainly as data acquisition platforms
- In the near future, we can expect drones to collect data, process it on-board, use it to make decisions, and collect additional, optimized, higher quality (e.g. definition) data

Nepal 2015 Earthquake co-seismic Landslides

Collect

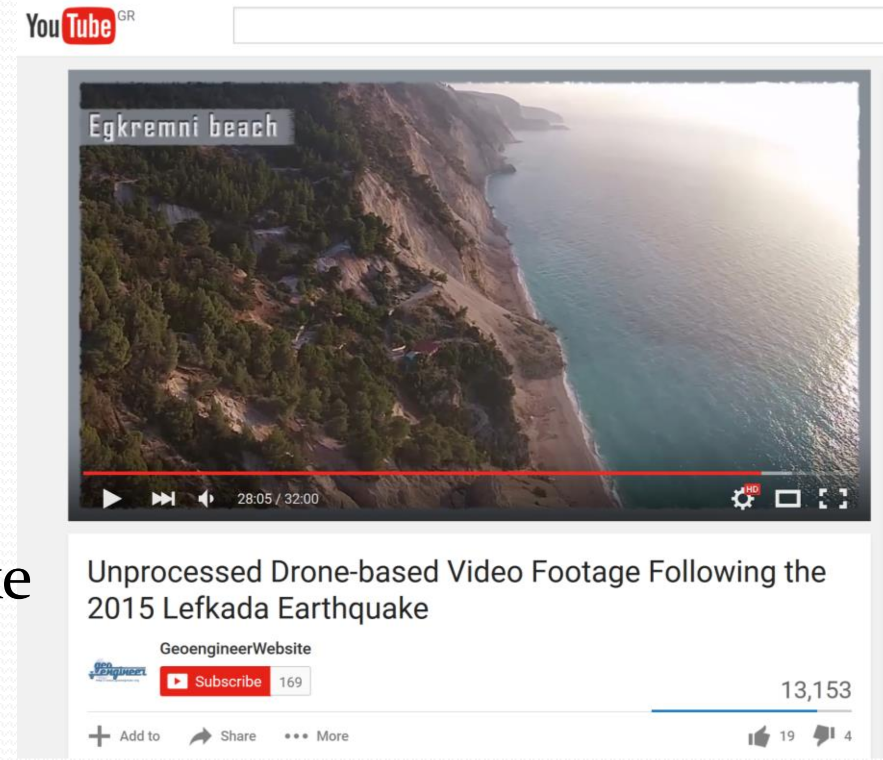


Analyze & Make Decisions

Satellite Dataset analyzed by Prof. Marin Clark, University of Michigan

UAVs for Data Dissemination and Decision Making

- Drones can **now** be used as standard data acquisition and dissemination platforms
- Dissemination can promote feedback by remotely connected professionals and experts



e.g., Lefkada 2015 Mw 6.4 Earthquake drone data collection

-Acquisition: 2 days after the EQ

-Dissemination: 4 days after EQ via Youtube

-6,000 views within a week

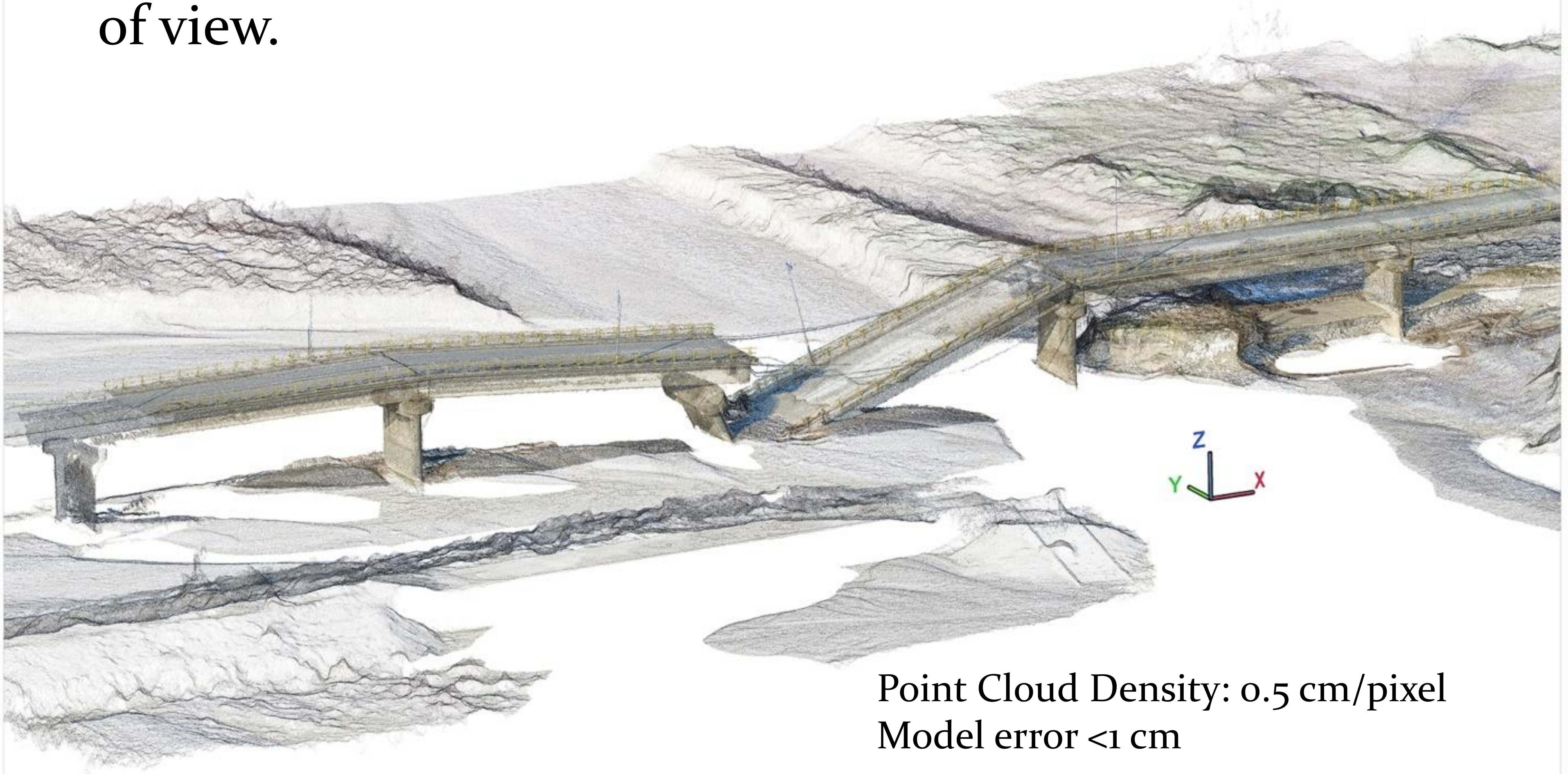
CASE HISTORIES

Bridge Scour Failure in Kalampaka, Greece

- Failure location was physically inaccessible due to river
- 3-hr survey 2 days after the failure
- Failure was mapped using SfM

3D point cloud of the model

Mapped using 649 photos from a UAV at different points of view.

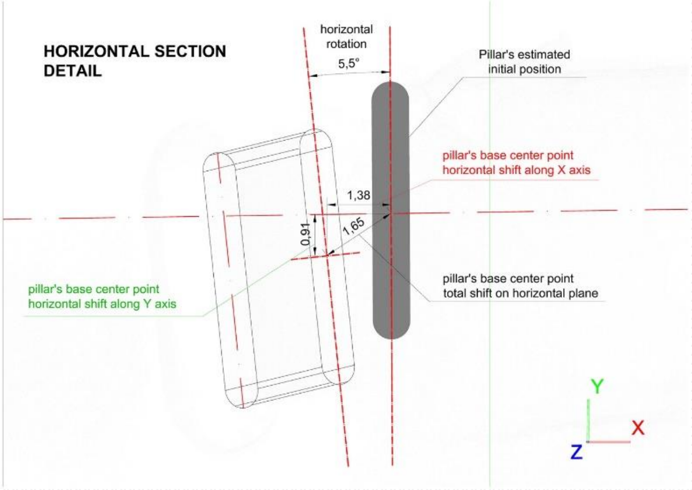


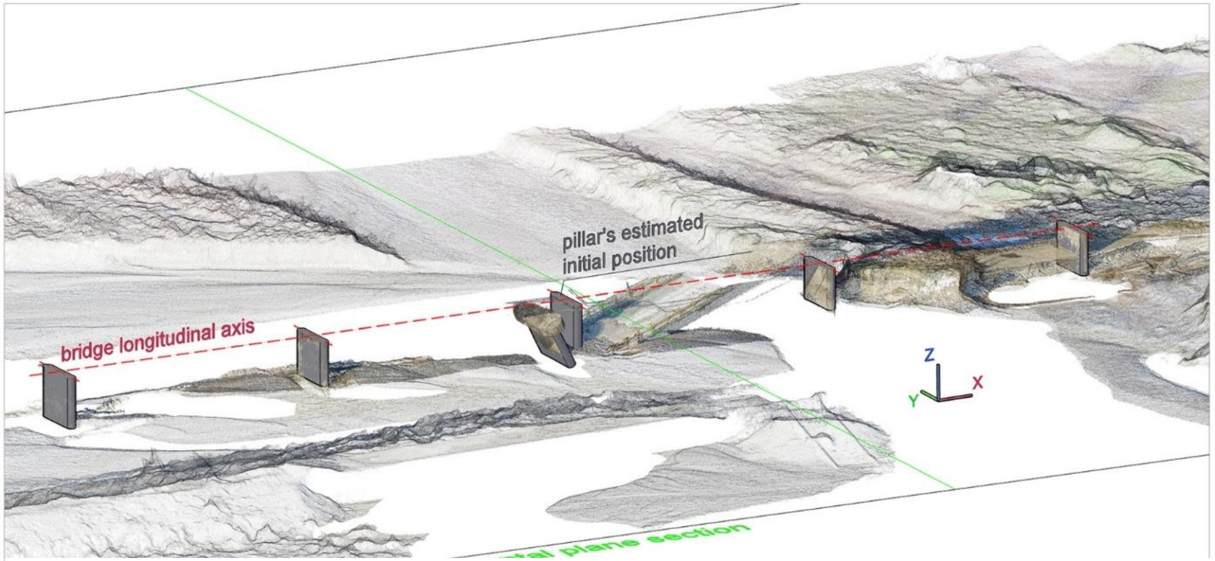
Point Cloud Density: 0.5 cm/pixel
Model error <1 cm

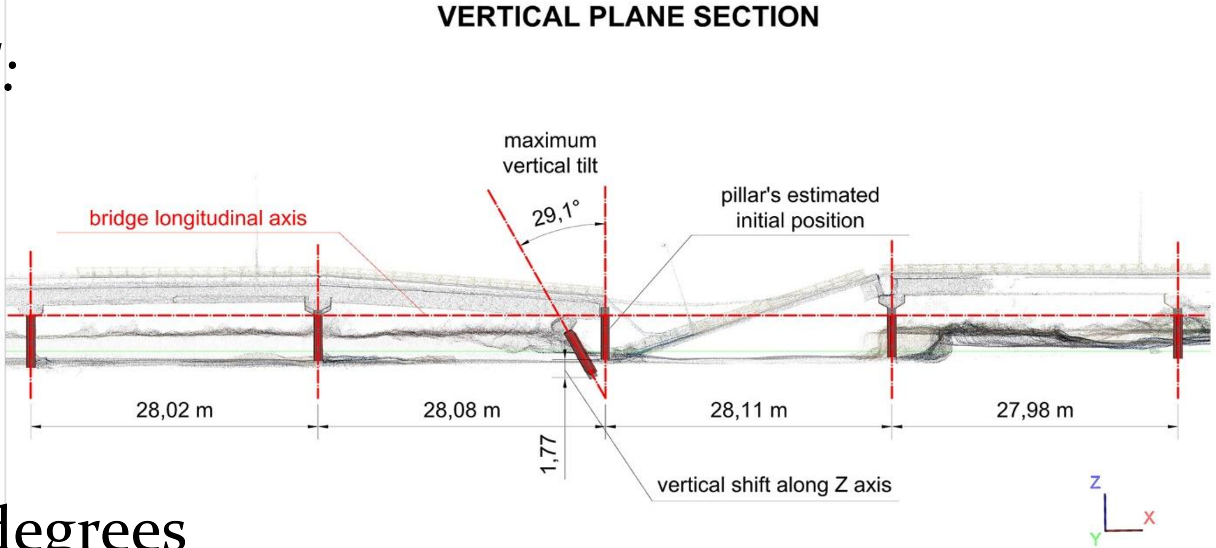
Zekkos et al. (2016). "UAV-based Reconnaissance following Recent Natural Disasters in Greece." International Conference on Natural Hazards and Infrastructure, 28-30 June 2016, Chania, Crete Island, Greece.

Dataset developed in collaboration with John Manousakis

Remotely-collected Quantitative Displacement Measurements





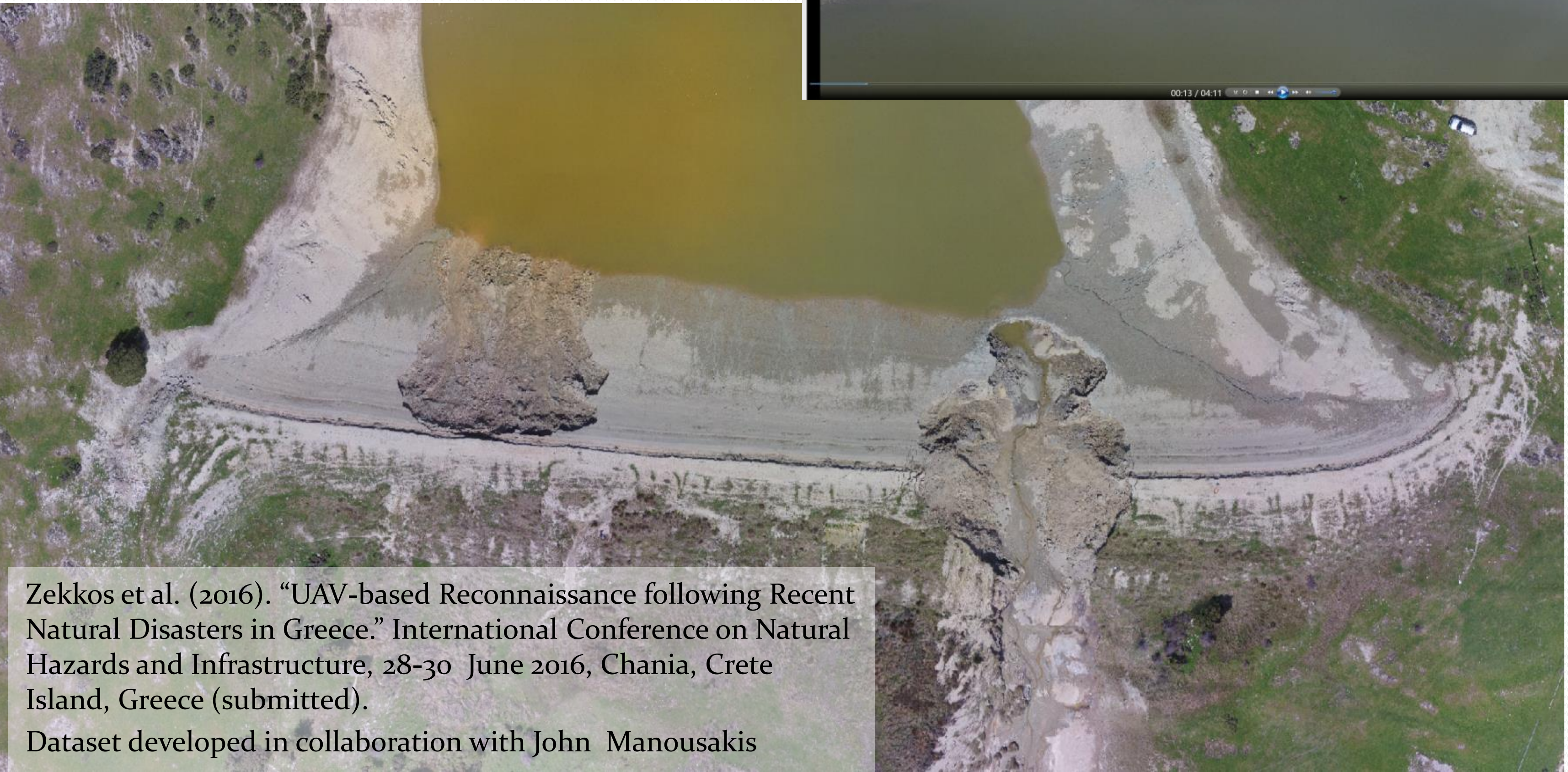


The bridge pier *displaced:*
1.38 m along bridge axis
0.91 m perpend. to axis
1.77 m vertically
The bridge pier *rotated*:
5.7 degrees horizontally
Vertical inclination 29.1 degrees

UAV Case History #2

Sparmos Dam Failure & Flood Mapping

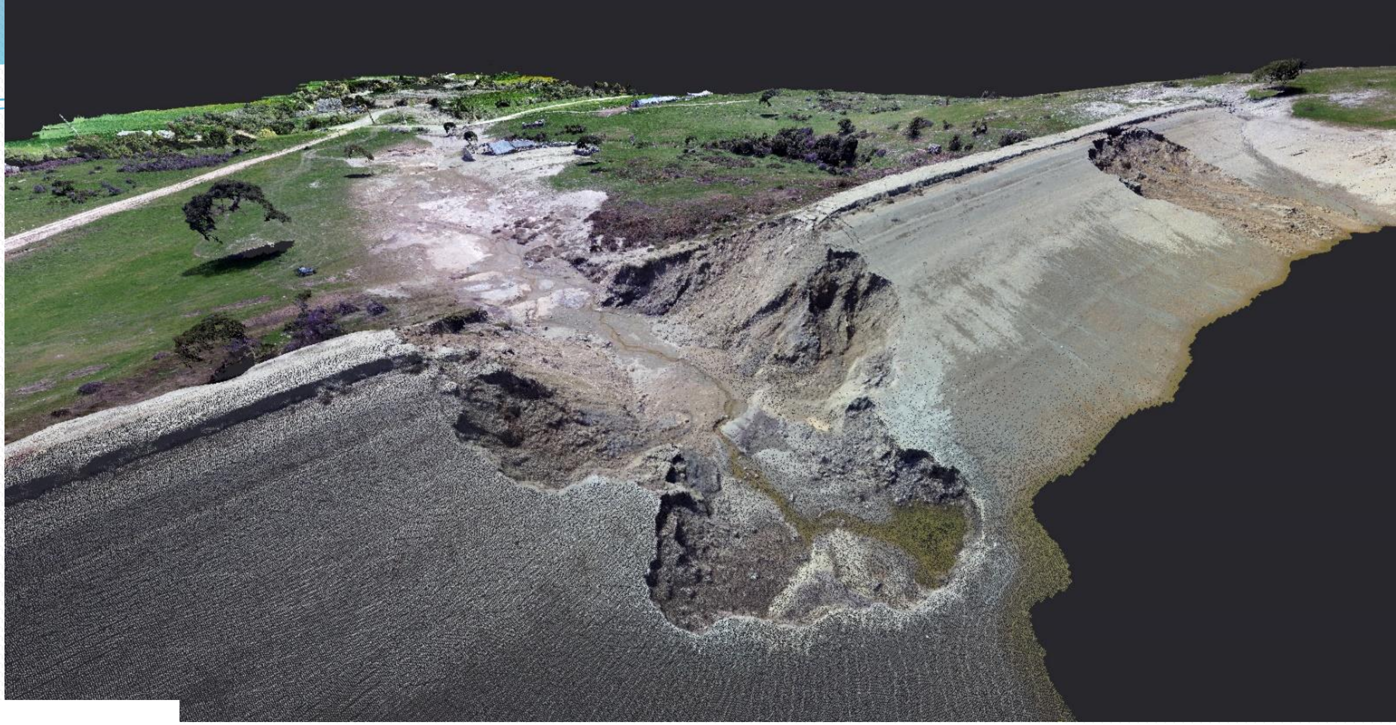
- 15 m high earth dam for irrigation
- Failure due to under-seepage
- Subsequent failure upon emptying due to rapid drawdown
- Survey conducted 2 days after failure in 4 hrs

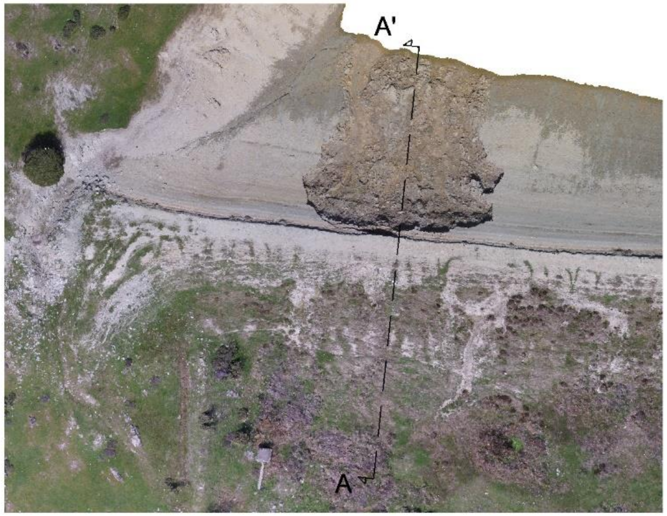


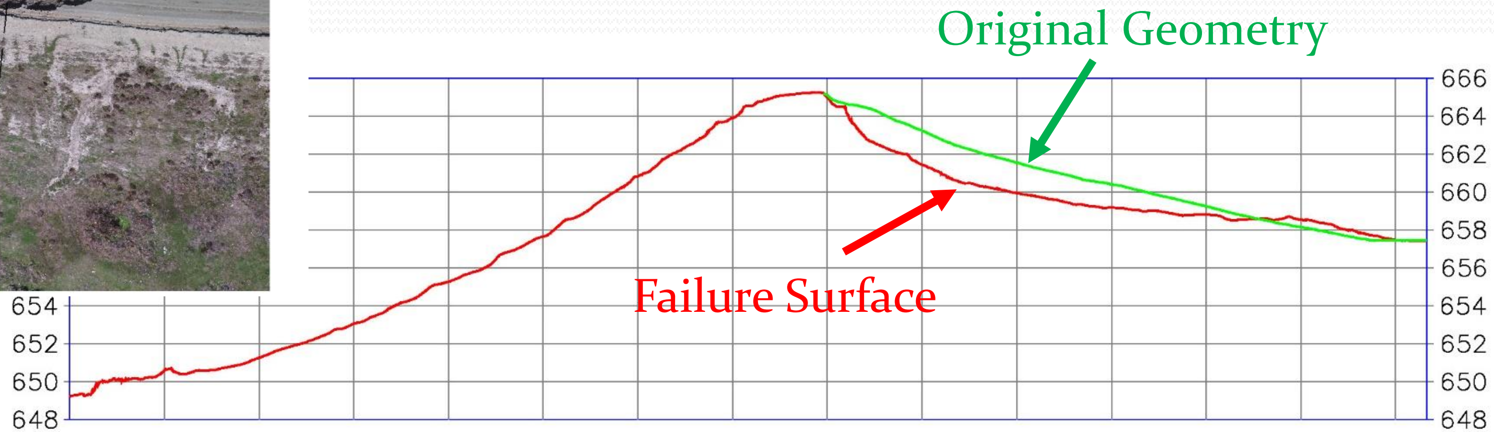
Zekkos et al. (2016). “UAV-based Reconnaissance following Recent Natural Disasters in Greece.” International Conference on Natural Hazards and Infrastructure, 28-30 June 2016, Chania, Crete Island, Greece (submitted).

Dataset developed in collaboration with John Manousakis

Mapping of rapid drawdown failure







UAV Case History #2

Dam Failure & **Flood Mapping**

Volume of Water Release: 85,000 m^3

Structural Damage Assessment

- Model scaled using RTK GPS
- 12 GPS points used for model scaling
- 6 GPS points for model error assessment
- Total Mean Error ±2.5 cm

Water flooded area: ~100,000 m^2

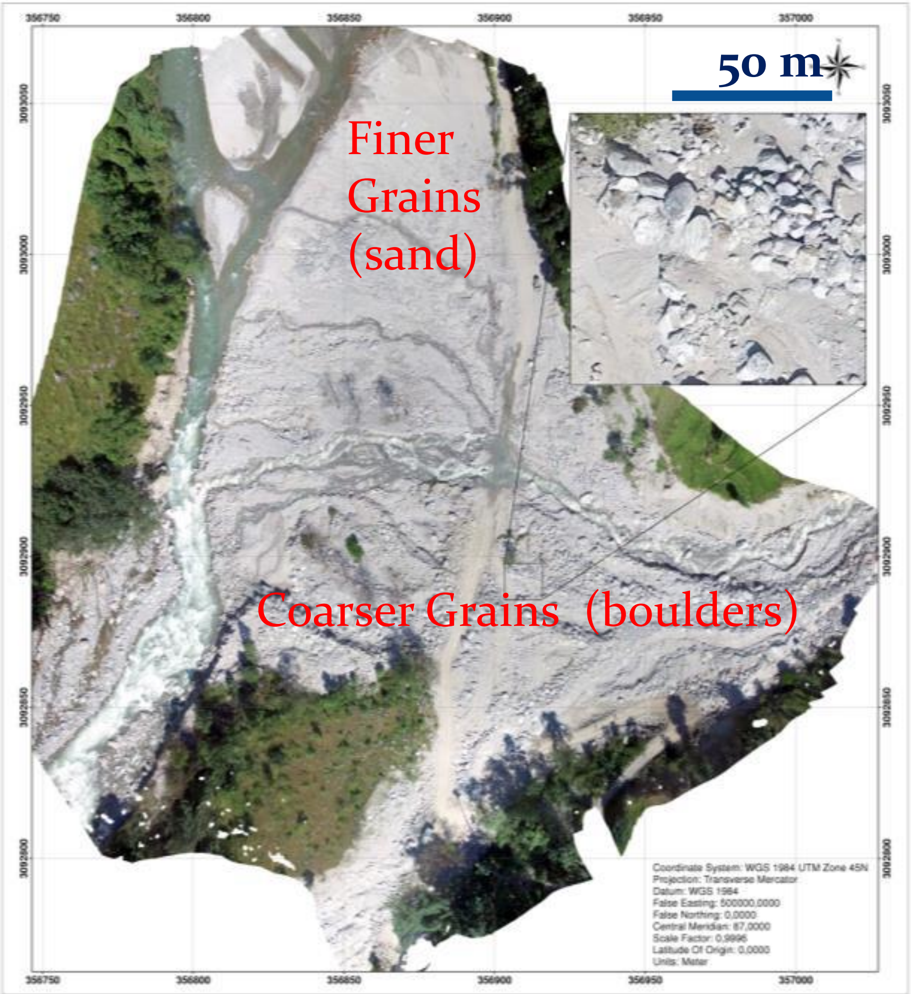
Zekkos et al. (2016). "UAV-based Reconnaissance following Recent Natural Disasters in Greece." International Conference on Natural Hazards and Infrastructure, 28-30 June 2016, Chania, Crete Island, Greece (submitted).

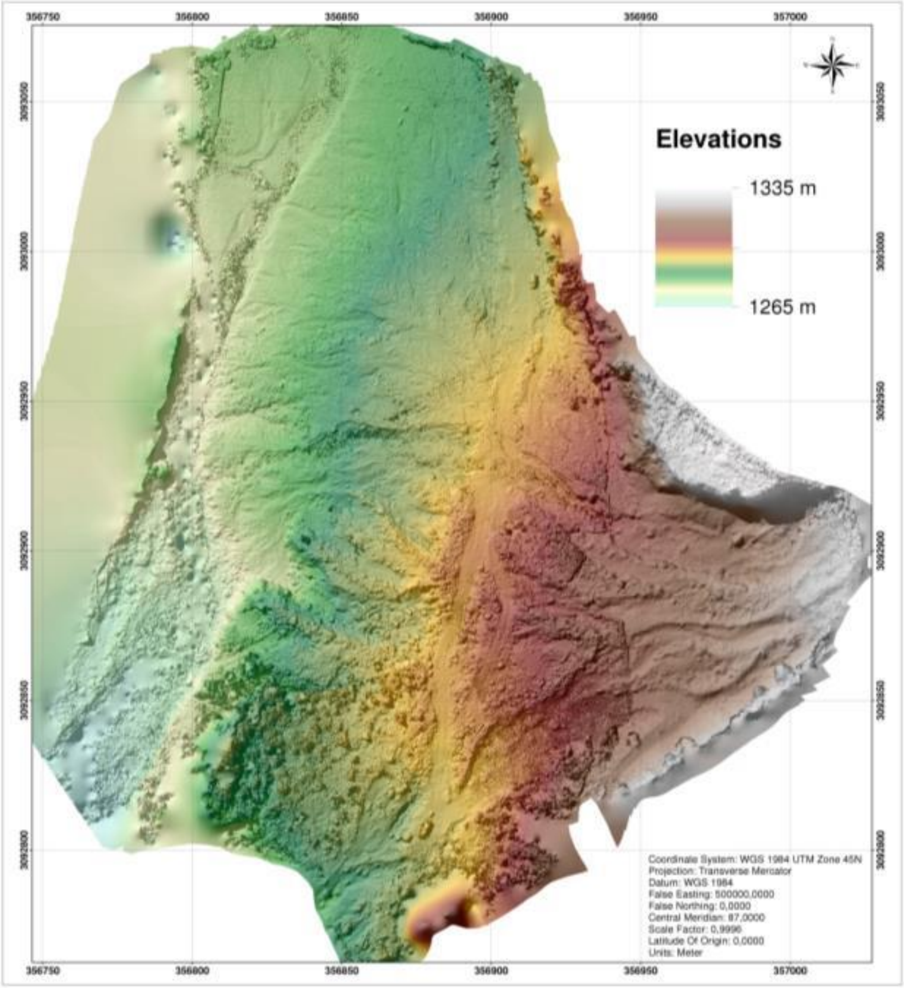
Dataset developed in collaboration with John Manousakis

UAV Case History #3

Characterization of Monsoon-induced Debris Flow

- DTM generation (Ground Sampling Distance – GSD = 5.0 cm/pixel)
- ~ 3 cm total mean error between GPS measured coord. and 3D model generated coord.
- Imagery can be used for grain size analysis to gain insights on dynamics of debris flow





Dataset collected in collaboration with Prof. Marin Clark, University of Michigan, and Prof. Joshua West, USC

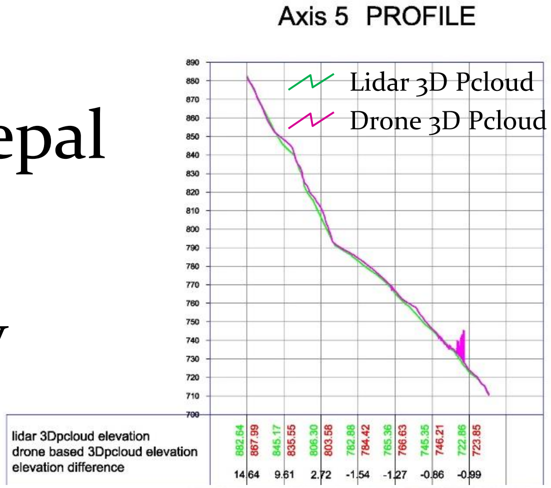
Vasiliki Port Pier Damage during 2015 Mw 6.4 Lefkada earthquake, Greece

- 12 m wide, 73 m long port pier
- 7 min flight length
- 5 m flight height
- Ground Sampling Distance 0.5 cm/pixel

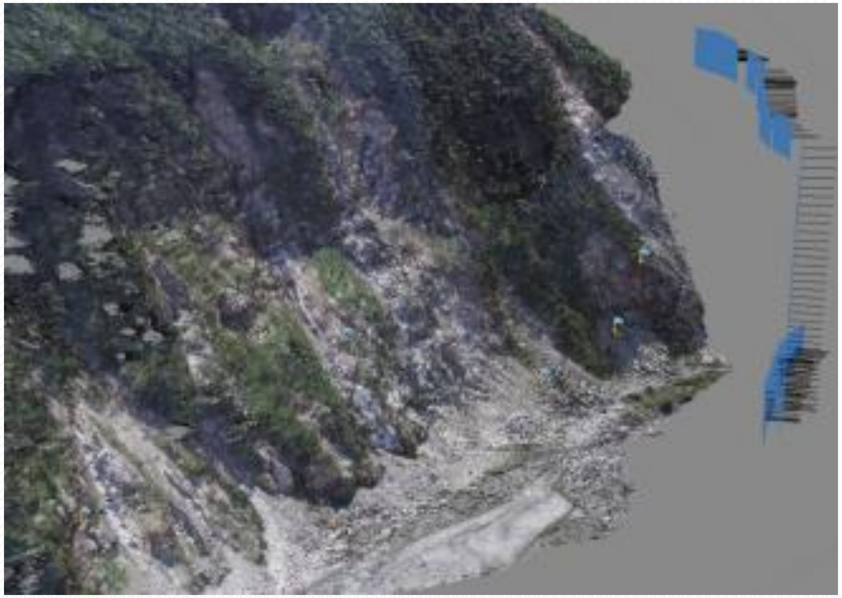
Automatic identification of cracks per Jahanshahi et al. 2011

Jahanshahi, M. R., Masri, S. F., Padgett, C. W., Sukhatme, G. S. (2011). An innovative methodology for detection and quantification of cracks through incorporation of depth perception. Machine Vision and Applications, DOI 10.1007/s00138-011-0394-0

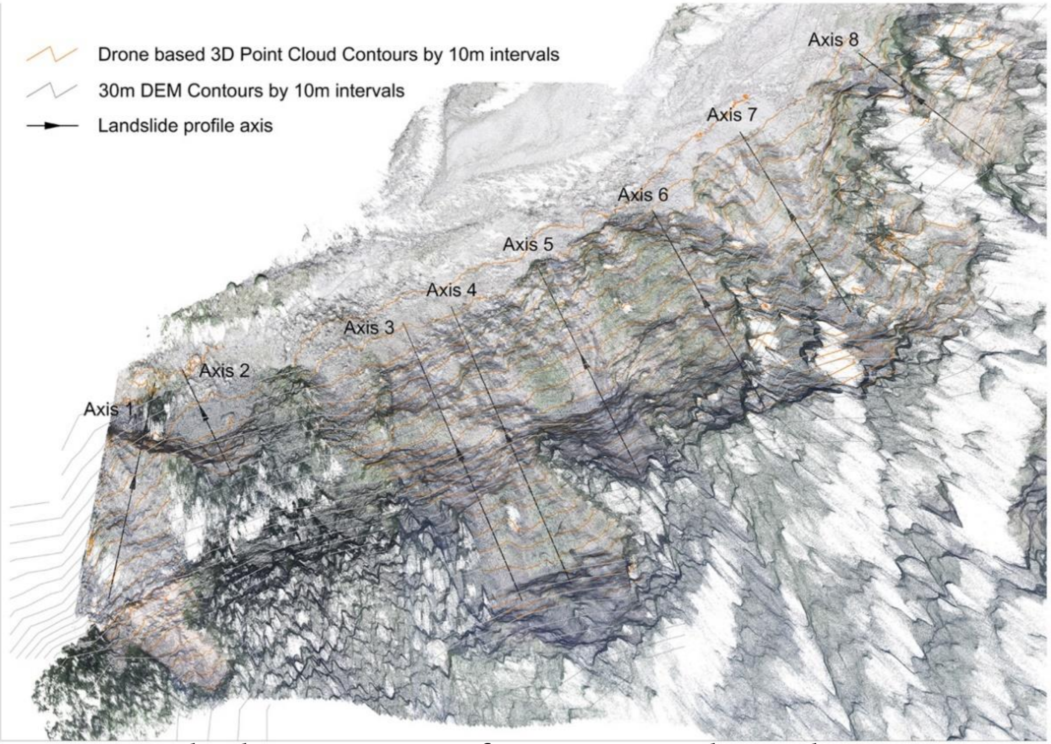
LIDAR vs. SfM 3D point Clouds



- Complex set of co-seismic landslides in Nepal
- Landslides ~200 m in height
- 10 cm/pixel with drone flying ~120 m away
- 3D point clouds practically identical



Oblique View of drone-based SfM 3D point cloud



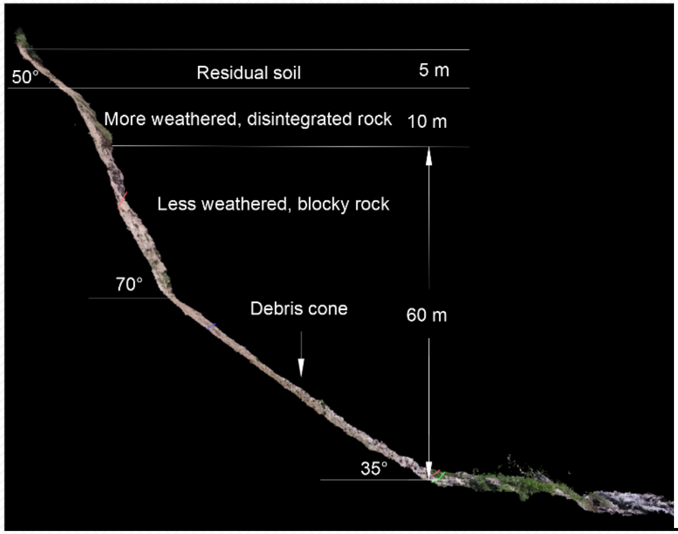
Lidar dataset courtesy of Dr. Kristen Cook, Potsdam University

UAV Case History #6

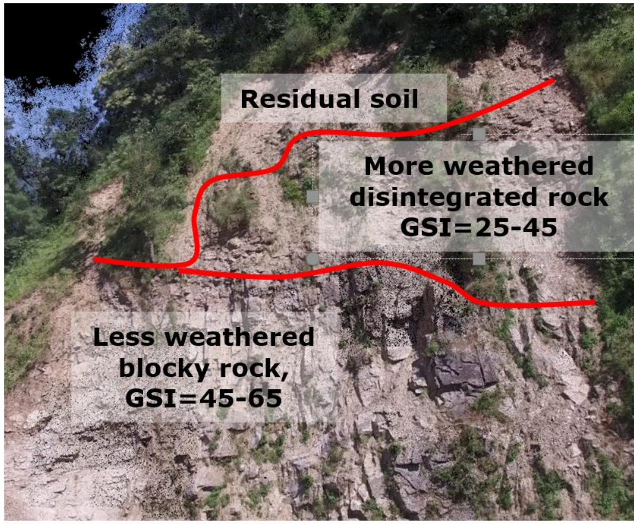
Quantitative Rock Mass Characterization

- Large Rock Slope Slides in Nepal

3D point cloud (geometry)



Cross-section (geometry)



Characterization of Geological Strength Index GSI (material property)

Image Analysis can be used to characterize the mechanical characteristics of rock (e.g. GSI for Hoek and Brown materials) or attitude of discontinuities for structurally controlled failures

Greenwood, W., Zekkos, D., Lynch J., and Bateman, J., Clark, M., 2016.UAV-Based 3-D Characterization of Rock Masses and Rock Slides in Nepal. 50th US Rock Mechanics/Geomechanics Symposium, American Rock Mechanics Association, Houston, TX., 26-29 June 2016 (accepted).

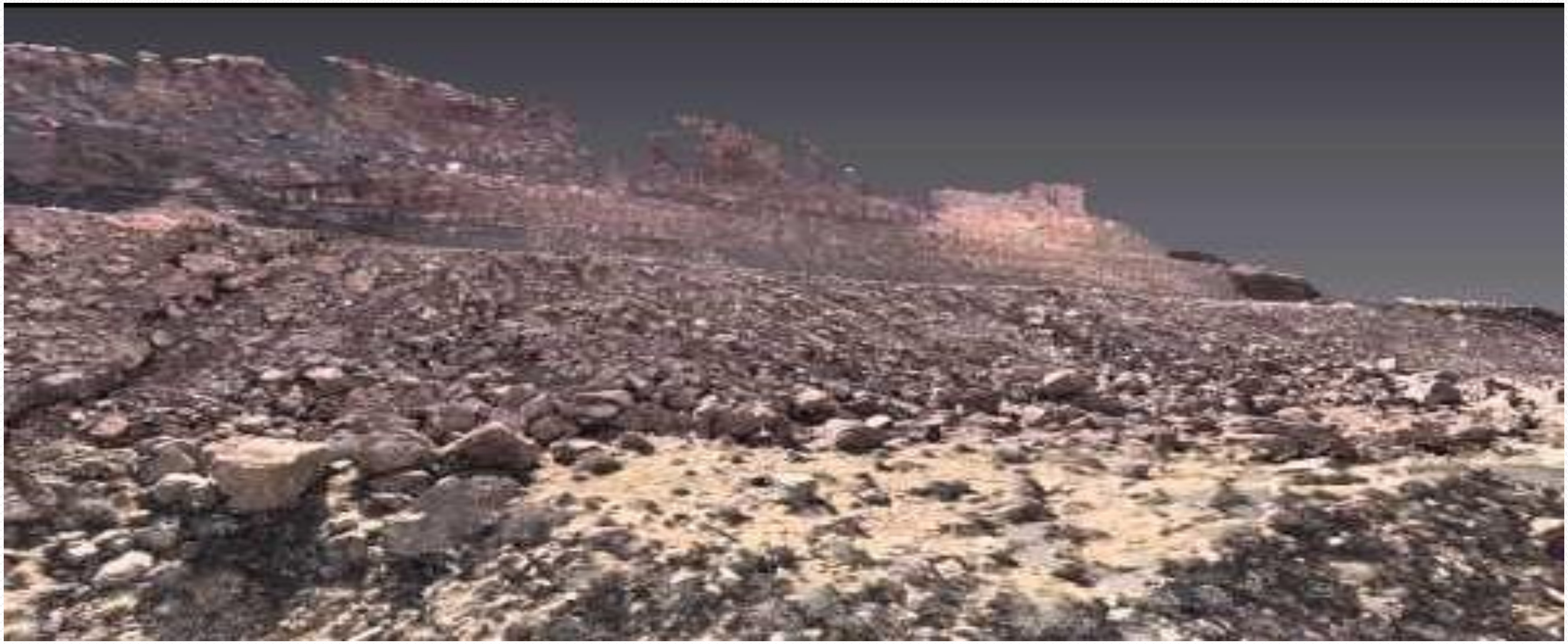
Landslide Modeling and Deformation Measurement

- Landslide in North Salt Lake, Utah – August 2014
- Slide started moving again this week! …Over 5 inches!

https://www.youtube.com/watch?v=IP4bSv7apcA

Landslide Modeling and Deformation Measurement

- Landslide on US-89, south of Page, AZ – July 2014
- Landslide has now been stabilized, highway repaired



https://www.youtube.com/watch?v=IGE4ySPd5RU

Rock Outcrop Modeling and Critical Layer Detection

- Book Cliffs, Son of Blaze Canyon, Central Utah – June 2014
- Interest in manually identifying rock layers of interest, including sandstone and/or coal seams

https://www.youtube.com/watch?v=gLzKkhhR7Q4

LESSONS LEARNED FROM THE FIELD

UAV Field Lessons Learned

Major Considerations

- UAVs control and sensing capabilities evolving greatly
- Regulations are also evolving
- Safety → UAVs can cause injuries or even death. Safety Protocols need to be followed
- Flying a UAV well does require practice
- Acquiring good quality technical field data requires even more practice, experience and appropriate equipment: Type of drone, flight parameters (*elevation, distance from target, point of view*), sensor (e.g., *camera characteristics*), type of data and acquisition parameters (e.g. *frequency*), will impact quality of data (*resolution, density of cloud, ability to identify feature*).
- Each flight should have a specific objective of collected data
- For quantitative measurements of UAV data, land-based GPS or other similar

UAV Field Lessons Learned

Environmental/Weather Considerations

- It is crucial to match the UAV and pilot to the environment/weather considerations
- Many UAVs are sensitive to wind (>15-20mph) and moisture
- Some UAVs (particularly multi-rotors) can be sensitive to temperature
- Single-rotors are usually more robust to the environment than multi-rotors

Example: An attempt to fly a small quadrotor to image a large rockfall failed when a sudden wind gust made the UAV lose radio connection with the operator. The UAV initiated auto-landing, but the wind blew the descending UAV into the mountain. It was buried under 6 feet of snow, and retrieved nearly 5 months later.

(Before Crash...)

(After Crash...)

UAV Field Lessons Learned

Necessary Hardware/Software

- Good UAVs do not need to be expensive, particularly if you manually upgrade a hobbyist aircraft
- Commercial ready-to-fly UAVs can be $$$ (>$40k in cost), particularly if they have lots of specialized features (e.g., automation)
- Larger UAVs require LOTS of maintenance. Helps to have an experienced technician oversee them. Small hobbyist UAVs usually require minimal maintenance unless you crash them
- Plan on having multiple sets of batteries and means to charge them in the field. Batteries must be replaced annually if you fly a lot
- Reliable sensor gimbals are a challenge, particularly with larger sensors
- There are LOTS of SfM software options. To operate SfM in-house, best to have a workstation computer (cost ranging from $5k to $20k+ depending on configuration. Needs LOTS of graphics memory)
- SfM cloud computing becoming quite popular, but limits the ability to control the 3D reconstruction

UAV Lessons Learned

The Realities of UAV Automation

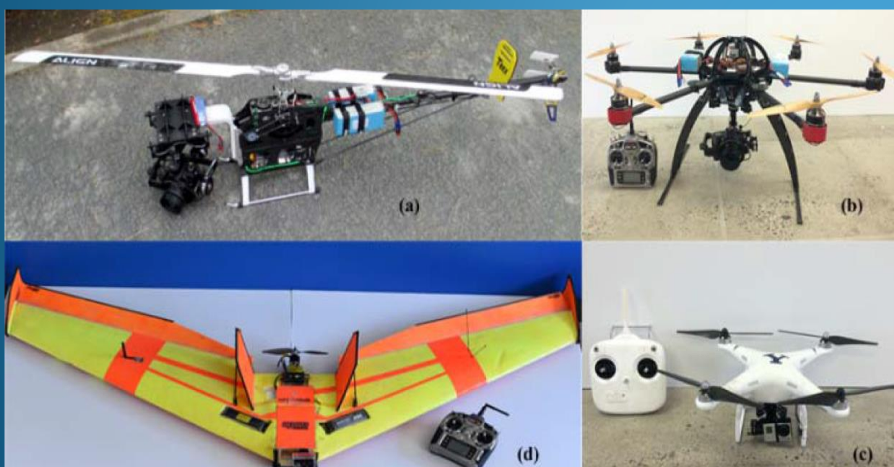
The Internet sometimes leads us to believe that UAVs are much more intelligent than they really are. We hear stories about UAVs delivering packages, repairing infrastructure, stopping crimes, etc.,

UAV Lessons Learned

The Realities of UAV Automation

- Internet UAV videos usually show one unique skill that the UAV has been trained to do in a known environment
- The reality is that UAV/robotics experts are still struggling to solve basic automation problems such as “perch and stare” and “vision-based navigation”
- Almost all useful UAV automation that is available on commercial hobby aircraft today is dependent upon GPS. Without GPS, most UAV automation does not function well or at all
- Most current automated algorithms allow flight plans to be programmed pre-flight or mid-flight, but these will lock the UAV altitude (i.e., the UAV can only maneuver horizontally, not up or down)
- Automatic take-off/landing functions generally work well when GPS signal is present and good weather conditions exist
- Windy weather + automated flight = significant increase in battery drain!

The Use of Small Unmanned Aerial Vehicles for Post-Disaster Geotechnical Reconnaissance



Webinar Given April 20, 2016

by

Kevin Franke, Ph.D., P.E.
Assistant Professor, CEEn
Brigham Young University

and

Dimitrios Zekkos, Ph.D., P.E.
Associate Professor, CEEn
University of Michigan