Structure from Motion (SfM) Photogrammetry

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RAPID Facility Workshop
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Structure from Motion (SfM)

• SfM is a photogrammetric method for creating 3D digital “point cloud” models of a feature (or of topography)

• Created from photographs taken of feature from different perspectives

• Differs from traditional photogrammetry in that camera positions are back-computed in the SfM algorithm (rather than being known)

• Technically, the entire process is known as SfM-multi-view stereo, or “SfM-MVS"

• Increasingly popular approach owing to cost, computation, and ease-of-use

Carrivick et al. (2016)
SfM Example

Alaska test site overview photo

Field data acquisition: camera and locating survey points

Data product (point cloud)
SfM applications

Archeology

Models from crowd sourced photos

Autonomous navigation/guidance

Augmented reality

SfM applications

Post-disaster reconnaissance (Prof. Kevin Frankie, BYU)

http://prismweb.groups.et.byu.net/PL/App/?scene=Italy_Pescara_Landslide&cx=252.1335&cy=-185.9897&cz=929.8260&upx=0.0000&upy=0.0000&upz=1.0000&tX=-1.0696&tY=-21.5576&tZ=752.4222
SfM applications

Post-disaster reconnaissance (Prof. Kevin Frankie, BYU)

http://prismweb2.groups.et.byu.net/Condesa_A1/App/?scene=Condesa_Area1&cX=210.7903&cY=362.9145&cZ=2301.7393&upX=0.0000&upY=0.0000&upZ=1.0000&tX=189.6081&tY=297.7224&tZ=2274.2073#%2F
SfM applications

Observe:

- Types of structures
- Nature of structural damage/non-damage
- Deformation measurements
- Types of businesses
- Tents/recovery staging (with time/repeat surveys)
SfM Applications
SfM applications
SfM applications
SfM applications

Figure 3.28. Interpreted progression of the flowslide at Jono Oge. The large red arrows indicate primary movements, while the yellow arrows indicate secondary movements.
Main Steps

1. (Automated) identification of matching features ("keypoints") in multiple images

2. Track features image to image, which allows initial estimates of camera positions and object coordinates to be made

3. Errors are minimized in an iteratively least-squares fit process (as multiple solutions become available from the wide range of features in the image database)

4. Multi-View Stereo algorithm is used to develop an enhanced density point-cloud

5. Georeferencing with control points

Westoby et al. (2016) and Carrivick et al. (2016)
Step 1. Keypoint extraction

- Identify features in individual images that can be used for image correspondence
- Scale Invariant Feature Transform (SIFT) object recognition system transforms local image gradients into a representation that is largely insensitive to variations in illumination and orientation
- These descriptors are unique enough to allow features to be matched in large datasets.
- The number of keypoints in an image is dependent primarily on image texture and resolution (complex images are better)

**Fig. 2.** Scale Invariant Feature Transform (SIFT). Lowe’s (2004) algorithm decomposes a given image (left) into a database of ‘keypoint descriptors’ (right). Lines represent individual keypoints, proportionally scaled according to the radius of the image region (pixels) containing the keypoint (SIFT code available: http://www.cs.ubc.ca/~lowe/keypoints/).

Westoby et al. (2016)

SIFT by Mikolajczyk et al. (2005)
Step 2. Structure from Motion algorithm

- Keypoints in multiple images are matched

- "Tracks" comprising a minimum of two keypoints and three images are used for point-cloud reconstruction (those which fail to meet these criteria are discarded)

- Triangulation is used to estimate the 3-D point positions and incrementally reconstruct scene geometry

- Produces sparse point-clouds.

Figures from UNAVCO (Katherine Shervais) and http://www.theia-sfm.org/sfm.html
Step 3. Multi-view Stereo

From Carrivick et al. (2016)

- An enhanced density point-cloud is developed using a Multi-View Stereo algorithm
- Camera positions derived from SfM are used as input
- MVS then decomposes overlapping input images into subsets or clusters of manageable size and independently reconstructs 3-D data from these individual clusters
- Results in a (very) dense point cloud

Carrivick et al. (2016)
Step 4. Georeferencing and Post-Processing

- Transformation model from relative to absolute coordinate system using known ground control points

- Use a rigid body transformation decomposed into a rotation and a translation matrix, and a scale factor.

- Artifacts or "pixie dust" (erroneous points resulting from keypoint descriptor mismatches) are manually removed
Practical Matters: Camera

• Ultimately need well exposed, medium to high resolution photographs

• SfM model f(camera resolution, distance to feature, number of photos)

• Fixed focal length cameras a best (use a fixed "prime" lens)

• Depth of field of a lens (range in distance that can be accommodated without image distortion); can be increased by reducing aperture (lens opening, with a higher f/ value). Alternatively, small apertures can result in diffraction that blurs images.

• Shoot in RAW and JPEG

• Other considerations: GPS, good autofocus, weather resistant, large sensor

• Our cameras can also be used with gigapan and for general photography

  e.g.  http://www.gigapan.com/gigapans/197552
Practical Matters: Planning a project

• Plan the program in advance; walk to the scene

- Extent of the scene?
- Target locations
- Are features of interest fully visible? If you can not see it, it will not be modeled
- Drone flight time/resolution
- Time for best light (consistent, bright light)

• Scene must be static

• Excellent coverage and overlap (every point on object must appear in at least 3 photos from different positions, aim for 70%+ overlap)

• Convergence (vs. divergence), capture full subject and then in closer detail

• For flat surfaces, capture photos form orthogonal and near-parallel locations

• Set 4 to 8 targets (use some a check points); set widely and somewhat close to edges (helps with "warping" of point cloud model)

Figure from Micheletti et al (2015)
Scene: 12 km long river, aerial photographs are taken at 275 m by Vericat et al.
Practical Matters: Software

Agisoft PhotoScan
Agisoft PhotoScan is a stand-alone software product that performs photogrammetric processing of digital images and generates 3D spatial data to be used in GIS applications, cultural heritage documentation, and visual effects production as well as for indirect measurements of objects of various kinds.

Throughout various case studies PhotoScan proves to produce quality and accurate results.

Low cost, runs on Mac/Windows OS, history of use in academic community

Works for both drone and ground images, good support, well documented, AI modules, runs in cloud (option)

Open source codes also available
## Practical Matters: Platform

### Table 4.1
A summary of the key platforms for acquiring SfM-MVS imagery with the main associated advantages and disadvantages, and key references demonstrating their use.

<table>
<thead>
<tr>
<th>Platform</th>
<th>Payload</th>
<th>Key advantages</th>
<th>Key disadvantages</th>
<th>Approximate cost (GBP)</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ground-based (hand-held)</td>
<td>Effectively unlimited</td>
<td>Cost; full control over image frequency/position; fine image resolution</td>
<td>Limited image swath</td>
<td>No cost</td>
<td>Bemis et al. (2014) and James and Robson (2012)</td>
</tr>
<tr>
<td>Mast/pole</td>
<td>1–3 kg</td>
<td>Portability; cost; full control over image frequency/position</td>
<td>Poor stability in adverse weather; limited image swath</td>
<td>10–500</td>
<td>Mathews and Jensen (2012) and Plets et al. (2012)</td>
</tr>
<tr>
<td>Blimp</td>
<td>3–5 kg</td>
<td>Cost; low maintenance; unlimited flying time; wide swath possible</td>
<td>Poor portability (steel canister); unstable in adverse weather</td>
<td>500–5000</td>
<td>Vericat et al. (2009) and Fonstad et al. (2013)</td>
</tr>
<tr>
<td>Fixed-wing UAV/multicopter</td>
<td>5–10 kg</td>
<td>High maintenance costs; flying expertise required; pre-planned flight lines possible</td>
<td>Generally short battery life (flying time); high set-up cost for professional-grade systems</td>
<td>5,000–25,000</td>
<td>Bendig et al. (2012) and Dunford et al. (2009)</td>
</tr>
<tr>
<td>Kite</td>
<td>3–5 kg</td>
<td>Portability; cost; low maintenance; unlimited flying time; can be deployed at high-elevation sites</td>
<td>Irregular winds can prevent flying; limited control over image frequency/position</td>
<td>10–1000</td>
<td>Smith et al. (2009) and Westoby et al. (2015)</td>
</tr>
<tr>
<td>Heli/gyrocopter or light aircraft</td>
<td>Effectively unlimited</td>
<td>Wide swath imagery; full control over image acquisition</td>
<td>Cost; flying not possible in adverse weather</td>
<td>250–10,000 (flying time only)</td>
<td>James and Varley (2012) and Javernick et al. (2014)</td>
</tr>
</tbody>
</table>
Case Study: Rock Slope Model

(O’ Banion et al (2018))

• Site: Rock slopes in Alaska (10-30 m high); lots of "texture"

• Issue: line of site to benches; used both ground and drone cameras

• Previous studies assess the accuracy of SfM with lidar, or residuals from surveyed ground control points (GCPs) or based on discrepancies with (a few) surveyed check points. We used 100+ reflectorless total station points

• SfM error = f(distance, keypoint matching performance, surface texture and lighting conditions, GCP characteristics)
Case Study: Rock Slope Model

(O’ Banion et al (2018)

- Holes filled in combined model
- High density ground camera
- High density lidar on ground

FIG. 4. Point density “heat” maps for RS3 SfM- and TLS-derived 3D point cloud data.
Case Study: Rock Slope Model (O’Banion et al. (2018))

**Findings**

- Sharp edges from rock discontinuities were rounded and smooth compared with lidar.
- Drone SfM outperforms lidar for seeing beneath sparse vegetation.
- In dense ground cover, however, lidar outperform drone SfM (active vs. passive light source).

### Table IV. Statistics regarding 3D geometric discrepancies between SfM- and TLS-derived 5 cm resolution 3D surfaces and the rock-slope total station (TS) points.

<table>
<thead>
<tr>
<th>Site</th>
<th>Type</th>
<th>Mean difference (m)</th>
<th>σ (m)</th>
<th>RMSE (m)</th>
<th>Error (95% confidence) (m)</th>
<th>% of surface in front of TS points</th>
</tr>
</thead>
<tbody>
<tr>
<td>RS1</td>
<td>Ground SfM</td>
<td>-0.001</td>
<td>±0.015</td>
<td>±0.015</td>
<td>±0.025</td>
<td>57.14</td>
</tr>
<tr>
<td></td>
<td>UAV SfM</td>
<td>-0.032</td>
<td>±0.041</td>
<td>±0.052</td>
<td>±0.084</td>
<td>82.69</td>
</tr>
<tr>
<td></td>
<td>Combo SfM</td>
<td>-0.006</td>
<td>±0.020</td>
<td>±0.021</td>
<td>±0.033</td>
<td>56.19</td>
</tr>
<tr>
<td></td>
<td>TLS</td>
<td>0.002</td>
<td>±0.009</td>
<td>±0.010</td>
<td>±0.015</td>
<td>41.90</td>
</tr>
<tr>
<td>RS2</td>
<td>Ground SfM</td>
<td>0.002</td>
<td>±0.024</td>
<td>±0.025</td>
<td>±0.040</td>
<td>48.98</td>
</tr>
<tr>
<td></td>
<td>UAV SfM</td>
<td>0.006</td>
<td>±0.029</td>
<td>±0.029</td>
<td>±0.047</td>
<td>36.73</td>
</tr>
<tr>
<td></td>
<td>Combo SfM</td>
<td>-0.001</td>
<td>±0.024</td>
<td>±0.024</td>
<td>±0.039</td>
<td>57.14</td>
</tr>
<tr>
<td></td>
<td>TLS</td>
<td>0.003</td>
<td>±0.009</td>
<td>±0.009</td>
<td>±0.015</td>
<td>31.25</td>
</tr>
<tr>
<td>RS3</td>
<td>Ground SfM</td>
<td>-0.001</td>
<td>±0.008</td>
<td>±0.008</td>
<td>±0.013</td>
<td>63.86</td>
</tr>
<tr>
<td></td>
<td>UAV SfM</td>
<td>0.013</td>
<td>±0.025</td>
<td>±0.028</td>
<td>±0.046</td>
<td>22.89</td>
</tr>
<tr>
<td></td>
<td>Combo SfM</td>
<td>-0.001</td>
<td>±0.011</td>
<td>±0.011</td>
<td>±0.017</td>
<td>53.01</td>
</tr>
<tr>
<td></td>
<td>TLS</td>
<td>0.001</td>
<td>±0.009</td>
<td>±0.009</td>
<td>±0.014</td>
<td>55.42</td>
</tr>
</tbody>
</table>

3 cm!!
SfM vs. Lidar

Figure modified from Carrivick et al. (2016)
Real-World Issues with Drone Deployment in Post-Disaster Settings

- In post-disaster settings, local officials may prohibit drone flights to accommodate for increased low altitude helicopter flights.

- Rules and regulations vary by country and must be checked before deploying for a foreign mission.

- Bad weather (e.g., rain, snow, fog) can ground flights, or produce poor quality images.

- Batteries must be hand-carried on flights; international carry on rules vary.

- *It is important to have a contingency plan in the event drones can not be used.*
SfM vs. Lidar

Benefits of SfM
- cheap
- lightweight/portable (very important in some settings)
- easy to learn
- draping of images make more visually appealing 3D models
- easy to make into ortho photographs
- works across spatial scales

Disadvantages of SfM
- still needs placement of GCP, or surveying
- less repeatable than lidar (user and camera factors)
- can not preview results in the field

* Use SfM when you desire a aerial overview of a large area
* Use SfM in lightweight reconnaissance of large features/scenes
* Use SfM to develop fast qualitative models

Benefits of lidar
- spatial extent/reach and thus speed
- active remote sensing, not dependent on light or time of day
- independent of surface texture
- multiple returns, and thus penetrates vegetation
- intensity returns (infer something about surface)

* Use lidar when you have a site where you can not (or do not want to) set up targets
* Use lidar when vegetation is present and bare earth models are needed
SfM Key References

British Geomorph. Soc., "Structure from Motion (SfM) Photogrammetry," Natan Micheletti, Jim H Chandler, Stuart N Lane


Pix4D user's manual (available in an online format); video modules also available

UNAVCO SfM resources: https://serc.carleton.edu/getsri/teaching_materials/high-rez-topo/unit1-sfm.html

Structure from Motion (SfM) Photogrammetry - Pix4D Capture

Note: Many images are from the Pix4D capture online manual

Joe Wartman
RAPID Facility Workshop
Seattle, Washington
NSF Award Number: CMMI 1611820
Pix4D Capture: Getting Started

- I-pad/I-phone (IOS) software (Android version also available)

- Pix4D Capture is free to use, but requires a user account

- RAPID has purchased a multiple seat license of Pix4D package (we can provide you with login information as needed)

- Select your drone model (will automatically import drone and camera settings/parameters)

- Capture images at full resolution
Pix4D Capture: Planning a Mission

- **Grid**, for making 2D/3D maps of rectangular area. Nadir (typically). Best for:
  - 2D map products (DSM/DEM for relatively flat surface, orthomosaic images).
  - Surveying large area (efficient and fast to fly)

- **Polygon**: As above, and best for: areas with flight boundary restrictions or featured/properties/zones to avoid

- **Double grid**: for cases where vertical relief and/or features are important (e.g., building facades, fault scarps with uplift, etc.). Oblique camera setting (typically). Takes twice as long to fly than grid. Best for:
  - Accurate 3D models
  - Smaller areas

- **Circular**: Fly around an object. Best for isolated objects and features. (Not commonly used)

- **Free flight**: Manual flight with auto-shutter based on horizontal distance (Expert use only)

Note that flights can be duplicated and then edited/altere
Angle of camera: nadir (down) or oblique, typically suggested as being about 70 deg. below horizontal.

Front Overlap: Suggested to range between 70% and 90%.

Side Overlap: Suggest to be 60%.

Picture trigger mode: Safe, the drone stops to take every picture which significantly increases the flight time and drawing battery power; and fast, images taken while drone is moving. May need to use safe mode in high winds and/or low light.

Drone speed: Ranges from slow (60% of the max. speed) to Fast (max. speed). Slower speeds reduce likelihood of blurry images. Speed can sometimes important in low light settings.

White balance: Selects between Auto (default), Sunny or Cloudy.

Ignore homepoint: Select yes to start the mission even if the homepoint is further than 150 meters from the grid's center (i.e., to "fly to" a distant mission that is far from set up area)

Look at center: Defines whether the drone should be oriented towards the center of the grid (yes) when taking pictures. Typically set to "No"
**Ground Sampling Distance (GSD)** is the distance between two adjacent pixel centers measured on the ground. The larger the GSD, the lower the spatial resolution of the image.

A GSD of 5 cm means that one pixel in the image represents linearly 5 cm on the ground (5*5 = 25 cm²).

Because of 3D terrain/relief, GSD may differ

\[
\text{GSD} = f(\text{sensor size, camera resolution, } h)
\]

Pix4D GSD integrated into app

Calculation at right from www.propelleraero.com

When you project each pixel onto the ground they’re not perfectly square, so when we calculate the GSD, we use the greatest (worst) of:

\[
\text{GSD}_h = \frac{\text{Flight Height} \times \text{Sensor Height}}{\text{Focal Length} \times \text{Image Height}}
\]

\[
\text{GSD}_w = \frac{\text{Flight Height} \times \text{Sensor Width}}{\text{Focal Length} \times \text{Image Width}}
\]

For example, let’s figure out the ground sample distance of a Phantom 4 Pro at 80m above the ground.

We know the following from DJI’s spec:

- Image Width: 5472px
- Image Height: 3078px
- Sensor Width: 13.2mm
- Sensor Height: 8mm
- Focal Length: 8.8mm

So substituting the values (in centimeters) into the formulas:

\[
\text{GSD}_h = \frac{8000 \times 0.8}{0.88 \times 3078} = 2.19
\]

\[
\text{GSD}_w = \frac{8000 \times 1.32}{0.88 \times 5472} = 2.36
\]

Then we use the worst case scenario, so in this case: GSD = 2.36 cm/px.
Pix4D Capture: Special Considerations

1. Fly beyond your area of interest

2. Have at least two lines for corridors

3. Have overlap between areas for large study regions
Pix4D Capture: Pre- and In-flight views

- It is strongly recommended to plan flights **BEFORE** you arrive to the field (you need an internet connection to see background image)

- Having access to the internet (e.g., hotspot, or tethering to phone) in the field can be helpful for required drone updates (typically updated to no-fly areas)
Pix4D Capture: Planning Exercise
Pix4D Capture: Planning Exercise

- ground control point (GCP)
- Optional GCP
- Optional checkpoint

- **We strongly encourage** teams to employ ground control (GCP).

- If there is not time for ground control (e.g. pre-hurricane deployment), capture and geotag in RApp visible features that can be later surveyed, if needed. Use temporary spray paint to make "targets" if allowed.
Structure from Motion Using
Pix4DMapper: User Guide
Updated: 24 July 2019
Drone Rules and Regulations

Jake Dafni
Operations Manager
University of Washington

Intensive Equipment Training Workshop

NSF Award Number: CMMI 1611820
Small Unmanned Aircraft Systems (UAS) or "Drone" Use in the U.S.

- Business and Research: Need a remote pilot certificate (RPC)
  - Operate under FAA Part 107 or a Certificate of Waiver or Authorization (COA)
- Hobbyist: Do not need an RPC

"Small" implies drones less than 55 pounds
Some of the FAA Basic Rules (14 CFR part 107)

Operating Rules

- **Class G** airspace
  - Class B, C, D – need authorization from air traffic control
  - Check with B4UFly App

- Stay within line-of-sight
- Fly under 400 feet
- Fly during daylight hours
- Yield right-of-way to manned aircraft
- Do not fly over people
- Do not pilot from a moving vehicle

*Can request a waiver for all of above*

https://www.faa.gov/uas
DJI Geo Zone Map

**DJI GEO Zones**

- **Restricted Zones**: In these zones, which appear red on the DJI GO app, users will be prompted with a warning and flight is prevented. If you believe you have the authorization to operate in a Restricted Zone, please contact flysafe@dji.com or Online Unlocking.

- **Altitude Zones**: Altitude zones will appear in gray on the map. Users receive warnings in DJI GO, or DJI GO 4 and flight altitude is limited.

- **Authorization Zones**: In these zones, which appear blue in the DJI GO map, users will be prompted with a warning and flight is limited by default. Authorization Zones may be unlocked by authorized users using a DJI verified account.

- **Warning Zones**: In these Zones, which may not necessarily appear on the DJI GO map, users will be prompted with a warning message. Example Warning Zone: Class E airspace.

- **Enhanced Warning Zones**: In these Zones, you will be prompted by GEO at the time of flight to unlock the zone using the same steps as in an Authorization Zone, but you do not require a verified account or an internet connection at the time of your flight.

- **Densely Populated Area**: This area is shown in red on the map. Under normal circumstances, the population of this area is more concentrated, so please do not fly over this area. (Example: Commercial Block)

- **Regulatory Restricted Zones**: Due to local regulations and policies, flights are prohibited within the scope of some special areas. (Example: Prison)

- **Recommended Zones**: This area is shown in green on the map. It is recommended that you choose these areas for flight arrangements.

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https://www.dji.com/flysafe/geo-map
Can call 877-487-6867 for NOTAM
Warns other pilots to avoid area and elevations you will fly
Provide coordinates with a radius, time/date, and flight height, as well as pilot information

Can search for NOTAMS here:
- [https://pilotweb.nas.faa.gov/PilotWeb/](https://pilotweb.nas.faa.gov/PilotWeb/)

Can also find temporary flight restrictions here:
- [https://skyvector.com/](https://skyvector.com/)
Additional Basics (14 CFR part 107)

Aircraft
◆ Less than 55 lbs
◆ Must be registered
  https://www.faa.gov/uas/getting_started/register_drone/

Remote Pilot Certificate
◆ Easily accessible during UAS operations
◆ Valid for 2 years
  o Must pass a recurrent knowledge test
Becoming a Drone Pilot: U.S. Requirements

- At least 16 years old
- Read, speak, write, and understand English
- Physically and mentally able to operate a small UAS
- Pass initial aeronautical knowledge exam at FAA-approved knowledge test center (KTC)
Becoming Pilot: Application Process

Step 1: Schedule an appointment with a KTC

- [https://www.faa.gov/training_testing/testing/media/test_centers.pdf](https://www.faa.gov/training_testing/testing/media/test_centers.pdf)

- Bring government issued ID with current address (or some proof of current address) to the test

- Cost ~ $150
Step 2: Pass the test!

- Unmanned Aircraft General (UAG)
- FAA-CT-8080-2G supplied for test
- 2-hour exam
- 60 multiple choice questions
- Need 70% correct to pass
- Immediate Results
Step 2: Pass the test!

Test Topics:

- Applicable UAS regulations
- Airspace classification and rules
- Weather sources and effects
- UAS loading and performance
- Emergency Procedures
- Crew Resource Management
- Radio Communication Procedures
- Determining Performance of UAS
- Physiological effects of drugs and alcohol
- Aeronautical decision-making and judgment
- Airport operations
- Maintenance and preflight inspection procedures
Becoming Pilot: Application Process

Step 2: Pass the test!

Study Resources:

◆ UAG Knowledge Test Study Guide
◆ Part 107 Advisory Circular (AC No 107-2)
◆ Code of Federal Regulations
  o Title 14, Chapter I, Subchapter F, Part 107
◆ Aeronautical Chart User’s Guide
◆ UAG Knowledge Test Sample Questions
  o Will need Airman Knowledge Testing Supplement for Sport Pilot, Recreational Pilot, and Private Pilot (FAA-CT-8080-2G)
Becoming Pilot: Application Process

Step 3: Complete FAA Form 8710-13

◆ Register using the FAA Integrated Airman Certificate and/or Rating Application (IACRA) system

◆ Login and start new application
  - Type: Pilot
  - Certifications: Remote Pilot

◆ Enter 17-digit Exam ID
  - Can take 48 hours from test date to appear

◆ Sign electronically
Becoming Pilot: Application Process

**Step 4:** TSA background check
- Once complete, will receive a temporary pilot certificate

**Step 5:** Permanent remote pilot certificate sent in the mail
Beyond the FAA regulations

- FAA Part 107 or COA is not enough – need to be aware of additional city, county, and public works agency have their own rules and regulations for which you MUST be aware and comply

- Additional regulations vary by country – figure them out first, collaborate with locales, have documentation with permissions.
  - https://droneregulations.info/

- Even then, local law enforcement entities may shut you down.
Beyond the FAA regulations

◆ National Park Service does not allow drones
◆ Drones have been shown to cause distractions to drivers
  o Operate away from highway
  o Do not fly directly over road surface
  o Provide warning signage
◆ Be aware of privacy laws and best practices
  o Inform people if possible
  o Don’t fly over private property unnecessarily
  o Secure data against loss or theft
  o Don’t harass people
  o More info: http://knowbeforeyoufly.org/uas-best-practices/
In post-disaster settings, local officials may prohibit drone flights to accommodate for increased low altitude helicopter flights.

Bad weather (e.g., rain, snow, fog) can ground flights, or produce poor quality images.

Batteries must be hand-carried on flights; international carry on rules vary.

*It is important to have a contingency plan in the event drones cannot be used.*
Wrap Up, General Questions and Answers
Where to go from here?

• We will send a link to workshop slides and data via a google drive link; we will also set up a Designsafe folder.

• We will place workshop photos on the Designsafe folder (if you have any others you wish to contribute, please load them to the folder)

• We will send you travel reimbursement worksheet instructions via e-mail

• If you are interested in reconnaissance research, join GEER, SSEER, Steer or other organizations that lead and participate in field missions—but know too that you may organize your own reconnaissance missions and access RAPID instrumentation.

• Think about how reconnaissance can help answer your research questions, and how reconnaissance can be used to address the challenges and methods outlined in the science plans.

• Be in touch with us about any questions or suggestions (we are here to support your science). Become familiar with our web resources. (Contact NSF with rapid-mechanism specific questions).

• Stay in touch with each other. We need a robust natural hazards research community. Follow us on Twitter: @NHERI_RAPID & Facebook: @RAPIDNaturalHazardsRecon

• Use and re-use the open data developed by past, current, and future reconnaissance missions.

• Please... complete our workshop evaluation & demographics survey (for NSF reporting). How can we improve the workshop in future years?

• Spread the word about the RAPID facility (and our summer workshop program)!

• Thank you NSF, RAPID staff, Instructors, REUs, Designsafe, and... all of YOU!