# *Snow depth estimation using UAV-based LiDAR and photogrammetry*

*(And my research experience in Tasmania)*

Ben Vander Jagt

EGLR Fall Technical Meeting
10/25/2013

# Outline

- Why is snow important
- Overview of NSF EAPSI fellowship in Tasmania
- Data collection
- Methods
  - Photogrammetry
  - Computer Vision
  - Statistics
  - Calculus


- Results

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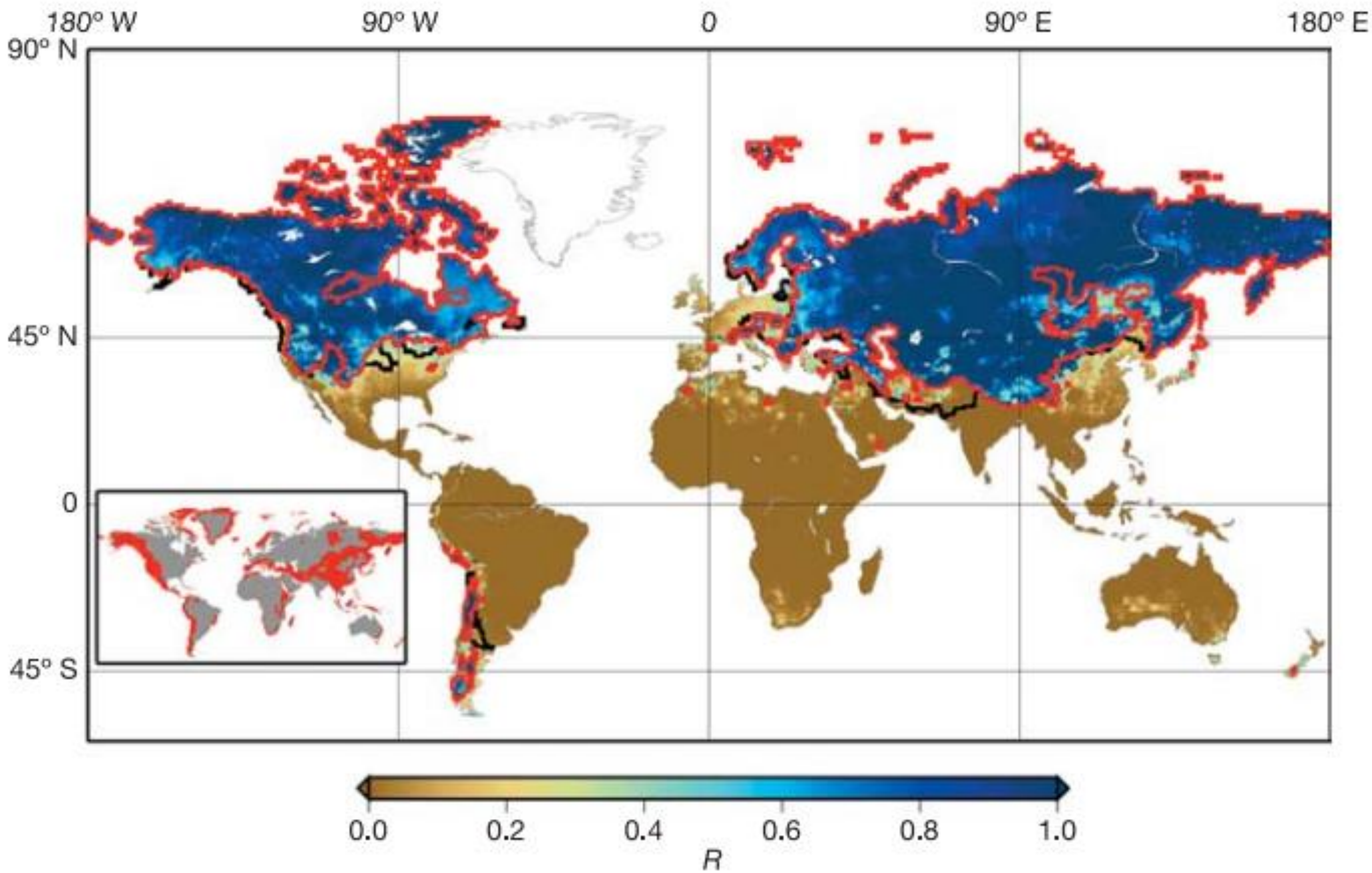
# Background




Snowfall divided by annual runoff (Barnett et al. *Nature*, 2005)

# Background

- Water is life, snow is water.
  - Municipal water supply (75% for Western States)
  - Agriculture
  - Recreation

- Think of snow as a reservoir
  - releasing water when needed most.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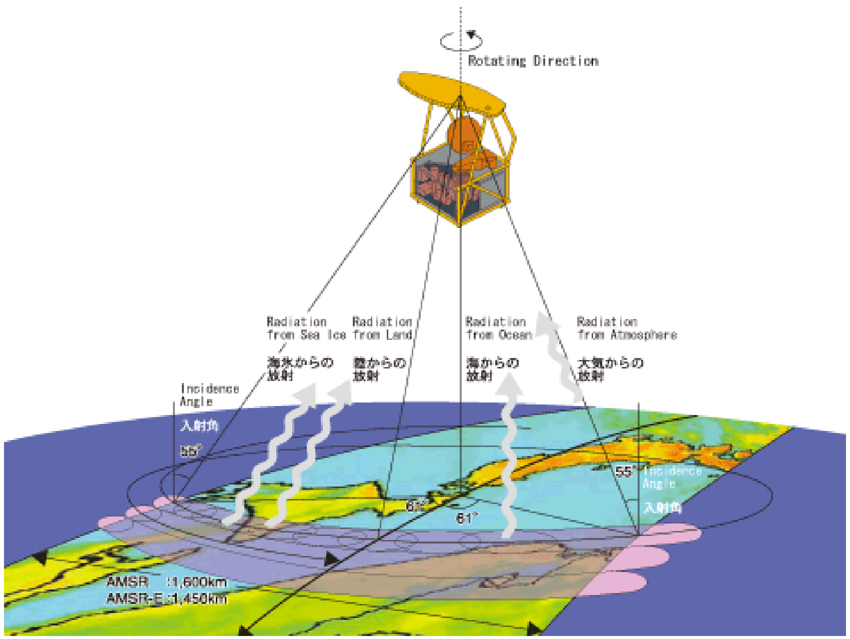
# Background

Dissertation focused on *<u>remotely</u>* estimating snow depth/water equivalent

- Hand measurements not very efficient!




- ✓ Mainly use spaceborne passive microwave techniques
  - Coarse resolution (8x14 km).
  - Physics are difficult; scaling problems.
  - Lets go <u>micro</u>!

# Unmanned Aerial Vehicles (UAV's)

- Lower cost
- Easy to maintain
- Excellent for boring and/or dangerous data collection.
- High Resolution!

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# Host Researcher

Arko Lucieer

*University of Tasmania*

*Hobart, Tasmania, Au*

Lab group- **Terra Luma**

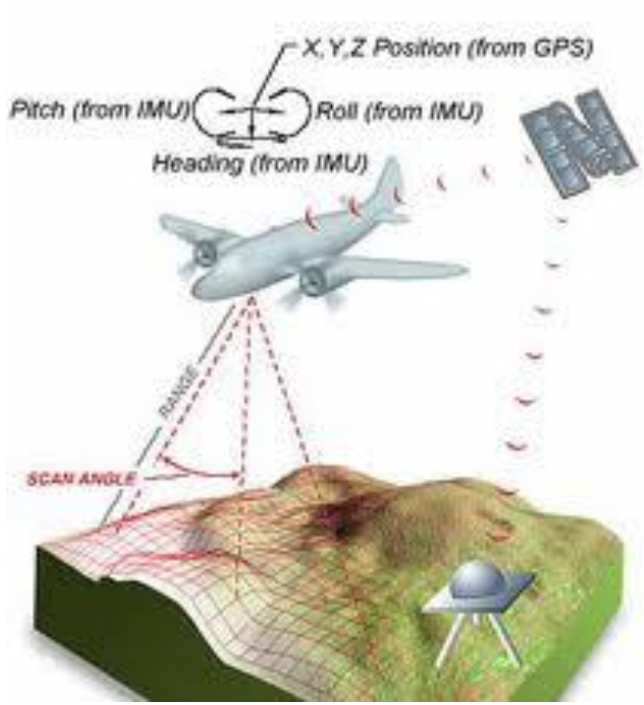
**Specialize in UAV-based remote sensing**

TERRALUMA

# Purpose

1. **To use Lidar and photogrammetric techniques aboard a UAV to determine snow depth**
   - Cost effective ✓
   - High Resolution ✓
   - High Accuracy?

2. Related to #1, **accurately georeference the point cloud, using GPS/IMU, ground control, and photogrammetry methods**.



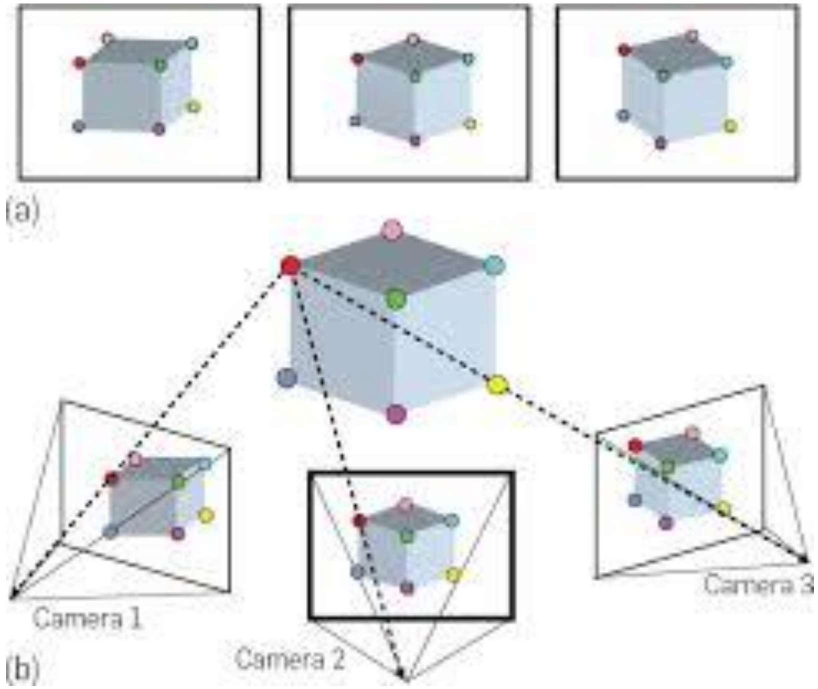

# LiDAR

- ***Laser ranging****- instrument sends light pulse, waits for return. Records time of travel.*

- Need to know position and orientation of instrument to to do accurate mapping.

- Timing is <u>very important</u>

- Expensive technology in mapping industry- ~$500,000
- Automotive grade lidar systems available- ~$10,000… ***<u>lightweight</u>***




# Photogrammetry

- *determining geometric properties of objects from images*
- Need > 1 images to reconstruct 3D
- Been around for ages, still a hot topic.

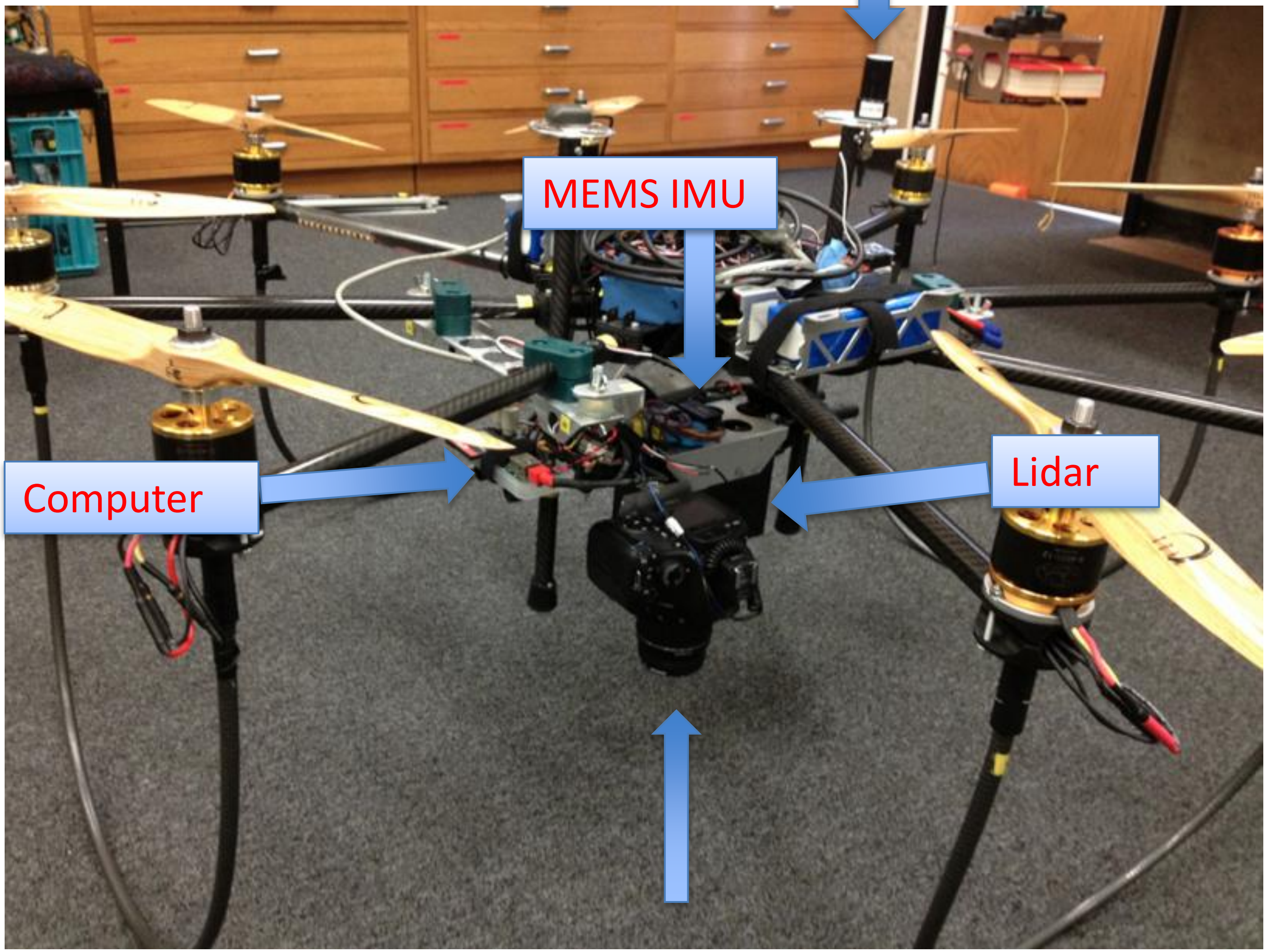
# Components

1. Octocopter
2. Dual Frequency GPS reciever (and base station)
3. Microstrain IMU (MEMS)
4. Canon DSLR Camera
5. Ibeo Lux Lidar



# Octocopter

GPS




DSLR Camera

# Study Site

*Lat: -42.68 S     Lon: 146.59 E*

## Mount Field Nat'l Park

At base of Mount Mawson/Lake Dobson


*"One of two mountains in Tasmania with downhill ski facilities"*

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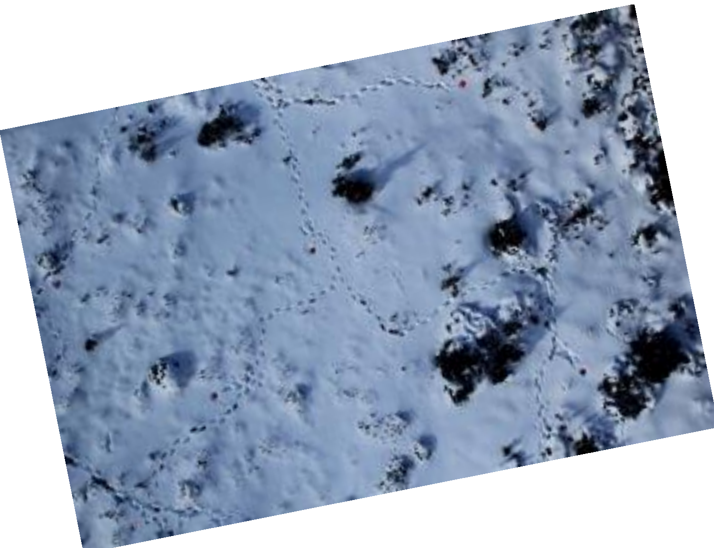
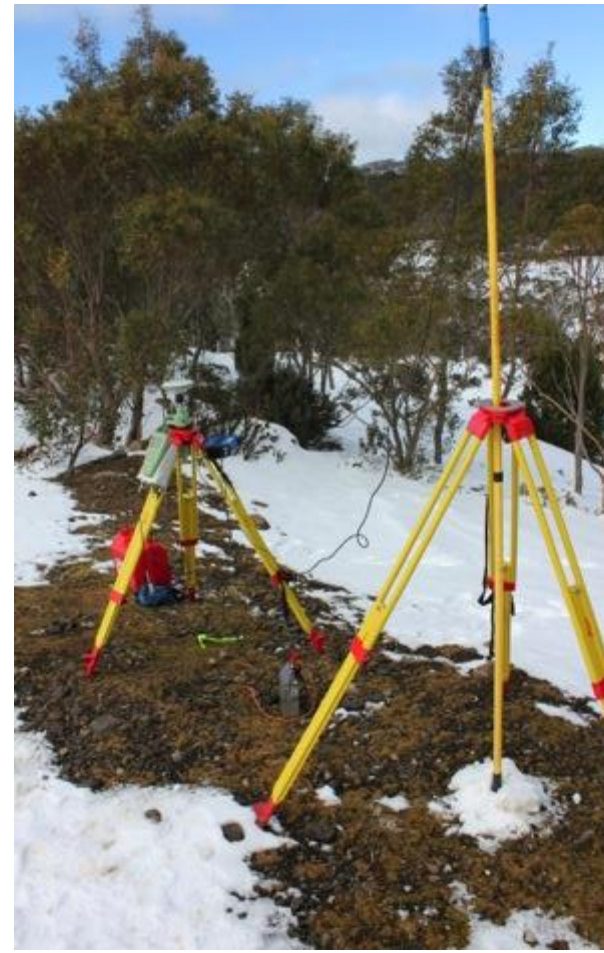
# Data Collection





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# Set Ground Control

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# Survey Ground Control

# Pray (that UAV doesn't crash)

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# Fly UAV (Lidar and Photogrammetry)

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# Work with the local indigenous wildlife

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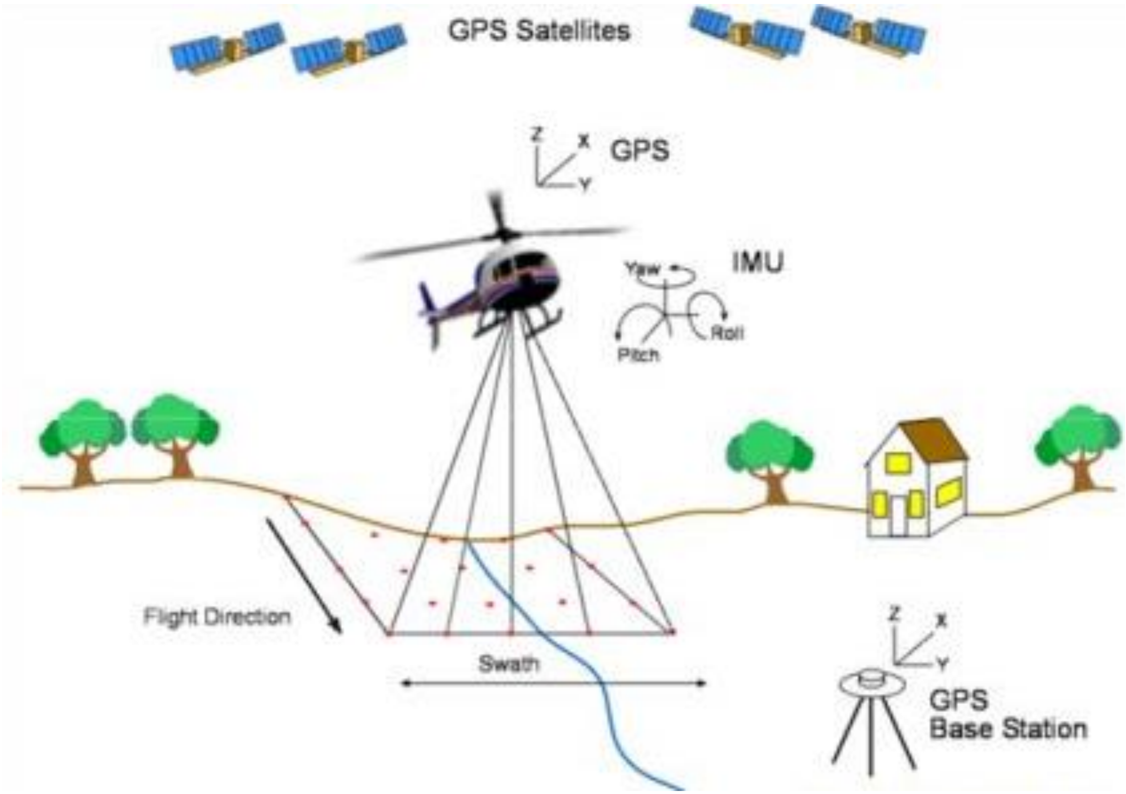
# Original Methodology




GPS – X, Y, Z

IMU- pitch, roll, yaw

Kalman Filter (GPS + IMU)

**DIRECT GEOREFERENCING**

Lidar Equation Form --->

$$\begin{bmatrix} x \\ y \\ z \end{bmatrix} = p_t + R_b^m [R_s^b r^s + a^b]$$

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# Original Methodology

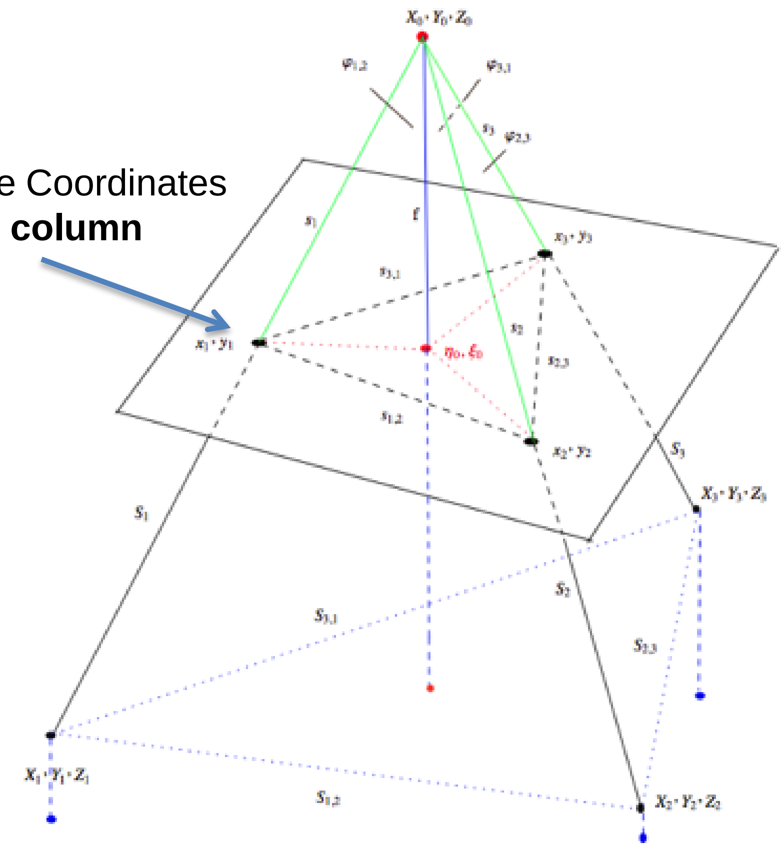
- Use onboard GPS-IMU for initial point cloud generation

- Use Ground Control Points (GCP's) to determine accuracy of navigation system
  - This requires adequate ground control in each image.
  - It also requires tracking the control through each image (otherwise I have to make manual measurements on 1000 images!)
  - Bundle adjustment

- Evaluate GPS/IMU accuracy

Camera Position
**Xo,Yo,Zo,ω,ϕ,κ**

Image Coordinates
**Row, column**



GC
P

GC
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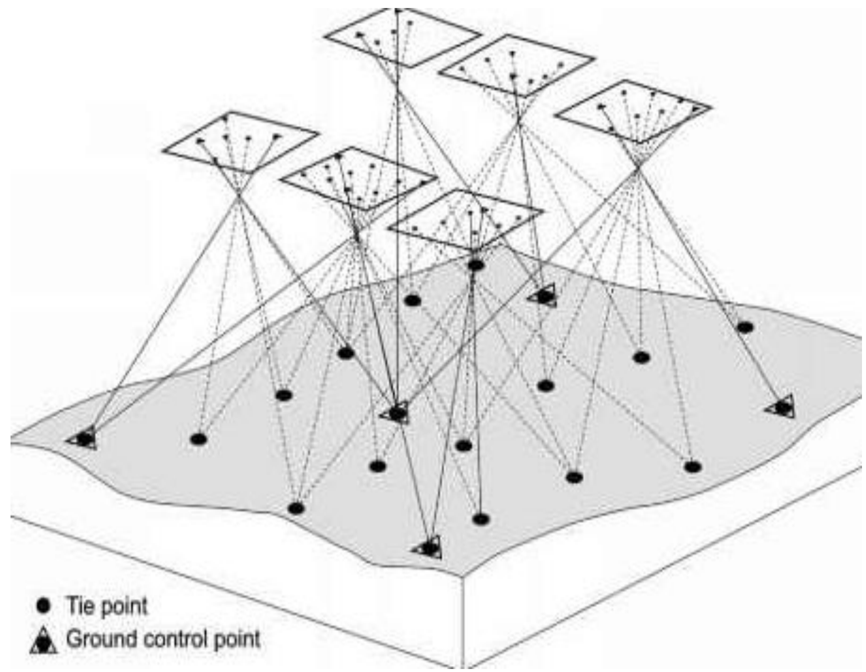
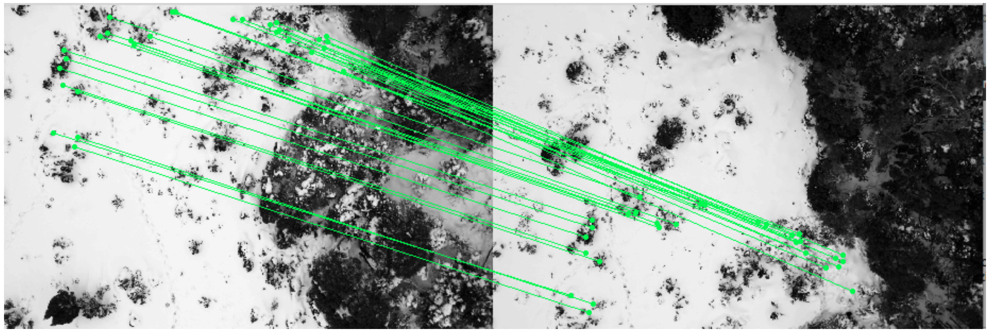
# Bundle Adjustment

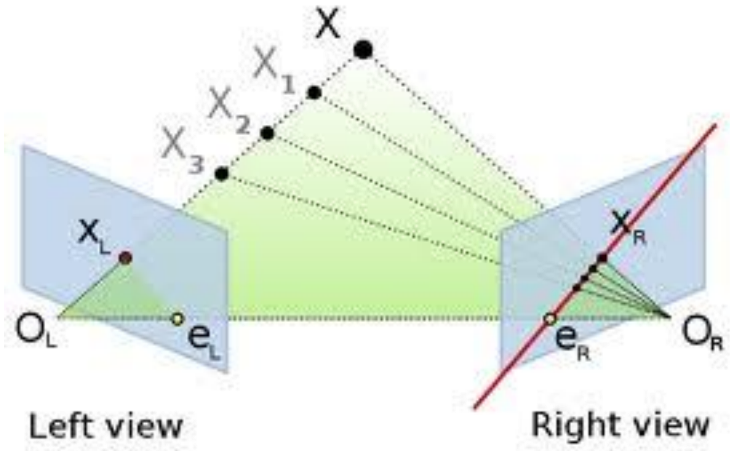
- Technique has been around for a while
  - Lots of *recent* development in computer vision community.
  - Optimization for non-linear iteration
- Useful with large strips of photos.
  - Minimize reprojection error over whole block.
- Typically GCP's are used.
  - NOT NECESSARY, used EOP's directly. **($X_o$,$Y_o$,$Z_o$,$\omega$,$\phi$,$\kappa$)**



# Bundle Adjustment

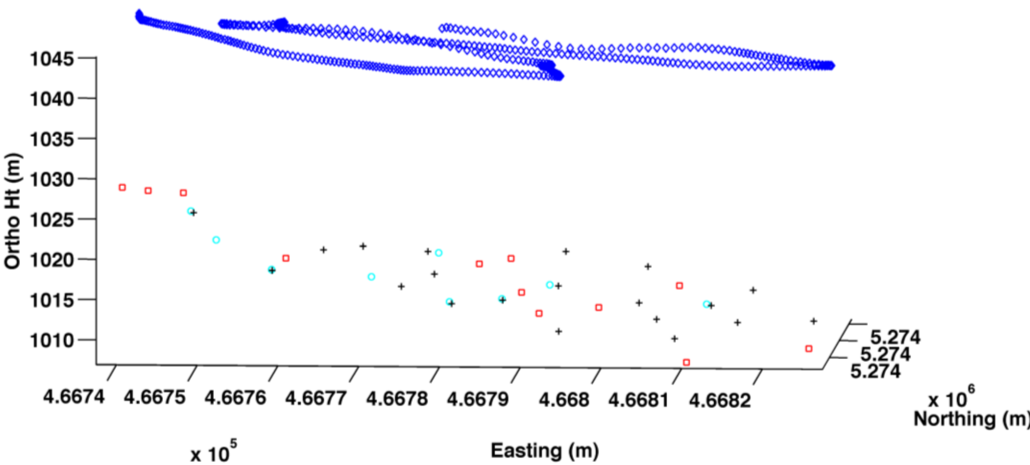
- Use epipolar geometry to match overlapping pixel from images once camera pose is known.
- **Problem** – *Snow is homogeneous, difficult to match pixels*.
- Solution- Do UAV's fly low enough for adequate image texture?
- Use photogrammetric intersection to estimate "real world" 3D coordinates of snow surface

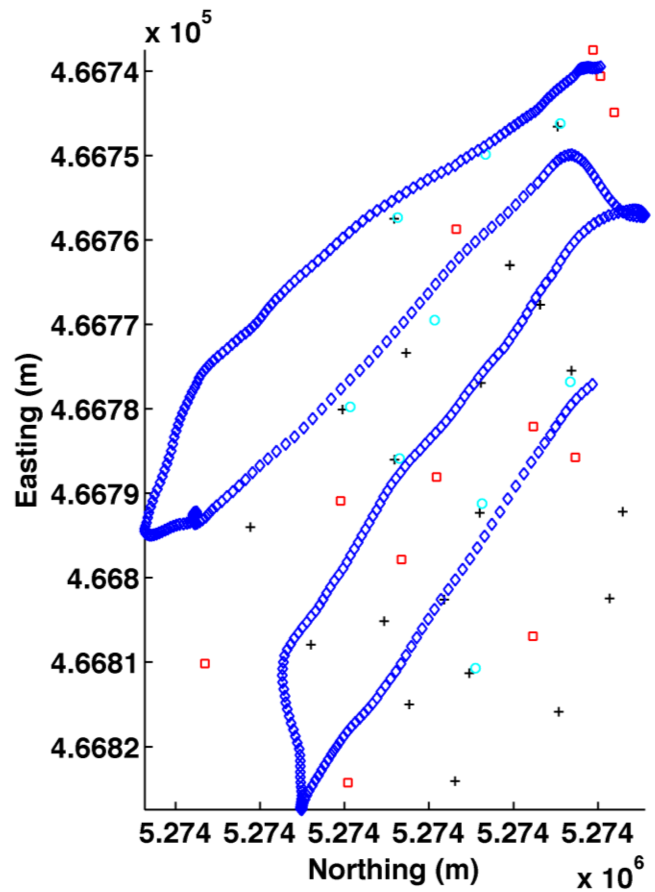





Epipolar Geometry

# Flight Paths



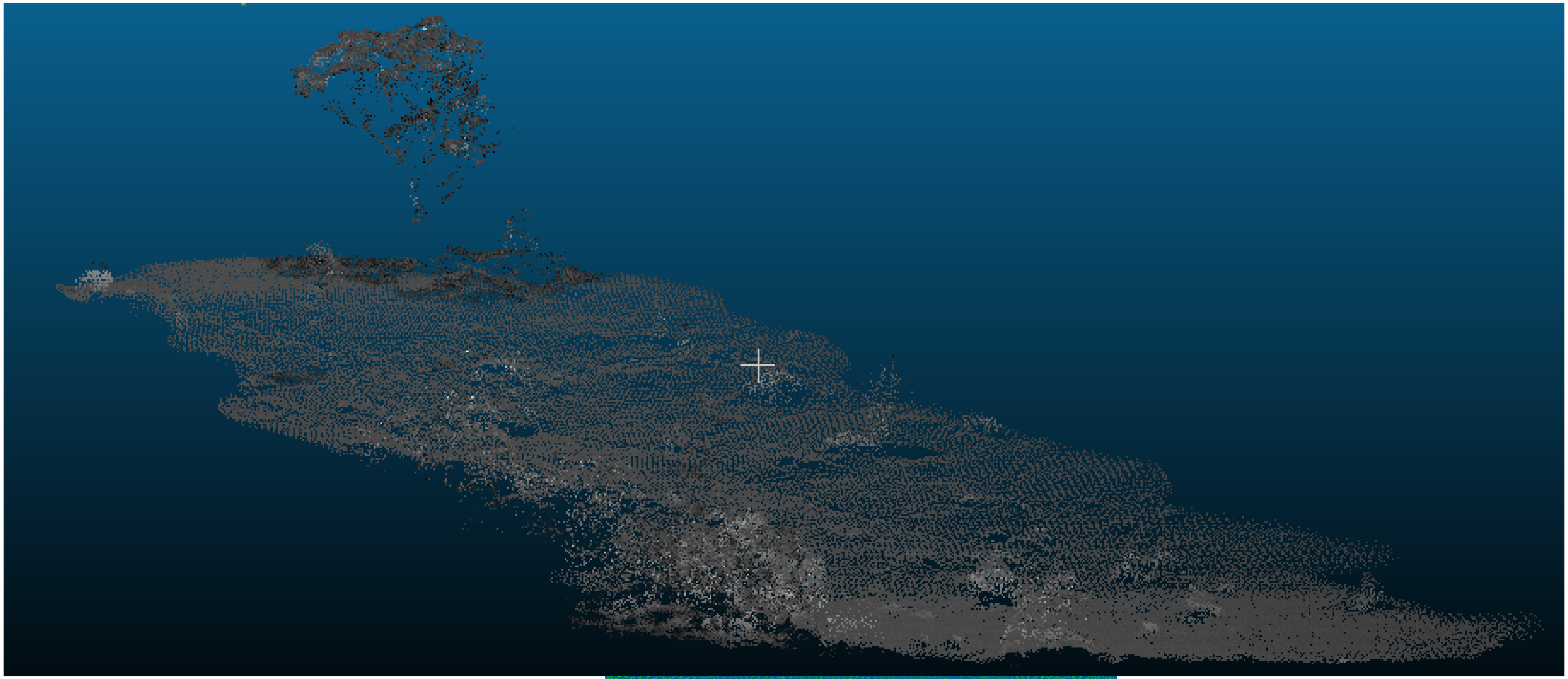

- **3 Flights Total**
  - Redudancy purposes
  - Forgot to turn on camera for second flight

Camera operating at ~3.5 Hz…lots of images!

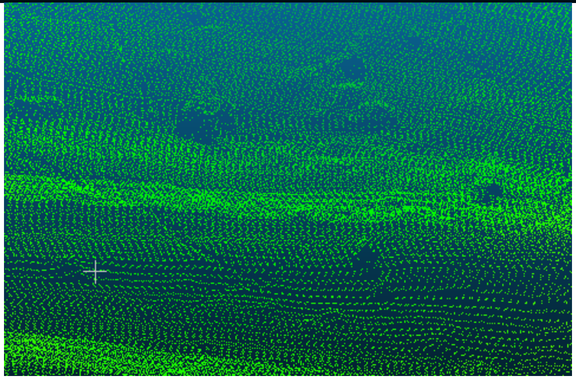
Lidar (500,000 points)

Heaps of Data!!!

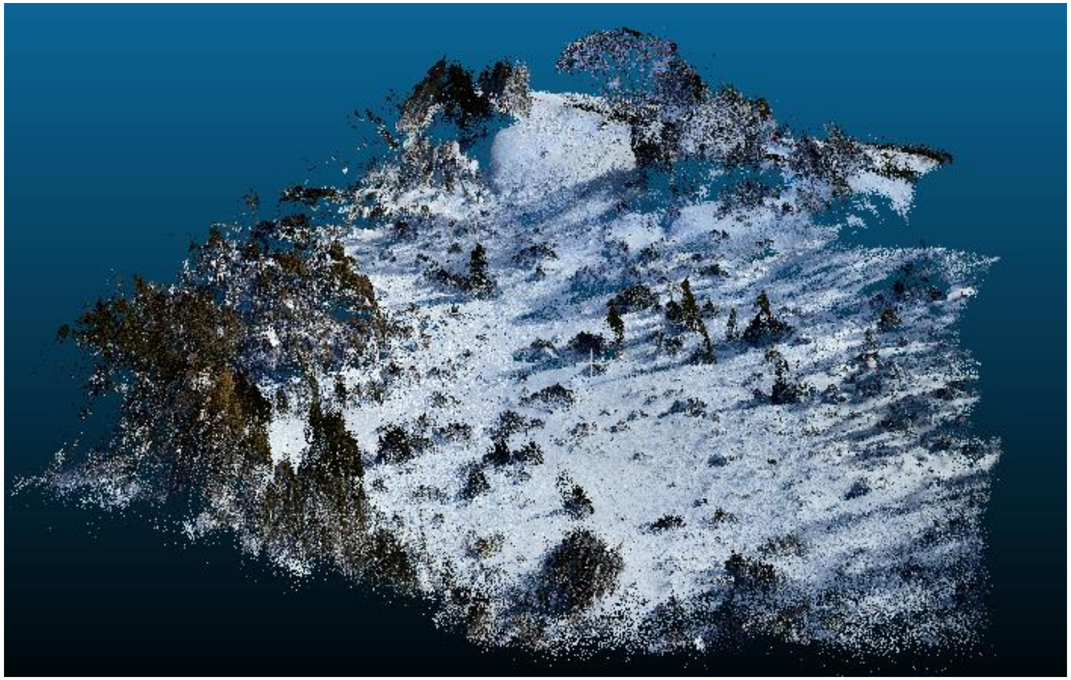
# Lidar Point Cloud

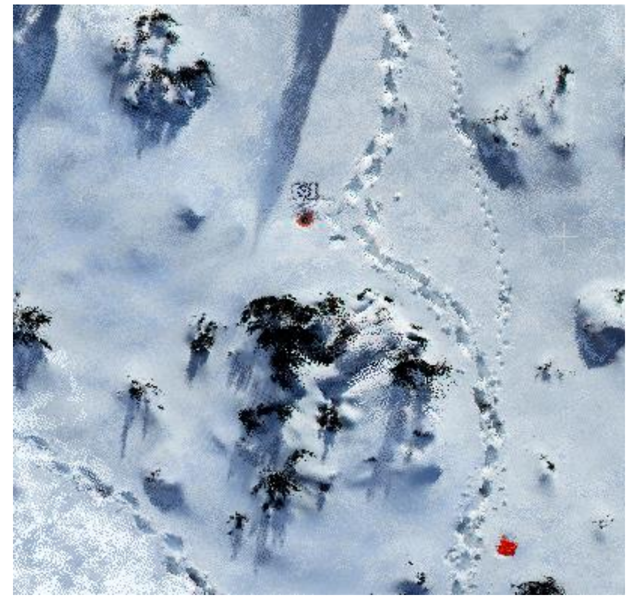


Footprints



# Photogrammetric Point Cloud





*111 million points!*

Sparse → Dense

# **Results thus far** (snow surface)

| | Lidar | Indirect BA (truth) | Direct BA |
|---|---|---|---|
| **X** | 0.047 m | 0.05 m | ~0.05 m |
| **Y** | 0.056 m | 0.041 m | ~0.05 m |
| **Z** | 0.123 m | 0.052 m | 0.19 m |

Lidar error in vertical **is biased** by ~12 cm (GPS/IMU), horizontal good

Direct BA is biased by ~19 cm in the vertical (camera positions biased)

Assuming the bias is repeatable, the 1σ error in total snow depth is **9 cm** for lidar measurements.

# Lever arm discrepancy

$$r_c^m = R_{wfk} \begin{bmatrix} X_{ant}^m - X_{cam}^m \\ Y_{ant}^m - Y_{cam}^m \\ Z_{ant}^m - Z_{cam}^m \end{bmatrix}$$

$$R_{wfk}^{-1} r_c^m = \begin{bmatrix} X_{ant}^m - X_{cam}^m \\ Y_{ant}^m - Y_{cam}^m \\ Z_{ant}^m - Z_{cam}^m \end{bmatrix}$$

**Known**

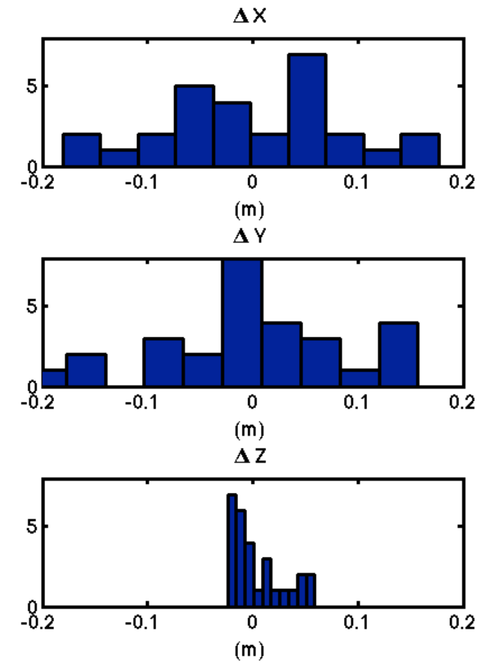
Xo,Yo,Zo (camera)

ω,φ,κ (camera)

X,Y,Z (GPS antenna)

**Unknown**

Lever arm (dX,dY,dZ)




$Ax = y$ **(linear)**

$$y + Ax = 0$$

$$x = (A'A)^{-1} A'y$$

Large errors in X,Y, less in Z (not much Z variation)

- Timing issue?
- Camera Calibration (temperature)?
- Gross mathematical misconduct on my part?

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# Conclusion

- Snow can be effectively mapped with a UAV (in theory)
  - Better stochastic modeling of errors
- Two complimentary methods can be used for point cloud generation
  - Lidar
  - Photogrammetry (via BA)
- Improving UAV and sensor technology will improve accuracy, scale, and reliability
- <u>The world **will** be a better place</u>