Unmanned Aerial Systems (UAS) for Snow Science: Shared Lessons for Pushing the Envelope

So you think you want to use a UAS for your research…

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This material is based upon work supported by the Broad Agency Announcement Program and the Cold Regions Research and Engineering Laboratory (ERDC-CRREL) under contract number W913E5-18-C-0005. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the Broad Agency Announcement Program and the Cold Regions Research and Engineering Laboratory (ERDC-CRREL).

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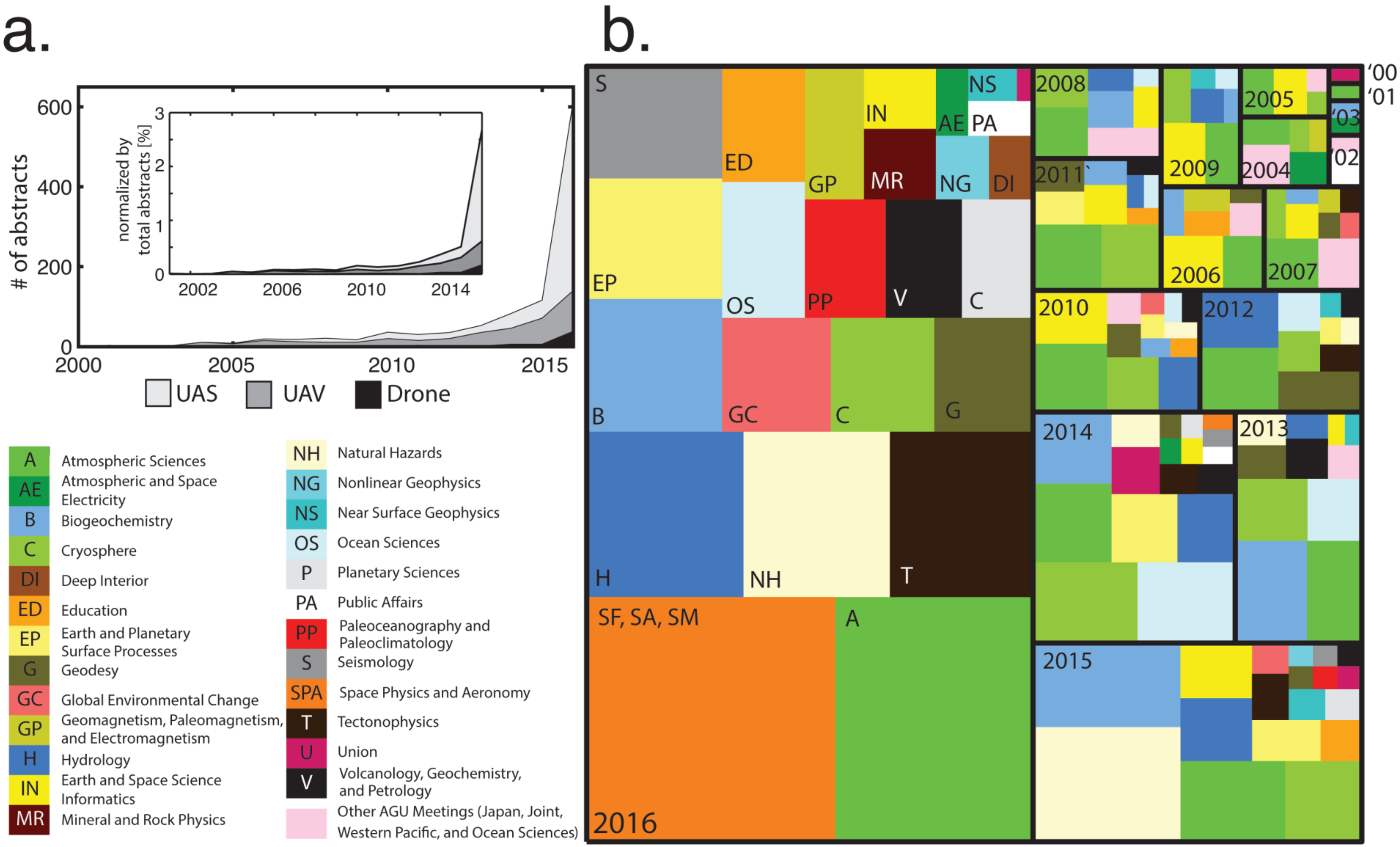
Drones Transforming Earth Sciences



Kelleher, C., C. A. Scholz, L. Condon, and M. Reardon (2018), Drones in geoscience research: The sky is the only limit, Eos, 99, https://doi.org/10.1029/2018EO092269.

Drones Transforming Earth Sciences

1. Drones characterize topography

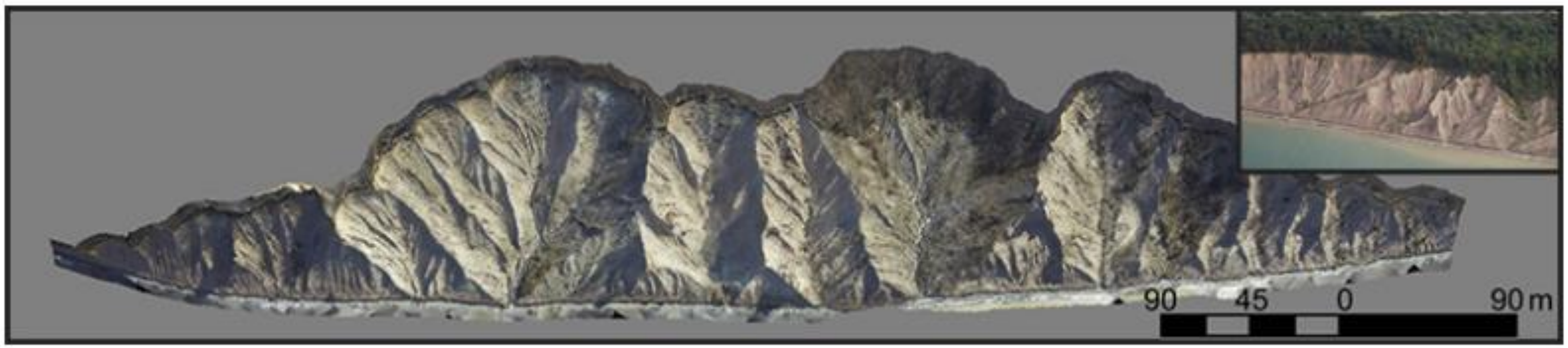


Fig. 2. A 3-D model produced using SfM photogrammetry obtained at Chimney Bluffs State Park in New York. Note the badlands landscape produced by severe shoreline erosion of Pleistocene age drumlins. The inset shows an aerial view of this type of topography on the southern Lake Ontario shoreline at Chimney Bluffs State Park. Credit: Main imaget: P. Cattaneo, J. Corbett; Inset: C. Scholz

1. Drones assess hazardous or inaccessible areas.
2. Drones image transient events.

A small tributary of the Clauge River, Jura, France, during the dry period. Credit: B. Launay

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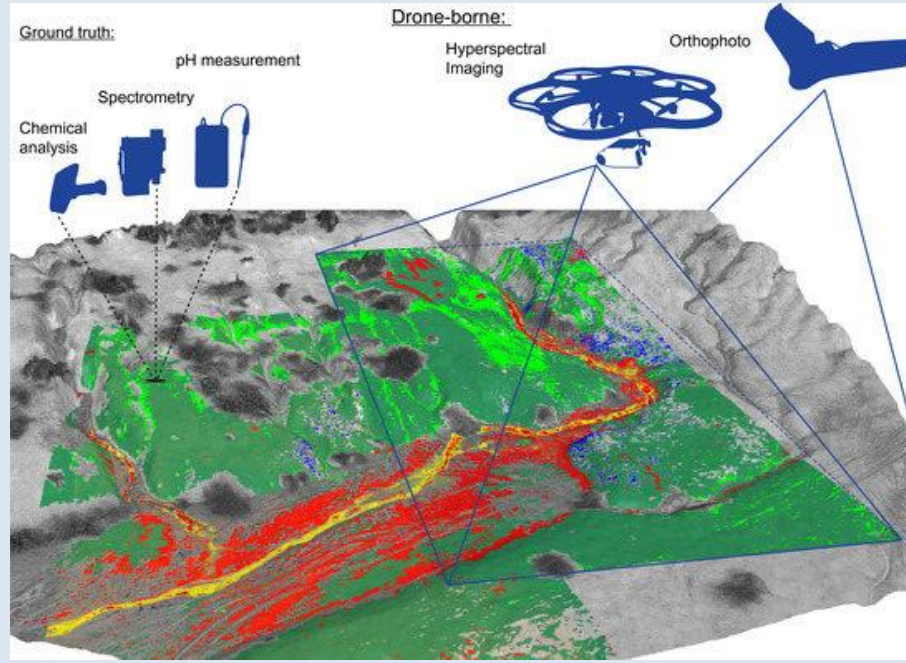
Drones Transforming Earth Sciences

4. Drones contextualize satellite and ground-based imagery
5. Drone imagery validates computational models
6. Drones make the world a better place



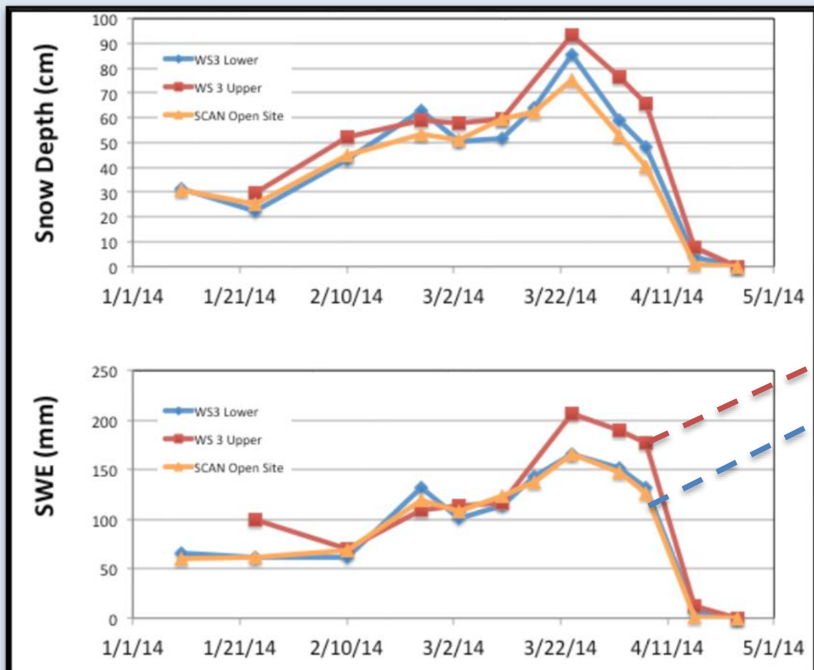
Acid mine drainage
Jackisch, R.; Lorenz, S.; Zimmermann, R.; Möckel, R.; Gloaguen, R. Drone-Borne Hyperspectral Monitoring of Acid Mine Drainage: An Example from the Sokolov Lignite District. Remote Sens. 2018, 10, 385.

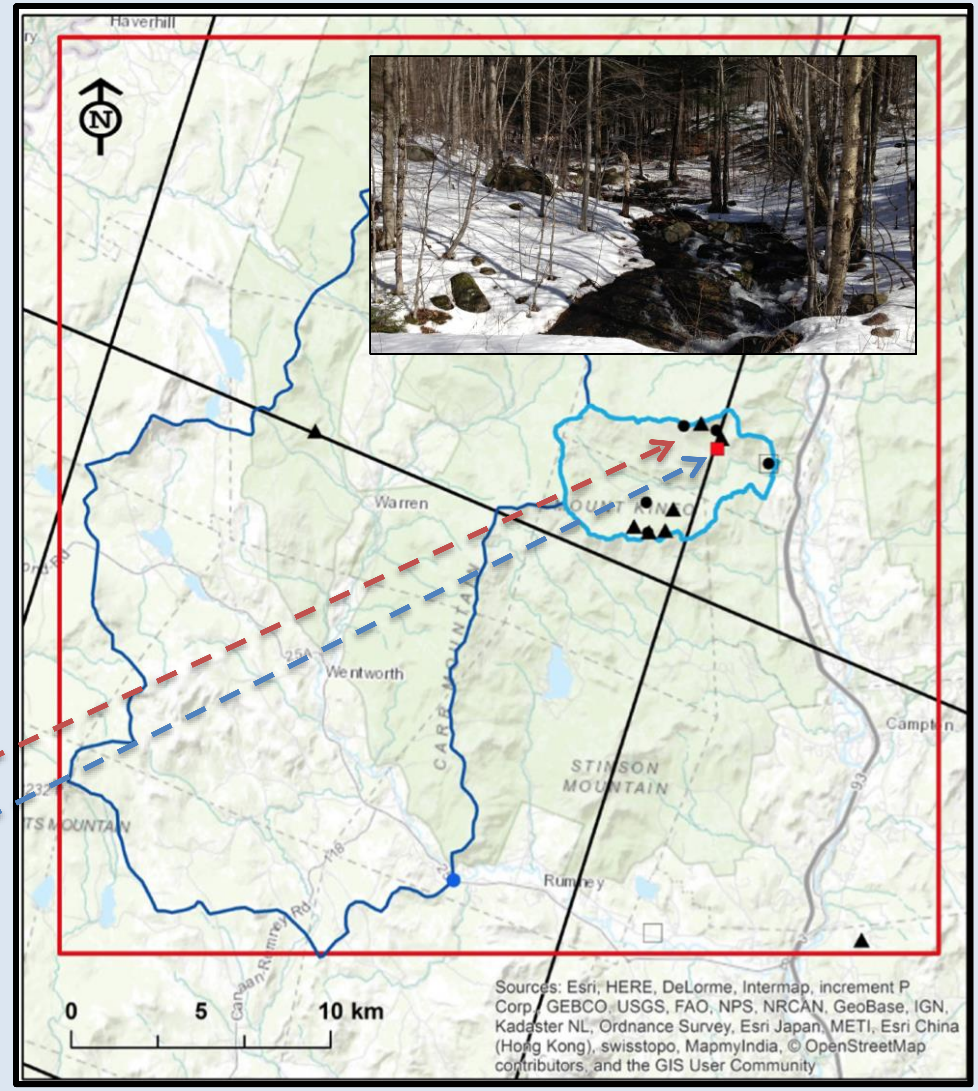
A remotely controlled quadcopter carries a temperature-sensing fiber-optic cable to investigate atmospheric mixing in an active wind farm.
Credit: Robert Predosa

Fiber Optic Carrying https://ctemps.org/uas

Motivation

Spatial Scale Mismatch Between Snow Depth and Snow Water Equivalent Observations via In Situ (pt) and Satellite (25 km x 25 km)





Motivation

High Cost of In Situ Observations

Weekly snow surveys at 5 locations

Wireless-network of snow depth sensors

Hand-logged and data-logged snowpack temperature profiles ground to 1 m at 10 cm intervals; 1 min resolution

Motivation

UAS observations can see this…

Motivation

UAS observations can see this…

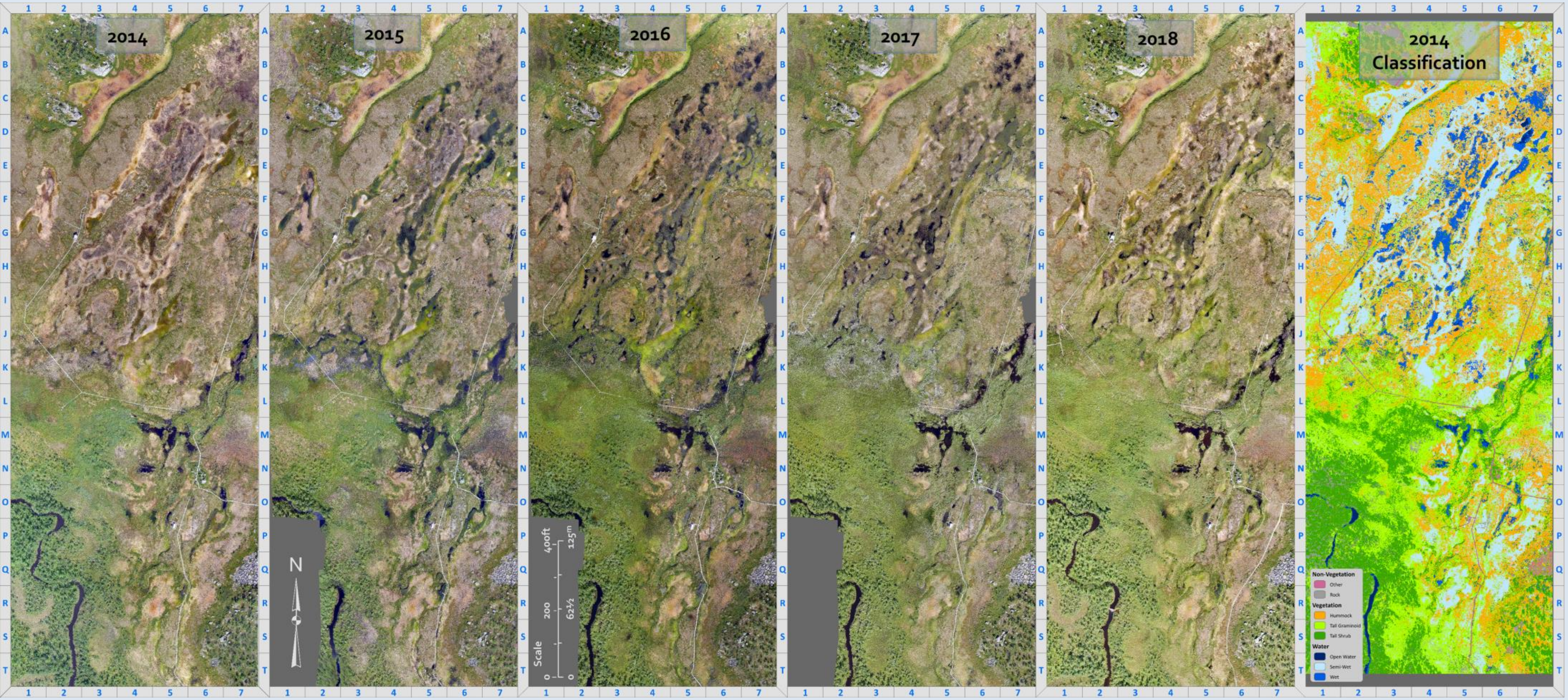
Goal: Characterize subpixel snow depth and spectra

Approach: Buy a drone and sensors, then magic happens

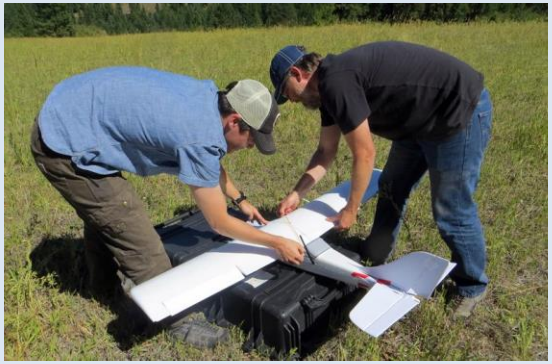
Lesson 1: Don't Skimp on the Team Expertise

Drones Transforming Earth Sciences

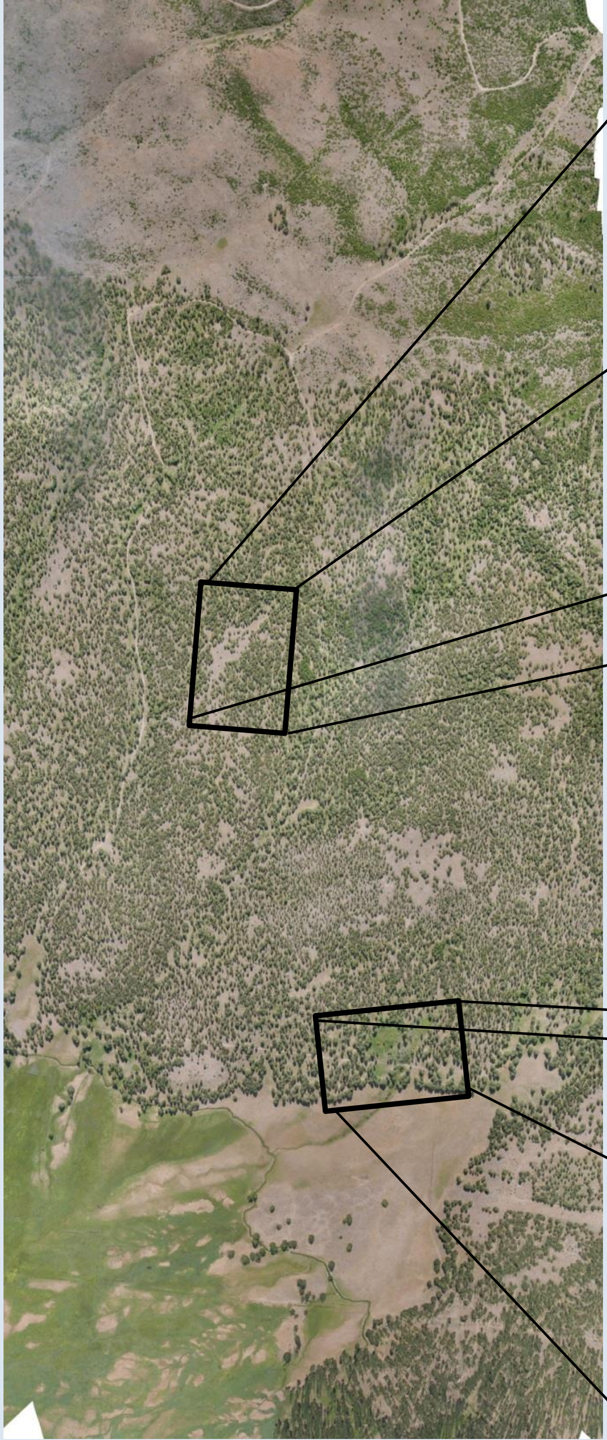
Mire Vegetation Classification

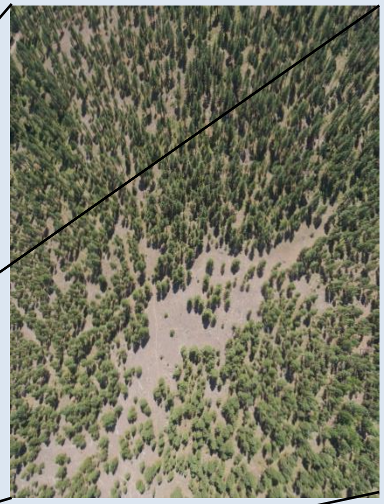


Palace M, C. Herrick, J. DelGreco, D. Finnell, A. Garnello, C. McCalley, K. McArthur, F. Sullivan, R. Varner, Determining Subarctic Peatland Vegetation Using an Unmanned Aerial System (UAS). *Remote Sensing*, **2018**, 10 (9), 1498. doi:10.3390/rs10091498.

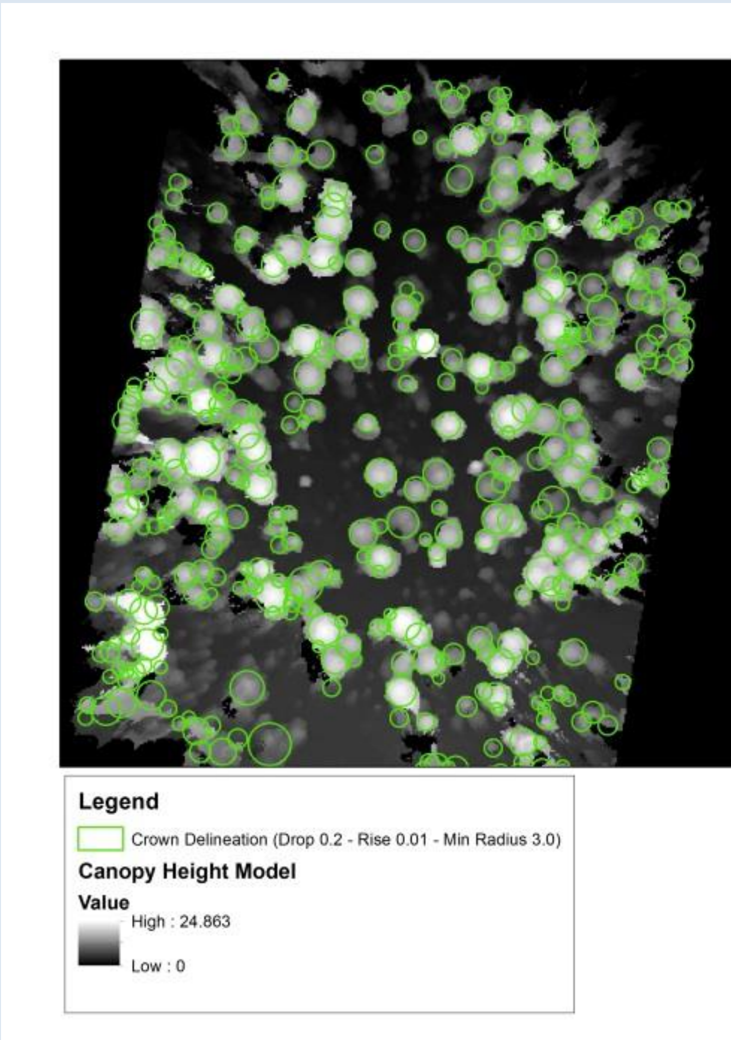


Fixed-wing Automated Flight Plan Robota.com





Unmanned aerial system image collected using a Robota Triton XL fixed-wing and a Panasonic Lumix-GM. Image is a composite of 700 images with overlap allowing for parallax analysis of tree heights. Image size is approximately 6 km by 1.5 km.



Exported x,y,z information from parallax image used to generate a canopy height model with a crown delineation algorithm applied.

UNH Unmanned Aerial System (UAS) Center

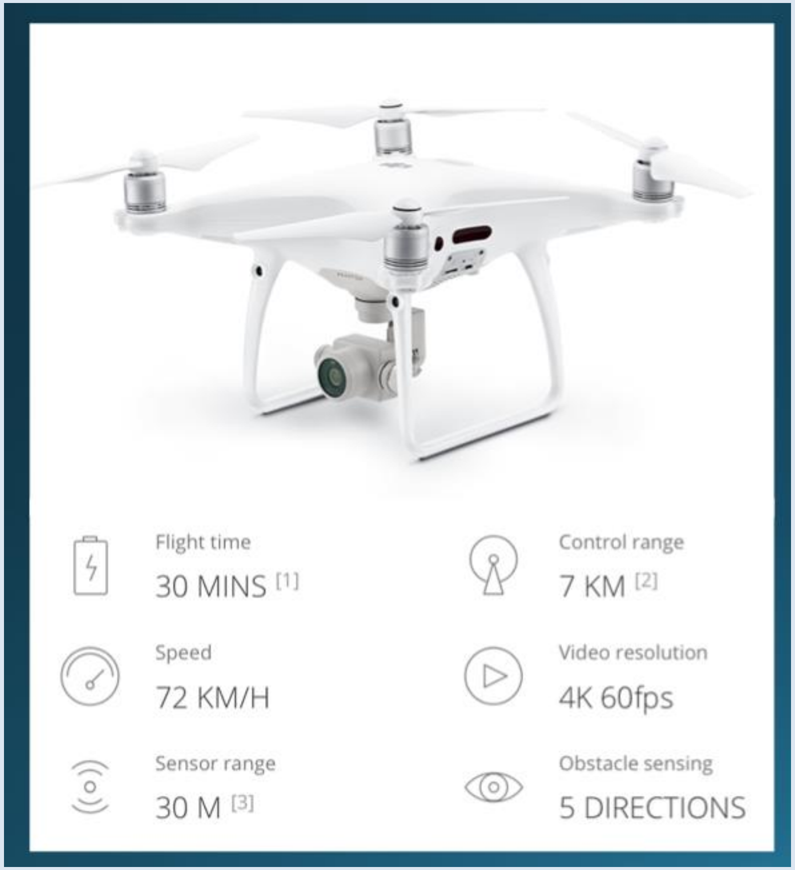
PI: Michael Palace

Overview of Capability

	Robota Triton Fixed Wing	DJI Matrice 600	Eagle XF/X8
Payload(s)	• Panasonic Lumix-GM1 • Tetracam ADC-lite (GR-NIR)	• Nano Hyperspec VNIR • Xsens GPS/IMU	• Nano Hyperspec VNIR + Velodyne Lidar VLP16 • Velodyne Lidar VLP16 • Applanix APX-15 (2)
Applications	• Extended flight times (~45 min.) • High spatial coverage (10s of ha) • Requires open area for landing safely	• Very high spatial resolution hyperspectral imagery (~5cm) • Moderate flight times (~15 min.) • Constrained take-off	• Short flight times (<10 min.) • Hyperspectral imagery (~5cm) and lidar point clouds (~155 returns/m^2) • High GPS accuracy

UNH Entry Level UAS: DJI Phantom IV

Not all are created equal



Entry Level

DJI Phantom ($1499)
Pros: Improved optics over smaller models, larger sensor provides 20MP photos and 4K 60fps video. Mechanical shutter, 30 min flight time
Cons: Larger unit so it requires a bulky backpack for travel; Great for basic aerial photography, provides a Great platform for 3rd party Apps - mapping waypoints

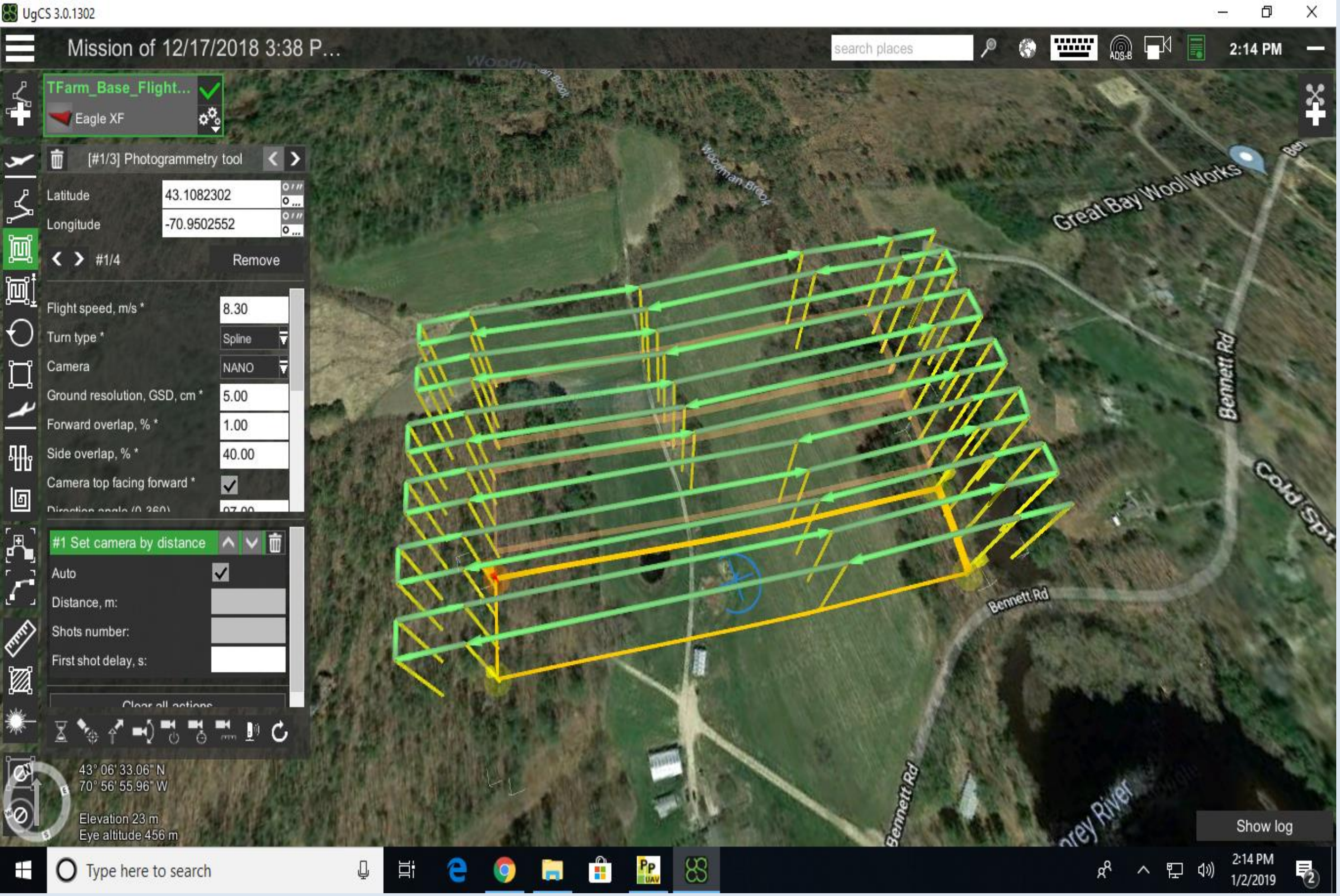
Flight controller (brains of the operation):
Pixhawk Flight Controller

UNH High End UAS

Not all UAVs are created equal

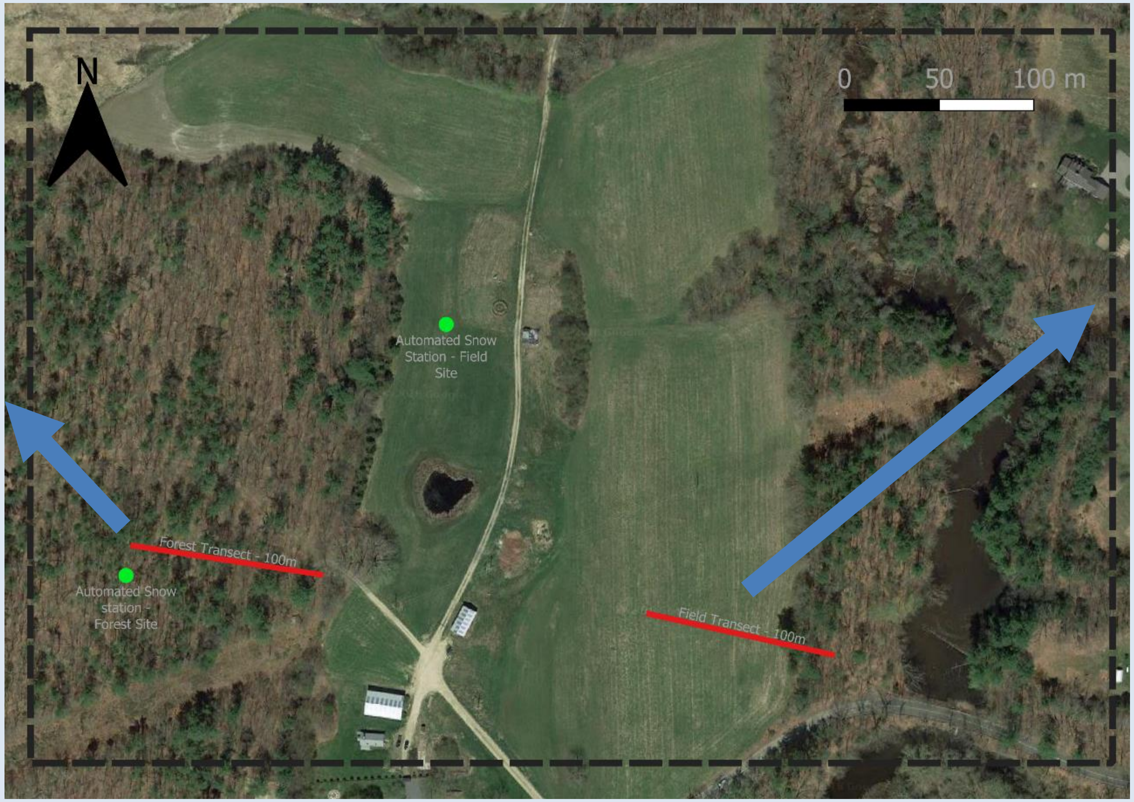
UAVA XF ($20,000)and X8 ($30,000)
Gimbel ($3,500)
IMU/GPS ($40,000)
Velodyne Lidar ($18,000) – includes
integrating software
Headwall Hyperspectral Nano ($30,000)
uGCS Flight control software ($650)

Pros: Sensor package is working well
Cons: Flight times are drastically shorter than manufacture statement, Issue with screws shearing on **the X8**
Cons: Data post-processing of lidar and hyperspectral data requires experience and has steep learning curve.
Flight control: Working well



UAV flight plan:

- Covers approximately 10 ha over Thompson Farm, Durham NH
- Covers large forested and open areas
- Flight plan was split into three segments to accommodate shorter than expected battery life



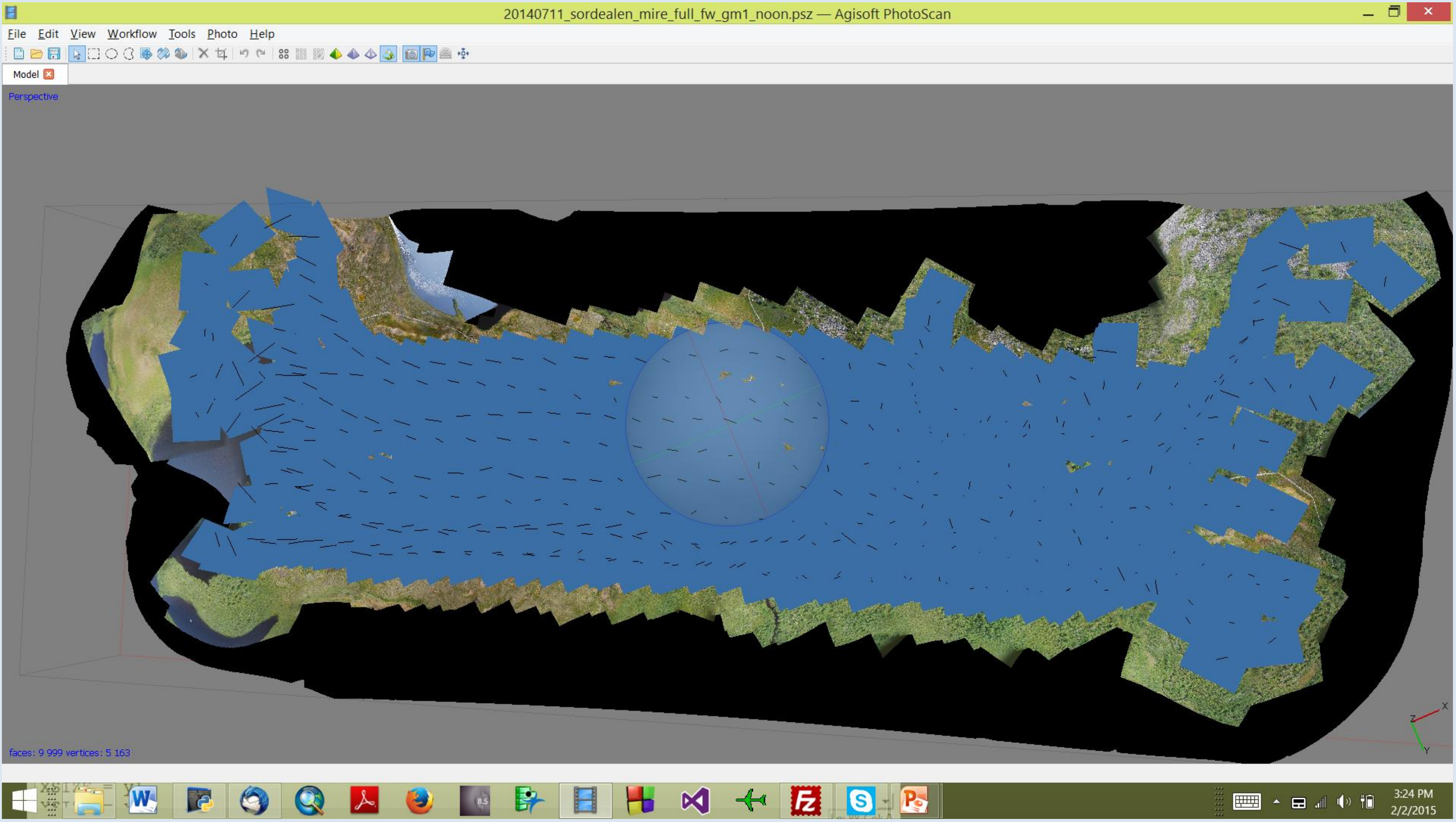
Field sampling strategy:

In-situ snow sampling is needed to validate UAV observations and to train snow parameter models derived from UAV observations while minimizing disturbance to site.

In-situ observations includes:

1. Snow depth and SWE measurements along transects
2. Downwelling and upwelling solar radiation
3. Optical snow grain size
4. Snow classification (snow card)
5. Georeferencing of all observations with high-res GPS unit
6. Automated stations provide continuous record of SWE, snowpack temperature and snow wetness

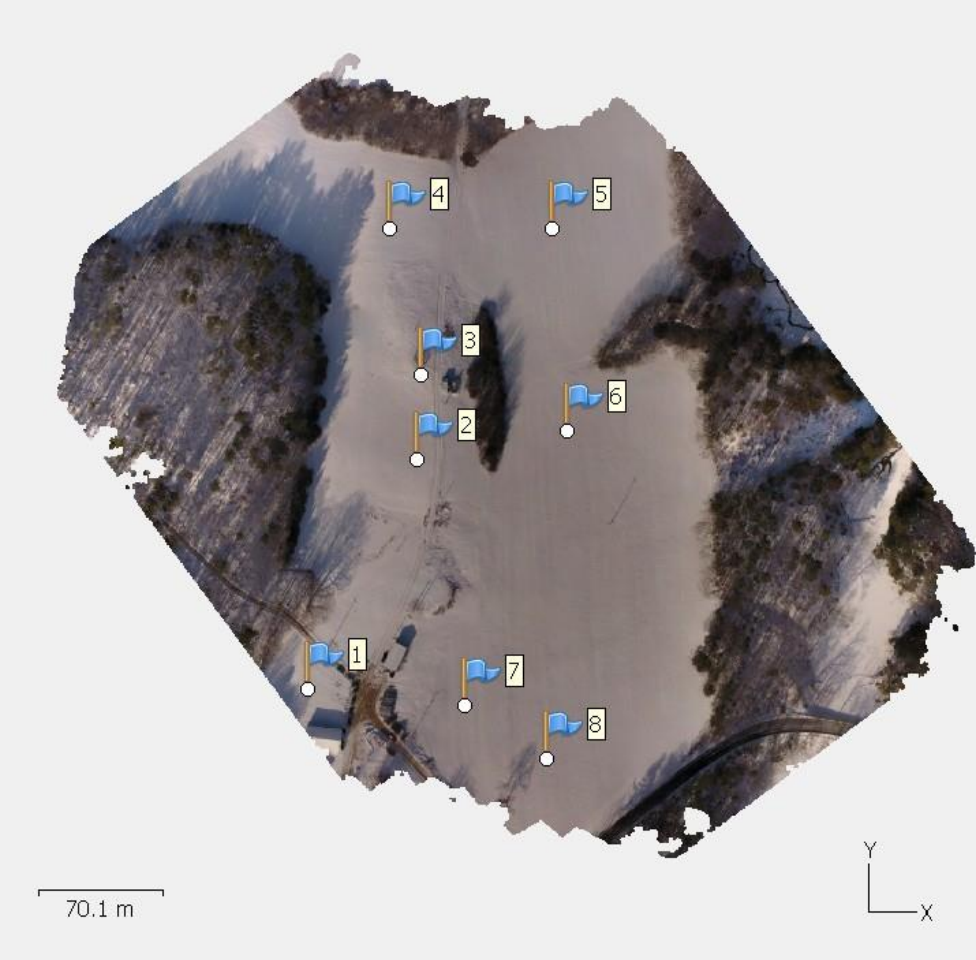
Goal: Map snow depth using a 3D model of surface DJI Phantom collected over 700 images



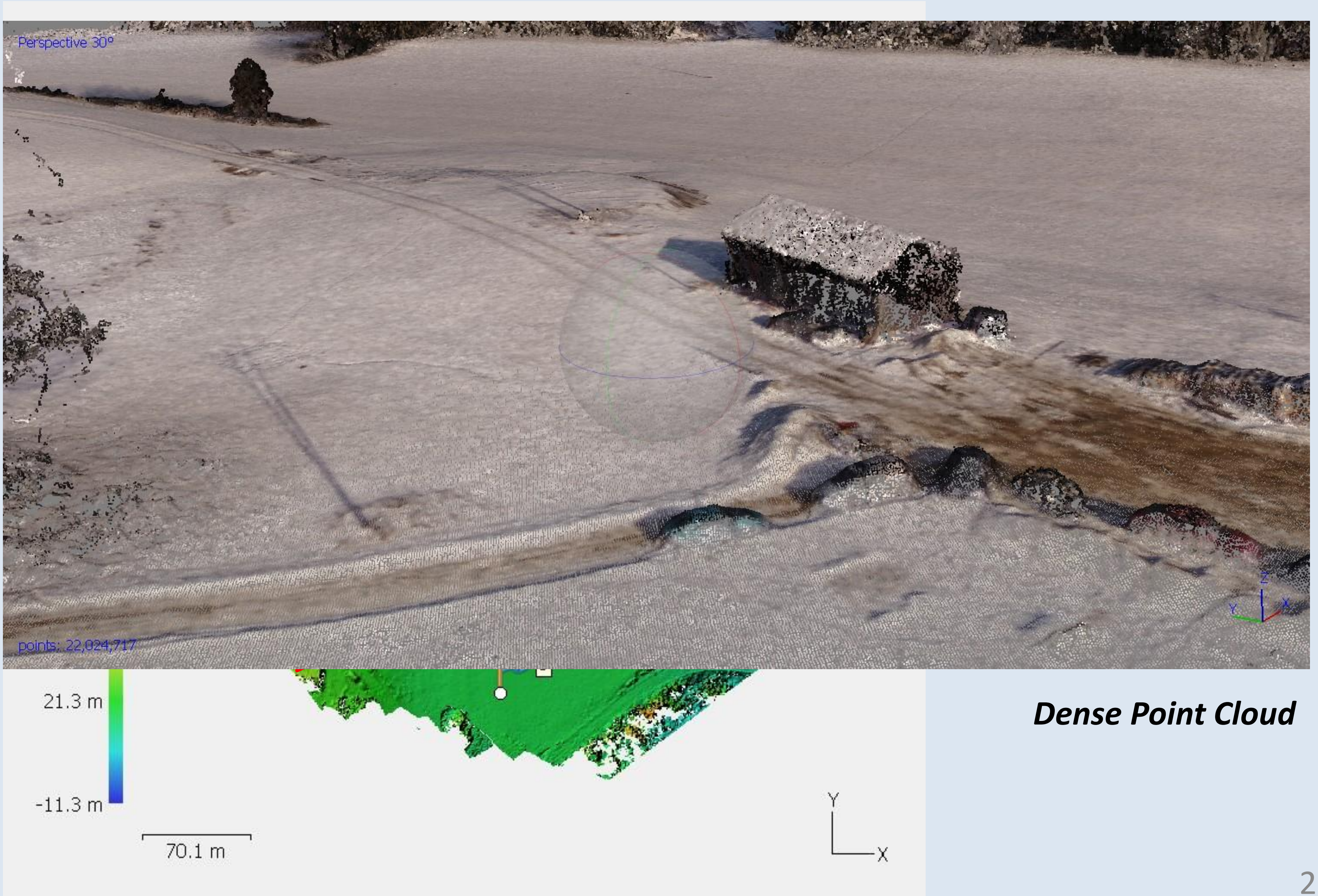
Goal: Map snow depth using DJI Phantom via SfM to create 3D Models (Structure from Motion SfM)

AgiSoft Photoscan Pro SfM Software

- Uses images to create models
- Pictures imported from drone flight
- Images overlap creates model points
- Use ground control points (GCPs) to recognize consistent reference points and georeference model
- **Need to survey in GPCs or use Aeropoints**



3D model of snow depth using DJI Phantom via SfM

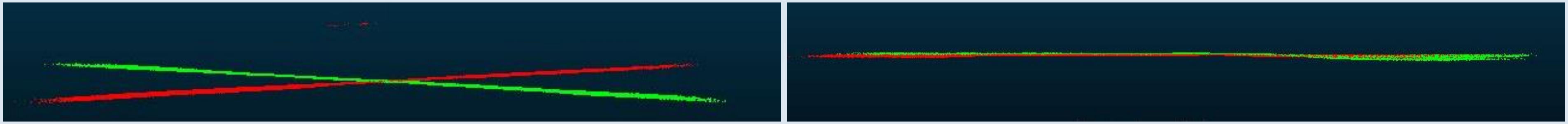


Dense Point Cloud

Goal: Map Snow Depth and Spectra

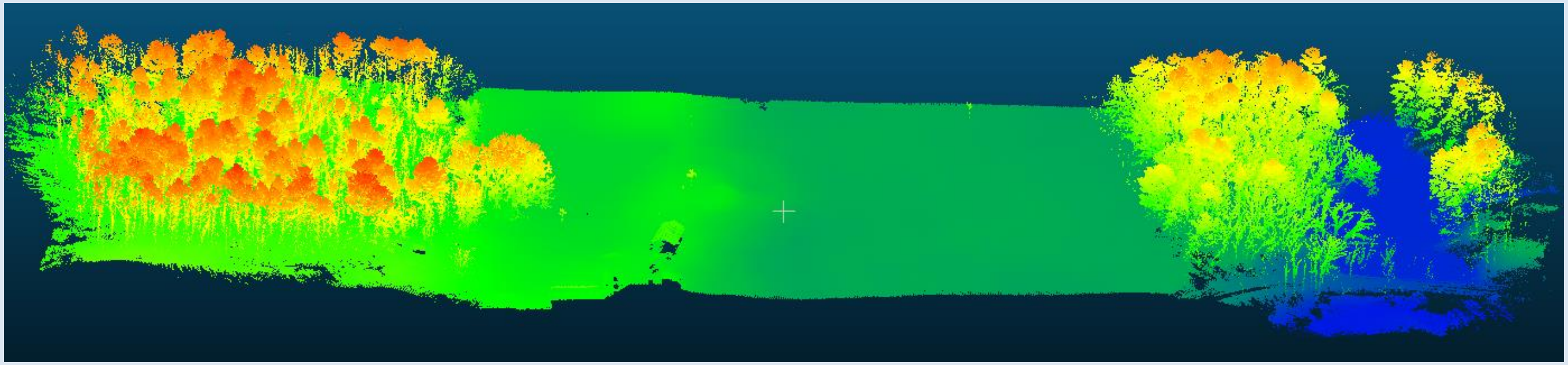
UAV LIDAR & Hyperspectral Processing

1. Plan & execute flights
2. Post-processing
   1. POSPac GPS/IMU correction
   2. Isolate flight lines for lidar post-processing
      1. Boresiting:
         1. Determine roll offset using anti-parallel flight lines
         2. Determine pitch & yaw offset using perpendicular flight lines
   3. Generate LAS file from all PCAP files using calculated offsets
   4. Calculate radiance using radiometric calibration files for hyperspectral data
   5. Calculate reflectance images
   6. Orthorectify hyperspectral imagery using lidar DEM and roll/pitch/yaw offsets
3. Point cloud classification (current approach uses lidR package in R)
4. Mosaic hyperspectral imagery, extract spectra, analysis

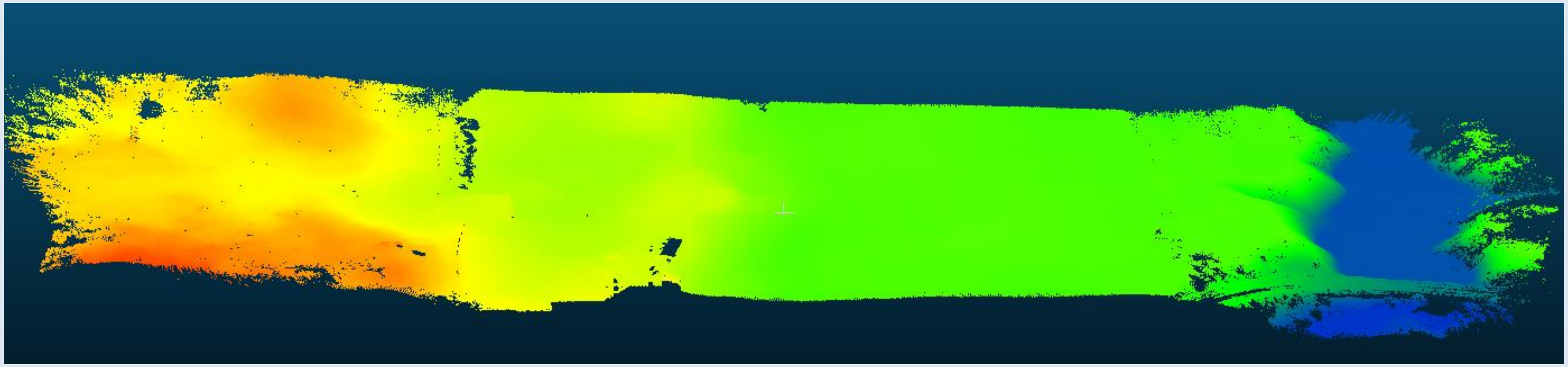


First pass post-processing usually results in flight lines showing significant offset (shown in different colors, left), which requires tuning for flight lines to correctly align. In this case, the roll offset was ~3 degrees.

Goal: Map Snow Depth via UAV LIDAR

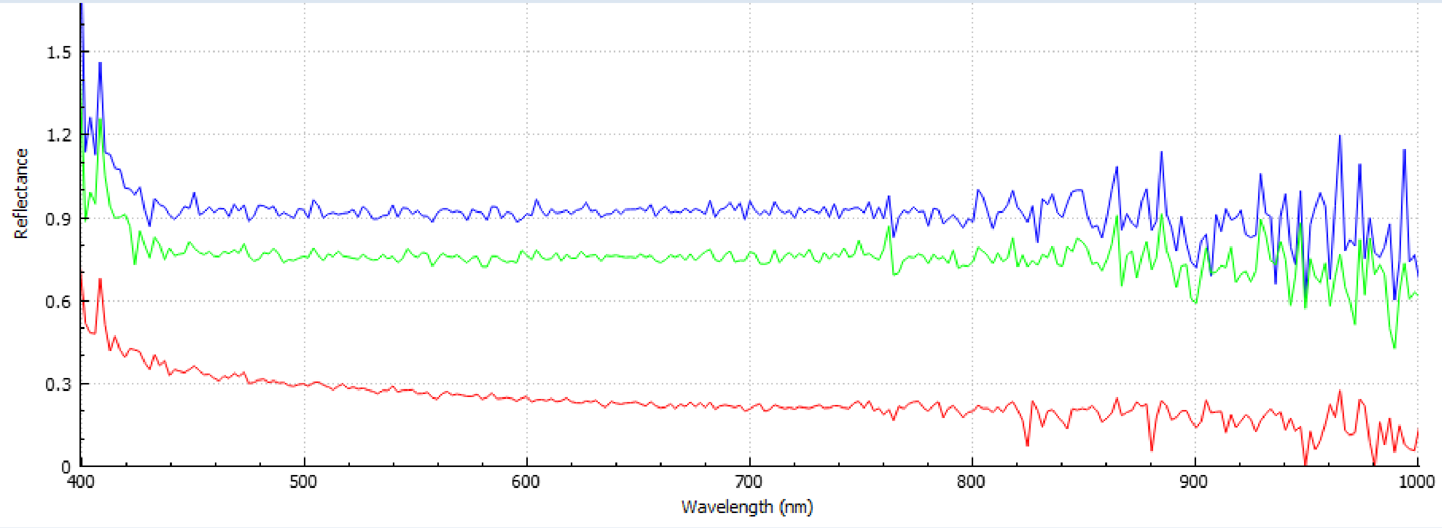


Flown at 81 m altitude at 7 m/s, four flight lines result in a lidar return density of ~155 returns/m^2 over a snow-covered field (top), which when classified using the Progressive Morphological Filter in the R lidR package, results in ~135 ground returns/m^2 (bottom)



Repeat flights will allow snow depth characterization and change detection

Goal: Map Snow Spectra via UAV Hyperspectral



RGB rendering of hyperspectral mosaic (top). These data allow characterization of snow in field and shade into NIR region of the electromagnetic spectrum (bottom). Reflectance of snow is informative of snow grain size, which influences albedo.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Lesson: Follow Safety Guidelines

- FAA Safety Regulations
  - Part 107 – Small Unmanned Aircraft Systems
- UNH Safety Regulations
  - Unmanned Aircraft Systems (Drones) Guidelines

In general any UNH employee or student seeking to operate a UAS as part of a UNH activity will be considered to be conducting commercial operations and must first obtain permission from the UAS Officer, who must be provided with evidence of compliance with all applicable FAA requirements, which may include: Registration of UAS, Weight less than 55 lbs, Speed less than 100mph, and Altitude less than 400ft, Daytime flight within the line of sight, No flights in covered structures or over people in the open, and Pilots with remote pilot airmen certificates.

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Field Support: Simon Kraatz, Mahsa Moradhi, and Al Datillo

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Other Projects using UAS

- Additional projects that can leverage the use of the UAS hyperspectral-lidar sensor:
  - Spectral and structural diversity of vegetation – NSF-Macrosystem (PI Scott Ollinger UNH, Co-I Michael Palace)
  - Permafrost collapse and vegetation change – NASA IDS project (PI-Ruth Varner (UNH), Co-I Michael Palace)
  - Spectral signature of cyanobacteria outbreaks – NASA IDS (PI-David Lutz (Dartmouth), Co-I Michael Palace)
  - Microtopography of pre-contract cache pits – NSF Archaeology (PI-Meghan Howey, Co-I Michael Palace)

What sensors?

- Hyperspectral - Headwall Photonics Nano-Hyperspec VNIR (1)
  - 270 spectral bands across the spectral range of 400-1000nm
- Lidar - Velodyne LiDAR VLP-16 sensor “the puck” (2)
  - 2-3 cm accuracy at a distance of 100 m
  - 360^{o} horizontal field of view, 30^{o} vertical field of view
- High performance GPS/INS-Headwall Photonics p/n 1004A-31277 (2)
  - GPS for best orthorectification
  - UAV post processing software
  - SmartBase Tool set-post processing
- FLIR Vue Pro R thermal imaging sensor (2)
  - 640x512 pixels
  - radiometric temperature range of 0^{o}C to 40^{o}C
  - operating temperature range of -20^{o}C to 50^{o}C