A. Background and Motivation
The distribution, abundance, and phenology of arctic flora are influenced by environmental factors operating at multiple spatial and temporal scales. This drives patterns of vegetation heterogeneity that in turn impact processes across all levels of ecological organization, yet individual-level vegetation heterogeneity is poorly quantified in Arctic systems beyond the plot scale. This data gap presents a challenge to both understanding and predicting ecological responses to rapid regional warming. Furthermore, quantifying how the distribution, abundance, and phenology of individual plants varies across landscape extents (hundreds to thousands of meters) is critical to ultimately linking plot-based research with the broader-scale signals of vegetation change captured by satellites.

Carefully planned image acquisition from Unmanned Aerial Systems (UAS, i.e. drones) captures spatially continuous, individual-level information about plant productivity and its context in the environment via both structural and spectral models. These data are relevant to many ecological research programs, but will hold greatest value to long-term records, cross-site syntheses, and comparisons with satellite records if they are gathered with consistent methods and philosophies.

For the 2017 High Latitude Drone Ecology Network (HiLDEN) data collection season, we propose implementing common UAS tundra mapping protocols with the immediate aim of producing data and insights for a concepts and synthesis paper (details below) and to act as a stimulus for funding applications. These protocols are designed to apply across a variety of platforms and sensors (and are thus not optimized for any one particular set up) with a specific focus on cross-site comparisons. To participate, contributors will be asked to follow the guidelines below to collect and contribute high-quality, spatially referenced aerial photos of tundra landscapes captured during the peak of the 2017 growing season. These images will be centrally hosted, processed, and analyzed with inputs from data contributors to address the following cross-site questions:

1. How does the relationship between landscape structure (microtopography/hydrology) and plant distribution/productivity predictably vary at sites across the arctic?

2. What is generalizable in how these relationships scale as a function of increasing spatial grain?

3. Do plant distribution/productivity patterns across scales correspond with satellite records among sites?

B. Site Selection
We will address these simple questions in tundra locations distributed throughout the Arctic to look for generality in these findings. Field site locations will span diverse light, moisture, and exposure regimes.

Contributing teams at each field site location should establish a minimum of three (or more if time permits) predominantly low-shrub (priority to Betula sp. and Salix sp. cover) and graminoid dominated
tundra blocks (500 x 500m area). This extent is chosen to balance between the flight capabilities of various UAS and as an extent that is large enough to effectively compare with satellite-derived products of varying grains. We discuss tradeoffs in UAV platforms and sensors elsewhere in these documents, but acknowledge larger extents will be a goal for future seasons when hardware can be better standardized.

When selecting blocks, choose at least one that is relatively flat topographically, and at least one with some topographic relief, e.g. a drainage. Try to avoid areas with heavy human traffic over large portions of the site as this may impact vegetation conditions (via trampling). Also, consider selecting for areas that correspond with long-term ground measurements (value added) and/or areas that would be amenable to revisits and potential experimental manipulation in future seasons (like smaller scale herbivore exclosures).

Make sure to mark the block corners with a semi-permanent/permanent marker before data collection, either with a Ground Control Point (GCP) marker, or even a cairn or landmark that can be easily identified from the air and will not move. Ideally, take a dGNSS (e.g. dGPS) point of these locations. If dGNSS capability is not available, a traditional handheld GPS/GNSS device can be used to record points these points using point averaging to increase the precision.

![Examples of different tundra vegetation communities from the Qikiqtaruk field site.](image1.jpg)

C1. Data Collection

**Objectives for Data Collection Missions:**
Collect high quality photos with sufficient metadata and supporting ground information to build effective orthomosaics and terrain models that will inform downstream analyses.

**General Photo Capture Guidelines:**
UAS acquired photos – both RGB and multispectral – must be properly exposed, non-blurry with good contrast, be geotagged (very strongly encouraged, but not critical if high quality GCP available). Examine images for motion blur or exposure issues immediately after flight. Avoid days when there are changing cloud conditions during flight, as this will affect spectral properties and the mosaicking process. Shoot in RAW+jpeg or TIFF when possible, but if you are only able to use jpeg,
be consistent with white balance settings across all flights. Make sure your camera’s time and date is properly set and remains accurate throughout different flight periods. Clearly note if this is local time or UTC (what GPS uses). These time and date records will be stored in the .EXIF files associated with your images and can be of great archival value.

Gather pre and post flight photos of calibration targets (in addition to in flight targets if available) for each mission to allow for better radiometric correction and cross site comparisons. These comparisons will be of less value for some cameras (especially consumer RGB) than others, but consistent methods here will provide insights for future protocols and will be of value for downstream analyses. Calibration Protocols and guides: HiLDEN: Spectral Calibration and Guidance and Additional Information on Pre-/post-flight Calibration Targets.

Multi-scale tundra mapping for structural and spectral data:
At each tundra block, teams should map nested plot samples stratified by altitude (detailed below) during the peak of the growing season (priority) and other times when time and resources are available (i.e. vegetation emergence period, mid-greenup, senescence). This should be done for both RGB and Multispectral sensors (if available).

We chose standardized flight altitudes for 2017 rather than standard ground sampling distance (GSD, i.e. pixel size) to simplify protocols for the data collection this summer. To be clear, we will not be directly comparing multispectral data (often much coarser native grain at given altitude) from one site to RGB data (often might finer native grain) at another site. Instead, where both Multispectral and RGB data are available, we will pair them with each other to generate synthesis products. Furthermore, as most groups do not have terrain-tracking capabilities in their flight planning this summer, actual GSD will vary in part as a function of terrain. The variability in GSD among common high-res (~15-20 megapixel) RGB sensors flown at given altitudes will be relatively small (1-3cm difference) and will be dealt with analytically.

We ask that teams fly a sample of each tundra block at four flight altitudes (so 4 RGB and/or 4 multispectral if available) detailed in the list and figure below:
In sum, this hierarchy of flights and sensors at a given blocks is equivalent to one ‘block’ replicate. We would like a minimum of three block replicates per field site. In the figure above we have nested two 50m flights within the 80m flight level box. When choosing specific layout for nested plots, avoid putting smaller plots alongside edges of the larger tundra block to reduce the impact of edge artifacts that often arise during model construction on downstream analyses.

We ask that you fly these missions at our around the timing of peak vegetation productivity (generally towards the end of July or first week of August at most tundra sites). This will allow for standardized comparisons across sites. If time and resources allow, you are welcome to contribute data from outside of peak season as well, as some teams will also be gathering time-series for phenological monitoring, though this is not a primary focus for the 2017 cross-site analysis (if enough teams are interested, however, we can also focus on this too!). If you are not in the field during peak season, fly at a date during the green-up period. Other particular time periods of interest are just prior to/during onset of growing season or during senescence.

**Note:** Most projects are using multi-rotor drones, and some are using both fixed-wing and multi-rotor units. If you ONLY have a fixed wing unit, it is unlikely you will be able effectively gather data at 50m or perhaps even 80m in some environments. In these cases, skipping lower-altitude data collection is completely understandable – please do not try to do anything unsafe/beyond the capabilities of your platform or out with the local regulations for flight altitudes or other flight parameters.

**Mission Planning Background:**
There are a variety of software ‘apps’ or programs that enable systematic flight planning and image capture. This is preferable to manual/semi-manual flights over the mapping areas for repeatability,
analytical, and safety reasons. If you have a software system you prefer, feel free to utilize that as long as you are able to: a.) keep consistent records of flight plans, and b.) it is capable of creating flights resulting in proper image overlap/quality. If you are unable to meet this requirements, please keep as detailed records as possible with points a.) and b.) in mind.

Suggested mission planning apps:

- For Pixhawk/3DR systems – Mission Planner (available only on PC)
- For DJI systems – DJI GS PRO (http://www.dji.com/ground-station-pro), other available apps include Pix4D Capture (https://pix4d.com/product/pix4dcapture/), Altizure (https://www.altizure.com/), DroneDeploy (https://www.dronedeploy.com/), etc. but not all of these apps can currently provide the same functionality as DJI GS PRO.

Each of these apps will be able to generate a lawnmower-style (like this screenshot from Mission Planner below) or cross-gridded flight path. These plans result in several overflights of the same area with automated camera triggering to generate desired image overlap. The combination of app, airframe, and camera will differ for each working group and site. There are several excellent tutorials on YouTube and elsewhere online that can be used to go over the specific details of these hardware/software pairings for less experienced pilots. We can also offer specific advice – particularly for MissionPlanner, DJI GS PRO and Altizure systems upon request (jtkerb@gmail.com). Ultimately, there are many systems that can produce high quality data, but regardless of system, special care needs to be taken by all contributors to ensure data meet the shared mission planning objectives listed below that are designed to allow for consistent comparisons across sites and through time.

![A lawn mower flight plan in the Mission Planner software.](image)

**Mission Planning Protocols for HiLDEN:**

When planning missions, have mission plans extend 20m beyond the desired mapping area. The edges of orthomosiacs are prone to stitching errors due to reduced image overlap in these regions, especially if they are located upslope from the takeoff location. For most flights, you will want to fly with the cameras facing nadir, i.e. directly downward, although for some structural models you may want additional flights with the camera at a slightly oblique angle (specific angle off nadir will depend
on environment, start with 20 degrees). If your drone tilts at a predictable angle while in motion and you are using a static camera mount, try to adjust for this selecting the angle you mount the camera at when planning for nadir images.

Image overlap is critical for building structural models and orthomosaics. There are different ways to optimize data collection for these builds to address specific questions, but many include planning for specific environments go beyond the level of detail of a general protocol and HiLDEN questions. For the cross field-site analysis, we ask groups to plan for missions that have >20 overlapping images for any given point being mapped. This can be achieved via adjusting the sidelap, forelap, and number of mission overflights for a given area. For example: 66% sidelap and 80% forelap should yield ca. 15 photos per location, whereas 66% sidelap and 90% forelap should yield ca. 30 photos per location. 95% sidelap and 33% forelap should also yield ca. 30 photos per location, but might be a more attainable combination for particular hardware configurations (e.g. low trigger rate camera on a fixed wing).

If you are unable to work out these specific calculations, a safe bet is to aim for at least 80% front and 80% sidelap in their images, a concept illustrated below from a graphic from DroneDeploy. This combination of overlap creates multiple images of a given area, even over varying terrain. Some drone companies/software programs suggest lower overlapping values for image capture. This is a reflection of them thinking about the analytical stage of processing assuming perfect data collection with no error between mission plan and real world data acquisition. Error propagates during structural builds as a function of the angle that overlapping images are acquired from (this is optimized around 65% overlap at about 100m). However, this perspective does not factor in real-world flying conditions! The consequences of having too little overlap (due to drone mission being affected by wind or varying terrain) are much more impactful on model output (i.e. model failure!) than having too much overlap (increased noise to signal ratio in structural builds – however, this can also be addressed in post-processing using filtering algorithms). These insights reflect field experiences from many research teams.

If you are unable to program in overlap parameters into your mission plan (first try another program!), then you may want to set your camera's interval timer to the shortest interval setting that it allows for continual image capture (i.e. somewhere around every 2 seconds). Calculating image footprint and grain sizes to address these problems manually can be done via simple geometry with camera and flight inputs. A spreadsheet template for this approach can be found here (from Pix4D): [https://s3.amazonaws.com/mics.pix4d.com/KB/documents/Pix4D_GSD_Calculator.xlsx](https://s3.amazonaws.com/mics.pix4d.com/KB/documents/Pix4D_GSD_Calculator.xlsx)
An illustration of front and side overlap from a graphic from DroneDeploy. We recommend HIGHER fore- and sidelap than the image above (see previous paragraphs).

When planning the flight speed of your missions, you need to balance tradeoffs between faster speed to cover a large area and slower speed to generate higher quality images. This tradeoff varies with flight and camera specifics, so a little bit of trial and error is required to find the optimum where photos are of high quality and you are able to cover the desired extent. Some extents will require two or more flights to cover the entire flight area depending on the hardware being used. As noted earlier, it is unlikely a fixed wing will be able to flow slow enough to capture data at 50m, or in some cases, even 80m.

**Ground Control and Truthing for Synthesis Paper**

Building high-fidelity structural models and orthomosaics benefits from having information on camera location, and is best constrained by ground control markers. A thorough review of this process and its optimization is forthcoming, but by following the procedures below, these protocols will be standardized across sites.

**Ground Control Markers:**

As mentioned in previous posts, ground control markers should be readily visible from the air, stand out in all spectral bands being captured, and be immobile during the flight period. Ideally the center of these ground control markers should be geolocated using a differential Global Navigation Satellite System (dGNSS) like a dGPS down to a few centimeters. Place approximately 20 markers within each 500m x 500m block, with at least 6 of them in the smallest 150m x 150m sample areas. Try to spread them evenly throughout the extent and associate each with a unique ID. Consider placing permanent markers in some areas if you will return in future years, even if it is a smaller marker than can be used to re-place a larger marker in the future. Also consider taking high-accuracy dGNSS location points at
clearly defined edges/landmarks of naturally occurring (non-mobile) features (e.g., large rocks, ponds, etc.). A good place for GCP is also the corner markers of your plots.

If no dGNSS system is available, we will most likely use the camera geolocation data as the primary source of spatial constraint during model builds. That said, it is still valuable to place GCP that are marked with traditional GNSS (e.g. GPS) in case .EXIF photo geolocation data are lost/corrupted. If no dGNSS is available, place GCP in clusters ~10 to 50m apart from each other. Assign a GPS location to each, and carefully measure the distances between these GCPs using a field measuring tape and/or laser range finder (and record these distances). You can even use your drone’s GPS to mark points! The GPS locations will be used as reference to visually locate these GCP in the final ortho, and the model can then be accurately scaled/validated using these distance measurements (in lieu of dGNSS points). Aim for four of these GCP clusters (of 3 – 4 GCP) in these situations.

Marking the location of a ground control marker in the field using a handheld GPS (left) or using a GNSS system (right).

**Landcover Ground Truthing Data Collection:**
For each tundra block, teams should write a descriptive statement about the types and form of vegetation in the landscape and provide any general information known about site history. Please include photographs of dominant vegetation species as seen from the ground, and include an annotated (for example via powerpoint) sample of 4 – 6 drone photographs that identify these species and phenophase from above (example below from 120m altitude flight) and any signs of disturbance, herbivore presence, or anything you think is noteworthy.
Selected Examples:
1. *Betula nana*, leaves out
2. *Cerastium alpina*, mature, a few flowers in wet area
3. *Salix glauca*, leaf buds opening, some leaves out
4. *Tussock field*, mostly *Eriophorum* sp. and *Festuca* sp.
5. Exposed rock in wind eroded area.
   Also visible: trails used by caribou & researchers, etc…

Furthermore, teams should collect canopy height measurements from 30 or more locations within each block stratified across land-cover types and locations. Associate these height records with a GNSS (i.e. GPS) record and/or with a point identified in a drone image (for example, like those above).

Reminders to check before capturing image data:
- Geotagging is enabled
- Camera Date/Time are accurate
- Front and side overlap for images in mission plan is >80%
- RAW+jpeg capture is turned on
- Try to use (camera limitations and conditions may require adjustments):
  - Fixed aperture
  - Fast shutter speeds (1/1000 or faster)
  - Low ISO of around 200 or less
- Fly slower the lower you are to the ground (to avoid image blur)

C2. HiLDEN: Spectral Calibration and Guidance

By Jakob Assmann (j.assmann@ed.ac.uk), Jeff Kerby (jtkerb@gmail.com) and Isla Myers-Smith
The following protocol is the outcome of two years of multispectral drone work in the Canadian Arctic. Two three-months field seasons provided opportunities to learn through trial and error. Should you have any feedback, suggestions, questions or comments please let us know.

The information below is distilled into a blog post (pdf link below this paragraph) / and is currently in preparation for submission as a short scientific communication manuscript. Once published, this will be shared on the HiLDEN mailing list. If this protocol has influenced your method of data collection it would be great if you could cite the above publications in resulting manuscripts.

Updated: Multispectral Flight Protocol-16 May 2017

**Time of Day**

All flights should be conducted between 3 hours before and after solar noon, and at most within 6 hours before and after solar noon.

You might want to harden this rule depending on the latitude of your field side / time of year, also consider mountains and other obstacles that might influence the illumination of your field site. The NOAA solar position calendar and other similar resources are useful tools to calculate solar position at your field site.

Shadows are the main reason for this, the lower the solar angle the more prominent shadows become in your images. More shadows mean a lower proportion of the surface is illuminated resulting in inaccurate estimates of surface reflectance and its derived data products, like NDVI. This becomes less of a problem on overcast days with diffuse illumination. The spectral composition of the sunlight also changes with solar elevation. This can be compensated to some degree with radiometric calibration, but extremes should be avoided.

**Radiometric calibration**

Radiometric calibration is the most important step of this protocol. Clouds, haze, time of day and solar position influence the spectral composition of sunlight, it is therefore key that a standard of known reflectance is used to calibrate the relative measurements of the multispectral sensor. Otherwise, comparisons between flights, sites and satellite imagery are not possible.

*Pre- and post-flight calibration*

Radiometric calibration is best carried out by taking calibration imagery of a known standard panel directly before or after the flight. The resulting imagery is then later used in the photogrammetry software (e.g. Pix4D) to calibrate the reflectance maps.

Only one of the two sets of calibration imagery (pre/post) will be used for radiometric calibration, but you might find that light conditions change during long flights (e.g. clouds moving in) and that conditions at the end of the flight are more representative of the majority of the flight.

We recommend using a traceable Spectralon target (or standard of similar quality) of approx. 15 x 15 cm (6” x 6”). For vegetation surveys a standard with a reflectance value of 70% would be ideal, but 40-70% should be sufficient. If you are planning to survey snow covered surfaces a pure white standard > 90% reflectance might be required.

Please be aware that, if you are using MicaSense reference panels, these are intended primarily for commercial use and may degrade due to temperature extremes or improper handling. We experienced some degradation of our 2016 MicaSense reference panels. Long-term durability of the panels has not been tested, and after discussion with the MicaSense Support Team they
recommended the use of Spectralon targets for high sensitivity academic/scientific data collection (personal communication, April 2017). These are significantly more expensive, but are field and wear tested under a variety of conditions. Spectralon targets can be sourced through the manufacturer Labsphere in the US or retailers world-wide.

Pre-/post-flight calibration images should be taken so that a large number of pixels are covered by the target and so that the target ID is clearly visible in the image. Ensure that the target is level on the ground and free of shadows. If your calibration photo captures many pixels of the calibration panel, a larger statistical sample can be used by the photogrammetry software to calibrate the orthomosaic reflectance maps. In this instance, a larger sample is a better sample.

As a rule of thumb with the Parrot Sequoia sensor: Hold the drone just below hip height over the target with your back to the sun, take a step aside while holding the drone in position to avoid casting a shadow over the target.

Ensure that the target in the calibration imagery is not overexposed (i.e. saturated in the upper end of the digital numbers), as radiometric calibration will otherwise not be possible. If you are using a Sequoia Sensor, use the ‘Radiometric Calibration’ feature of the WiFi interface to obtain a bracket of calibration imagery with different exposure levels. Placing the calibration target on a high reflectance surface (such as a landing pad) may also help reduce the chance of incorrect exposures. Finally, if you’re using a filter or lens protector during the flight, ensure that calibration imagery is taken with the filter/protector in place. Likewise, remove any filters/protectors before taking the calibration imagery if they are not used in flight.

**In-flight reflectance targets**

In-flight reflectance targets serve two purposes: a) as surfaces with known/calibrated reflectance they allow for quality control in the outputs of photogrammetry software (such as the reflectance and NDVI maps produced by Pix4D), and b) they are a back-up if for some reason the pre-/post-flight calibration imagery fails (e.g. deterioration of standard over time, overexposure of imagery and unintended shadows covering the target).

In-flight targets should have even reflectance values within the bands of your sensor and match roughly the reflectance of the surface of interest. For vegetation surveys we recommend 40-60% reflectance. Additional targets of higher and lower reflectance may be employed to cover a larger range of reflectance values, but this might not be practical in all situations.

In-flight targets should be at minimum 5 x 5 the Ground Sampling Distance (GSD) (25 Pixels), but 10 x 10 GSD (100 Pixels) is desirable, if not more. Again, the larger the statistical sample of pixels the better the quality control. For reasons of practicality (transport and weight) large target sizes for high altitude flights might not be achievable.

The material of the in-flight target should be as durable and Lambertian (even reflectance independent on angle of view) properties as possible. Spectralon would be ideal, but is likely not a cost-effective as an in-flight target. In our experience, it is more difficult to keep in-flight targets away from environmental influences such as water splashes, dirt and dust. Instead of Spectralon we therefore suggest selecting from the following options. They are ordered by most desireable reflectance properties, but we realize you will need to make your decision based on intended uses, budget, and time for preparation and availability.

- Calibrated felt targets produced by the finish company MosaicMill, 44% reflectance for vegetation surveys; standard size 50 cm x 50 cm, approx. 350€ per piece, custom sizes also available (discounts for more than one purchase).
Grey-cards made out of ‘Kodak card’ cardboard type material, obtainable from photography suppliers. Often only available in smaller sizes around paper A4 or letter format, unsuitable for large GSD. Tend to come in approx. 18% reflectance (grey) and 80% (white). Warning: Spectral properties may vary strongly across the spectrum – test in lab before use!

Sail-cloth and canvas sheets may be alternatives, particularly for large GSD of known even spectral reflectance. Ensure the material is 100% opaque and test reflectance and lambertian properties in lab!

For uncalibrated targets, we highly recommend measuring reflectance properties before going out into the field the first time. However, in the end a bad in-flight target is better than no target. Also see ‘Care and Quality Control’ Section below.

Finally, we suggest that at least two in-flight targets should be employed; one at either extreme of the flight paths. For larger sites (> 1 ha) more target might be desirable, but only if practically feasible. Position the targets so that the aircraft passes directly over it.

Care and Quality Control of Reflectance Standards and Targets
Handle reflectance standards and in-flight targets with as much care as possible! Avoid touching the surface, exposure to rain, dirt and water splashes particularly of the Spectralon pre-/post flight calibration targets). Prolonged exposure to sun may also have a negative impact on the surface. Return the targets to a protective container as soon as possible after use.

All targets should be calibrated before and after each field season, then cleaned according to manufacturer’s recommendations and re-measured ahead of the next field season. We suggest determining the absolute reflectance of the targets using a spectroradiometer in a dark room. In the past, we carried out five contact measurements per target, one in the centre and four towards each corner (but not in the very corner), average reflectance values can then be calculated for the target and band averages determined.

Ground Control Points
In addition to following the general ground control point (GCP) recommendations of the HiLDEN a few particular considerations apply to GCPs used with multispectral sensors. GSDs for the multispectral sensors are large compared to high resolution RGB sensors and the monochromatic nature of single band imagery can therefore make identifying GCPs difficult.

We recommend the use of large GCPs (8 x 8 to 10 x 10 GSD, absolute minimum 5 x 5 GSD) with a checkboard pattern, in our experience these work best (Figure 1). The checkboard pattern works well, as the squares show up as clearly defined surfaces in the monochromatic imagery. Before heading out into the field with new GCPs, ensure that they show up well in all bands. Not all whites are white and not all blacks are black in the near-infrared (NIR). Furthermore, make sure that surface reflectance properties do not vary strongly with orientation to the sun and solar angle. A good way of testing the suitability of new GCPs is taking images with the multispectral sensor on the ground and then conducting tests flights. We have made life difficult for ourselves by not testing GCPs in the past, assuming that surfaces that show up well in the visible spectrum would show up well in the NIR as well.
Sequoia NIR image of 60 cm x 60 cm GCP on grass. The GCP is made from self-adhesive tiles obtained in a local hardware store. Ground sampling distance: approx. 7.4 cm/pixel. Image courtesy of Tom Wade and Charlie Moriarty, University of Edinburgh.

**Flight Pattern**

Flight plan and pattern will vary depending on the site. However, if a lawn mower flight pattern of parallel flight lines is used we recommend introducing some flight lines diagonally or across the pattern. See Figure 2 for a suggested flight plan. This will likely improve the outputs of the photogrammetry process, particularly if vegetation surfaces are mapped that are not very varied in their nature.

Lawn-mower flight pattern (blue) with diagonal flight lines after take-off and before landing.

**Weather Conditions and MetaData**

In addition to usual flight data, it is worthwhile to log weather conditions, as well as the standards and targets used. Noting weather, wind and sky conditions are particularly useful for multispectral data collection, as they influence surface behaviour and solar irradiation. For sky conditions, we suggest a scale from 0-9 (Table 1).

In addition, temperature and information about vegetation surface wetness/dew should be recorded.
Please also see HILDEN Flight log spread-sheet in the metadata section (may be filled in on paper or digital on a tablet).

Table 1 Sky Codes – adapted from NERC Field spectroscopy Facility’s Log Sheets

<table>
<thead>
<tr>
<th></th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Clear sky</td>
</tr>
<tr>
<td>1</td>
<td>Haze</td>
</tr>
<tr>
<td>2</td>
<td>Thin cirrus – sun not obscured</td>
</tr>
<tr>
<td>3</td>
<td>Thin cirrus – sun obscured</td>
</tr>
<tr>
<td>4</td>
<td>Scattered cumulus – sun not obscured</td>
</tr>
<tr>
<td>5</td>
<td>Cumulus over most of sky – sun not obscured</td>
</tr>
<tr>
<td>6</td>
<td>Cumulus – sun obscured</td>
</tr>
<tr>
<td>7</td>
<td>Complete cumulus cover</td>
</tr>
<tr>
<td>8</td>
<td>Stratus – sun obscured</td>
</tr>
<tr>
<td>9</td>
<td>Drizzle</td>
</tr>
</tbody>
</table>

C3. Additional Information on Pre-/post-flight Calibration Targets

By Jakob Assmann (j.assmann@ed.ac.uk), Jeff Kerby (jtkerb@gmail.com) and Isla Myers-Smith with input from the NERC Field Spectroscopy Facility

Buying a pre-/post-flight calibration target is a big investment, but good targets are essential for comparison between flights, across sites and with other sources of reflectance measurements (such as satellites). We hope that this additional material proves to be a helpful guide in the process of purchasing or loaning a target.

This document is the result of two years of trial and error collecting multispectral imagery with drones in the Canadian Arctic and has been informed by many conversations with the experts at the UK NERC Field Spectroscopy Facility (we are particularly in debt to Chris MacLellan). However, it is by no means exhaustive and we are still at the early stages of developing best practises. Please get in touch if you have any questions, comments and suggestions.

PDF: Additional Information On Panels 22 May 2017

Target reflectance value

Surface reflectance values for vegetation lie on average between 40-60%. Ideally, a calibration target would match the surface of interest as best as possible. In practice, a target close to this range should be sufficient.

Spectralon and similar targets are available off-the-shelf at set reflectance values, such as 50% and 75%. Customised targets with other reflectance values are also available.

The response of a multispectral sensor is likely to be linear in most of its range (enquiry for Parrot Sequoia pending) and the error of the radiometric calibration in the software (e.g. Pix4D mapper) can be expected to be symmetrical around the reflectance value of the surveyed surface (Pix4D Support, personal communication, May 2017). Hence, going a bit above or below should not make any difference.
Panels with lower reflectance values are less likely to overexpose in the calibration imagery and small amounts of contamination will have proportionally less of an impact on their reflectance value compared to whiter targets (NERC Field Spectroscopy Facility, personal communication April 2017). For practical reasons, we would therefore recommend a 50% target for pre-/post-flight calibration; advice also shared by Pix4D (Pix4D Support, personal communication, May 2017).

Size and weight
In theory, the larger the statistical sample of pixels (and hence the size of the target), the better the calibration. However, the larger the target, the bulkier and heavier it becomes. For Arctic fieldwork going bigger might not always be better. Finding a healthy optimum is therefore important. Currently, we are not aware of any tests that have been conducted to identify minimum / optimum target sizes.

We recommend something between 15 x 15 cm (6” x 6”) and 20 x 20 cm (8” x 8”), but smaller 12.5 x 12.5 cm (5” x 5”) or larger 25 x 25 cm (10” x 10”) targets should work as well. The standard, pure Spectralon targets can be quite heavy, particularly the 10” x 10” version. Zenith Lite Targets (or alike) can be a more practical alternative (available in 50% reflectance and 20 x 20 cm).

Casing, protection and tripod use
To facilitate protection and easy handling of the targets a good container is needed. We suggest using a hard-case container that will protect the target from physical damage and from the elements. Some options are available also with removable lids and tripod mount attachments. Spectra Vista Corporation (UAS) produces light-weight wooden cases (with tripod attachment) that seem to be a good option (recommended by NERC FSF, personal communication May 2017). The NERC FSF, recommends the use of tripods to elevate the target above ground, allow for optimal levelling (using a spirit level), reduction of shadows and protecting the target from dirt etc.

Loaning/sharing targets
Good quality targets are expensive and purchasing them might not always be an option. It might be worthwhile considering loaning a target from someone in your institution (most people doing field spectroscopy are likely to have one) or buying a target shared with someone. In the UK, NERC funded research projects might be eligible for support from the NERC Field Spectroscopy Facility, from which various targets and calibration panels can be loaned.

Redundancy and Degradation
For long field seasons, it can be good to have multiple targets for redundancy. Plus, it might allow you to measure target degradation. The latter could be done with a stable tungsten halogen light source (or the sun at noon) and your multispectral sensor or a field spectroradiometer (if available). A ‘safe’ standard panel that is kept at your base station could be helpful for this.

For the field season 2017, we are planning on taking two 50% 20 x 20 cm Zenith Lite targets for in-field operations and a 75% 25 x 25 cm Spectralon target as a ‘safe’ standard. We are planning to use or Sequoia sensors to obtain a ‘calibration’ picture showing all panels simultaneously at regular intervals (weekly). This will be done at the base station, in a dark room using a tungsten halogen light source at a set angle to the targets. This might also allow us to assess sensor degradation – assuming no degradation of the ‘safe’ standard.

Final note on pre-/post-flight calibration
At the moment, little information is available on the quality and error of ground-based pre-/post-flight calibration with reference panels.
Standing next to the target and holding the drone above it, is likely to change the irradiation hitting the target even if no shadows are cast on it. Beware of wearing highly reflective clothing, particularly red colors. It is difficult to say whether or not the resulting error is within the accuracy of data collected with drone-based multispectral sensors.

Also, there have been a few methodological questions about the Sequoia’s pre-flight radiometric calibration process. The automated calibration photos the Sequoia captures a set of photos bracketed to different exposures. This ensures that one of them is most likely accurately exposed even if the auto-exposure setting is influenced by background colors (i.e. dark grass contrasting with the white exposure plate). When taking radiometric calibration photos with other sensors, be mindful of this potential hazard, i.e. make sure you are not overexposing your photos during calibration as that means data can be lost.

In the long run, in-flight calibration with large high-quality targets could prove to be the most reliable way of calibrating multispectral drone imagery. However, for this, affordable, practical and reliable in-flight targets need to be developed and then data collected to compare the two methods of calibration.

Useful Links (not exhaustive):
- Labsphere, USA (Spectralon Targets)
- Sphereoptics, Germany (Zenith Light Targets)
- Spectra Vista Corporation, USA (Target cases)
- NERC Field Spectroscopy Facility, UK (Target loans and support for UK NERC funded grants)
- MicaSense Best Practices Data Collection, MicaSense Website

D. Metadata and Data Management

Detailed and organized record keeping is critical for drone ecology work, especially for cross-site comparisons.

Metadata records:
- Site Master Log 13 June 2017

More information on metadata records (GCP, etc) is available in the above spreadsheet (pdf version Site Master Log 13 June 2017 Sheet1). Keep general mission records here, even if mission must be aborted/fails.

Flight Log Sheet 13 June 2017 Sheet1 (Flight Log Sheet 13 June 2017)

Detailed metadata sheet for each flight. It is CRITICAL that these are filled out for each flight and stored in the associated FlightID folders.

We will set up a cloud-based data repository accessible to network members late this summer for teams to upload flight metadata, ground truthing data, and UAV imagery.

In the field, it is recommended that teams keep triplicate (at a minimum) backups of all data on separate hard drives. Please store data in folders using the naming convention detailed in the Master Log Sheet file (avoid spaces and uncommon characters):

FieldSite (choose unique 3 letter code) -> BlockIdentifier ->FlightID

E.g., QHI_PS1HE_FL001M
HiLDEN protocol

High Latitude Drone Network Flight Log Sheet

for comments and suggestions please contact: j.axmann@ed.ac.uk and j.tkerb@gmail.com

Flight ID:  
Pilot:  
Principle Investigator:  
Site Name:  
Subsite ID:  
Date (yyyy/mm/dd):  
Aircraft Type:  
multicopter / plane  
Take-Off (hh:mm):  
Landing (hh:mm):  
Aircraft ID:  
Flight Altitude (m):  
Duration (min):  
Sensor Type:  
Sensor ID:  
Estimated GSD (cm/pixel):  
Tundra Block ID:  
# of Images captured:  
Image Start/End Names:  

Weather

Windspeed (m/s)  
Sky conditions:  
Temperature (°C):  

Comments:  
(e.g., dew on vegetation due to recent fog, 
or surface is wet due to recent rain)

Radiometric Calibration

Pre-Post Flight Calibration  
[ ] pre-flight  
[ ] post-flight  
which is most representative?  
[ ] pre-flight  
[ ] post-flight

Inflight Calibration Targets

<table>
<thead>
<tr>
<th>Target ID</th>
<th>Position (GPS coordinates or relative description on site)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

General Comments

Sky Codes:  
0 Clear sky  
1 Haze  
2 Thin cirrus – sun not obscured  
3 Thin cirrus – sun obscured  
4 Scattered cumulus – sun not obscured  
5 Cumulus over most of sky – sun not obscured  
6 Cumulus – sun obscured  
7 Complete cumulus cover  
8 Stratus – sun obscured  
9 Drizzle
E. Postprocessing
The protocols detailed above will generate high quality image and ancillary data required to build consistent structural and spectral models of tundra landscapes. There are many approaches to generating these models, and the step-by-step details change frequently as technology and software develops. We currently do most of our processing using the two industry standard software environments: Agisoft Photoscan Pro and Pix4D.

An excellent tutorial on the general Photoscan workflow can be found here: http://adv-geo-research.blogspot.com/2015/06/photoscan-crash-course-v1-1.html

Many other general tutorials for both Pix4D and Photoscan are available on YouTube.

Data processing for 2017 will be centralized, most likely using a workflow from one or both of the above software environments. This will be laid out in detail after the field season and will be another chance for input from various teams.

We will also build a general tutorial for generating these models, but that will have to wait until after the field season!

F. Planned Products and Next Steps
Participants in HiLDEN during the 2017 season (and beyond) will be contributing data to a synthesis paper focused on using UAS data to address cross-site questions about tundra ecology. This paper will use the data contributed from the 2017 field teams to address fundamental cross-site questions and develop new lines of investigation. We will target an international ecological/global change journal for this manuscript. There may also be opportunities for separate methods focused manuscript(s) targeted at remote sensing journal.

We will tentatively plan on holding a side meeting in association with the Arctic Change meeting in Quebec City (http://www.arcticnetmeetings.ca/ac2017/) for those who can make it to discuss what was achieved this summer, data analyses to date, the further development of protocols and data collection for 2018.

We are also exploring funding opportunities for work beyond 2017. If any network members hear of other funding opportunities that we should apply for or would like support in applying for, please let us know.

Appendix A. Platforms and Sensors
Choice of platform and sensor requires evaluating associated trade-offs in: desired grain vs. extent of mapping area, the spectral vs. structural data requirements for a given question, and logistical issues like cost, ease-of-use, and platform customizability.

Platforms
The two most common UAS platform types are best classified as ‘multi-rotors’ and ‘fixed wings’. Multi-rotors commonly have 4 to 8 spinning rotors that provide both lift and navigation through differential thrust. In contrast, fixed wings typically have one propeller providing thrust while generating lift and navigation over a wing(s) with dedicated control surfaces (like a rudder or elevons). Kites and balloons can also be effective sensor platforms in some conditions, and hybrid Vertical Take-Off and Landing (VTOL) systems may have widespread uses after a few more years of development.
### Performance / Platform

<table>
<thead>
<tr>
<th></th>
<th>Multi-rotor</th>
<th>Fixed-wing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Optimal cruise speed</td>
<td>Slower (&lt;10m/s)</td>
<td>Faster (&gt;14m/s)</td>
</tr>
<tr>
<td>Flight duration</td>
<td>Shorter (~6-30 min)</td>
<td>Longer (25-120 min)</td>
</tr>
<tr>
<td>Flight operations</td>
<td>Requires only limited training</td>
<td>Requires more experience*</td>
</tr>
<tr>
<td>Best Mapping Use</td>
<td>Small extent, fine grain</td>
<td>Larger extent, coarser grain</td>
</tr>
</tbody>
</table>

*specifically for takeoff and landings and optimizing flight-time via mission planning

**What we’re using and other suggested* platforms:**

*There are many solutions out there — tell us what you think/like!

**Multi-rotors:**

**Tarot 680 (custom built from kit)** – These UAVs are based on the Tarot 680PRO Hexacopter folding frame and a Pixhawk flight controller running ArduCopter software. We used these extensively in 2015 & 2016, and they offer a customizable platform for a variety of sensors but have required significant time investment in trouble shooting and have a short flight time (<10min when carrying sensors). [Costs for original components including RC, etc. was around $1000 USD, but we spent several hundred dollars replacing and modifying parts and more on sensor and ground control station.]

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*DJI Phantom 4 Advanced or Pro* – widely used, easy to fly, good value [~$1100 – 1600 USD with accessories and spare parts], good flight duration (25+min), comes with relatively high quality RGB camera (20mp 1-inch sensor that captures in RAW, same as Sony RX100 [below]) useful for RGB mapping and outreach videography. Can be modified to carry small multispectral cameras – **recommended entry point model** due to reliability and flexibility for cost level. Other DJI models will
also be tested this summer by various participants (DJI Mavic Pro [~$1000 USD], DJI Phantom 3 Pro [~$600 USD]).

3DR Solo or Iris+ – lowest cost [~$300-500 USD without sensor], compatible with open source mission planning software, readily customizable – models may not be available everywhere. Slightly less of a ‘turn key’ solution than the DJI Phantom 4 models with significantly shorter flight times.

A 3DR Solo in a retrogressive thaw slump.

**Fixed wings:**

*Zeta FX-61 (kit)* – custom built in-house with a pixhawk/pixhawk2 flight controller. Customizable platform, but benefits from past experience piloting and planning missions helpful to optimize flight times and to fly consistent missions. Can share build specs and tips with interested parties. [Costs ~$700 USD (pictured below) – $2500 USD without sensor depending on the set up].
A Zeta FX-61 with the innards visible in the field.

*Parrot Disco Ag* – Will be field testing this summer – looks like a promising trade off between much more expensive commercial options and custom built systems. Expecting this unit to be relatively user friendly and designed to carry small multispectral camera (Parrot Sequoia). Stay tuned! Costs [~$4995 USD, but this includes the cost of a $3,500 USD multispectral sensor].

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A Parrot Disco AG carrying a Sequoia Multispectral Sensor

*SenseFly eBee* – A relatively high-cost [~$7,000 – 30,000 USD] commercial option that is widely used and tested – though not by core team members. Can carry a small point-and-shoot RGB or multispectral cameras like the Sequoia.

**Sensors**
UAS can carry almost any sensor-type that fits their loading capacity, but we will focus on imaging sensors here.

**RGB:** Traditional digital camera sensors that capture spectral information in the Red, Green, and Blue (RGB) parts of the electromagnetic spectrum that correspond with colors visible to the human eye. Suggested models:

- Sony a6000/a5100 (Qikiqtaruk team 2015/16 Multirotor)
- Sony RX100ii-v series (Qikiqtaruk team 2016/2017 Fixedwing)
- DJI Phantom 4 RGB (same sensor as Sony RX100 series, Qikitaruk team 2017)
- DSLR models – e.g. Nikon D810 (only for very large multirotors)
- CHDK enabled Canon S100 or similar
- Note: avoid GoPros if possible. The significant lens distortion affects data product quality.

**Multispectral:** Capture spectral information from a broader range of the electromagnetics spectrum, often inclusive of the near infrared (NIR), infrared (IR), or ultraviolet (UV) parts of the spectrum that can be used to provide more information about plant health/productivity. Suggested models:

- Parrot Sequoia ([https://www.micasense.com/sequoia/](https://www.micasense.com/sequoia/))
- NIR modified Sony a6000 ([http://www.mosaicmill.com/products_other/ndvi-cameras.html](http://www.mosaicmill.com/products_other/ndvi-cameras.html))
Mounting your sensor on your drone platform will take some consideration. Options include multi-axis gimbals to static mounts. It is now possible to 3D print mounts for certain sensors including the Parrot Sequioa for some drone platforms, and some of these sorts of mounts could be adapted for other platforms.

Drone sensor mounts can be 3D printed such as this Sequoia mount for a 3DR Solo for example available on thingiverse (https://www.thingiverse.com/thing:1674587/apps).