# Appendix E:
# Calibration Guide for Offshore Motus Stations

Erik Carlson, University of Rhode Island, Department of Physics (erikvcarlson@uri.edu)

Pam Loring, U.S. Fish and Wildlife Service Division of Migratory Birds, North Atlantic-Appalachian Region (pamela_loring@fws.gov)

v. March 15, 2023

## Introduction:

This document describes suggested workflows for calibrating offshore Motus stations. Calibration surveys should be completed at every offshore Motus station to better understand the detection range and coverage of the station's antennas at each frequency the station monitors (typically 434 MHZ and 166.380 MHZ). Specifically, these surveys use a calibration tag for each frequency to collect data on the received signal strength values of the station by each of its antennas as the tags move along transects covering a range of distances, altitudes, and orientations from the station. This is accomplished by elevating calibration tags on a pole, kite, UAS (Unmanned Aerial System), or airplane within the vicinity of active Motus station(s) and recording the trackline and altitude of the calibration tags using a co-located barometric GPS unit. Data collected during calibration surveys provide valuable information on antenna reception coverage, range estimates, and identification of antenna blind spots. As part of this effort, we have developed a pilot version of an online Calibration Data Analysis Tool to help generate basic transects for calibration surveys and produce simple summary reports of data collected during calibration surveys. Future efforts conducted by the University of Rhode Island will explore using data from dedicated calibration survey efforts to develop antenna radiation pattern modeling and tracking algorithms for use in more detailed estimates of tag movements and flight altitudes within a wind project area.

## Specifications of calibration tags

Calibration tags are Motus tags that are specifically used to evaluate a station's detection range and coverage. There are several key specifications that Motus tags must have in order to be used for calibration. First, each tag must have a power regulator so that the power output of each transmission is consistent. Examples of power-regulated tags that are suitable for calibration include: CTT PowerTags (434 MHz) and Lotek 'NanoTags' (166.380 MHz). There are also several types of solar tags and hybrid-solar tags available for use in Motus, but these tags should not be used for calibration because the power output of each transmission varies depending on available light the tag receives and the status of battery charge. In addition to having variable power output, these solar tags and hybrid-solar tags may stop transmitting altogether when insufficient light and power is available. Thus, solar-powered or hybrid-solar tags are not recommended for calibration efforts because their power output is inconsistent.

Calibration tags should otherwise be identical to Motus tags used for avian and bat monitoring except for the battery life and burst rate interval, which may vary with species tagged and study objectives. Calibration tags should otherwise transmit at the same power levels as tags deployed on birds and bats. Every receiving antenna and transmitter type will have slightly different interactions and thus require separate calibrations to fully account for variation. To minimize the amount of calibration required, it is strongly recommended that a standard calibration tag (model, specifications) and standard dual-mode Motus station designs (for 166 MHz and 434 MHz, respectively), utilizing the same make and model antenna for each respective frequency, be used for an entire wind project area.

Calibration tags should have a short burst interval (≤ 5 seconds) to allow for the maximum number of signals received during a calibration survey. The calibration tag's burst interval should match the temporal resolution of the barometric GPS used for calibration surveys (described in section below on barometric GPS units). We recommend using a temporal resolution of 1-second for the barometric GPS unit and calibration tag burst interval maximize data collected during each calibration survey.

Calibration tags should be able to be activated and deactivated at the user's discretion. The short burst interval of calibration tags may result in shorter overall battery life relative to tags with a longer burst interval (i.e. > 5 seconds). Because of this, to save resources, tags should be compatible for use with an activator to allow tags to be turned on and off at the start and end of each calibration survey.

Studies should use at least one calibration tag for each frequency (166.380 MHz and 434 MHz). The following tag specifications are currently recommended for calibration:

434 MHz 'PowerTags' (CTT)

- Weight = 5 g
- Burst interval (range): 1 second (minimum) to 5 seconds (maximum)
- When purchasing, specify that you want an 'activator tag' so that it can be turned off to conserve battery life when not in use
- You will also need to order an activator

166.380 MHz 'NanoTags' (Lotek Wireless)

- Weight: 3-g,
- Burst interval (range): 1 second (minimum) to 5 seconds (maximum)
- For calibration tags, Lotek will assign the following ID codes: 2, 3, 4
    - To designate other tag ID codes as calibration tags, please contact Motus (motus@birdscanada.org) to ensure the tag(s) are identified correctly in the database
- When purchasing, specify to avoid the following ID codes: 1, 5, and 67 (these codes are prone to high rates of false positive detections in marine environments).
- You will also need to order an activator.

## Specifications of barometric GPS units

A stand-alone barometric GPS is necessary to accurately record 3-D locations of test tags during calibration surveys and provide standardized trackline data for analysis. GPS devices without a barometer, such as those used for marine navigation, rely on GPS positioning to estimate altitude, and are not recommended for use in calibration surveys because the altitude data are too unreliable.

Light-weight barometric GPS models (e.g. Garmin Edge 130 Plus) have suitable specifications (33 g, 41 x 63 x 16 mm) for attachment to kites and UAS. The GPS should be set to record locations at a temporal resolution of 1 second. For best results, the barometric GPS's can be calibrated to a known altitude to provide the most accurate measurements over the course of a calibration survey.

## Types of calibration surveys

Boat-based and aerial calibration surveys are used to collect station calibration data across a range of flight altitudes. The distances at which Motus stations can detect tags tend to increase with the altitude of the tags. Therefore, it is important to conduct calibration surveys across a range of altitudes to better understand the detection range of stations to track tagged birds and bats flying at different altitudes. The main types of calibrations surveys and their timetables are discussed in detail below.

### Basic calibration surveys

Basic, boat-based calibration surveys should be conducted on the station deployment date or within seven days after the initial deployment of that station. These surveys should be repeated on an annual basis throughout the operational lifetime of the station. Detection data from each calibrated station should be downloaded on the date of the calibration survey after all calibration activities are complete.

To conduct a basic calibration survey, a barometric-based GPS device, as well as two power-regulated (e.g., battery-powered, without solar) Motus tags (434 MHz CTT 'PowerTags' and 166.380 MHz 'NanoTags') should be attached to the top of a non-conducting (e.g., wood or fiberglass) pole and placed with a clear line of sight to the surroundings. The pole should be placed at the highest point of the vessel to prevent the tags' signals from bouncing off the ocean. Using a dedicated barometric GPS that is co-located with the Motus tags is essential for optimizing accuracy of the trackline data and standardizing data output for use with consistent analysis methods across sites. If battery power permits, the barometric GPS should be powered on and recording data, and calibration tags should be activated immediately upon leaving the dock to maximize potential detections on the Motus station.

The basic calibration survey should be conducted along transects in an outward rectangular spiral from the station with the initial leg being 500 m (0.3 mi) in length out to a minimum distance of 5 km and a minimum spacing distance of ≤ 1 km between spirals. Surveys of turbine stations with Yagi antennas should also include additional linear transects for each Yagi antenna, whereby a singular track is taken centered on each Yagi antenna at the same bearing as the antenna, starting at the station and extending out to 5 km from the station along the bearing of the antenna. This allows for a basic estimate of the range of each antenna.

## Aerial calibration surveys

To more fully evaluate the detection ranges of stations to track birds and bats across a range of flight altitudes, aerial calibration surveys should be conducted within one (1) year of station deployment and repeated on an annual basis throughout the operational lifetime of the station. These surveys provide more detailed information for analysis of detection data and are essential for using detection data for analyses of movements within a wind project area.

Multiple calibration techniques are used to collect high-altitude calibration data. These techniques are listed in decreasing order of effectiveness:

1) Test tag and GPS attached to an Unmanned Aerial System (UAS). Effective altitude 0 to ~450 m ASL (0 to 1477 ft ASL). Calibration activities to be conducted within a circle centered on station to outer radial distance of 15 km.

2) Test tag and GPS attached to a small aviation aircraft. Effective altitudes ~450 m to 3,000 m ASL (1,500 to 10,000 ft ASL). Calibration activities to be conducted within a circle centered on station to outer radial distance of 42 km.

3) Test tag and GPS attached to a kite that is flown behind a boat. Effective altitude 0 to 50 m ASL (0 – 164 ft ASL). Calibration activities to be conducted within a circle centered on station to outer radial distance of 5 km.

Aerial calibration surveys should minimally collect 15,000 detections (approximately 4.2 hours using 1 second burst rate tag, such that minimally 10 detection points per cubic km are collected) on each antenna on a target station. The total area covered by each calibration survey varies by aerial calibration method (see details below), covering an outer radial distance of 5 km to 42 km from the target station.

Data from aerial calibration surveys are essential for use in antenna radiation pattern modeling and tracking algorithms currently under development to provide more detailed estimates of tag movements and flight altitudes within a wind project area. Increasing the number of calibration data points increases the quality and resolution of the estimated antenna radiation pattern in 3-D. Data points need to be unique and cover a wide range of altitudes. To be able to model 3-D animal tracks, these points must be collected at a variety of altitudes with particular emphasis between 0 m above-ground level (AGL) to 200 m above the upper limit of the rotor swept zone. Additionally, these surveys should aim to introduce further altitude information by frequently varying the altitude of the calibration tags, e.g., in a vertical zig-zag type pattern. Altitude information is most easily collected using a UAS or small aviation aircraft.

## Annual maintenance calibration surveys

Basic and aerial calibration survey should be repeated on a yearly basis. These surveys should be conducted to the same intensity as the calibration surveys conducted after the initial deployment of the station. These calibration surveys allow for the quantification of any change in detection range or receiver pattern that might occur due to the buildup of white dielectric material on the antennas. Follow-up calibrations should implement more altitude information and fill areas where previous calibrations did not. Aerial survey efforts could be coordinated on a regional scale to maximize resources. Additional information on regional coordination of calibration surveys is found in the Monitoring Framework.

### Opportunistic calibration efforts

Opportunistic calibration efforts can be used to collect additional, supplemental calibration data requiring the least amount of additional time and funding. Similarly, to basic calibration surveys, opportunistic calibration efforts may be conducted with calibration tags and a barometric GPS located on a non-conducting pole attached to the highest point of a vessel. Ideally, these calibration efforts should be conducted any time operations are occurring within 18.6 mi (30 km) of a tracking station. These calibration efforts will provide information about which antennas are active, as well as contribute detection data to help inform targeted calibration surveys.

Opportunistic calibration efforts can also be conducted during boat-based or aerial activities conducted by academic, governmental and cooperate partners. For example, scientists conducting aerial wildlife or geotechnical surveys could contribute calibration data to projects which they are within 50 km of active Motus stations. If recommended Motus tags and barometric GPS units are used, and the data is reported following the workflow described here, any signals detected by surrounding stations can contribute to the station’s calibration portfolio.

## Preparing equipment for a calibration survey with an Unmanned Aerial System (UAS)

The following section identifies the items and the recommended attachment mechanism for a calibration survey conducted with an UAS.

The following items (or equivalent) are recommended for collection of standardized calibration data:

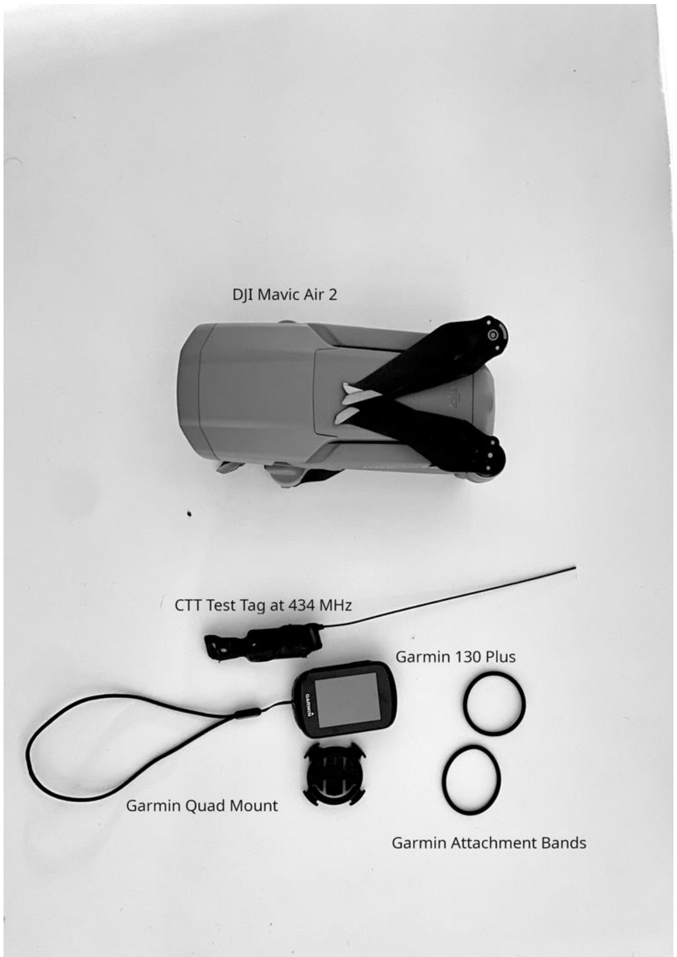
1) Garmin 130 Plus (or similar barometric GPS)

2) Test Tag and Activator

3) Small UAS (e.g., DJI Mavic Air 2 or similar)

4) At least 2 hours' worth of UAS batteries

6) Garmin Edge Quarter Turn Bike Mount with Attachment Bands

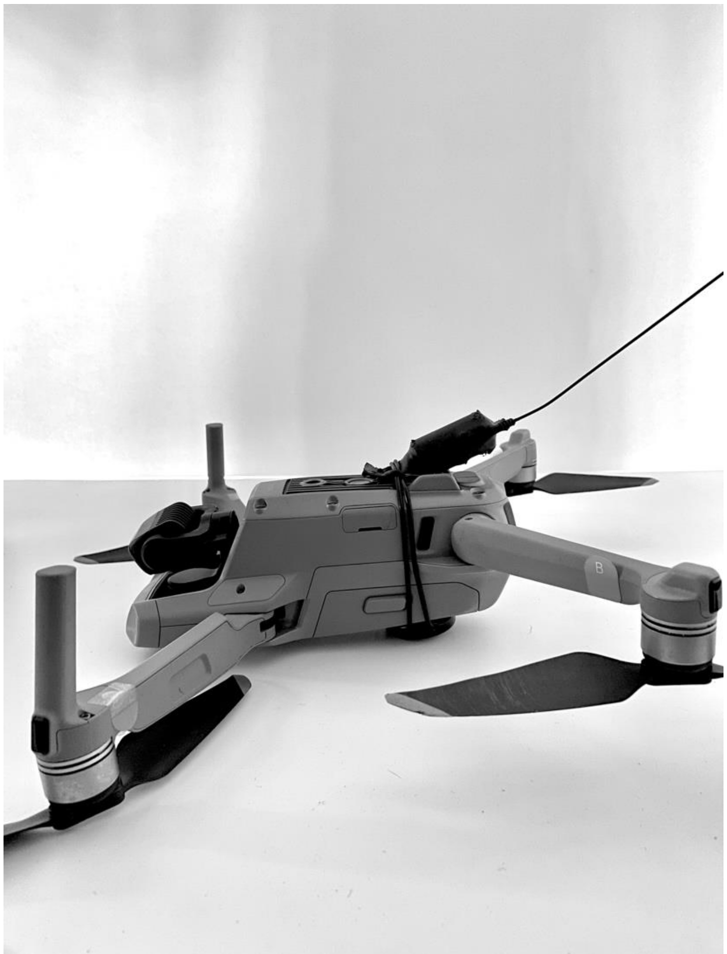



The first step in preparing the UAS for flight is to knot the two rubber attachment bands as seen in the image below:

Second, the UAS should be unfolded and a preflight should be completed as recommend by the manufacturer.

Next, the bands will be used to secure the quarter turn lock to the UAS. The UAS should look like the following when this step is complete:

The tag should be affixed to the bottom of the UAS such that it is clear of the rotors. Here I utilize the bands to hold the tag in place. Later, I will also use the safety lanyard attached to the Garmin 130 to provide additional support to the test tag.



Once the test tag is affixed, we can attach the GPS to the quarter-lock-mount such that our final configuration looks similar to the following.

## Workflow for Calibration Data

This section describes some key steps to include in a workflow for calibration survey data collection. First, the barometric GPS needs to be set to a known elevation or 0 if at sea level before each calibration run. Reference the manufacture manual for instructions on how to complete this step. This step should be repeated every 30 minutes or if there is any significant drop in atmospheric pressure, such as inclement weather rolling in.

Furthermore, it is critical to activate calibration tags before attachment to the calibration platform (pole, kite, plane, UAS) prior to a calibration survey. The calibration tags should be separated from each other such that their transmitter antennas will not come in contact during the calibration survey. Transmitting antennas from all calibration tags should point in the same direction and have a clear, unobstructed view of the surrounding airspace. The calibration tags should be co-located with the GPS unit. The GPS will have a vent which cannot be covered by any waterproofing or attachment adhesive.

Every calibration survey should collect standardized metadata. A printer-ready "Metadata Field Sheet for Calibration Surveys" is available to assist with standardized metadata survey collection. Alternatively, the online Calibration Data Analysis Tool (described in next section) can be used to automatically generate a printer-ready calibration metadata sheet and survey transects.

Minimum metadata standards for calibration data include:

Calibration survey information:

- Date
- Name of lead surveyor
- Type of calibration survey (e.g., tag on pole, kite, UAS, plane)
- General location of calibration survey (e.g., wind project area)
- Start and end time of survey
- Targeted Motus stations being calibrated

Equipment information:

- Test tag IDs
- Test tag model
- Test tag frequencies
- Test tag burst rates
- Barometric GPS make and model
- Barometric GPS temporal resolution of data collection (e.g., every 5 seconds)

Weather conditions

- Altimeter
- Barometric Pressure
- Dewpoint
- Humidity
- Temperature
- Cloud Ceiling
- Precipitation and Type

***Note:*** Most of the weather data are available through the FAA Flight Weather Service: https://www.aviationweather.gov/

To obtain these data:

1. Go to www.aviationweather.gov
2. Select METARs
3. Scroll down to Request METAR data
4. Enter ID of nearest airport (example for Block Island: KBID) - note if the calibration
5. Click get METAR data
6. Click: 'decoded'

The complete trackline of each calibration survey must be recorded using the barometric GPS. This will provide fine time-resolution GPS and elevation data which will be saved to the GPS in the form of GPX file.

Once the calibration is complete, the GPS needs to be mounted to a computer and the GPX file needs to be transferred to that device. See manufacture manual for exact directions on accessing and transferring GPX files to a computer.

Detection data should be downloaded from each calibrated station and uploaded to Motus for processing. The data should then be downloaded using the Motus R package. As part of this effort, we have developed a preliminary version of an online Calibration Data Analysis Tool to aid in generation of a simplified automated report from calibration data.

## Calibration Data Analysis Tool

To simplify the calibration data workflow, we developed a preliminary version of a Calibration Data Analysis Tool as an online web application (https://birdsdev.uri.edu/). In general, this tool serves three primary functions: 1) survey planning, 2) data analysis, and 3) automated reporting.

For survey planning, the tool has an "Initial Transect Calculator" that allows users to input the latitude and longitude of stations to generate a field metadata sheet for the calibration survey that includes waypoints for rectilinear transects to aid in survey design for basic, boat-based calibration surveys (Fig. E1). The tool also produces a printer-ready metadata field sheet that automatically pre-populates the code of the nearest airport for use in acquiring METAR data.

Upon completion of the survey, the Calibration Report Generator allows users to upload Motus detection data and GPS data from the survey as .csv files. Example .csv file formats of Motus detection data and GPS data are provided with the tool. Outputs from the tool provide the user plots of the location and signal strength of calibration tag detections. The tool also generates summary statistics to include the number of detections per antenna, overall calibration efficiency, and the detections range of each antenna. This tool is currently deployed in a docker container at https://birdsdev.uri.edu. Please contact Erik Carlson (erikvcarlson@uri.edu) for questions or feature requests.

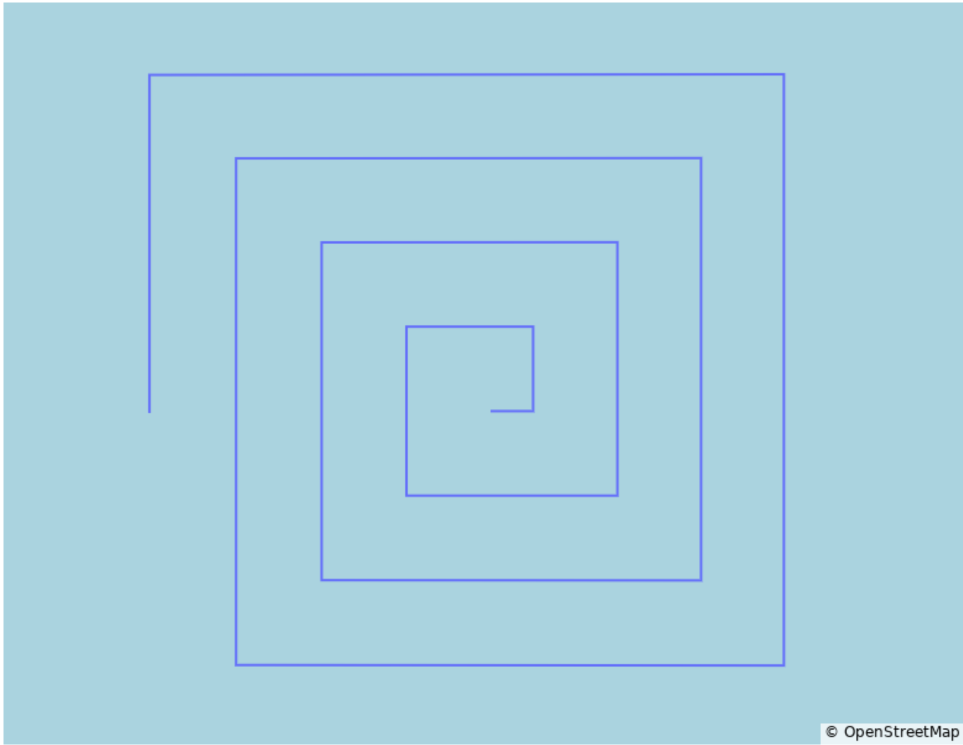



Figure E1: An example of transects generated for a basic calibration survey in an outward rectangular spiral from the station with the initial leg being 500 m (0.3 mi) in length out to distance of 5 km (3.2 mi) and a spacing distance of 1 km (0.6 mi) between spirals.

**Table E1.** List of equipment and supplies for calibration surveys.

| Item | Qty | Desc | Link |
|---|---|---|---|
| **Equipment for data download** | | | |
| Laptop computer | 1 | To download data from SensorStation (sufficient battery power for field use) | |
| USB to Ethernet adapters | 2 | Ethernet Adapter USB | https://www.amazon.com/UGREEN-Ethernet-Adapter-Nintendo-Chromebook/dp/B00MYT481C |
| Ethernet cable | 1 | Cat-6 Ethernet Patch Internet Cable - 5 Feet (1.5 Meters) | https://www.amazon.com/AmazonBasics-RJ45-Cat-6-Ethernet-Patch-Cable-5-Feet-1-5-Meters/dp/B00N2VILDM |
| USB with MS DOS or Fat32 formatting | 1 | To manually download detection data | https://www.amazon.com/Memory-Computer-Laptop-Backup-Indicative/dp/B08CX89MK2/ |
| **Transmitters for testing station** | | | |

| Item | Qty | Desc | Link |
|---|---|---|---|
| CTT PowerTag | 1 | 5-g. Specify 1-second burst interval for tags used in calibration surveys. Otherwise specify 5-second burst interval for tags for general station checking (on/off). Order version compatible with activator so tag can be turned on and off. | https://celltracktech.com/collections/digital-radio-products |
| CTT PowerTag activator | 1 | | https://celltracktech.com/collections/digital-radio-products |
| Lotek NanoTag | 1 | 5-g. Specify 1 second burst interval for tags used in calibration surveys. Otherwise specify 5 second burst interval for tags for general station checking (on/off). When purchasing, specify 'TEST' tags and ID codes # 2,3, or 4 will be issued. Avoid ID codes #1, 5, and 67 so tags can be used for station calibration (these codes are prone to high rates of false positive detections in marine environments) | https://www.lotek.com/products/nanotags/ |
| Lotek NanoTag activator | 1 | | https://www.lotek.com/products/nanotags/ |
| **Calibration surveys** | | | |
| Lightweight GPS with barometric altimeter | 1 | Garmin Edge 130 Plus | https://buy.garmin.com/en-US/US/p/698436 |
| Mount for GPS attachment to calibration platform | 1 | Garmin Edge Quarter Turn Bike Mount with Attachment Bands | https://www.garmin.com/en-US/p/65215 |
| Pole (altitude range = height of pole ASL) | 1 | 3 m (10 ft) pole made from non-conductive material (e.g. plastic) | https://www.homedepot.com/p/JM-eagle-2-in-x-10-ft-PVC-Schedule-80-Conduit-67561/100172008 |
| Kite: altitude range 0 to 50 m ASL (0 to 164 ft ASL). | 1 | Suggest 'delta' type and enough line to fly at target altitudes | https://www.amazon.com/Beginners-Stunning-Materials-Meticulous-Guarantee/dp/B0167ZL9CO/ref=asc_df_B0167ZL9CO/?tag=hyprod-20&linkCode=df0&hvadid=198072474455&hvpos=&hvnetw=g&hvrand=5531421778217463542&hvpone=&hvptwo=&hvqmt=&hvdev= |

| Item | Qty | Desc | Link |
|---|---|---|---|
| | | | c&hvdvcmdl=&hvlocint=&hvlocphy=1027019&hvtargid=pla-377461825886&psc=1 |
| UAS: altitude range 0 to approx. 450 m ASL (0 to 1477 ft ASL). See US Federal Code 14 CFR § 107 for further restrictions. | 1 | DJI Mavic Air 2 or similar. At least 2 hours' worth of UAS batteries needed. | https://www.dji.com/mavic-air-2 |
| Aircraft: altitude range approx. 450 m to 3000 m ASL (1,500-10,000 ft ASL). See US Federal Code 14 CFR § 107 for further restrictions | 1 | See 14 CFR Part 91 for further restrictions) | United States Civil Air Patrol Rhode Island Wing: https://riwg.cap.gov/ |

## Statement of use

This study was funded by the New York State Energy Research and Development Authority under Agreement No. 143771. This information is preliminary and subject to revision. It is being provided to meet the need for timely best science. The information is provided on the condition that neither the U.S. Fish and Wildlife Service nor the U.S. Government shall be held liable for any damages from authorized or unauthorized use of the information. Any use of trade, firm, or product names is for descriptive purposes only and does not imply endorsement by the U.S. Government. The findings and conclusions in this article are those of the author(s) and do not necessarily represent the views of the U.S. Fish and Wildlife Service.