User Manual for IDIOMS: the Study Design Tool to Inform the Design and Implementation of Offshore Motus Stations

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IDIOMS is available at: https://briloon.shinyapps.io/IDIOMS/

Disclaimers

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Contents

Background

Automated radio telemetry systems consist of radio tags (small transmitters attached to birds, bats, or insects) and receiver stations (receivers with antennas that automatically record signals from "tagged" organisms within a certain detection range; Figure 1). The Motus Wildlife Tracking System[1] ('Motus') is an international collaborative research network that uses cooperative automated radio telemetry to track tagged organisms on coordinated frequencies (currently 166.380 MHz and 434 MHz in North America). Collaborators using Motus have collectively tagged tens of thousands of birds and bats and tracked their movements using an international network of automated radio telemetry stations. Motus also serves as a hub for data from thousands of receiving stations and hundreds of tagged species worldwide.

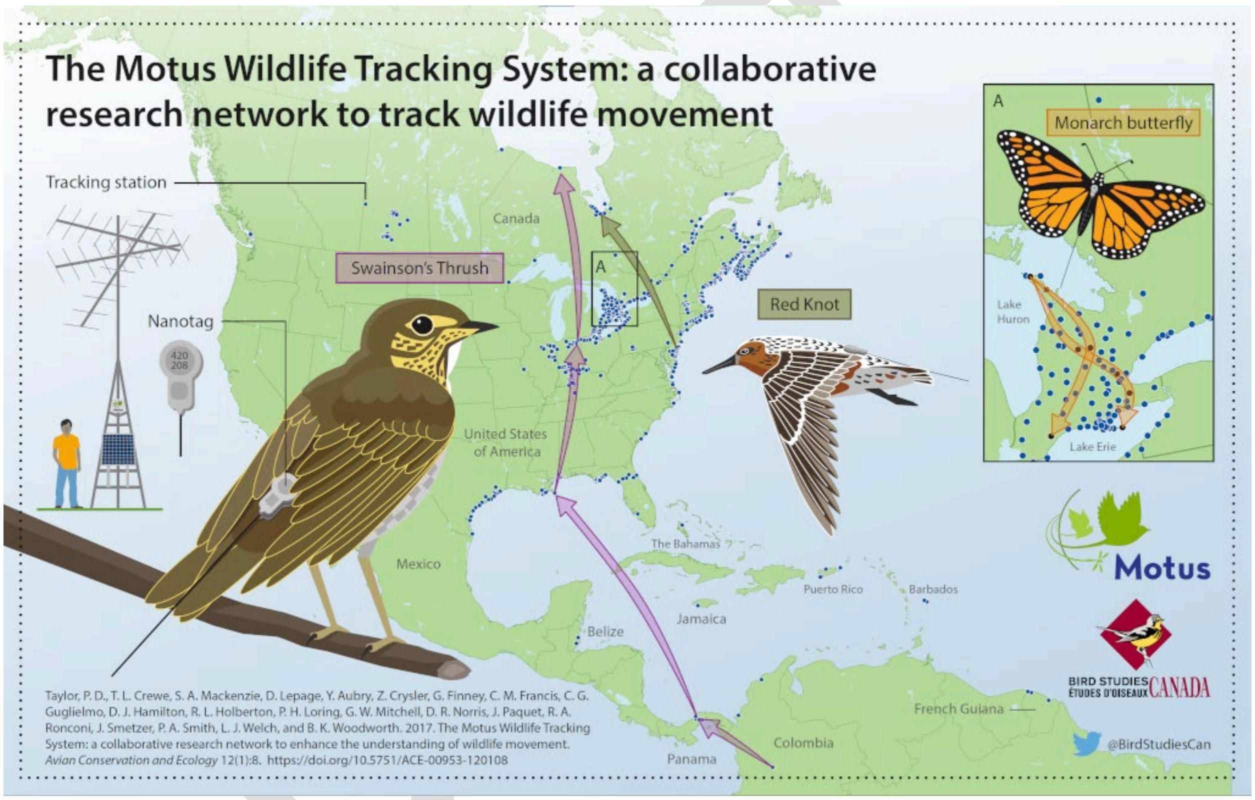

Figure 1. The Motus Wildlife Tracking System.

This user manual and the associated study design tool, "Informing the Design and Implementation of Offshore Motus Systems" (hereafter "IDIOMS"), are part of an effort to develop standardized protocols for the use of Motus in pre- and post-construction monitoring for birds and bats at offshore wind energy projects. Detailed protocols will enable the offshore wind industry to use standardized approaches to monitor a wide range of avian and bat taxa, including threatened and endangered species, and improve our understanding of how these species use offshore environments. This effort, titled "Development of Monitoring Protocols for Automated Radio Telemetry Studies at Offshore Wind Farms[2]," includes the following components:

[1] https://motus.org/
[2] https://briwildlife.org/offshore-motus-guidance/

- Monitoring framework – strategic framework and guide for using Motus technology to monitor wildlife in relation to offshore wind energy development;
- Guidance document – detailed guidance for setting up and operating Motus stations on offshore wind turbines and buoys;
- Online study design tool (IDIOMS) – interactive tool to help arrange arrays of Motus stations to optimize site-specific study designs at offshore wind projects and map detection coverage of offshore receiving stations;
- Simulation study – modeling study using animal movement data to inform estimates of detection and uncertainty using Motus technology;
- Motus data framework – centralized framework and portal to coordinate data within the Motus Wildlife Tracking System from all birds and bats detected by stations on offshore wind turbines, monitoring buoys, and receiving towers along the Atlantic coast and Outer Continental Shelf (OCS).

All products from this effort are publicly available on the project webpage[3] (and at the AMBC page?). These products are intended to be living documents that are updated as new information and technology becomes available.

The free online tool, IDIOMS, was developed to help optimize site-specific study designs at offshore wind energy facilities, including the number and locations of receiving stations necessary to cover a given offshore wind energy project area relative to factors such as the project size and configuration, key species and questions of interest, and specific Motus technology being used. Input on the design of the tool and early beta testing was provided by a range of offshore wind-wildlife stakeholders to help ensure its robustness and utility. A partial list of these contributors is included in Gulka et al. (2021). For detailed, standardized recommendations on the actual deployment of Motus stations on offshore structures, including reference guides, recommended station configurations for offshore wind turbines and buoys, and equipment specifications, please see "Guidance Document for Deploying Motus Automated Radio Telemetry Stations on Offshore Wind Turbines and Buoys" (Loring 2022). For additional detail on the simulation study used to inform to determine the effectiveness of Motus receiver arrays in detecting movements of birds in and around offshore wind farms under varying designs and conditions, and with different focal species of interest, see Adams et al. (2022). A final report for this effort will be submitted to NYSERDA in September 2022 and will be available at nyserda.ny.gov/publications.

How Motus Stations Work

Details on the components, setup, and operations of Motus stations can be found in Loring 2022 guidance doc. There are also a variety of resources available on the Motus Wildlife Tracking System website[4]. It is assumed that users of the study design tool have a basic understanding of the design and components of these stations.

In North America, Motus tags transmit on either 166.380 MHz (hereafter also referred to as "166 MHz") or 434 MHz. Motus tag detections at automated radio telemetry stations typically include

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[3] https://briwildlife.org/offshore-motus-guidance/
[4] https://motus.org/resources

the following data: unique bird ID, time stamp, receiving antenna (bearing), and signal strength. Exact location data are not provided. The main components of Motus stations include: one or more antennas (tuned to specific frequencies), a mast, coaxial cables, a receiver, and a power source. To monitor tags at 166 MHz, a receiver station must have at least one receiving antenna tuned to 166 MHz. Likewise, to monitor tags at 434 MHz, a station must have at least one receiving antenna tuned to 434 MHz. IDIOMS specifically addresses the antenna receiver station component to understand how the arrangement and number of antennas at a particular frequency (166 or 434 MHz) affects detection pattern and distance across the study area.

The recommended specifications of antennas, coaxial cables, and mounting configuration for a typical station on an offshore wind turbine is described in Loring et al. (2022 guidance document; Appendix A).

Antennas

Antennas receive signals from tagged animals that pass within the antenna radiation pattern of a station. Detection range primarily depends on the power and frequency of the tag, the size and type of antenna, and line-of-sight distance between receiving station antennas and tags. Thus, detection range varies with several factors including the gain and height of the receiving antennas, receiving station surroundings, atmospheric conditions (e.g., dense fog can attenuate signals), and the flight height of the animal carrying the tag. There are two main types of antennas used for automated radio telemetry:

1) Omni-directional antennas (omnis): Provide presence/absence data at close range – typically within a maximum outer detection range from the antenna of 500 m to 1 km given sufficient gain (≥5 dBi). Patterns are roughly donut-shaped (Figure 2).
2) Yagi-Uda antennas (Yagis): Directional antennas that receive signals from one main direction (Figure 3). They consist of a long transmission line with a single driven element consisting of two rods connected on either side of the transmission line. They also include a single reflector on one side of the transmission line and a number of parasitic elements which act as directors. Yagis sacrifice omni-directional coverage for increased detection range (<5 to 15 km in some studies). An individual tracking station needs at least four Yagi antennas for coverage in all cardinal directions. Because Yagi beam patterns are so strongly directional, however, there are blind spots in coverage between adjacent Yagi antennas that need to be considered in station setup and data analysis.

The polarization of Yagi antennas affects how signals are received from tags. Linearly polarized Yagi antennas are designed to concentrate their receiver patterns in a narrow plane and are optimized for when the tag orientation is controlled. Using linearly polarized Yagi antennas may provide the user greater range in the plane of the polarization but will reduce the likelihood of off-axis detections. The radiation pattern from a circularly polarized Yagi antenna travels conically outward from the antenna and is optimized for when the tag orientation is uncontrolled, as is the case with flying animals. This reduces detection range but increases the number of animal detections that occur. Circularly polarized antennas are thus recommended when they are available (e.g., for 434 MHz) and are the modeled 434 MHz antenna shown in IDIOMS.

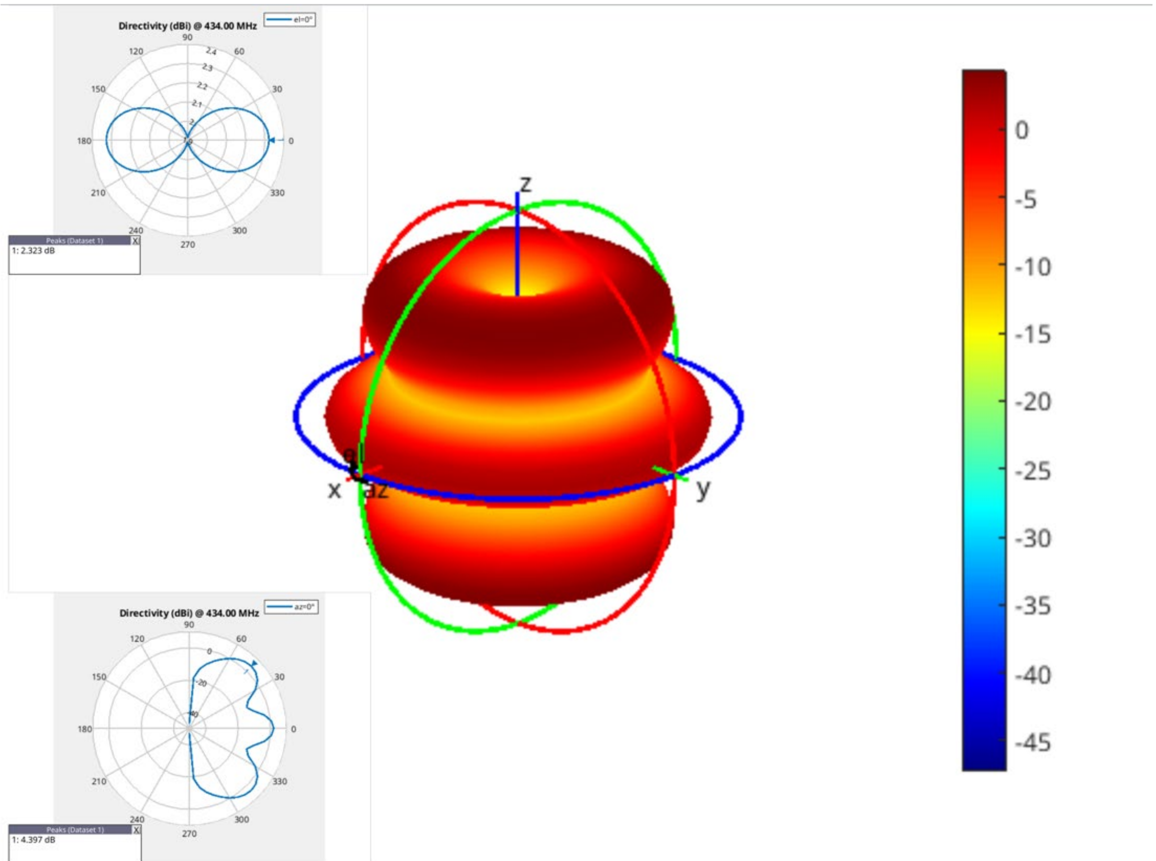


Figure 2. A theoretical omni-directional antenna radiation pattern derived at 434 MHz with the same characteristic structure as those deployed at the Block Island Wind Farm. Omni-directional antennas prioritize 360-degree coverage over detection range and directional information. Image credit: E. Carlson (URI).

Antenna(s) must be attached to an elevated mast that provides line-of-sight to the surrounding airspace. On smaller structures such as buoys, where space is typically limited, the mast should be at least 3.5-ft (1 m) above surrounding objects to minimize reflection of signals. On larger structures, such as wind turbine platforms or electronic service platforms, the mast should be at least 10 ft. (3 m) above surrounding objects to further minimize reflection and increase line-of-sight for tag detection. Calibration of the receiver stations is necessary to understand the actual patterns of detection and interference for a given receiver station setup. IDIOMS provides only a generalized indicator of receiving station performance, as the antenna detection patterns are modeled using measurements from specific receiver stations and may not be representative of conditions at other locations with varying surroundings and station setups. To standardize stations as much as possible, all users should reference Loring et al. (2022 guidance doc).

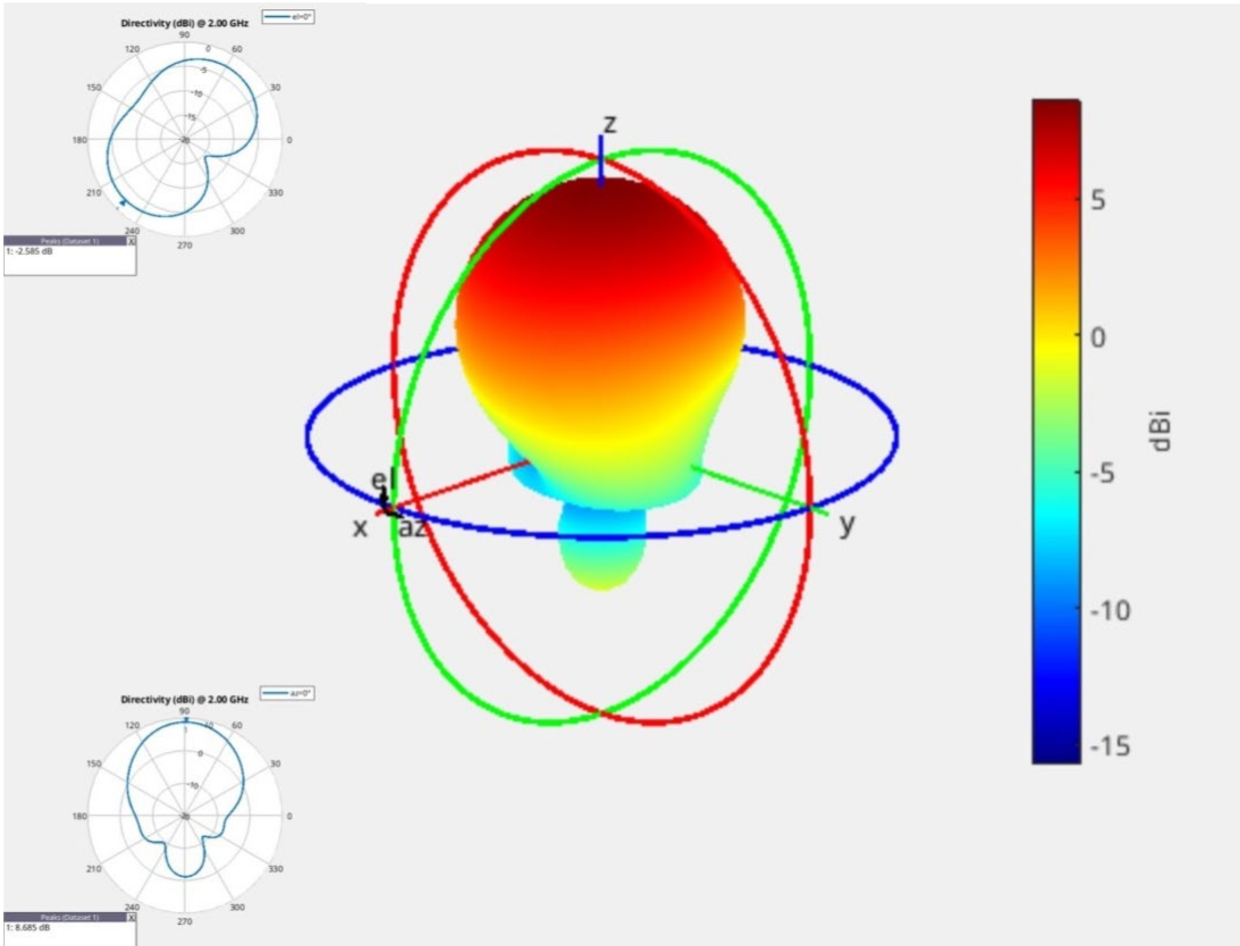


Figure 3. A theoretical Yagi-Uda antenna radiation pattern derived at 2.0 GHz with the same characteristic structure as those deployed at the Block Island Wind Farm. Yagi antennas prioritize detection range and directional information over 360-degree coverage. Image credit: E. Carlson (URI).

Receiver

A receiver unit converts received signal from antennas into tag detection data and stores these data. There are currently two types of receivers that are capable of monitoring **both** 166 and 434 MHz frequencies in the Motus system in North America: the CTT SensorStation (v 2.0, Cellular Tracking Technologies[5]) and the Sensorgnome[6]. Motus-compatible receivers are also available from Lotek[7] that will only detect tags on 166.380 MHz.

Recommended Antenna Configuration for Offshore Wind Turbines

The recommended configuration for a Motus station on an offshore wind turbine uses an array of four Yagi antennas and an omni-directional antenna. The recommended dual-mode station on an offshore wind turbine uses four Yagi (directional) antennas tuned to one of the Motus frequencies and a single omni-directional antenna tuned to the other Motus frequency (Loring et al. 2022). We recommend that each wind project area deploy multiple stations with alternating

[5] https://celltracktech.com/
[6] https://sensorgnome.org
[7] https://www.lotek.com/

configurations such that each frequency has approximately the same number of Yagi and omni-directional antennas per site. However, if a single station is used, we recommend using Yagi antennas for the higher-priority frequency and the omni-directional antenna for the lower-priority frequency. Frequency prioritization should be determined by the number of tags operating at a specific frequency on species of interest during the time that the receiver is in operation. Information on number of tags deployed per frequency during a given time period can be found at the Motus Wildlife Tracking System website[8]. Decisions on frequency prioritization should be made in coordination with regulatory agencies to address the need for best available information in monitoring programs.

Antenna Pattern Detection Modeling

Antennas patterns at 166 MHz and 434 MHz were both modeled from calibration data for antenna receivers installed at Block Island Wind Farm (BIWF). However, antenna beam patterns for the two frequencies (166.380 and 434 MHz) were modeled independently by different investigators, using very different modeling approaches (Janaswamy et al. 2018, Carlson et al. 2022). As such, the implementation of these models in IDIOMS to generate the antenna detection patterns is not directly comparable between the two frequencies. Estimated differences in beam pattern, range, and other characteristics should be interpreted with extreme caution.

Antenna modeling 166 MHz

TODO- describe methods briefly

Antenna modeling 434 MHz

TODO- describe methods briefly

[8] www.motus.org

Using Motus to Inform Offshore Wind Energy Development

The simplest method of Motus data analysis involves treating detection data as presence/absence at stations. This method allows for straightforward evaluation of regional movement patterns among stations, but does not use antenna bearing or signal strength data that provide valuable information on approximate bird locations and flight directions. Such information is especially important when researchers aim to use Motus to estimate space use and movements. In addition to more detailed two-dimensional movement, triangulation methods (i.e. full consideration of the relationship between signal strength, antenna height, and distance between spatially separated receivers detecting the same bird at the same time) can be used to estimate flight height. These methods have been piloted in several studies (e.g., Janaswamy et al. 2018, Loring et al. 2018, 2019, 2020) but have not yet been incorporated into an analysis tool that is available to the research community.

As such, applications of Motus receiving stations offshore include:

- Collecting data on small-bodied species of regulatory or conservation concern for which other types of transmitters are not feasible options, including protected species such as Piping Plover, Red Knot, and Roseate Tern.
- Collecting coarse-scale data on occupancy, macro-avoidance, and space/habitat-use.
- Opportunistic monitoring of non-target species tagged by other Motus collaborators.
- Collecting data to inform collision risk models (one such model using Motus data is under development in 2022 with funding from the Bureau of Ocean Energy Management).

It may also be possible to use Motus to collect fine-scale data on flight paths and flight altitudes (attainable with sufficient antenna coverage, as fine-scale location data requires that two or more receivers detect the animal simultaneously; Paton et al. 2021). However, it should be noted that uses of the data requiring finer-scale resolution (e.g., that require reasonably accurate three-dimensional location estimates) may require additional technological or analytical development to be adequately addressed using Motus.

As a result, automated radio telemetry is not a viable approach for answering fine-scale questions relating to micro-avoidance and collisions; Motus simply does not provide the three-dimensional spatial resolution required. Likewise, Motus technology is not useful for species that spend most of their time at the water's surface (such as waterfowl), as species must spend most of their time aloft in order to be adequately detected. Other limitations of Motus technologies include:

- Tag detections are limited by the location and/or capabilities of the receiving station.
- Antenna coverage is affected by many factors, including antenna type and number, antenna altitude, configuration, gain, and behavior of the tagged animals (including flight height), among other factors.
- Metal or other types of objects may block tag detection. Electromagnetic interference may also reduce antenna coverage. Therefore, due to small-scale differences in the environment, each site needs ground-truthing (e.g., calibration) of the detection range of the receiving station.

Identifying a clear goal for Motus studies is important, as very different scales of information are required to estimate occupancy of an area vs. assessing habitat use or flight paths. Study design –

including how many stations are used and in what spatial configuration, the number and type of antennas on each station, and the frequency of antennas/tags used – all have a strong influence on the effectiveness of Motus technologies for meeting study goals. Characteristics of the focal species (e.g., how the species of interest moves through the environment, heights at which they typically fly, and whether they spend a lot of time resting on the water) should also be carefully considered. IDIOMS is designed to assist users in designing offshore Motus station arrays in light of their specific location and study goal of interest.

Overview of the Tool

IDIOMS is intended to assist users in designing an array of Motus receiving stations that can be deployed on offshore wind turbines or other offshore wind energy-associated structures (such as a meteorological buoy, meteorological tower, or substation). The tool provides 3-D models of station detection ranges, based on user-specified station and antenna placement within a wind farm layout, and also provides models of simulated birds movements (generalized seabirds and shorebirds only) through the modeled antenna array to determine the effectiveness of the array at detecting tagged birds moving through or around the project footprint. The user can vary the antenna array design to compare estimates of tag detection within the project area, estimate antenna coverage within a wind farm area, identify viable study designs based on study objectives and other factors, and determine an optimal layout for questions of interest.

The overall goal is to develop a freely available interactive tool that provides study design guidance based on the objectives of the study and other parameters such as the species of interest, details of the study area (including locations of turbines or other platforms), and details of the antenna array. With these and other input data, the tool produces a map of approximate antenna coverage and data on estimated detection probability for animals moving through the area at different flight heights.

The study design tool was built using the publicly available web application Shiny[9]. A user interface (UI) allows the user to specify a range of parameters, including: species data; wind farm-specific parameters, including turbine size and spacing and size of the wind farm; Motus receiver parameters and antenna type; and study objective. Outputs include the ideal distribution and number of receiver antennas based on the above inputs, antenna height and orientation, and other study-specific design options.

Back-end statistical models and empirical data gathered from prior and ongoing studies focused on calibrating and testing station beam patterns and detection ranges at both 166 MHz (Janaswamy et al. 2018) and 434 MHz (Carlson et al 2022?). These model outputs were used in IDIOMS to estimate Motus tag signal range based on location of animal (height, distance and angle) relative to receiver towers with different parameters and antenna types. While some basic parameters can be changed, the base models for these antennas are specific to the tested setups for each frequency and should be considered merely indicative of the antenna pattern and range for the planned deployment, and not an actual pattern for the deployed receiver station (which will vary based on metal and electromagnetic interference in the vicinity of antennas, station height above sea level, and other parameters). Calibration and testing of a specific receiving station must be performed post-deployment to get an accurate understanding of the true pattern and range of detection, as a multitude of variables can affect their performance. Station calibration processes following deployment of a new station are discussed in detail in Loring et al. (2022).

Tool Assumptions

The tool currently assumes that other turbines do not affect detection rates. However, we know that metal turbine structures can block tag detections, and that electromagnetic interference from

[9] https://shiny.rstudio.com/

the turbines can reduce antenna range. Thus, tool detection ranges should be interpreted to some degree as best-case scenarios (maximum detection ranges) dependent upon careful placement of stations and antennas to avoid as much interference as possible. For more information, see Loring et al. (2022 guidance doc).

Video Demonstration of IDIOMS Tool

Project collaborators will provide a demonstration of the tool via webinar in September 2022. A recording of this webinar will be made available on the project website[10].

[10] https://briwildlife.org/offshore-motus-guidance/

Using IDIOMS

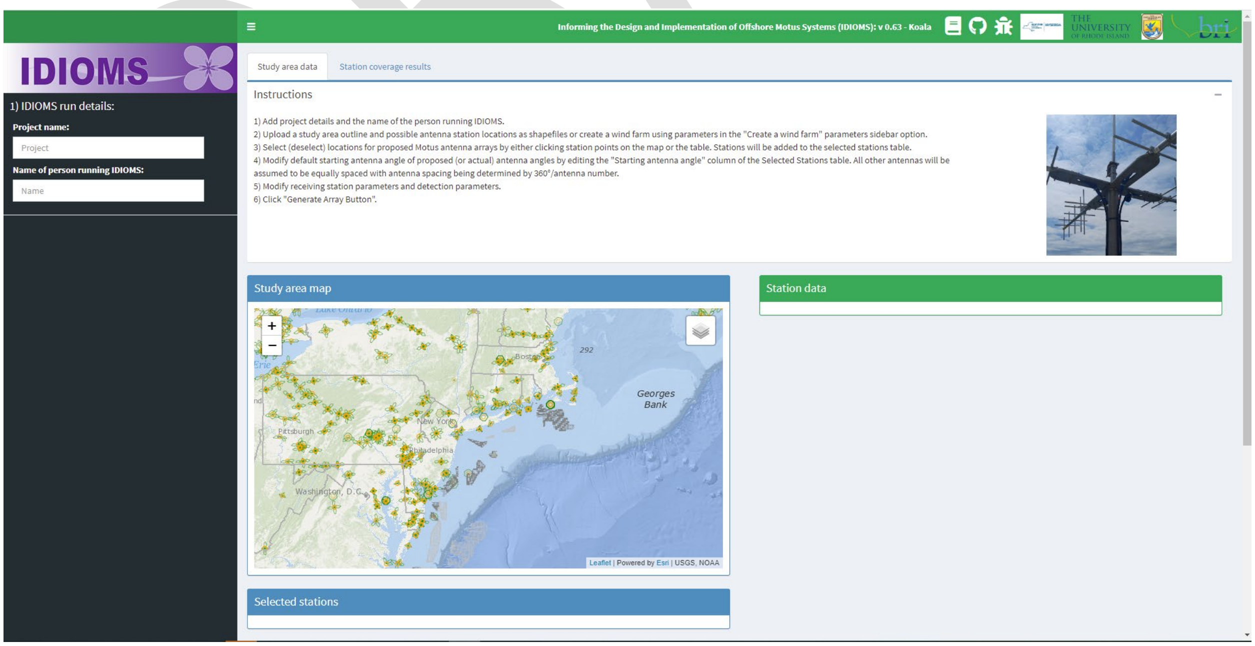
IDIOMS was designed to intuitively lead the user through the steps needed to operate the tool. When possible, the user is asked to provide data before being able to proceed to subsequent steps. We outline these steps below, with screen captures and inputs and outputs at each step of tool use. The final output can be downloaded both as raw data files and a PDF report.

The major steps to conduct an analysis with IDIOMS are:

1) Enter the project/user details
2) Add study area and array details by either uploading a study area outline and possible antenna station locations as shapefiles or creating a wind farm using parameters in the "Create a wind farm" option
3) Add input parameters, including antenna angle (for manual array designs), other receiving station parameters, and detection parameters
4) Select detection array optimization method (manual selection of locations for proposed Motus antenna arrays; optimization for coverage of project/wind farm area; or optimization of coverage within a buffer area outside project area to detect macro-avoidance)
5) Simulate bird tracks (optional)
6) Export data and report (optional)

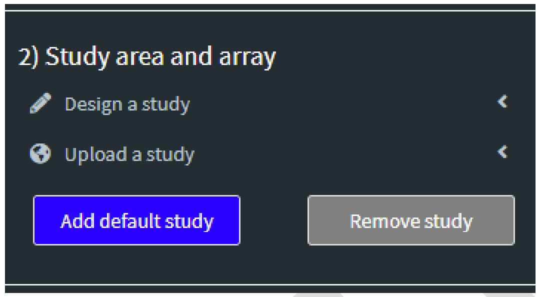
Project/User Details

The user will be required to enter the project name and the user conducting the analysis in the IDIOMS pane on the far left of the screen. Until these are entered, no further parameters will be available to enter and the user will not be able to run the tool. Users can choose any values that are meaningful to them; values will be included in output reports.



Study Area and Array Details

The user will be prompted to either design a rectangular study area with equally spaced turbines laid out in a grid pattern, or to upload a custom study area as a shapefile. The user will also be asked to specify the locations that may be considered for receiver stations (e.g., wind turbines and other platforms).

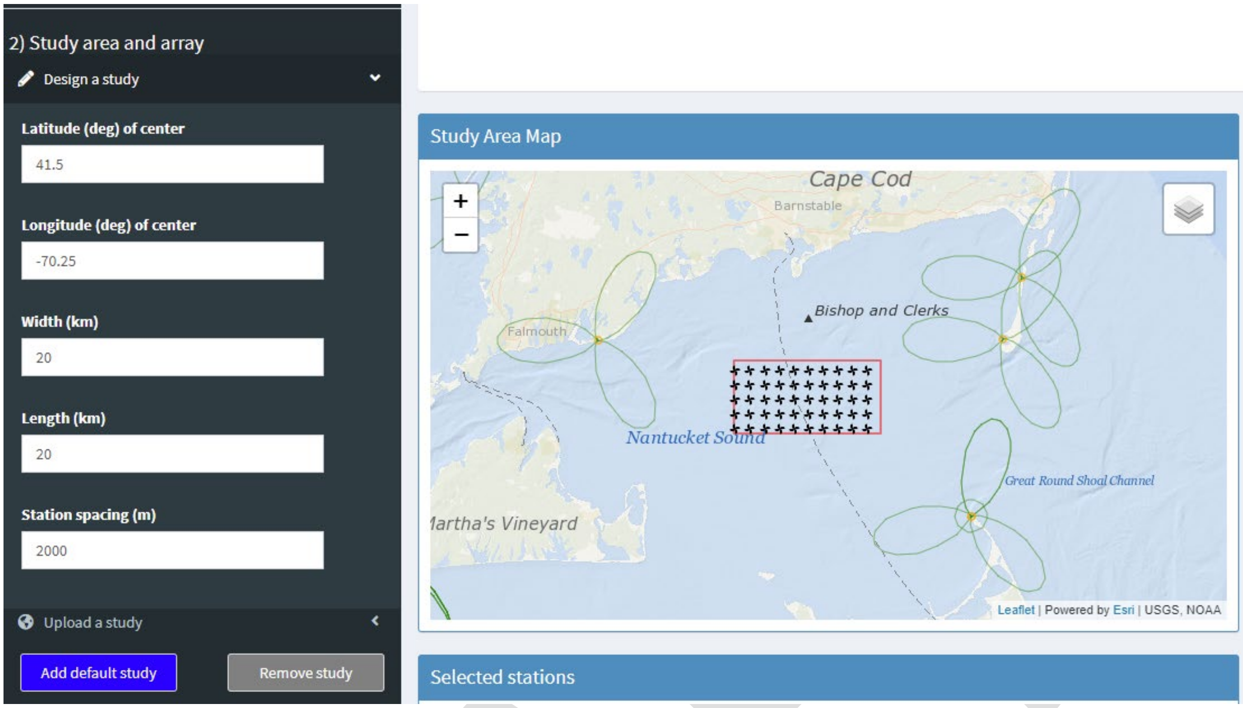


Design a study

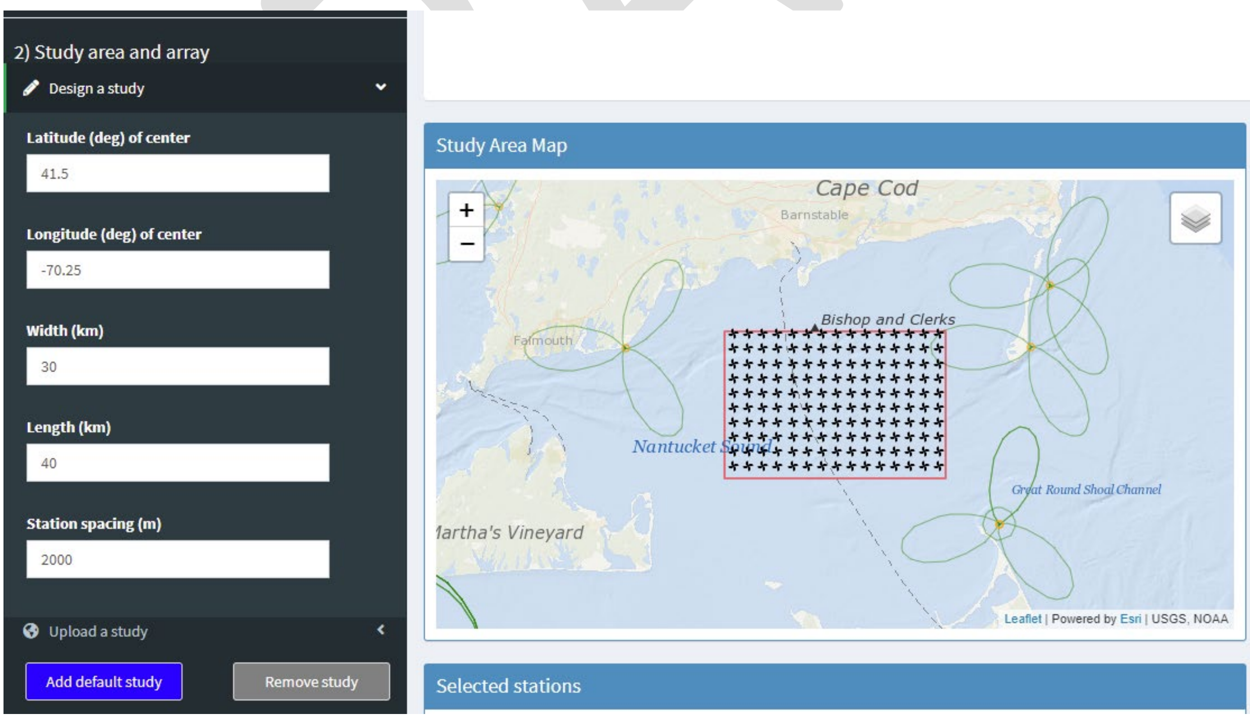
You can design a rectangular study area with specified turbine array spacing using the “Design a study” option at the left. Click the “<” to expand the detailed parameters that are used to create the study area and stations. Alternatively, a default study can be added to learn how the tool works. Click the blue button “Add default study”. The default study area can be modified as various parameters are changed in the tool. If you’d like to clear an added study, click the gray “Remove study” button.

To design a custom study area and station array, add the following input parameters:

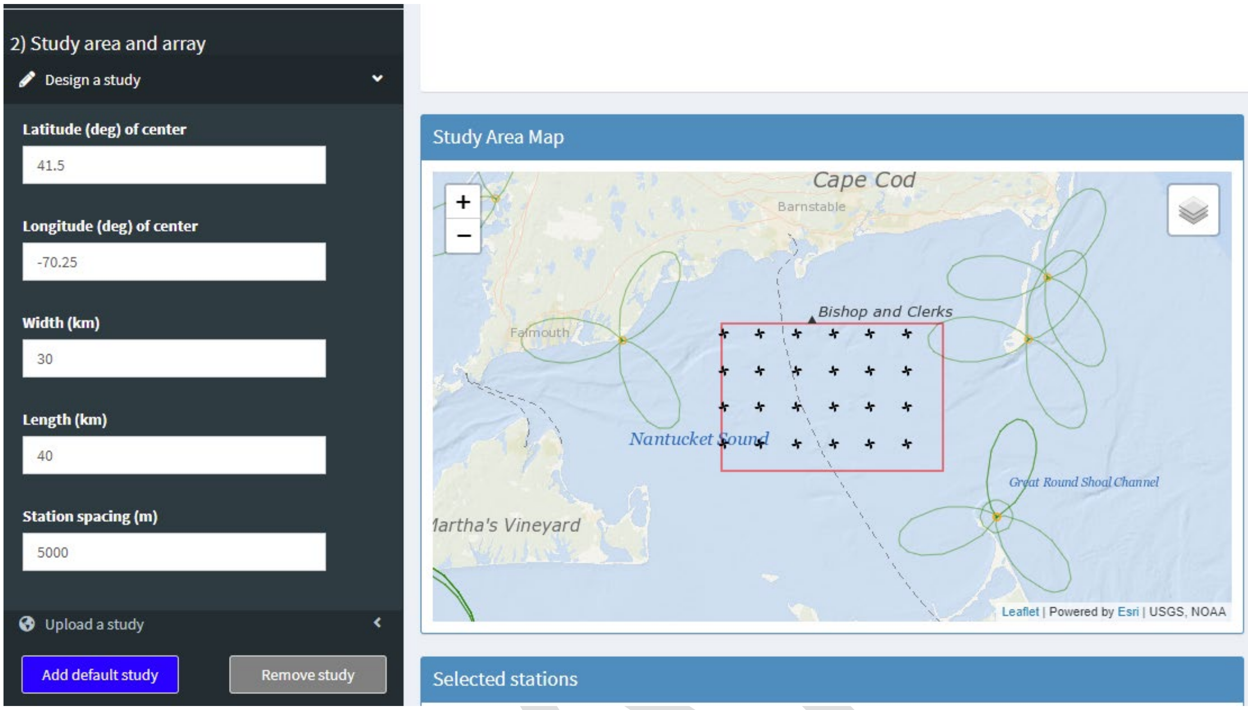
1) Latitude of center of the study area in decimal degrees
2) Longitude of center of the study area in decimal degrees (note locations in the United States are west of the Prime Meridian, and thus have negative longitude values)
3) Width of the study area east-west in kilometers (km)
4) Length of the study area north-south in kilometers (km)
5) Spacing of the stations in the array in meters (m)



Once a study area is created it can be changed, and the study area and station array automatically changes to reflect the newly changed parameters. For example, changing the length from 20 to 40 km and width from 20 to 30 km for the study area yields the following changed study area and array.



Changing the station spacing (e.g., 2000m to 5000m) will also change the underlying station grid that can be generated to model the antenna array for as shown below:

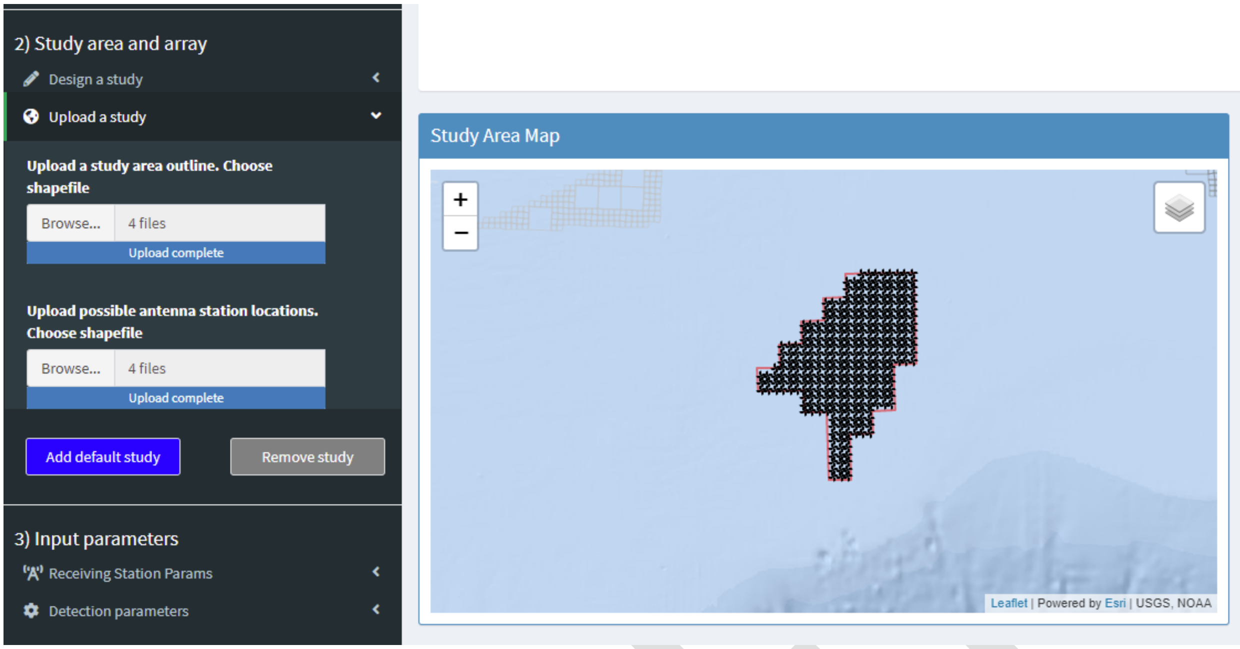


Ignore the button in the top right corner of the map view for now; this shows layers that can be viewed in the map of model output and is discussed further later in this manual.

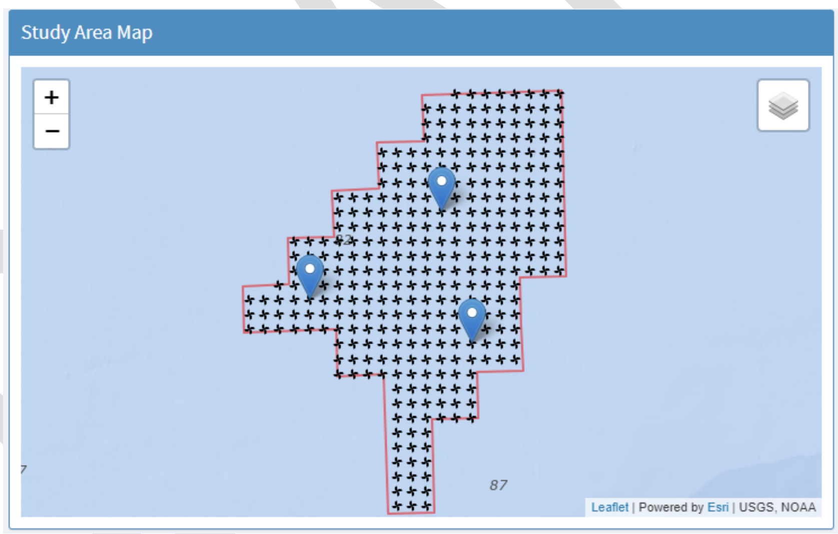
Uploading an existing study

Instead of designing an array within IDIOMS or adding the default study, the user can also upload a shapefile of a study area outline and structure locations. All relevant files must be selected in order to completely upload the data necessary for mapping in the correct projection, including the feature geometry (.shp), the index (.shx), the database (.dbf), and projection information (.prj) files. A file of possible station locations (e.g., locations of planned structures) must also be uploaded in the same manner. The array need not be regularly spaced, but can reflect the planned pattern of installed equipment in the study area.

The study area and stations are shown as they were using the “Design a study” input method.

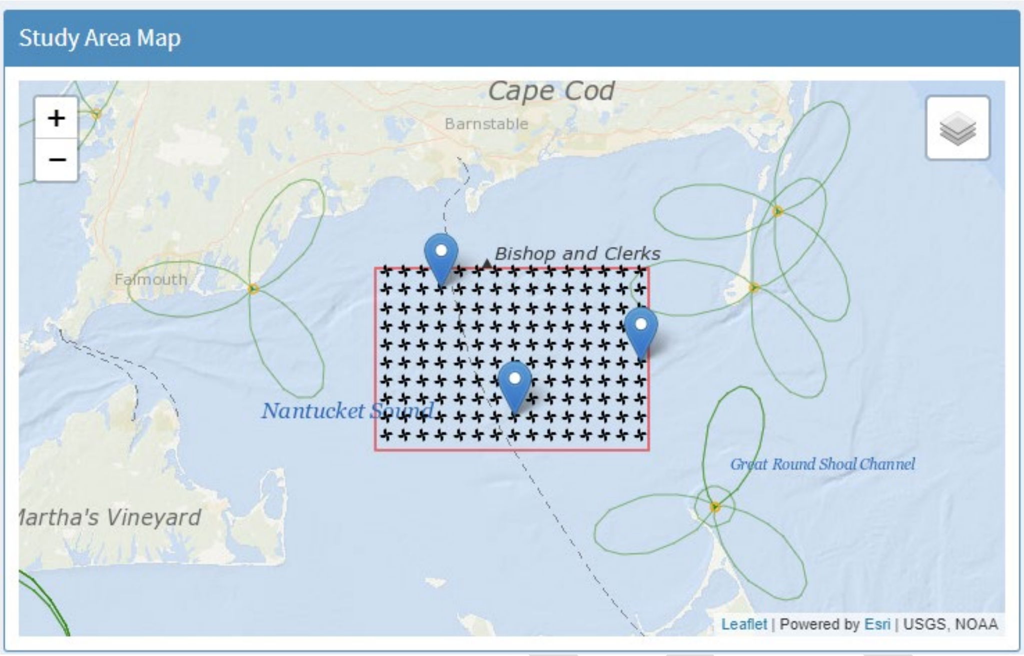


Station locations can then be manually selected, or IDIOMS can place stations to optimize the Motus array to answer different types of questions (see "detection array creation," below).



Manually selecting receiver station locations for a designed study

Once the station array is created, IDIOM generates a table of station locations with IDs. If you want to manually select station locations rather than allowing IDIOMS to optimize array coverage using one of the options in the "detection array creation" section, manually designate locations for stations by clicking on possible station locations (turbines) on the map, or by selecting stations in the "station data" table. When a station is selected a marker symbol appears on the map and the row is highlighted in the "Station data" table (in blue).

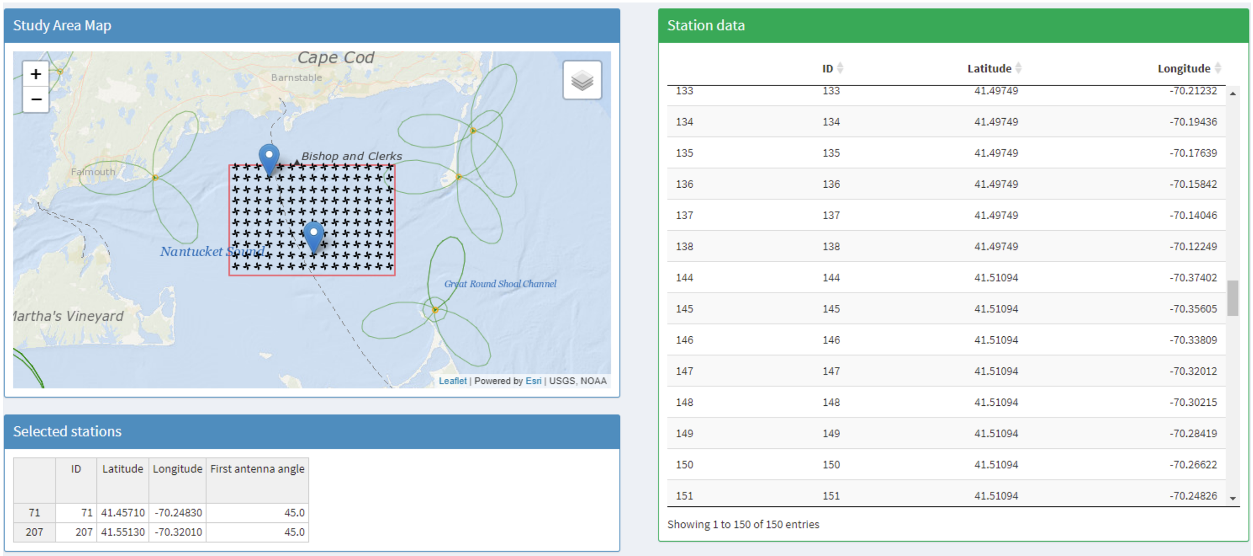


Station data

	ID	Latitude	Longitude
133	133	41.49749	-70.21232
134	134	41.49749	-70.19436
135	135	41.49749	-70.17639
136	136	41.49749	-70.15842
137	137	41.49749	-70.14046
138	138	41.49749	-70.12249
144	144	41.51094	-70.37402
145	145	41.51094	-70.35605
146	146	41.51094	-70.33809
147	147	41.51094	-70.32012
148	148	41.51094	-70.30215
149	149	41.51094	-70.28419
150	150	41.51094	-70.26622
151	151	41.51094	-70.24826

Showing 1 to 150 of 150 entries

Clicking on the marker on the map or on the blue row in the Station data table deselects it and removes it from consideration again. You can add and remove as many times as desired. The final list in the “selected stations” table will be the one submitted for processing by the tool.



Antenna angle specification

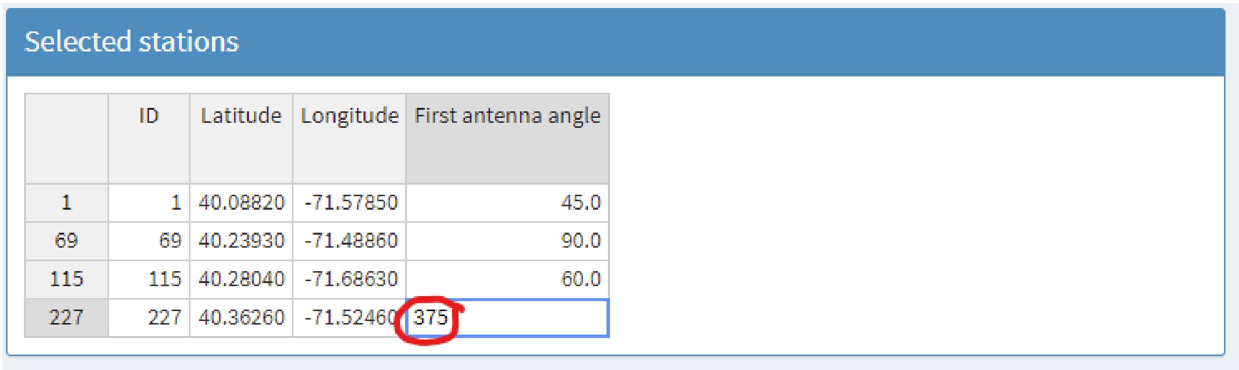
If the detection array is being designed manually, the antenna angle of the first antenna at each station can be specified (in degrees). All other antenna angles for each station will be assigned in relation to the first antenna to provide equal spacing given the number of antennas specified in the input parameters (see below).

The angles are modified in the table that shows up below the "Study Area Map" (the default of 45). Note that if the array design is changed (for example, another station is manually added), all antenna angles in the selected stations table will reset.

Selected stations

	ID	Latitude	Longitude	First antenna angle
1	1	40.08820	-71.57850	45.0
69	69	40.23930	-71.48860	90.0
115	115	40.28040	-71.68630	60.0
227	227	40.36260	-71.52460	360.0

Angles must be in the range of 0-360 degrees, or you will not be able to leave the cell before it is corrected. See example cell circled in red below.



Selected stations

	ID	Latitude	Longitude	First antenna angle
1	1	40.08820	-71.57850	45.0
69	69	40.23930	-71.48860	90.0
115	115	40.28040	-71.68630	60.0
227	227	40.36260	-71.52460	375

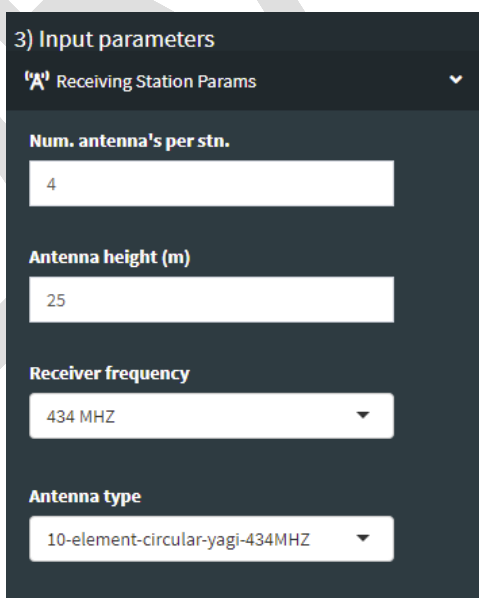
Input Parameters

In addition to antenna angle, several other "Receiving station parameters" and "Detection parameters" can also be modified in IDIOMS.

Receiving station parameters

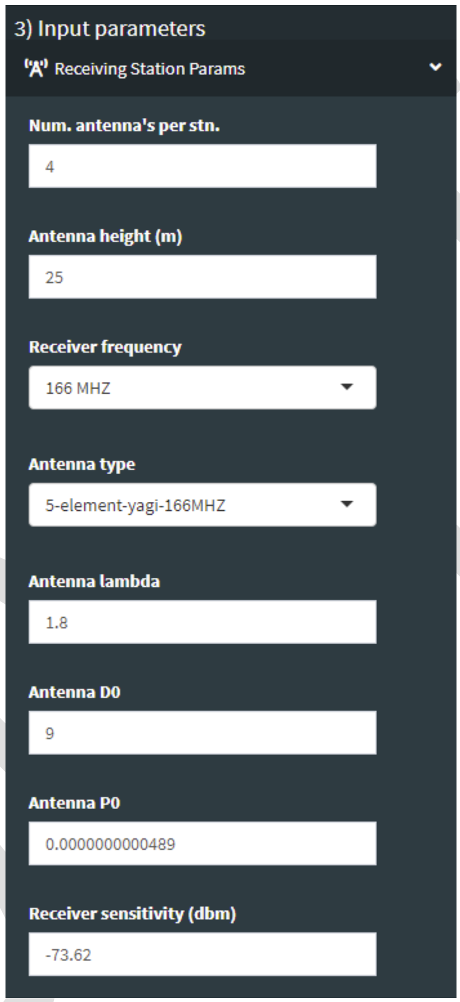
Receiving station parameters include:

1) **Number antennas per stn.** – the number of receiving antennas on each receiver station. This is a fixed number and represents a single kind of antenna (omni or Yagi). In the current iteration of IDIOMS, mixed antenna types and frequency options are not supported during a single run.
2) **Antenna height (m)** – the height of receiving stations in meters above mean sea level (MSL).
3) **Receiver frequency** – Frequency of the receiver antennas, either 166 MHz or 434 MHz.
4) **Antenna type** – antenna model receiver frequency, e.g., 10-element-circular-Yagi-434MHZ, omni-166MHZ.



If the frequency selected is 166 MHz, additional parameters are needed and will be displayed. None of these parameters need to be changed, as default values are provided based on the those derived from original antenna calibration and models (see Janaswamy et al. 2018 for details). These additional parameters are:

1) **Antenna lambda** – wavelength in free space.
2) **Antenna D0** – dB gain of the antenna, which changes when the antenna type is changed.
3) **Antenna** P0 – a constant related to noise in the system.
4) **Receiver sensitivity (dbm)** – The sensitivity of the receiver to detect a signal above the background noise.

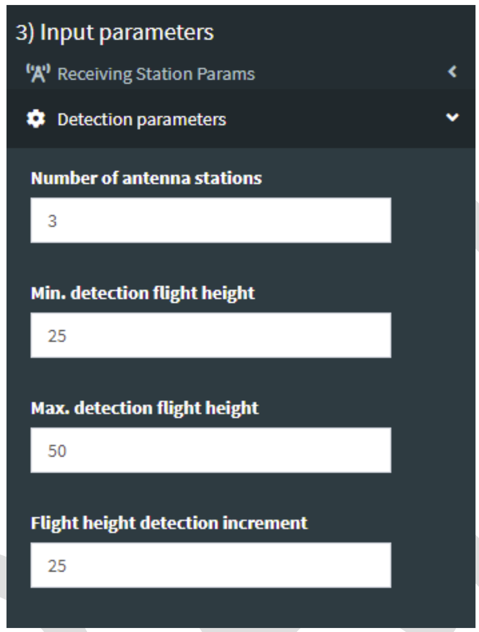


Detection parameters

The following detection parameters are available to be set for IDIOMS:

1) **Number of antenna stations** – number of Motus stations in the design. When an optimization routine of "Coverage optimized" or "Avoidance optimized" is selected, the optimization routine uses this parameter to generate receiver stations. This parameter is ignored when performing no optimization (manual selection of receiver station locations), as the number of stations is determined via manual placement.
2) **Min. detection flight height** – the minimum flight height of an animal for which you would like to estimate detection polygons (meters).

3) **Max. detection flight height** – the maximum flight height of an animal for which you would like to estimate detection polygons (meters).
4) **Flight height increment** – the increment (meters) for which you would like to generate steps between minimum and maximum detection flight heights. For example, specifying a range of 10-100 by increment 10 will give model outputs every 10 meters between 10 and 100 m flight height. Note that the selections of number fo increments will affect model run time.



Once all parameters are set, users can move on to the last step of data input before running IDIOMS – the “Detection array creation”.

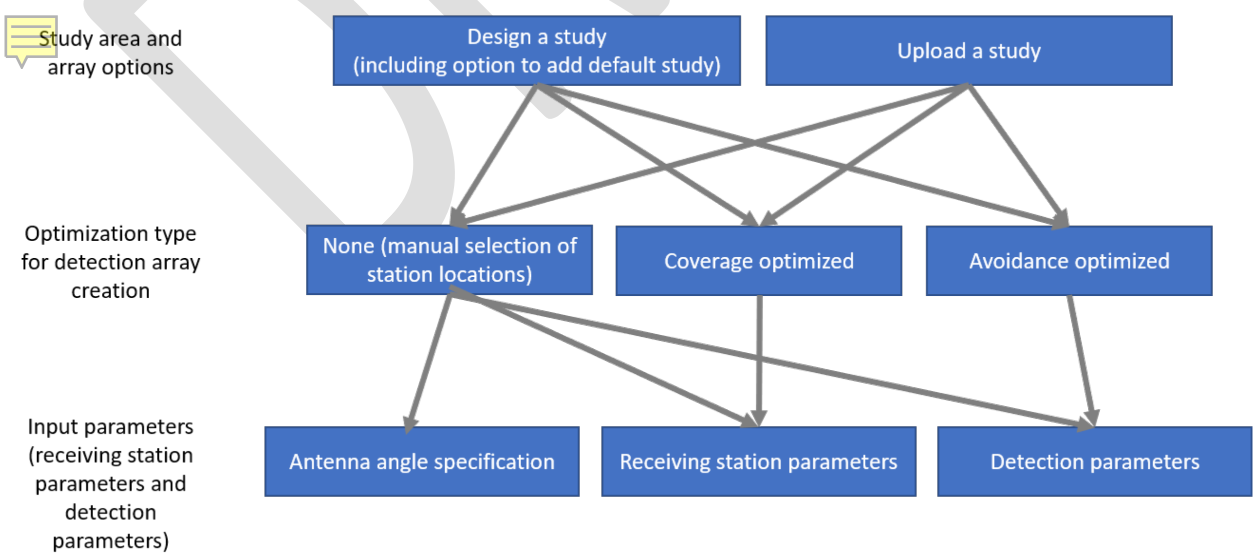
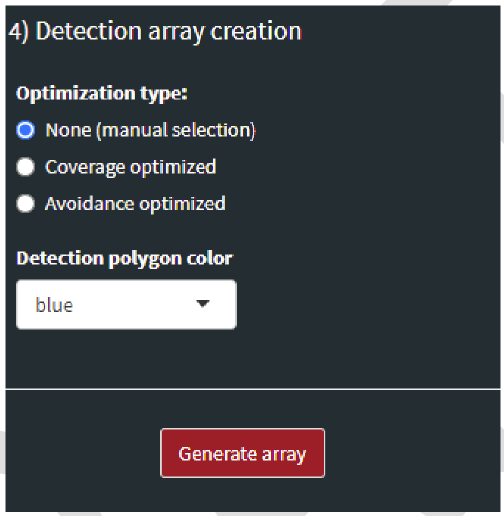


Figure 4. Decision tree of major options in the IDIOMS tool. In the "Study area and Array options" section, users must choose whether to upload project shapefiles or design a project area within the tool using several input parameters. Secondly, they must select an optimization type to inform the design of the Motus station array (optimizing for coverage of the project footprint, coverage in an "avoidance zone" outside the footprint, or manual selection of station locations). Thirdly, a range of input parameters for receiving station designs and detection variables must be selected, with some input options (such as antenna angle specification) being specific to the manual array creation, while others such as "number of antenna stations" are specific to the optimization routines.

Detection Array Creation

There are three options for creating a detection array: manual receiver station modeling or an optimization routine for coverage optimization or avoidance optimization (Figure 4).



Manual selection

Manual selection (no optimization) requires the user to select stations manually and enter the antenna angles for receiver station modeling. IDIOMS will generate the antenna models for all antennas across all stations and map them for each flight height increment requested in "Detection parameters" inputs. Models will be compiled for output and display. Once you are satisfied with the input parameters you can click the red "Generate array" button to process the request and the results will be shown in the "Station coverage results tab".

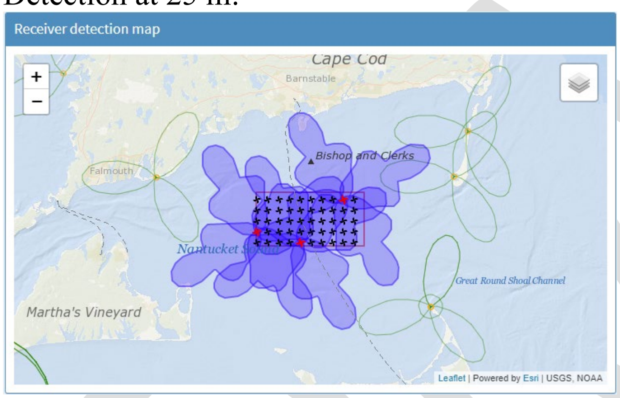
Coverage optimized

The "Coverage optimized" receiver station optimization routine attempts to maximize coverage of the study area (e.g., the area inside the specified study boundary). The routine uses a method coded by Nicholas Tierney in a slightly modified R package maxcovr 0.1.3.9200 (Tierney and Padgham 2022) developed to "solve the maximum covering location problem" (Church and ReVelle 1974) using free and opensource solvers available in R. This method optimizes coverage of an area given a location and maximum detection distance using circular coverage area over a dense grid of points. The dense grid of points is created to cover the study area for the maximum coverage estimator to solve for. The routine optimizes the solution to select the desired number of receiver station locations from the group of existing stations that will cover the most points in that dense grid. We modified the code to not have any existing stations. Further, the routine attempts to determine the best antenna angle orientation by also maximizing coverage of the study area. This was a challenging problem due to the sheer number of possible antenna orientation options and was optimized by comparing only a few stations at a time, reducing complexity at the expense of finding the absolute best solution which was computationally too expensive. This tool merely provides a guide as to the best orientation to maximize coverage, if these orientations can be achieved on the ground. In practice, the actual orientation of the antennas must be determined by the wind turbine support structure so as to minimize the interference from the tower itself.

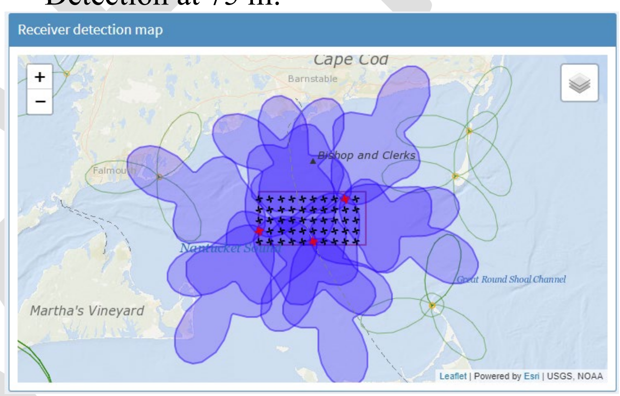
This method requires the user to enter the number of stations for which you want to optimize coverage (in the "receiving station parameters," above). Once you are satisfied with the input parameters you can click the red "Generate array" button to process the request and the results will be shown in the "Station coverage results tab".

We encourage the user to look at a range of flight heights, based on flight height patterns for species of interest, in order to come up with an optimal arrangement. Stations and antenna arrangements at 25 vs. 75 m are presented for comparison below (note that station locations and antenna angles vary slightly between target altitudes).

Detection at 25 m:

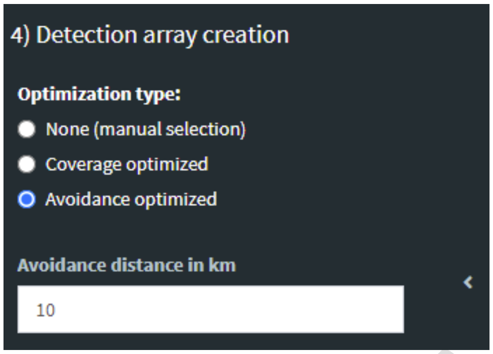


Detection at 75 m:



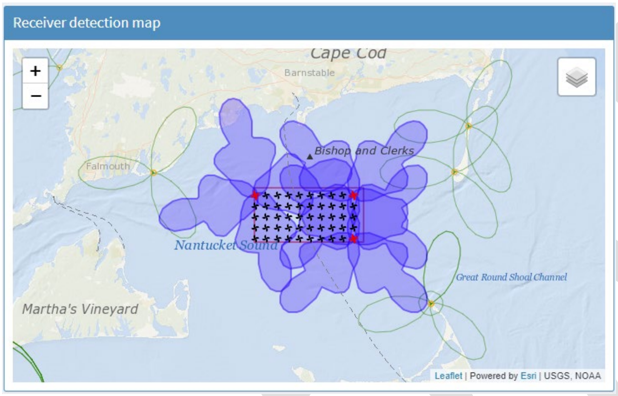
Avoidance optimized

The avoidance optimization routine uses the same maxcovr optimization routine as with "Coverage optimized" except that we optimize for coverage within a zone immediately OUTSIDE of the study area, defined by a buffer distance applied to the study area boundary (the study area is the location to which the optimization scheme described in "Coverage optimized" is applied). The size of this prospective avoidance zone is set as a parameter "Avoidance distance in km" which is shown when the Avoidance optimized routine is run (default 10 km).

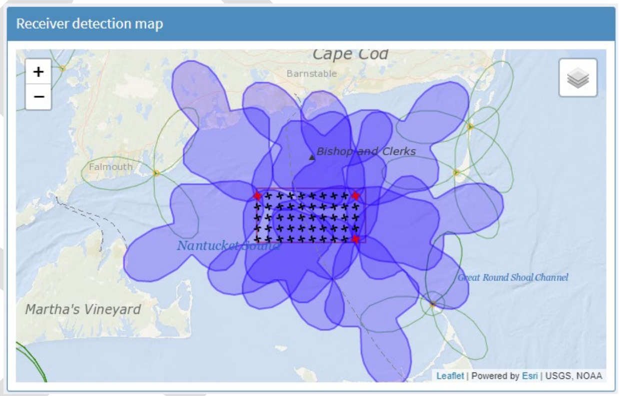


This optimization routine, not surprisingly, tends to place antenna stations at the periphery of the study area to maximize coverage of this buffer:

Detection at 25 m:



Detection at 75 m:



In the resulting antenna station coverage table, “study area covg.” shows coverage of the buffer, not the internal wind farm boundary, as a proportional value between zero and one.

Antenna station coverage

Flight height (m)	Max detection range (m)	Study area covg.	Antenna coverage overlap	Min. covg. flag
25	18,183	0.79	0.27	1
50	28,067	0.94	0.45	1
75	28,067	1.00	0.38	1

Station Coverage Results

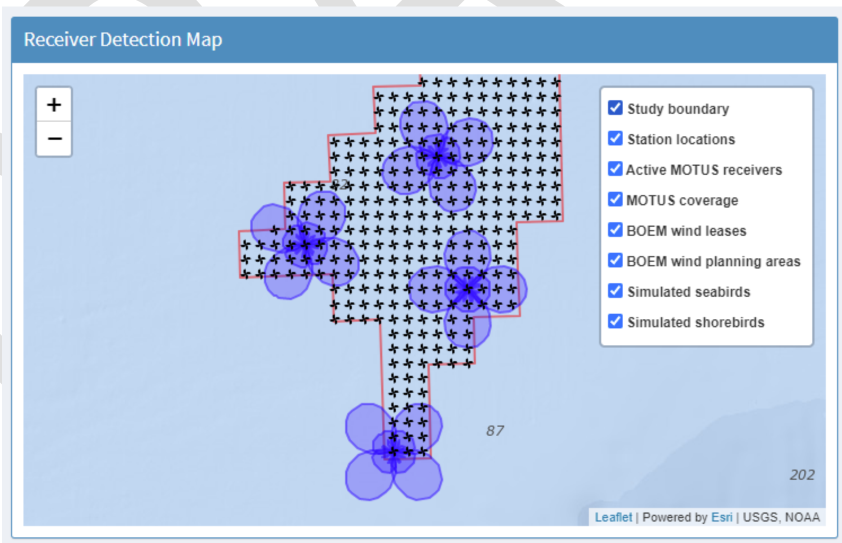
Upon successful completion of the antenna pattern array generation, IDIOMS will automatically move to the “Station coverage results” tab.

The “station coverage results” pane includes the following components: receiver detection map, tag detection range plot by flight height, the station antenna angles table, a table of simulated bird track detection by flight height, a table of antenna station coverage, and several “next steps” buttons. Results of the antenna pattern generation for the receiving station array will be displayed here and further steps can be taken as described below.

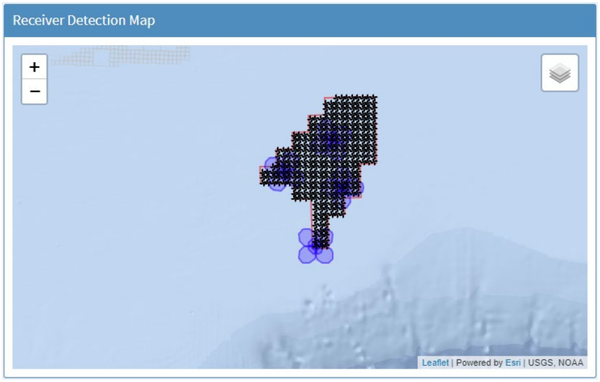
Receiver detection map

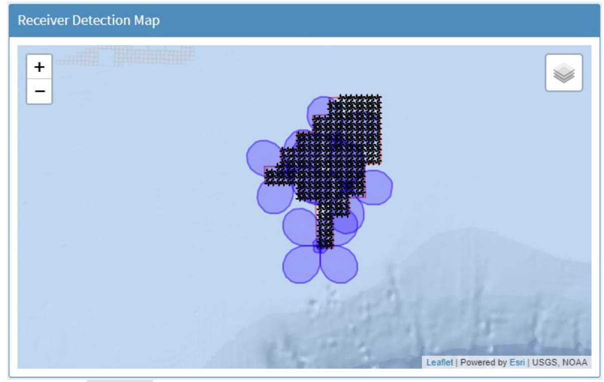
This map shows the output antenna models by flight height. Maps are dynamic and can be zoomed in or out and panned. Layers can be turned on or off when selecting on the map. The following layers are available to be turned on (checked) or off (un-checked).

a) **Study boundary** – the study area created or uploaded.
b) **Station locations** – the station array created or uploaded.
c) **Active Motus receivers** – active Motus receiver locations, i.e. the position at centers of the stations (drawn from current data in the Motus Wildlife Tracking System).
d) **Motus coverage** – the approximated coverage of existing Motus receiver stations as polygons overlaid on the map (drawn from current data in the Motus Wildlife Tracking System).
e) **BOEM wind leases** – the current set of active renewable energy leases associated with offshore wind in the U.S.
f) **BOEM wind planning areas** – the current set of planning areas associated with offshore wind in the U.S.
g) **Simulated seabirds** – tracks of simulated seabirds (if that option is run).
h) **Simulated shorebirds** – tracks of simulated shorebirds (if that option is run).



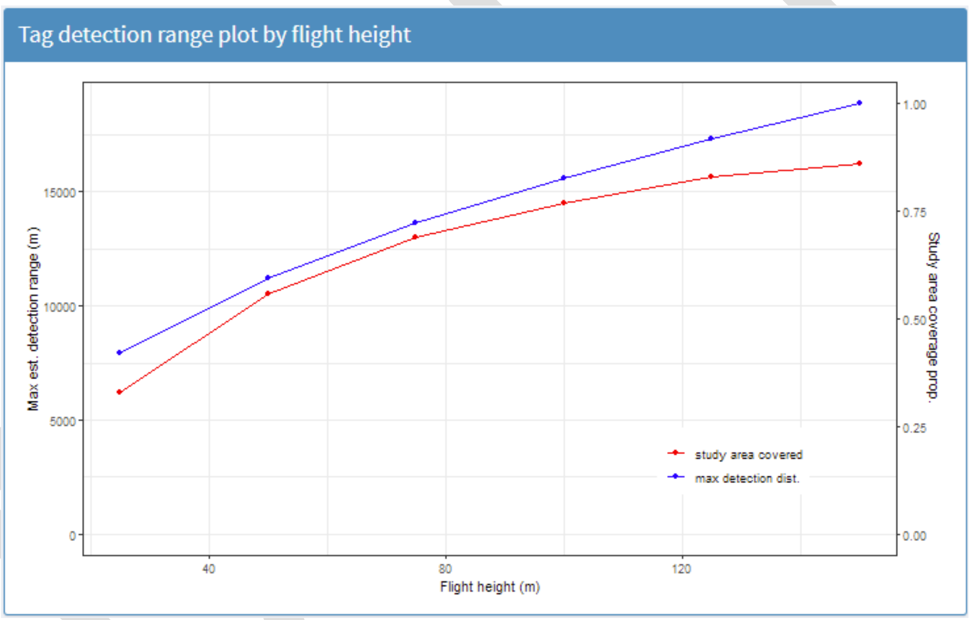
Changing the flight height selected in the “Antenna station coverage” box to another flight height (it defaults to the minimum flight height) changes the map display to show the antenna coverage at that flight height (the selected flight height row is in blue). For example, changing flight height from the minimum of 25 m (left) to 125 m (right) gives a different coverage map for this 166 MHz example:





Tag detection range plot by flight height

This plot shows the maximum detection range (y-axis, m) at each flight height (x-axis, m) shown as a blue line, and the proportion (0-1) of the study area covered by the antenna array, shown as a red line.



Station antenna angles

This table shows the list of all stations by ID and their associated antenna angles that were either manually selected or determined using an optimization routine. Depending on the number of stations and antennas, you may need to scroll to see all data.

Station #	Antenna angle
1	45
1	135
1	225
1	315
69	0
69	90
69	180
69	270
115	60
115	150
115	240
115	330
227	25
227	115

Station antenna angles

Showing 1 to 16 of 16 entries

Simulated bird track detection by flight height

If this option is selected, this table shows a summarization of the bootstrap mean proportion detected (and 95% CI) by flight height for simulated seabirds and/or shorebirds moving through the study area (see "nest steps in the station coverage results tab" below for additional information).

Simulated bird track detection by flight height

Species group	Flight height (m)	Mean prop. detected	Lower 95% CI prop. detected	Upper 95% CI prop. detected
seabirds	25	0.412	0.369	0.455
seabirds	50	0.535	0.492	0.579
seabirds	75	0.487	0.443	0.531
seabirds	100	0.483	0.44	0.527
shorebirds	25	0.939	0.918	0.96
shorebirds	50	0.954	0.935	0.972
shorebirds	75	0.951	0.932	0.97
shorebirds	100	0.951	0.932	0.97

Antenna station coverage

This table includes detection ranges, study area coverage proportion (0-1), antenna overlap proportion (0-1) and a flag indicating study area coverage exceeding the arbitrary threshold of 0.75 for a given flight height value. Coverage exceeding the threshold is color coded green and coverage below the threshold is coded red. Note that the antenna overlap coverage is the overlap between antennas on the same receiver station and adjacent stations that have been selected in the tool. Note that this does NOT calculate overlap with receiver stations from adjacent projects (i.e, pre-existing stations), only within the current set of receiver stations for the project.

Antenna station coverage

Flight height (m)	Max detection range (m)	Study area covg.	Antenna coverage overlap	Min. covg. flag
25	7,961	0.33	0.22	0
50	11,186	0.56	0.20	0
75	13,608	0.69	0.21	0
100	15,605	0.77	0.18	1
125	17,323	0.83	0.22	1
150	18,836	0.86	0.25	1

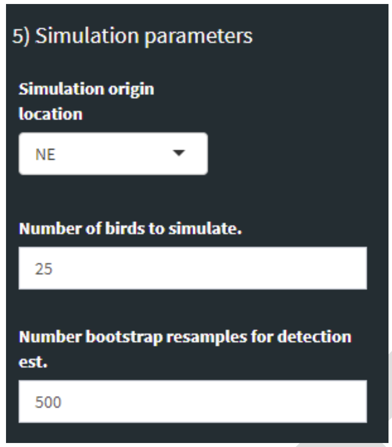
Next Steps in the Station Coverage Results Tab

At the top of the "Station Coverage Results" pane, there are four buttons with to pursue next steps following a model run: simulate seabird tracks, simulate shorebird tracks, download model results, and download results report. One or all of these options can be selected to provide additional information for a given model run or save the results.

Simulate seabird and shorebird tracks

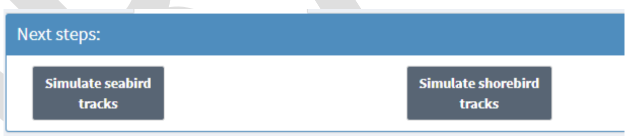
Simulated bird tracks are included in the IDIOMS tool for display purposes and to provide a coarse assessment of detection proportions for "seabirds" and "shorebirds". Simulated tracks were developed by Evan Adams as part of a simulation study that evaluates Motus design challenges by estimating detection probability of select avian taxa moving through simulated arrays of Motus stations within wind project areas (Adams et al. 2022). The simulated seabird tracks are based on GPS tracking data for Common Terns in the nonbreeding season, and the simulated shorebird tracks on Motus tracking data for Piping Plovers during migration (Loring *et al.* 2019, Loring *et al.* 2020). A large number (n=1,000) of simulated tracks were generated in the simulation study, which are sampled in IDIOMS for display purposes and to generate a bootstrap estimate of mean and 95% confidence interval for the proportion of simulated animals that will be detected by a given offshore station detection array. The number of bootstrap samples (with replacement) defaults at 500, but can be changed in the sideboard inputs.

When the detection array is created either by manual creation or optimization scheme, and the "generate array" button is selected to generate the results, another set of inputs is displayed in the sideboard specific to the simulations (this "Simulation Parameters" input section is optional, and is shown below the "generate array" button).



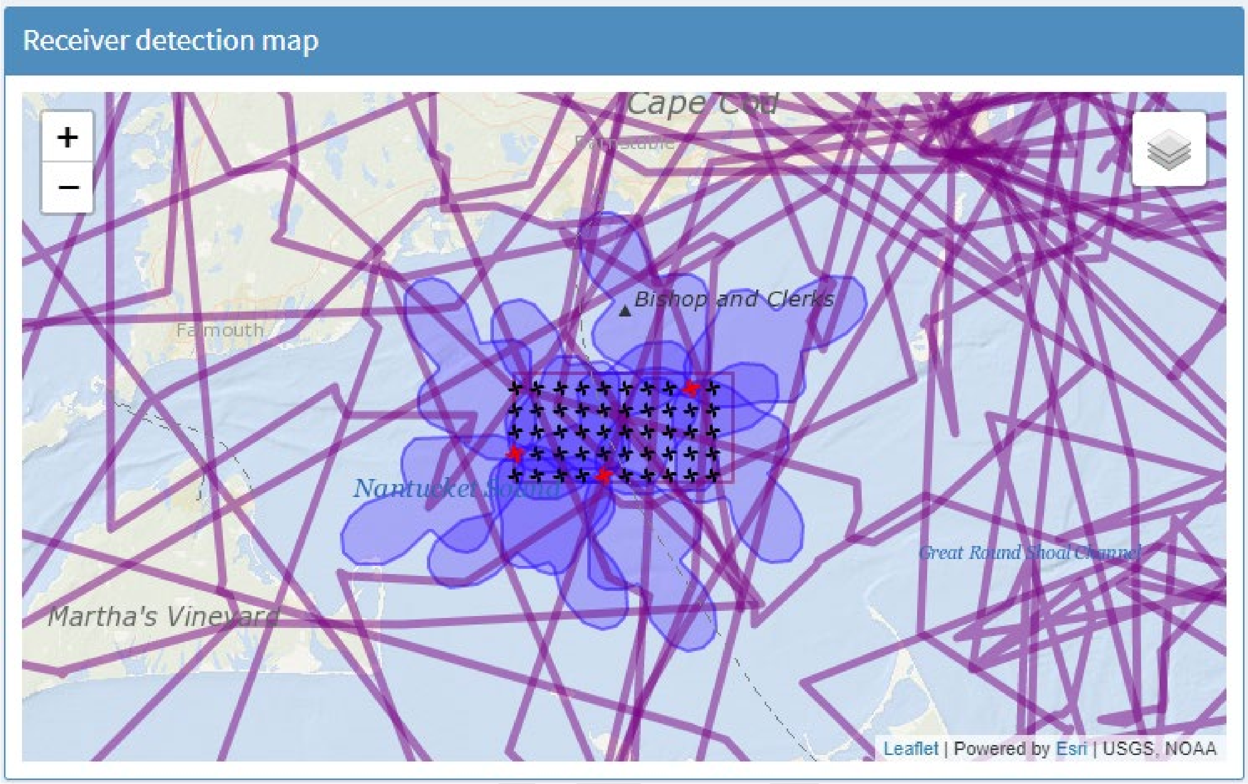
The inputs that can be changed are:

1) **Simulation origin location**: The ordinal direction relative to the center of the study area at which the simulated birds originate. The simulations all originate from location 0,0 (shifted to the study area center) and have a NE-SW directionality, as they were intended to estimate movements during fall migration and the wintering period in the northeastern United States. The origin location start will affect how many tracks will be detected by the simulated antenna patterns in the study area. One of 8 ordinal directions can be selected. Defaults to northeast (NE).
2) **Number of birds to simulate**: The number of birds that are selected in a bootstrap sample and mapped. Must be an integer (minimum is 5; default is 25).
3) **Number bootstrap resamples for detection est.**: The number of samples (with replacement) used to generate the bootstrap estimate. Must be an integer (minimum is 100, default is 500).

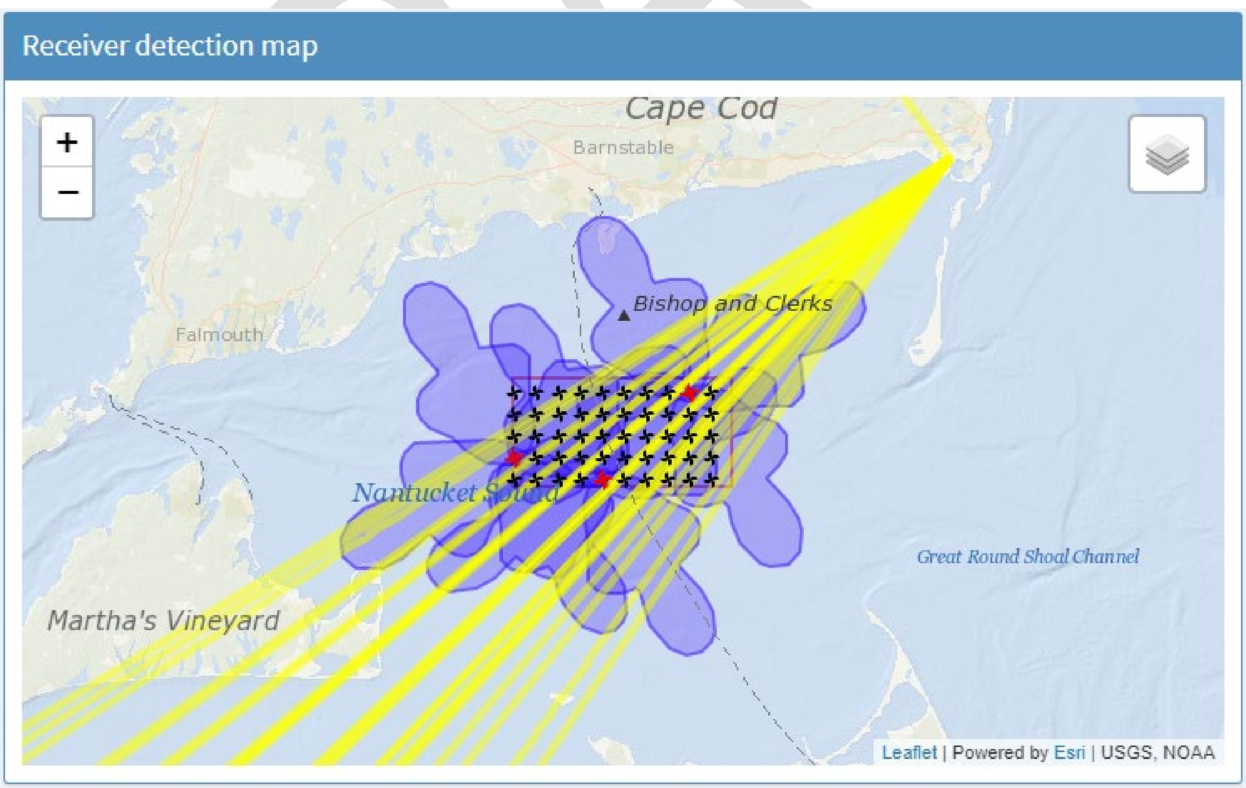


After the simulation inputs are adjusted as desired, the user must select either the "Simulate seabird tracks" or "Simulate shorebird tracks" button at the top of the station coverage results pane to start the process. Tracks are displayed on the detection map as separate layers. These layers can be toggled on or off using the button. The bootstrap mean and 95% CI for seabirds and/or shorebird detections is shown in the "simulated bird track detection by flight height" table below the map. This table includes the flight height, bootstrap mean proportion of tracks detected, and 95% CI of the proportion of tracks detected by the array. The simulation can be repeated for either shorebirds or seabirds in the same results pane, and additional tracks and detection results will be added to the receiver detection map and simulated bird track detection by flight height table, respectively.

Simulated seabird tracks (purple lines):



Simulated shorebird tracks (yellow lines):



Download model results

Once the model has run successfully and simulated bird tracks have been added (if desired), the user can download the full results using the “download model results” button at the top of the station coverage results pane. When the user clicks the button, a file save dialog box will appear with the ability to browse to a location for saving as well as change the compressed file name. A compressed file will be downloaded containing the following files:

- Model input parameters used in the model run in IDIOMS as a Rdata file that can be loaded in R
- The study boundary as a Rdata file that can be loaded into R
- GIS shapefiles of the study boundary
- Model output Rdata file that can be directly loaded in R
- GIS shapefiles of IDIOMS generated receiver station antenna patterns
- CSV output file of the selected receiver stations and antenna angles specified
- CSV output file of the study area coverage and antenna overlap for receiver stations calculated by IDIOMS

Download results report

Once the model has run successfully and simulated bird tracks have been added (if desired), the user can generate a custom PDF report summarizing the model results using the “download results report” button at the top of the station coverage results pane. The report provides details about the model run (IDIOMS version, run times, project, user, model input parameters) and results tables and figures, including maps of estimated antenna patterns (e.g., beam coverage) at all selected flight heights. If simulated bird tracks were added to the results, additional tables and maps will be included in the PDF showing these results.

Running IDIOMS with different parameters

Following completion of the initial model run for IDIOMS, the user can modify parameters and re-run IDIOMS for those new parameters. Users wishing to start fresh can re-load the window and start the analysis from the beginning.

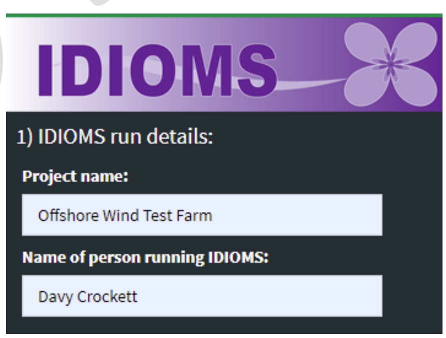
Example Scenarios

Several examples are presented below for how you might use IDIOMS to determine the number and arrangement of detection stations at one or more frequencies. These scenarios are meant merely to provide an illustration for practitioners to best understand the intent and use of this tool; factors such as study area layout, turbine placement within the wind farm, and other variables will often ultimately dictate the actual arrangement of receiver stations at offshore wind facilities. We encourage users to further vet proposed layouts with appropriate authorities (e.g., the U.S. Fish and Wildlife Service, BOEM) and also collaborate with neighboring wind farms to arrive at the best possible solution for Motus station placement.

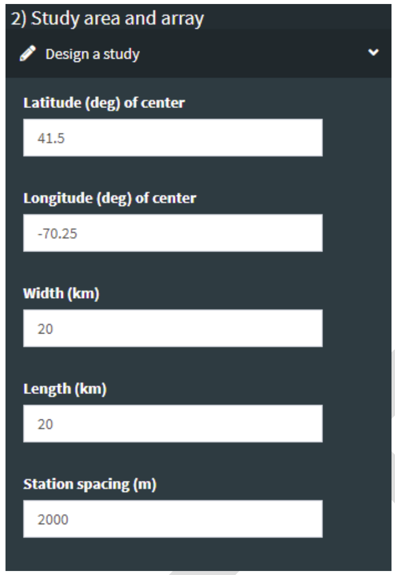
Optimize Both 434 MHz and 166 MHz Stations for Coverage of the Study Area

The current guidance for offshore Motus stations on turbine platforms suggests alternating station designs to obtain coverage at both 166 and 434 MHz (see "Recommended Antenna Configuration for Offshore Wind Turbines," above). In this scenario, we would like to set up both 434 MHz and 166MHz stations, each having four Yagi antennas and one omni antenna, and provide >95% coverage by at least one antenna within the station array for both frequencies at flight heights from 25-125 m (the typical lower portion of the rotor swept zone). In this scenario, the omni antennas, with a range of 500-1,000 m, when paired with four Yagi antennas will largely, if not entirely, overlap with the detection range of the Yagis and so for the purposes of planning coverage, we can rely on estimating the detection range and coverage using the Yagi antennas only. This simplifies our analysis. Unfortunately, at this time, IDIOMS is NOT designed to accept multiple antenna/receiver types at the same time. Analyses for each frequency must be run separately and brought together into the final study design plan. IDIOMS will provide GIS shapefiles that can be exported following each IDIOMS run for each frequency, so that these can be mapped together to show the final study plan and estimated coverage. The steps to take to complete this analysis are laid out below.

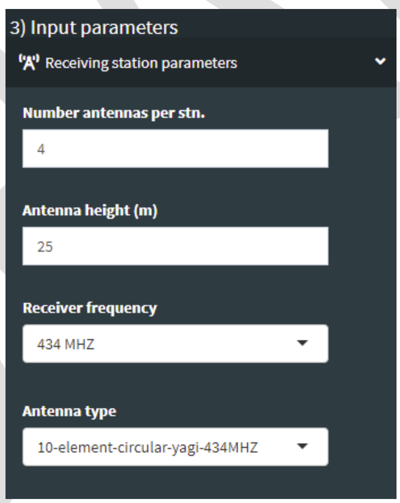
1) **Enter your IDIOMS run details**, project name and name of person running IDIOMS. This is recorded in the report that can be exported from IDIOMS.



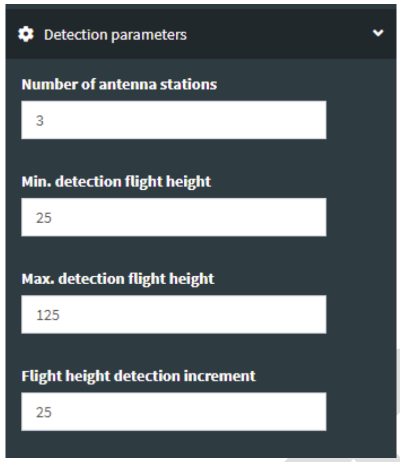
2) **Load study area and array shapefiles or design a study** using the center of the array latitude/longitude, width (km), length (km), and station spacing (m). Here we designed a study area and array:



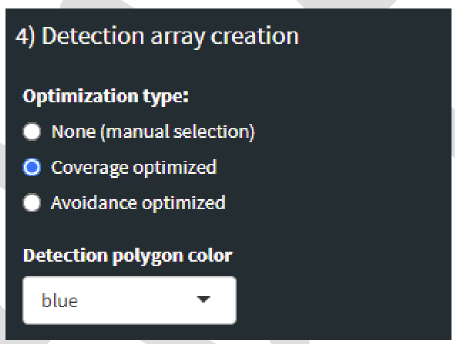
3) **Set "Receiving station parameters".** The defaults are set to 4 antennas per station, which we will leave as is. Enter a rough estimate for the station antenna height above mean sea level, as well as the receiver frequency, antenna type, and any frequency specific parameters. Initially we will run 434 MHz with a 10 element circular Yagi antenna:

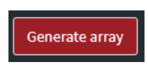


4) **Set "Detection parameters"**. The default is 3 antenna stations, a minimum 25 m flight height, and 125 m maximum detection flight height, incremented by 25 m. We suggest beginning here. If the site is very small you could reduce to two stations, or if very large, increase to four stations to start. In this initial run, we start with the defaults.



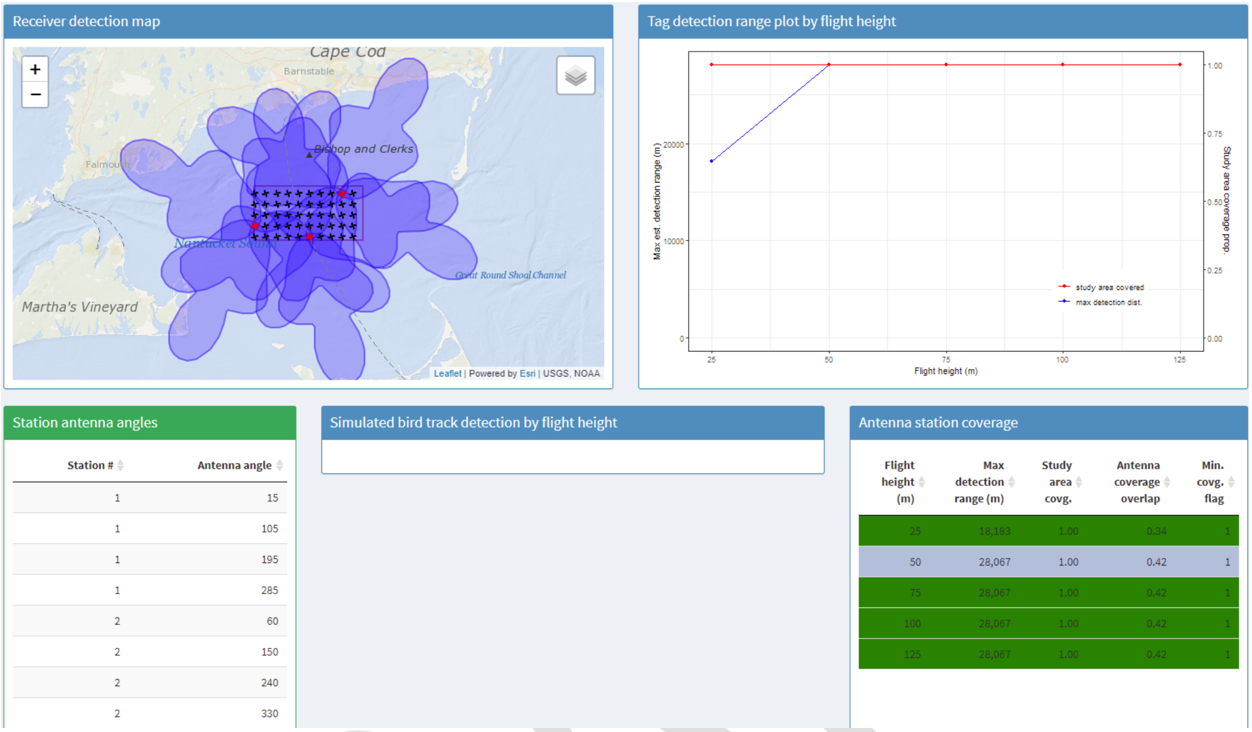
5) **Select the "Detection array creation" option.** For this example, we are trying to maximize the proportion of the wind farm footprint that is covered by at least one station, so we will select "Coverage optimized". You may select the color of the output polygons showing the antenna detection patterns and/or change the color after they have been generated, if desired.



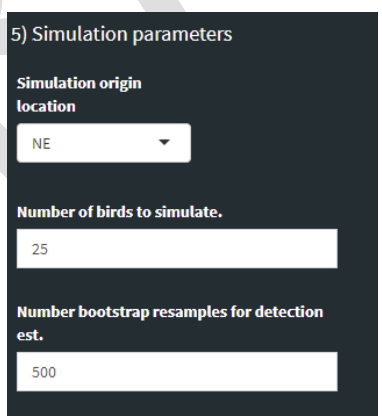
6) **Run the analysis by clicking "Generate array".** 

7) **Evaluate the output**. Once IDIOMS has completed its processing, the computed antenna patterns selected for each flight height with optimized antenna angles will be displayed on the map and details provided in the tables. You will notice that the 434 MHz antenna arrays, generated using the **best available data** when IDIOMS was developed, shows that maximum detection range is quickly attained below 50 m in this scenario. With that being the case, IDIOMS has identified that above 50m, the same arrangement and orientation of antenna stations applies. By clicking on the Antenna station coverage table rows you can see the different antenna array patterns in the "Receiver detection map" and also see the different station antenna angles specified at each station to arrive at the best solution for coverage optimization. This makes our work easy, so we can reasonably pick the arrangement at 50 m which will optimize the stations for at least 50-125 m, an altitude range that can present risk for collision by marine birds given typical flight patterns. Results with the 50 m flight altitude arrangement (row in gray) are shown below; at all examined altitude bins, you can see that study area overlap is 100%.

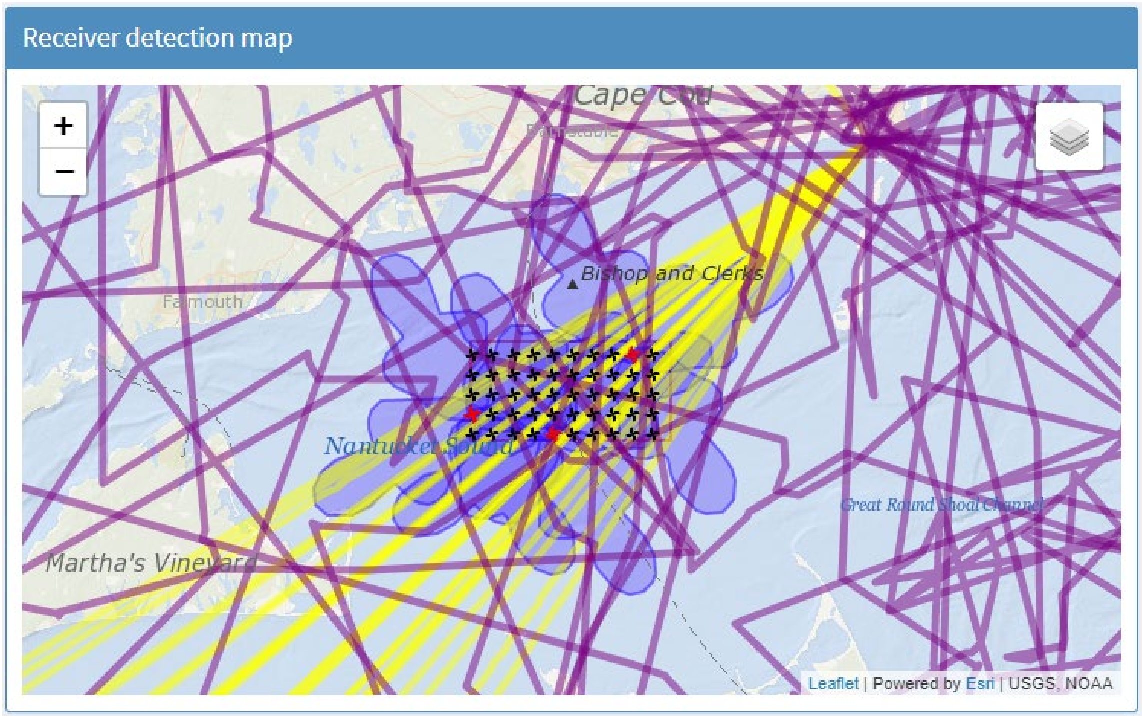
Adjacent antenna overlap is one third or better, so this arrangement does a good job of covering the study area.



8) **Simulate the seabird and shorebird tracks**. Use the default simulation parameters or modify for your use case. Here we use the defaults.



Here are the results of the simulated seabirds (purple lines) and shorebirds (yellow lines):

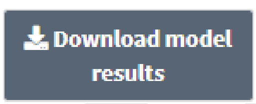


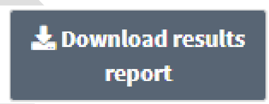
You can see that for birds originating in the northeast, the proportion of simulated birds that are detected is quite high for shorebirds (0.94-0.95) and less so for seabirds (0.40-0.54). Shorebirds on migration are simulated to have very directed movements, and after leaving Cape Cod move to the southwest and are frequently detected by the Motus station array. Simulated seabirds during the nonbreeding season are estimated to have a much more sinuous track, and are not as well detected because their movement is more geographically dispersed and much less directed. Keep in mind that these simulated tracks are meant merely as a guide for how Motus-tagged birds might encounter the station array; actual results will vary.

Simulated bird track detection by flight height

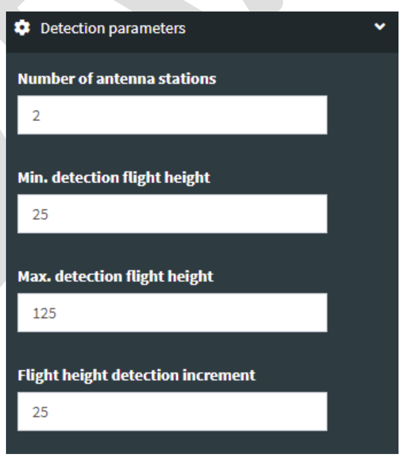
Species group	Flight height (m)	Mean prop. detected	Lower 95% CI prop. detected	Upper 95% CI prop. detected
seabirds	25	0.394	0.351	0.437
seabirds	50	0.527	0.484	0.571
seabirds	75	0.53	0.486	0.574
seabirds	100	0.526	0.482	0.57
seabirds	125	0.527	0.483	0.57
shorebirds	25	0.932	0.91	0.954
shorebirds	50	0.95	0.931	0.969
shorebirds	75	0.948	0.929	0.968
shorebirds	100	0.951	0.932	0.97
shorebirds	125	0.953	0.935	0.972

9) **Download model results and export report**.





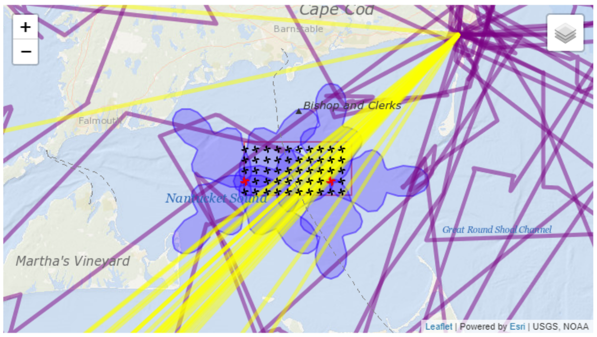
10) **Re-run 434 MHz with two (2) stations**. For comparison we can re-run this scenario with only two stations to see how coverage compares with the three-station scenario:



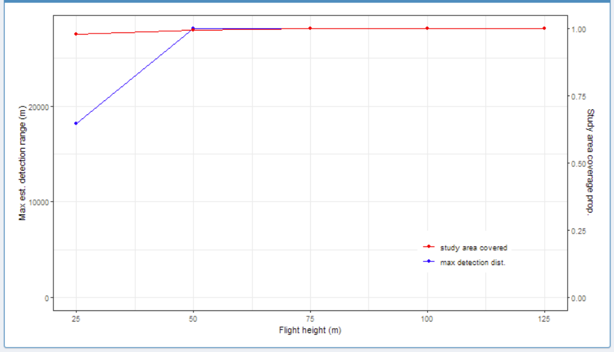
11) **Inspect the results**. As you can see, at least with predicted performance at 434 MHz and for this study area, coverage from two stations is very good. The proportion of simulated birds tracks that are detected is also fairly good. Given these results, for 434 MHz tags, we can probably just use two stations for a wind farm of this size and shape in this location. However, a third Motus station would offer some redundancy which is useful in

case a station goes offline due to equipment failure, particularly where stations are remote and access is likely very limited and infrequent. Multi-antenna detections are also extremely valuable for developing three-dimensional movement models from Motus data, and antenna coverage overlap of at least 0.XX is generally recommended.

Receiver detection map



Tag detection range plot by flight height



Station antenna angles

Station #	Antenna angle
1	45
1	135
1	225
1	315
2	0
2	90
2	180
2	270

Simulated bird track detection by flight height

Species group	Flight height (m)	Mean prop. detected	Lower 95% CI prop. detected	Upper 95% CI prop. detected
seabirds	25	0.382	0.34	0.425
seabirds	50	0.542	0.499	0.586
seabirds	75	0.517	0.473	0.561
seabirds	100	0.519	0.475	0.563
seabirds	125	0.515	0.472	0.559
shorebirds	25	0.94	0.919	0.96
shorebirds	50	0.952	0.934	0.971
shorebirds	75	0.95	0.931	0.969
shorebirds	100	0.948	0.928	0.967
shorebirds	125	0.946	0.926	0.966

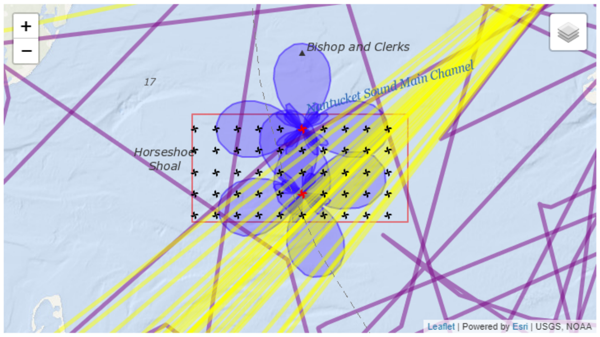
Antenna station coverage

Flight height (m)	Max detection range (m)	Study area covg.	Antenna coverage overlap	Min. covg. flag
25	18,183	0.98	0.15	1
50	28,067	0.99	0.34	1
75	28,067	1.00	0.21	1
100	28,067	1.00	0.21	1
125	28,067	1.00	0.21	1

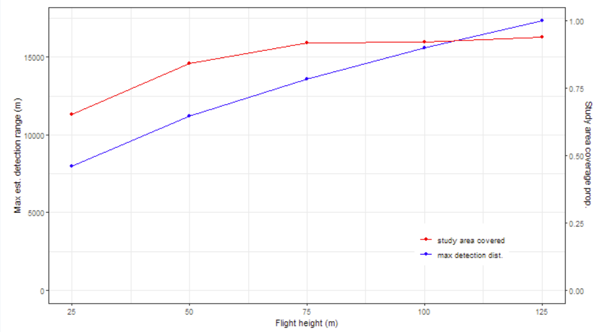
12) **Repeat process in steps 3-10 for 166 MHz with 2 stations**. Change the frequency to 166 MHz and select appropriate antenna (we selected a 9 element Yagi). Keep the other parameters the same unless you have reason to change. We could start with 2 stations since this seemed reasonable for 434 MHz or start again with 3. We will start with two (2) receiver stations this time.

13) **Inspect the results of 166 MHz two stations**. You can see from the output that except for an altitude of 25 m, two stations does reasonably well at covering the study area. However, since 25 m is a critical area just below or at the RSZ for some turbines, and to detect more animals below RSZ, it seems reasonable to run IDIOMS for 3 stations to see if this improves our detection at 25 m.

Receiver detection map



Tag detection range plot by flight height



Station antenna angles

Station #	Antenna angle
1	15
1	105
1	195
1	285
2	0
2	90
2	180
2	270

Simulated bird track detection by flight height

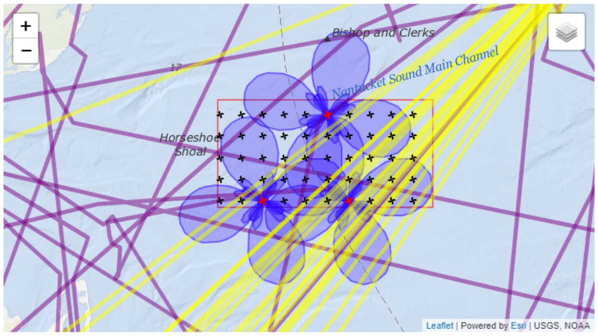
Species group	Flight height (m)	Mean prop. detected	Lower 95% CI prop. detected	Upper 95% CI prop. detected
seabirds	25	0.205	0.17	0.241
seabirds	50	0.309	0.269	0.35
seabirds	75	0.351	0.31	0.393
seabirds	100	0.362	0.32	0.404
seabirds	125	0.382	0.34	0.425
shorebirds	25	0.842	0.81	0.874
shorebirds	50	0.924	0.901	0.948
shorebirds	75	0.935	0.913	0.956
shorebirds	100	0.933	0.911	0.955

Antenna station coverage

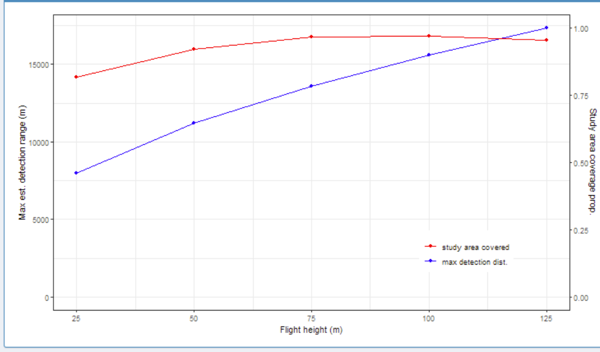
Flight height (m)	Max detection range (m)	Study area covg.	Antenna coverage overlap	Min. covg. flag
25	7,961	0.65	0.28	0
50	11,186	0.84	0.14	1
75	13,608	0.92	0.07	1
100	15,605	0.92	0.16	1
125	17,323	0.94	0.15	1

14) **Repeat process in steps 3-10 for 166 MHz with 3 stations.** We can see from the results for the 166 MHz computations that coverage at 25 m is much improved and so we would recommend for this frequency having at least 3 receiver stations to allow for more complete coverage.

Receiver detection map



Tag detection range plot by flight height



Station antenna angles

Station #	Antenna angle
1	15
1	105
1	195
1	285
2	15
2	105
2	195
2	285
3	75
3	165

Simulated bird track detection by flight height

Species group	Flight height (m)	Mean prop. detected	Lower 95% CI prop. detected	Upper 95% CI prop. detected
seabirds	25	0.237	0.2	0.274
seabirds	50	0.317	0.276	0.358
seabirds	75	0.355	0.313	0.397
seabirds	100	0.37	0.327	0.412
seabirds	125	0.425	0.381	0.468
shorebirds	25	0.88	0.852	0.909
shorebirds	50	0.914	0.889	0.939
shorebirds	75	0.927	0.904	0.95
shorebirds	100	0.935	0.913	0.956

Antenna station coverage

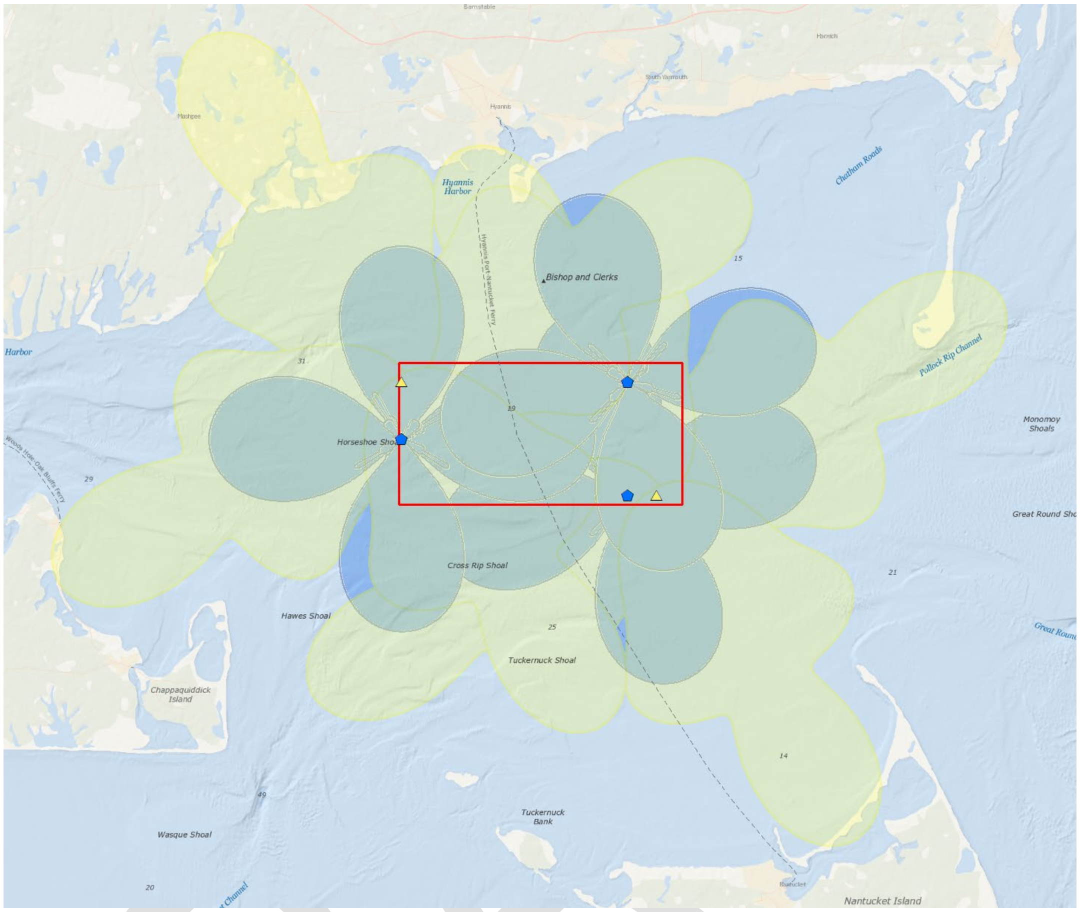
Flight height (m)	Max detection range (m)	Study area covg.	Antenna coverage overlap	Min. covg. flag
25	7,961	0.82	0.27	1
50	11,186	0.92	0.22	1
75	13,608	0.97	0.24	1
100	15,605	0.97	0.32	1
125	17,323	0.95	0.26	1

15) Map the proposed receiver stations. Check the placement of the proposed receiver stations at 166 and 434 MHz and confirm they don't conflict in space, since these receivers can't be on the same structure. If they do conflict, you can manually assign one of the stations to an adjacent structure and check the coverage by either moving these in GIS using a shift procedure, or manually selecting the desired receiver stations in IDIOMS along with antenna arrangements to generate the updated coverage (including new shapefiles and coverage estimates). The latter approach is recommended as it produces the additional coverage estimates and updated reports in IDIOMS.

    You can see from the map of these two receiver station arrangements (displayed beam patterns are at 75 m) that stations are all placed on their own structures, and that together they provide good coverage of the study area. You can check a couple of flight heights to see how the two station designs (166 and 434) align at different altitudes.

    The next step is to make sure that these wind turbine locations can accept receiver stations, and modify the locations if necessary. As noted above, antenna angles may be required to vary from initial designs; as much as possible, such logistical issues should be identified ahead of time in order to modify study designs (for example, by adjusting the antenna angles of other stations accordingly in order to maintain maximum coverage).

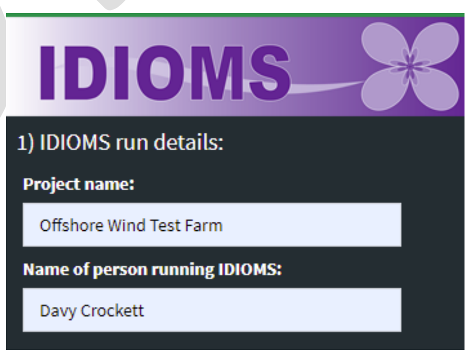
    Finally, IDIOMS gives you an understanding of the theoretical coverage for proposed receiver stations, but actual coverage will vary. Real-world beam patterns should be verified with calibration data at a range of flight heights at all deployed stations.



Display Coverage of an Omnidirectional Receiver Station on a Buoy

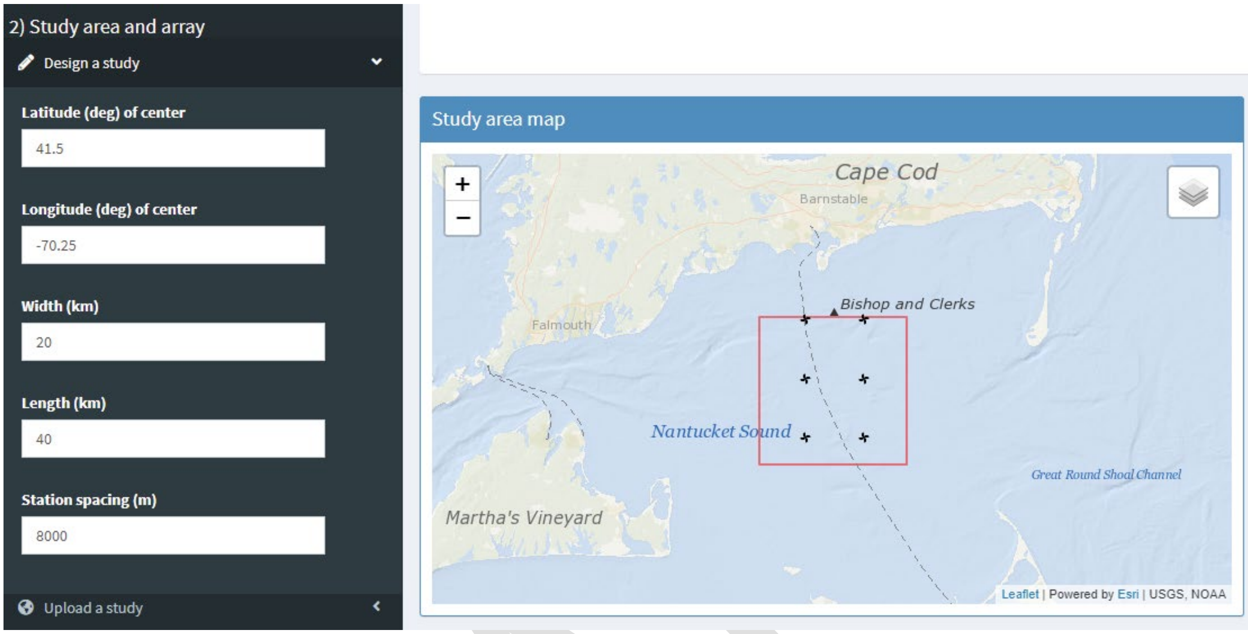
In this scenario we discuss the placement of an omnidirectional (omni) antenna on a buoy in the study area to demonstrate how to manually place the station and estimate receiver coverage within the study area.

1) **Enter your IDIOM run details**, project name and name of person running IDIOMS.

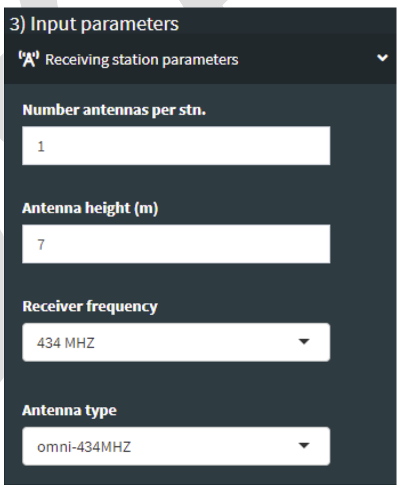


2) **Load study area and array shapefiles or design a study** using the center of the array latitude/longitude, width (km), length (km), and station spacing (m). Here we designed a

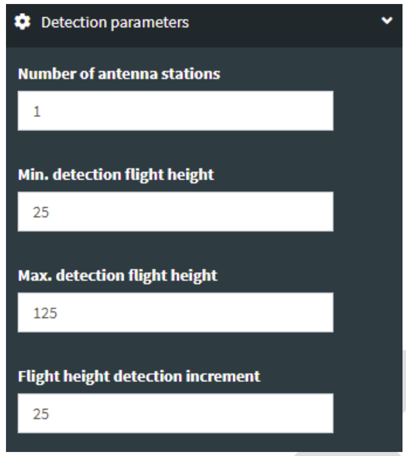
study area and small array of locations as options, but in the case of a single buoy with a predetermined location, this can be achieved by using the "Upload a study" option.



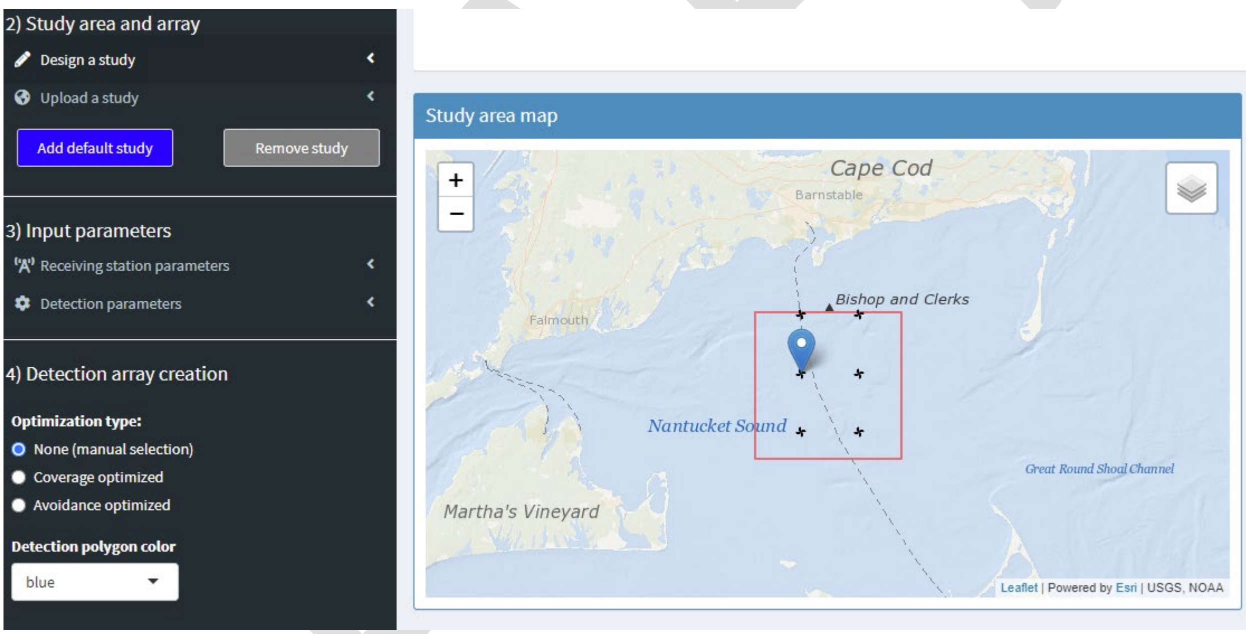
3) **Set "Receiving station parameters".** The defaults are set to 4 antennas per station with a station height of 25 m. Change this to 1 antenna at 7 m antenna height (or whatever your station height will roughly be). Initially we will run 434 MHz with an omni-434 MHz antenna.

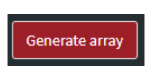


4) **Set "Detection parameters"**. The default is 3 antenna stations, a minimum 25 m flight height, and 125 maximum detection flight height, incremented by 25 m. You can choose 1 antenna station, but in practice it doesn't matter because you will be manually picking a location. You can leave the flight height values the same or change the range of values that you want to compute.

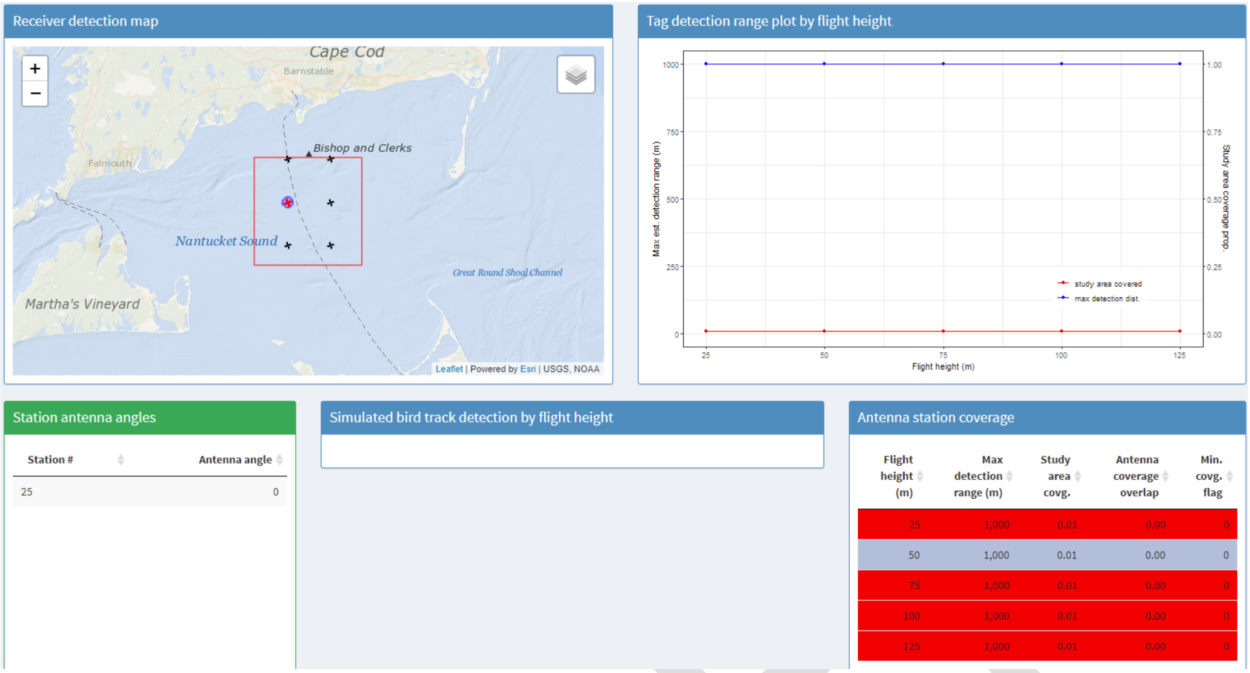


5) **Select the "Detection array creation" option**, for this example "None (manual selection)", which is the default. You may select the color of the output polygons showing the antenna detection patterns and/or change the color after they have been generated. Select the location for which you want to generate the receiver station antenna pattern.

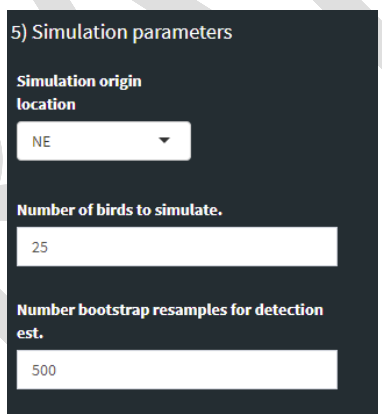


6) **Run the analysis by clicking "Generate array".** 

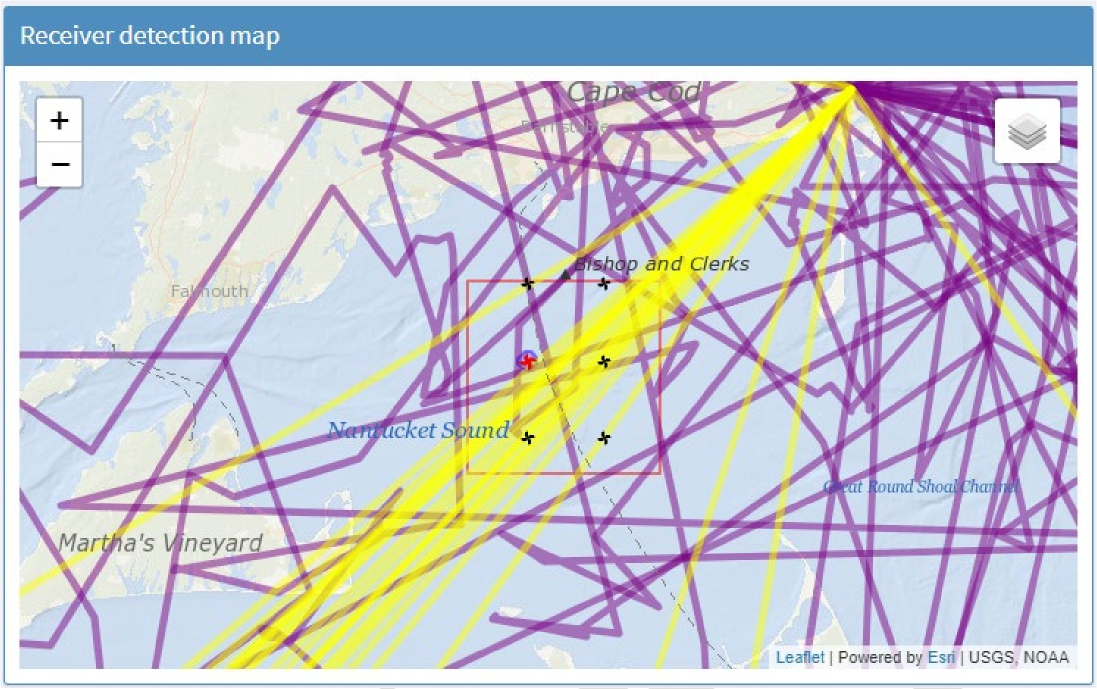
7) **Evaluate the output**. Once IDIOMS has completed its processing, the computed antenna patterns selected for each flight height will be displayed. By clicking on rows in the "Antenna station coverage" table you can see the different antenna array patterns in the receiver detection map. Currently, the antenna pattern displayed is a very simplistic circular pattern which does not vary by height and so the output also does not vary. Below results are shown at 50 m (row in gray). At all levels you can see that study area overlap is only 1%. Adjacent antenna overlap is zero as there are no adjacent antennas.



8) **Simulate the seabird and shorebird tracks**. Use the default simulation parameters or modify for your use case. Here we use the defaults.



Here are the results of the simulated seabirds (purple lines) and shorebirds (yellow lines):

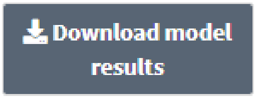


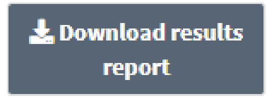
You can see here for birds originating in the northeast, the proportion of detected simulated birds is low for both shorebirds (0.09) and seabirds (0.03). The detection area of these omni antennas is relatively small, resulting in few birds being detected.

Simulated bird track detection by flight height

Species group	Flight height (m)	Mean prop. detected	Lower 95% CI prop. detected	Upper 95% CI prop. detected
seabirds	25	0.026	0.012	0.039
seabirds	50	0.026	0.012	0.041
seabirds	75	0.025	0.011	0.039
seabirds	100	0.024	0.01	0.037
seabirds	125	0.025	0.011	0.039
shorebirds	25	0.094	0.069	0.12
shorebirds	50	0.088	0.064	0.113
shorebirds	75	0.091	0.066	0.117
shorebirds	100	0.088	0.063	0.112
shorebirds	125	0.091	0.066	0.116

9) **Download model results and export report**.





10) **Repeat process in steps 3-9 for 166 MHz.** In practice this is not currently necessary, as the omnidirectional antenna patterns generated for both 434 and 166 MHz are the same in IDIOMS and thus results will be identical. IDIOMS currently provides very approximate coverage for an omni antenna, and these estimates should be verified with calibration data.

Next Steps

Due to the necessarily limited temporal and spatial sample that tagged animals represent, study design plays a key role in informing placement of receivers in strategic locations and thus maximizing the value of tagged individuals within the Motus Wildlife Tracking System. While the study design tool currently focuses on the placement of stations within individual wind farms, there is a clear need for coordination of study designs among offshore wind energy facilities, particularly for adjoining lease areas. Where possible, coordination of station placement across facilities will help to further optimize Motus telemetry studies to detect tagged individuals. It is strongly recommended that users collaborate and include more than a single facility's turbine locations in tool uploads, where possible, to develop coordinated study designs. Future iterations of the tool may further facilitate this type of regional-scale study design.

Updates to the Tool

Users experiencing problems with the operation of the tool should contact Andrew Gilbert at Andrew.gilbert@briwildlife.org. Updates to the tool and/or this user manual will be published at the following locations:

- https://briwildlife.org/offshore-motus-guidance/
- https://briloon.shinyapps.io/idioms/

Citations

Adams 2022 simulation study

Carlson 2022 calibration data

Church, R. L. and ReVelle, C. R. 1974. "The Maximal Covering Location Problem." Papers in Regional Science 32:101–18.

Gulka, J., Adams, E., Gilbert, A., Jenkins, E. , Loring, P., and Williams, K.A. 2021. Stakeholder Workshop: Online Study Design Tool for Informing Offshore Deployment of Automated Radio Telemetry Stations. Report for New York Energy Research and Development Authority. 11 pp. Available at https://briwildlife.org/offshore-motus-guidance/

Loring 2022 guidance document

Loring 2022 monitoring framework

Janaswamy, R., Loring, P. and McLaren, J., 2018. A State Space Technique for Wildlife Position Estimation Using Non-Simultaneous Signal Strength Measurements. arXiv:1805.11171.

Paton, P.W.C., Cooper-Mullin, C., Kouhi, S. Loring PH, Moore J, Miller J, Potty G. 2021. Assessing movements of birds using digital VHF transmitters: A validation study. OCS Study BOEM 2021- 009. Report to U.S. Department of the Interior, Bureau of Ocean Energy Management, Stirling VA. 222 p. Available at https://espis.boem.gov/final%20reports/BOEM_2021-009.pdf.

Nicholas T. and Mark P. (2022). maxcovr: A Set of Tools For Solving The Maximal Covering Location Problem. R package version 0.1.3.9200. https://github.com/njtierney/maxcovr