Draft Great Lakes Radar Technical Report

Fall 2017 Season at Cleveland, Ohio

U.S. Fish and Wildlife Service, Region 3

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2018

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INTRODUCTION

Global wind patterns help to move millions of migrating birds and bats through the Great Lakes region where shorelines provide important stopover habitat. Shorelines are thought to concentrate migrants as they offer the last refuge near a geographic obstacle and are likely used for navigation. Shorelines also offer areas attractive for wind energy development, which may cause mortality of birds and bats. With this potential for conflicting interests more information is needed on the aeroecology of the Great Lakes shorelines and potential offshore sites in the Great Lakes. We use avian radar systems to identify activity patterns, timing, and duration of migration that occurred along shorelines of the Great Lakes.

This draft report contains preliminary information from a study conducted by the U.S. Fish and Wildlife Service Avian Radar Team during the fall of 2017. The report is intended to provide data on the use of airspace in the vicinity of Cleveland, OH by aerial migrant birds and bats.

METHODS

An abbreviated description of methods relevant to the figures and data provided in this draft report is included here. A more thorough methodology can be found in Rathbun *et al*. 2016.

Study Area

During the fall 2017 season, we selected a site along Lake Erie for radar placement in the city of Cleveland, Ohio. We located the radar at 41.53181° N, 81.6519° W, within 50 m from the Lake Erie shoreline to monitor airspace above inland, shoreline and lake areas.

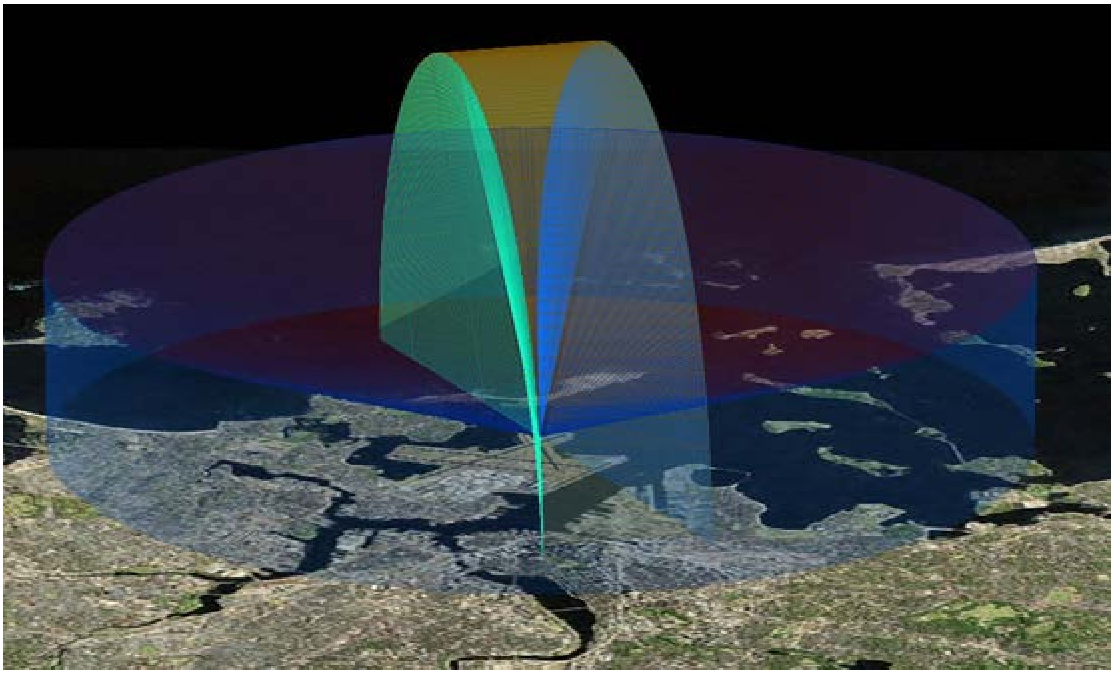

Figure 1. Computer representation of radar scanned volume. This is graphic displays the survey volume scanned by horizontal (blue) and vertical (green) radar antennas used by the U.S. Fish and Wildlife Service during fall 2017. Graphic provided by DeTect, Inc.

Equipment

We used a model SS200DE MERLIN Avian Radar System (DeTect Inc., Panama City, FL) to record migration movements. This system was selected because it is a self-contained mobile unit specifically designed to detect, track, and count bird and bat targets. The system employed two marine radar antennas that operated simultaneously: one scanned the horizontal plane (HSR) while the other scanned a vertical slice of the sky (VSR, Figure 1). Each antenna emanates a fan-shaped beam approximately 25° wide. Both antennas use S-band radar frequencies to enhance detection of birds and bats. This wavelength is less sensitive to insect and weather contamination than X-band (3 cm wavelength, Bruderer 1997). The radars spin perpendicular to each other at a rate of 20 revolutions per minute and were synchronized so as not to emit over one another. The horizontal surveillance radar was affixed to a telescoping base that was raised to approximately 7 m above ground for operation. This radar rotated in the horizontal plane with a 7° tilt to reduce the amount of ground clutter included within its view. The HSR had an approximate detection range of 3.7 km and the VSR had an approximate detection range of 2.8 km. The HSR was primarily used to provide information on target direction. The VSR provided information on the number of targets and the height of targets.

Radar Setup and Data Collection

The radar system was deployed during the first week of August, and maintained into the last week of November to capture the migration season, as well as the anticipated beginning of waterfowl migration, as requested by Cleveland Metroparks.

Establishing the radar system at the selected site involved micro-site selection, orienting the VSR, and making adjustments to ensure adequate information was captured and interference was minimized. We anticipated a primarily southbound direction of migration along the shoreline of Lake Erie during fall and oriented the vertical scanning radar to an angle that was slightly off perpendicular to anticipated direction of traffic. This orientation was a compromise between a perpendicular angle that would intercept the greatest number of targets (birds or bats) and a parallel angle that would maximize the amount of travel time within the vertical radar beam.

Cleveland Clutter Maps

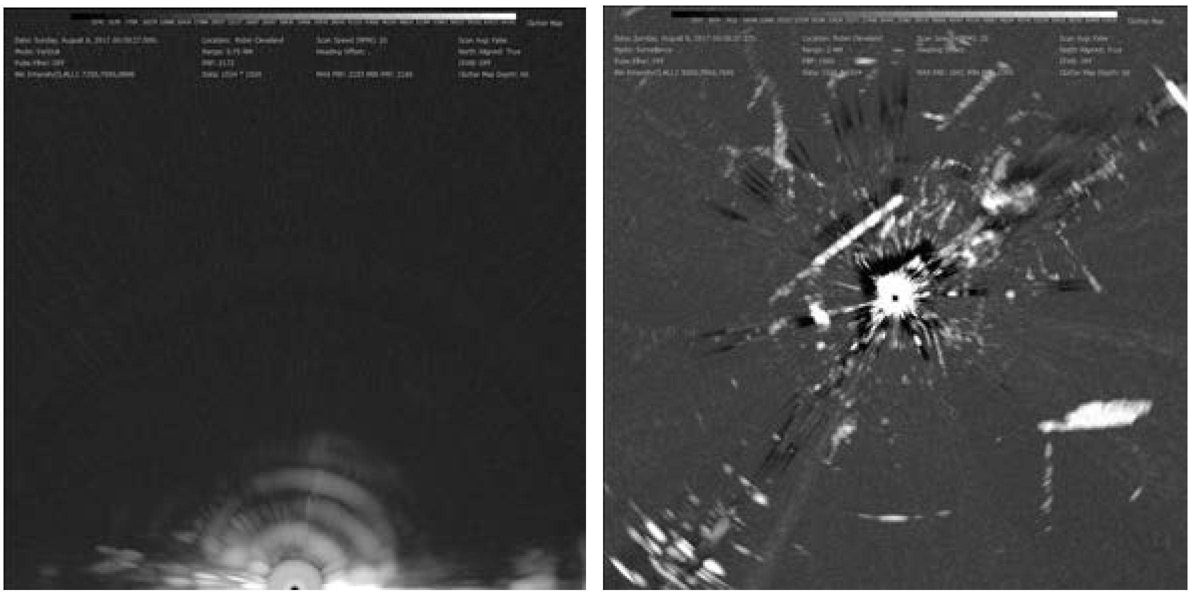

Figure 2. Clutter maps from vertical (left) and horizontal (right) scanning radars at study site in Cleveland, OH during the fall 2017 migration season. Brighter areas represent static returns from stationary objects such as tree lines and fencerows, or arcs from irregular radar returns. Detection of targets may be reduced or lost in these areas due to obstruction from these objects.

To improve data collection, clutter maps were generated using 60-scan composite images (Figure 2) at time periods with low biological activity. These maps identify areas with constant returns (areas that are white), such as treelines, fencerows and buildings. These objects reduced our ability to detect targets in certain regions of the sample volume, and as a result, those regions were assigned a reflectivity threshold that prevented the constant returns from being included in the data.

Following this initial set up, MERLIN software was fitted to site conditions. The MERLIN software provides real-time processing of raw radar data to locate and track targets while excluding non-targets and precipitation. However, parameters used by the tracking software require adjustments to account for site-specific conditions. Biologists established these settings to minimizing inclusion of non-targets while maximizing cohesive tracks of bird and bat targets. Biologists returned to the site periodically during the data collection period to ensure continuous function, monitor raw (unprocessed analog radar returns) and processed radar outputs, and manage data storage. In addition to processed data, we maintained all raw radar data for potential reprocessing.

Radar System Outputs

The MERLIN software records measurements of the target size, shape, location, speed, and direction of movement of each object (potential target) moving through the airspace. Objects detected on a sequence of scans may be classified as a biological "target" by the software and recorded in a database. To reduce potential false tracking, the MERLIN tracking algorithm removes tracks with fewer than five observations. A two-dimensional digital display of targets being tracked in real-time and static images of tracked targets over a specified period of time (Trackplots) are produced for both vertical and horizontal radars. During field visits, biologists viewed the real-time digital display to ensure it agreed with the raw radar display. Fifteen-minute Trackplots were also reviewed to assess target direction and height during recent activity.

Data Processing and Quality Control

Prior to data analysis, data processed by MERLIN software were further evaluated for potential contamination by non-targets. Biologists reviewed all data in 15-minute time increments and removed time periods that were dominated by rain. Data were also reviewed for time periods dominated by insects, waves, or other forms of transient clutter. Once contaminated time periods were removed, we summarized data for further analysis using database queries provided with the MERLIN radar system.

Data Summary and Trends Analysis

Data from the HSR were used to examine the direction of target movements. All targets within the detection radius (3.7 km) were included in the analysis. Data from the VSR were used to calculate target passage rate (TPR), as well as altitudes. VSR data were truncated to a 1-km "standard front," which is a common metric in radar research (Lowery 1951, Liechti *et al*. 1995, Kunz *et al*. 2007). The standard front is a volume that extends 500 m to either side of the radar and extends vertically up to the maximum height of 2.8 km.

To examine changes over the diel cycle, sunrise and sunset times were calculated and target counts were further segregated into four biological time periods: dawn, day, dusk, and night. Dawn was defined as 30 minutes before sunrise to 30 minutes after sunrise, day as 30 minutes after sunrise to 30 minutes before sunset, dusk as 30 minutes before to sunset to 30 minutes after sunset, and night as 30 minutes after sunset to 30 minutes before sunrise.

Temporal Trends

We plotted counts of targets per hour for both HSR and VSR antennas as a time series to identify pulses of nocturnal activity, season duration, and changes in patterns of activity over time. The HSR and VSR radars have different strengths that complement one another. Counts from both antennas are viewed as indices of target movement, and were plotted together. The HSR has a larger sample volume and generally tracks lower-flying targets in a 360˚ span around the radar unit. HSR detection is not affected by target flight direction, but it is much more affected by ground clutter than the VSR. Ground clutter, along with the shape of the HSR sample volume, can cause both under- and over-counting. Targets blocked from view by ground clutter may not get counted, and targets that fly into and out of areas with clutter may get counted multiple times. Consequently, HSR counts are more heavily influenced by surrounding site conditions than VSR counts. However, HSR can provide a better description of target activity under certain conditions, such as when targets are primarily at low elevation. The VSR index is a more reliable indicator of target passage through the standard front. The vertical sample volume is mostly unimpeded by clutter, except in the lowest altitude bands. VSR detection rates are likely affected by target direction, and vary with distance from the radar (Bruderer 1997, Schmaljohann *et al*. 2008). Plotting these indices together provided a more comprehensive view of changes in target activity over time.

Directional Trends

Flight directions were analyzed following methodology for circular statistics (Zar 1999) provided within DeTect queries. We used radial graphs to plot the number of targets per 8-cardinal directions (N, NE, E, SE, S, SW, W, NW) during four biological time periods (dawn, day, dusk, night) as well as by hour. Additionally, we used the circular mean direction of targets each night to examine potential origins of migrants, plotting the estimated direction of origination as a line with length representing the magnitude of migration. This measure does not indicate variance of directionality, which can be large, but does provide a visualization of the likely origin direction of many migrants.

Altitudinal Trends

VSR data include the estimated altitude of each tracked target within the standard front. However, the size and shape of the radar beam changes with altitude, producing a smaller sample volume at low altitudes and a larger sample volume at high altitudes. To address this, we calculated the volume of the radar beam within each 50-m altitude band by Monte Carlo integration (Figure 3, *et al*. 2007), and adjusted counts within each band to provide a more accurate representation of migrant density by altitude. We report density of targets per 1,000,000 m^3 per hour for each biological period. For more detail, see Rathbun *et al*. 2016.

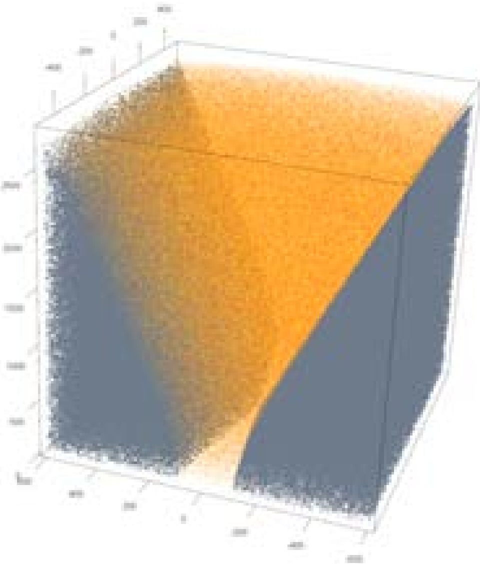

Figure 3. Graphical representation of the structural volume of the vertical scanning radar within the standard front used to estimate radar sample volume per 50 m altitude band. In this graphic the radar unit is located at the origin and the radar beam extends to 500 m on either side of the radar unit and up to a maximum height of 2800 m. The orange semi-transparent points represent the volume contained by the structure of the radar beam. Dark gray points represent the volume that is within the box but are not included in the volume of the radar beam.

RESULTS

Temporal Trends

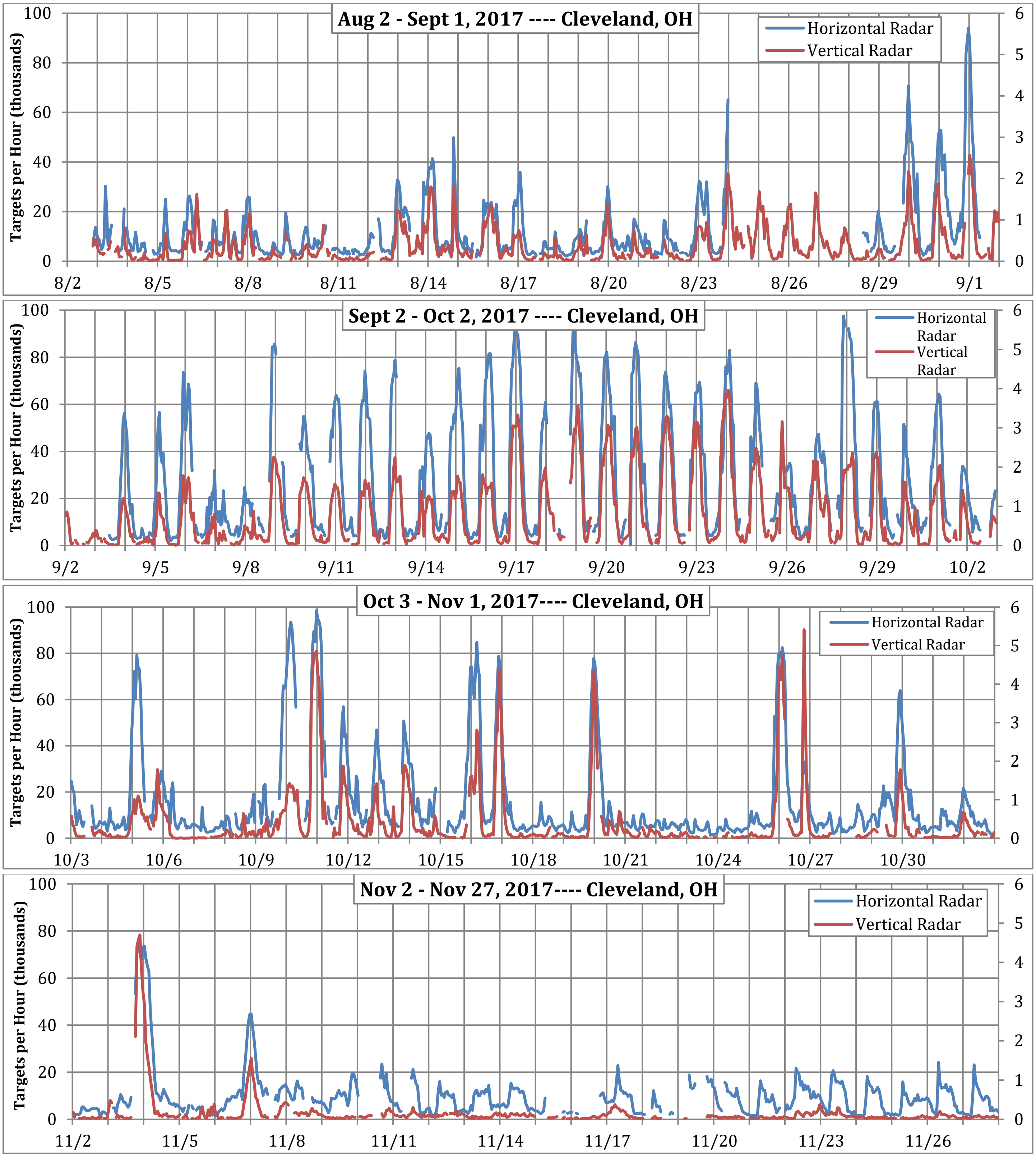

Figure 4. Time series of horizontal and vertical target counts. The horizontal counts (blue) are plotted on the left y-axis with the vertical radar counts (red) plotted against the right y-axis, both on the scale of thousands of targets per hour

The graphs in Figure 4 (above) show the counts from the radar units' two antennas for each hour over entire season. These two antennas sample different areas of the airspace, at different ranges, and with different strengths and weaknesses (see Methods for more detail). In general we use the vertical radar counts as a more reliable, albeit conservative estimate of migratory activity. Gaps in the lines represent hours with data missing, due to radar downtime for maintenance or malfunction, or due to the data being removed due to contamination from large amounts of clutter such as rain, insects, or waves. Vertical lines represent midnight on the specified date, and the night starts on the previous day, generally indicated by the rise in migrant counts.

Early in the season (top of Figure 4, night of August 2 until approximately the end of August), there is little activity on either radar antenna. Activity picks up just before the end of August and continues with a relatively constant level of movement each night through the beginning of October. In October, migration seems to change its pattern. Migration events occur much less regularly, however when they do occur they tend to be more intense. This pattern shift may be due to changing weather conditions or other factors influencing the large scale movements of migration. After the first week in November, migration has all but finished for nocturnal migrants. There is still some activity on the horizontal radar, but it is mostly confined to the diurnal hours and may represent the movement of mergansers and other waterbirds into and around the area.

Directional Trends

Direction by Biological Period

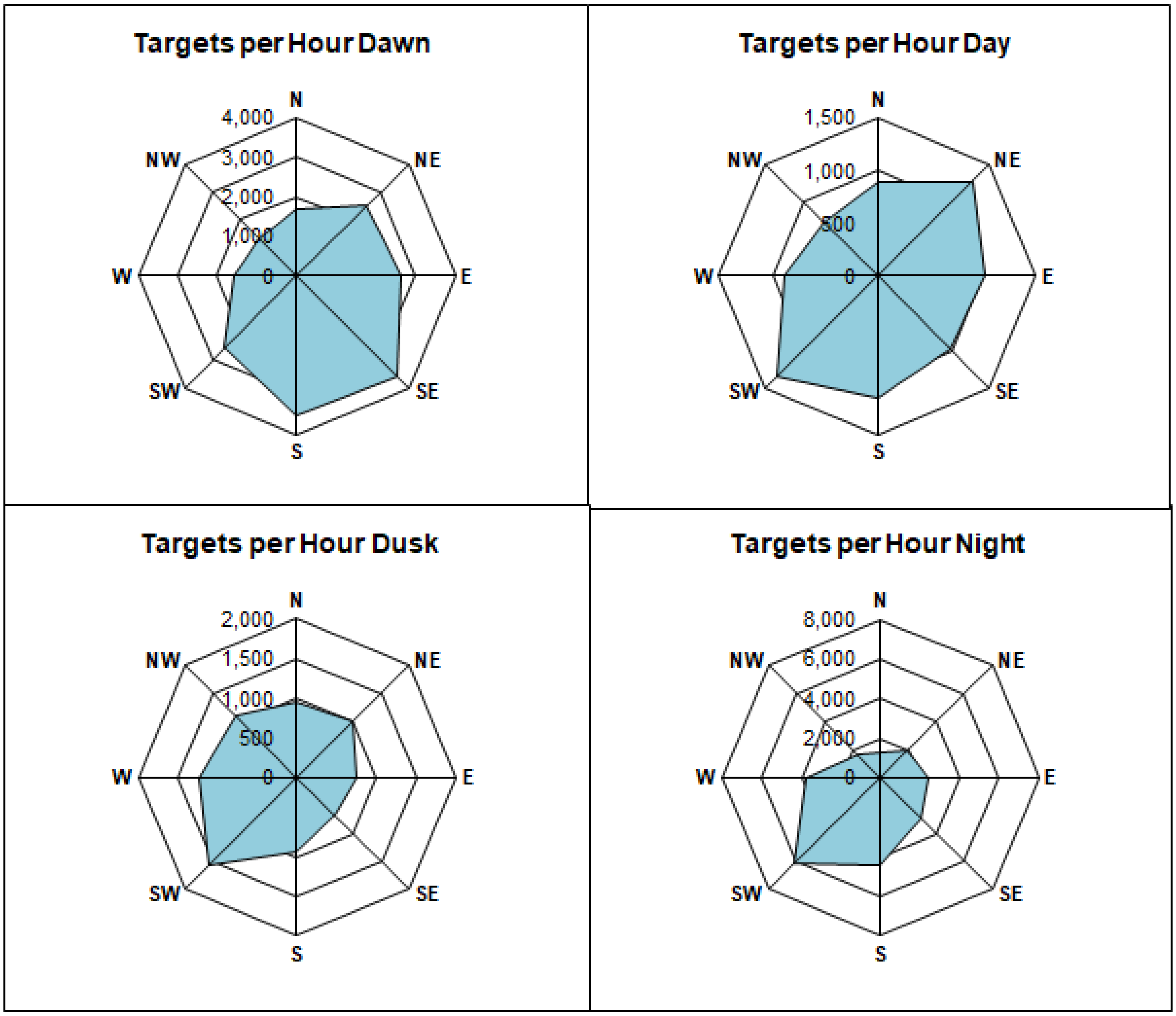

Figure 5. Rose graphs showing the movement direction of targets during the four biological time periods. The measures are in targets per hour, as there are a different number of hours in each biological time period. Please note the different scales between the graphs, as these are meant to illustrate differences in behavior and movement direction and not illustrate differences in activity levels.

Movement was oriented mostly along the shoreline during the day (top right panel of Figure 5). This often indicates gulls or other birds following the shoreline in search of food. At dusk, there are still large movements along the shoreline but there is increased movements to the northwest and west as well, likely indicating birds traveling from inland to the shoreline area to roost for the night. Movement to the southwest was higher than movement to the northeast, indicating that migration has started during this time period as well. The bulk of migration occurred at night, with large movements towards the south, southwest, and west. These are animals moving along the shoreline but also coming in from across the lake (Figure 6). Movement direction shifts at dawn, as we see at many other sites, with the targets moving perpendicular to the shoreline and heading towards the shoreline from out over the water to find a place to land after their migratory journey. This may mean that there was a turn towards the shore from migrants who are traveling parallel to the shoreline but are out over the water, but also may mean that there are targets finishing their flight after they cross over the lake, continuing their movement southward after the other migrants have stopped flying.

Example Migration Trackplots

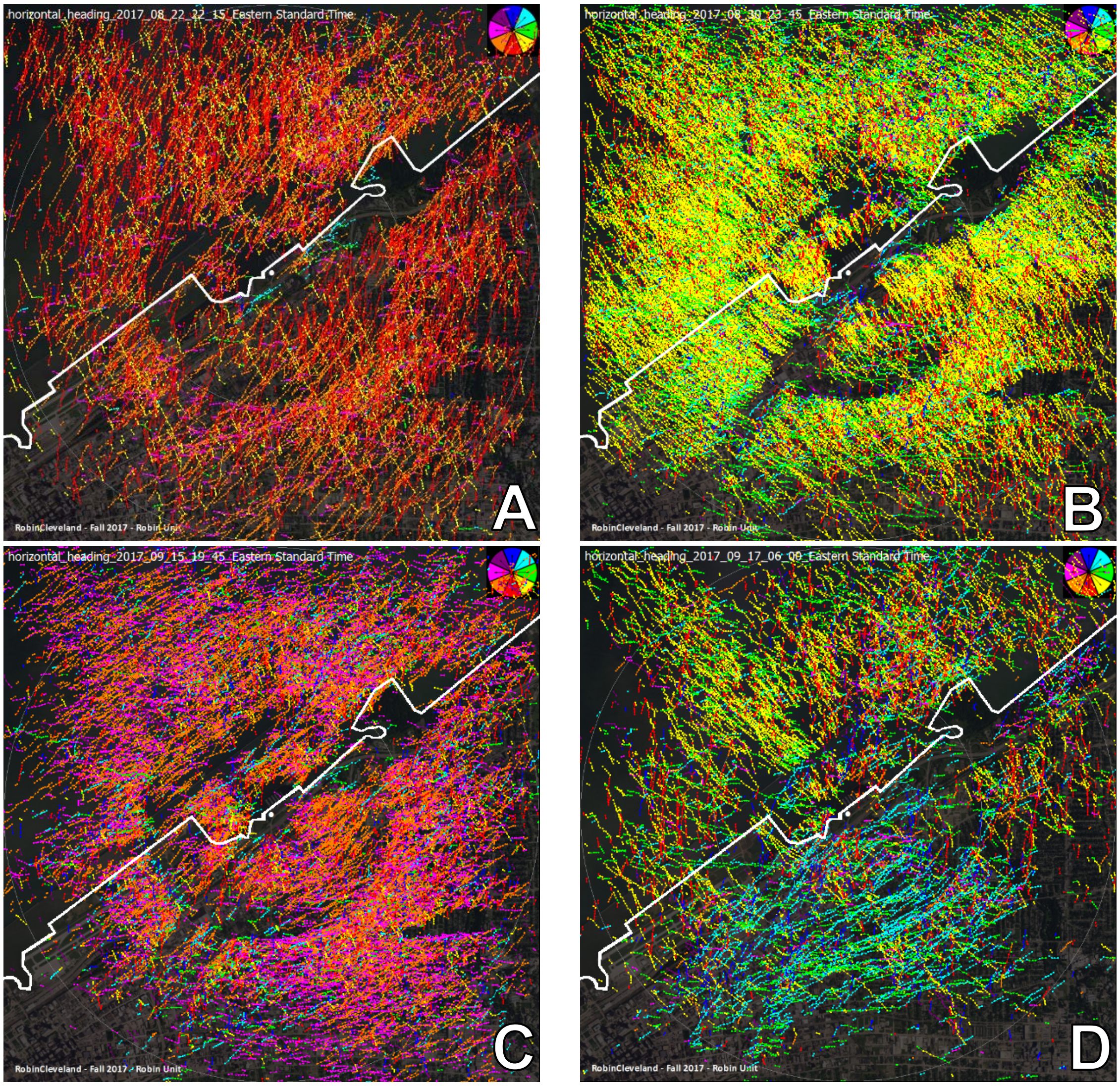

Figure 6: Examples of common Migratory events on Lake Erie in the Cleveland Area. Each colored line is a tracked migrant, with color indicating direction, as noted in the color-coded compass rose in the upper right corner of each figure (N=Blue, E=Green, S=Red, W=Purple). White point in the center of each panel denotes the location of the radar unit, while the white line denotes the local shoreline. Each panel depicts a 15-minute interval of time, starting at the time referenced.

- **A. High numbers of migrants moving predominately due south, crossing Lake Erie (August 22, 22:15)**
- **B. High numbers of migrants moving predominately southeast, also crossing Lake Erie (August 20, 23:45)**
- **C. High numbers of migrants moving along the shore of Lake Erie to the west and southwest (September 15, 19:45)**
- **D. Offshore migrants reorienting towards shoreline at dawn. Note the difference between the offshore and onshore directions (September 17, 06:00)**

Direction by Hour

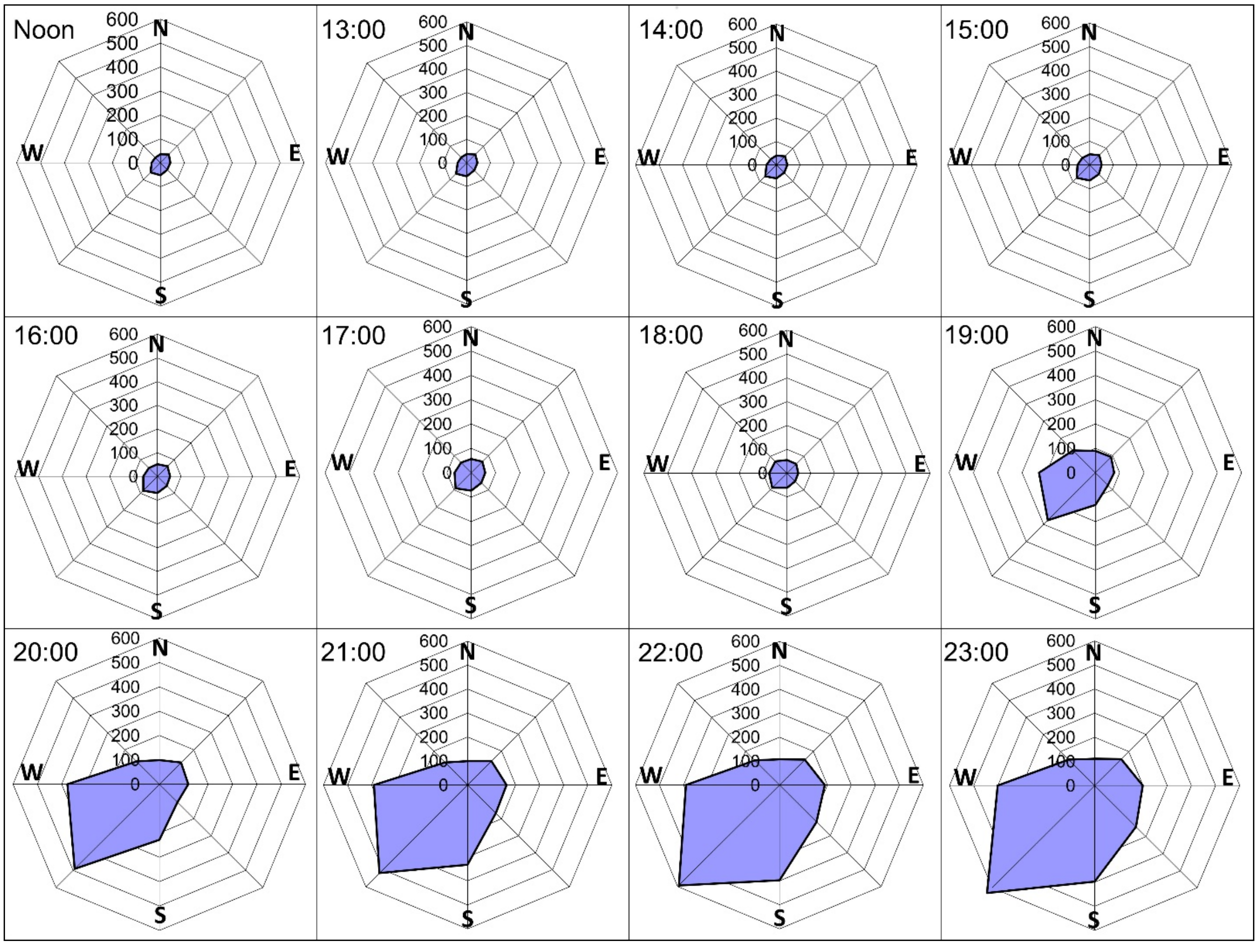

Figure 7. Rose graphs by hour. These graphs are the total counts of targets (in thousands) moving in each of the 8 cardinal directions during each hour over the course of the season. These rose graphs are all on the same scale, from 0 to 600,000 targets. They also show the changes in activity levels between the hours, representing the full daily cycle of activity.

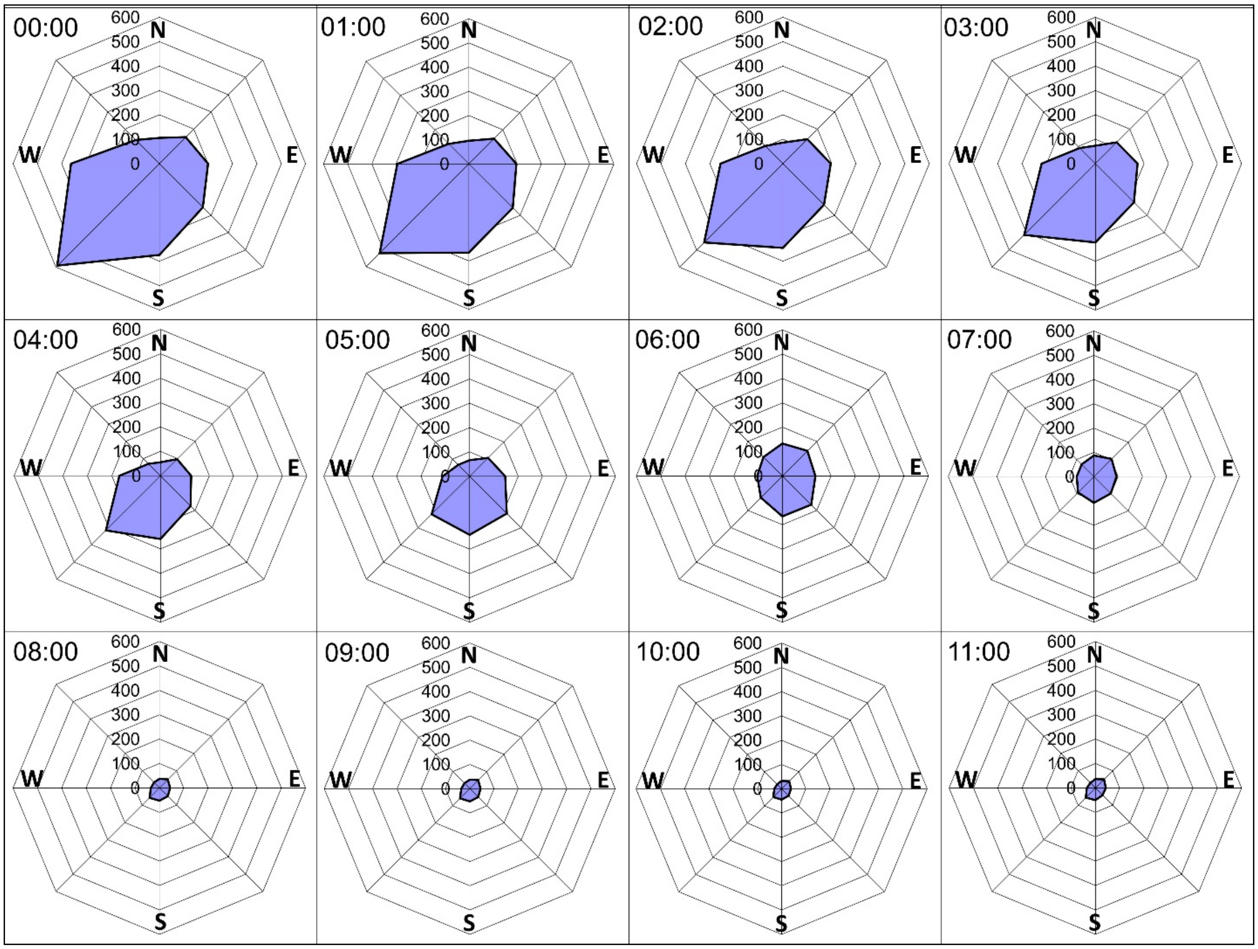

Figure-7 continued

Starting in the top left of Figure 7, for the 12:00 hour (from 12:00-12:59), activity is low during the day and has no main direction of movement. Around hour 19:00, migration starts to pick up. In the 19:00 and 20:00 hours, the main direction of movement is to the west and southwest, moving along the shoreline. However at 21:00, ~2-3 hours after migration started, the number of targets moving southward increases dramatically. This is about the time that it would take a bird or a bat to fly across Lake Erie and reach Cleveland from Canada (Bruderer and Liechti, 1998). As the night progresses, there are still large numbers moving to the west, southwest, and south. Around 02:00, the overall numbers of targets start to shrink, but the southward component decreases more slowly than the other directions, and movement to the southeast actually increases. This likely represents migrants both turning towards the lakeshore to land at dawn, as well as those that are finishing their lake crossing and coming in directly towards the shoreline. After dawn, activity returns to more typical daytime patterns with lower activity and no dominant direction of movement.

Direction of Origin

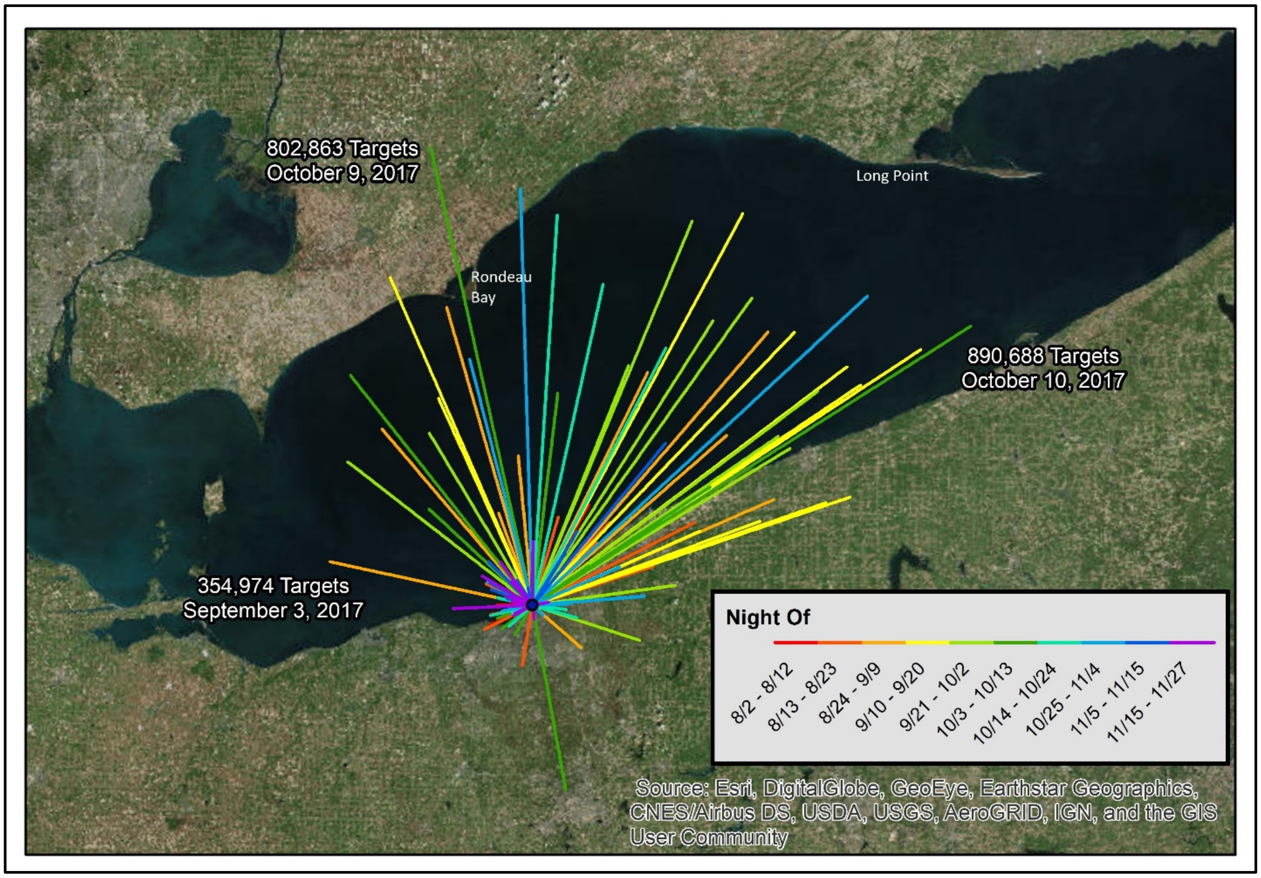

Figure 8. Estimated direction of origin each night. Lines represent the estimated direction of migrant origin and magnitude of movement each night of the fall 2017 season. Note that the dates of the night in this figure start at nightfall, before the midnight marker in Figure 4. The radar unit (blue dot) is on the Cleveland shoreline. The angle of each line is the circular mean of target headings, represented as movement toward the radar unit. Line length represents the number of targets detected on the horizontal antenna (HSR) each night. Night was defined as 30 minutes after sunset to 30 minutes before sunrise. Date is represented by color, with warmer colors earlier in the season and cooler colors later in the season. Map projection is UTM 17N.

In Figure 8, nocturnal target movement is heaviest from the northeast (down the coast) and north (across the lake), with only a few relatively low-activity nights when origination from the south (reverse migration) is indicated. Several nights in mid- to late-September suggest large movements parallel to the shoreline. Movement later in the season is more varied. Large movements from the NNW and NE, with a lull in the NNE direction may suggest frequent migrant crossing flights departing from shorelines near Rondeau Bay and Long Point.

Lines in Figure 8 do not indicate that all or even most migrants are moving in the same direction. Flight directions are usually spread out, with at least some migrants heading in each of the 360 compass directions each night. The line indicates the “typical” direction of flight by averaging headings among all migrants. HSR target numbers (length of line) provide a relative measure of migration intensity, but should not be interpreted as the number of migrants passing through. HSR target numbers may be inflated due to double-counting (see methods). Generally, short lines represent relatively low-activity nights and long lines represent high-activity nights. These lines also simplify the broader front migration and are not meant to indicate that migrants are only flying in from one area, but to estimate the general direction from which they are originating.

Altitudinal Trends

Altitude by Biological Period

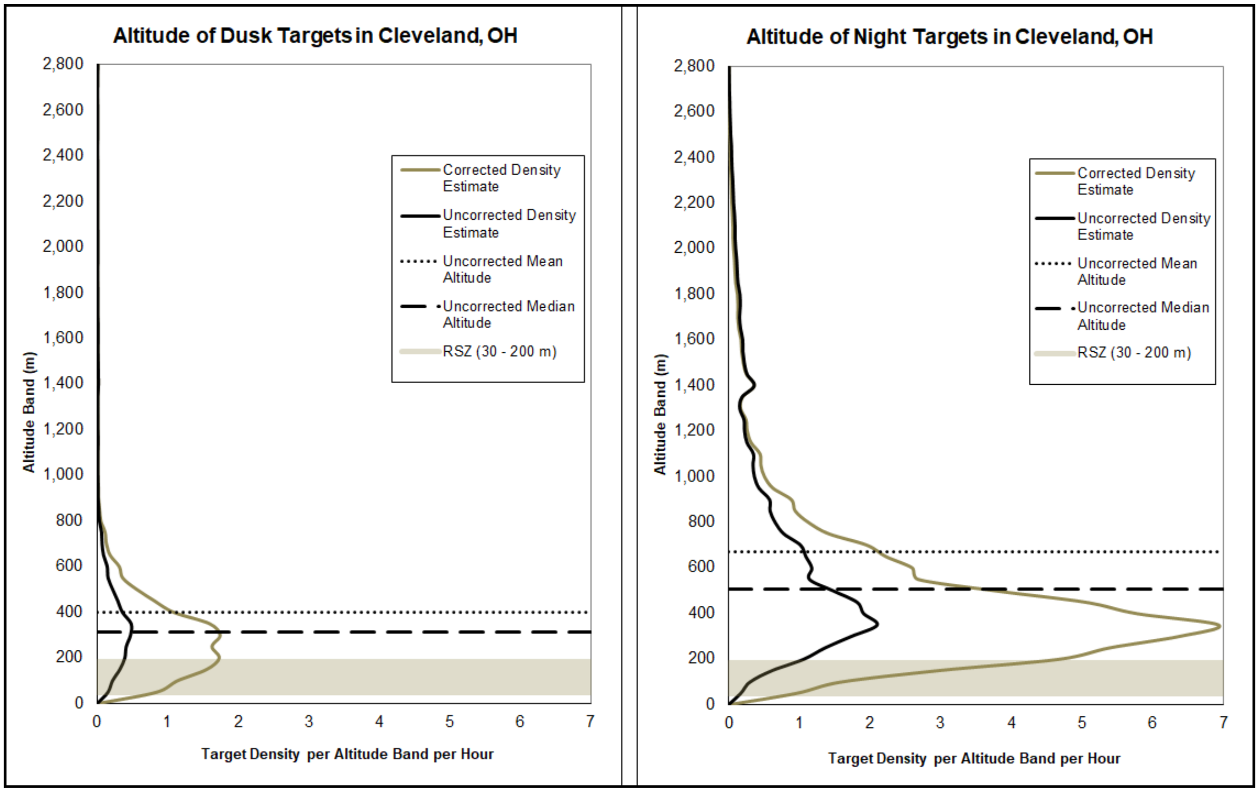

Figure 9. Corrected and uncorrected altitude distribution by biological time period. These graphs show the uncorrected (black) and corrected (gold) density estimates of targets moving on the vertical radar at different altitudes during the four biological time periods. The mean height for the time period is shown in a dotted line and the median height is shown in a dashed line. A shaded area represents a 30-200m rotor-swept zone (RSZ). These densities are corrected to account for the differences in sample volume between different altitude bands. As the radar beam travels out from the radar unit, it is cone-shaped so it expands, sampling a relatively narrow area at the lower altitudes until it increases in width at higher altitudes. Lower altitudes, including the altitudes in the RSZ, may have had lower detection due to clutter on the Vertical Scanning Radar (Figure 2). A paper on this correction is being prepared for publication and more information can be found in the Biological Technical Publications published by the USFWS Avian Radar Team: https://www.fws.gov/radar/factsandfiles/index.html. Note the overall larger numbers of migrants moving during the nighttime hours as compared to the other periods. Altitude distributions also indicate seasonal totals, and do not account for differences in flight altitude on particular nights.

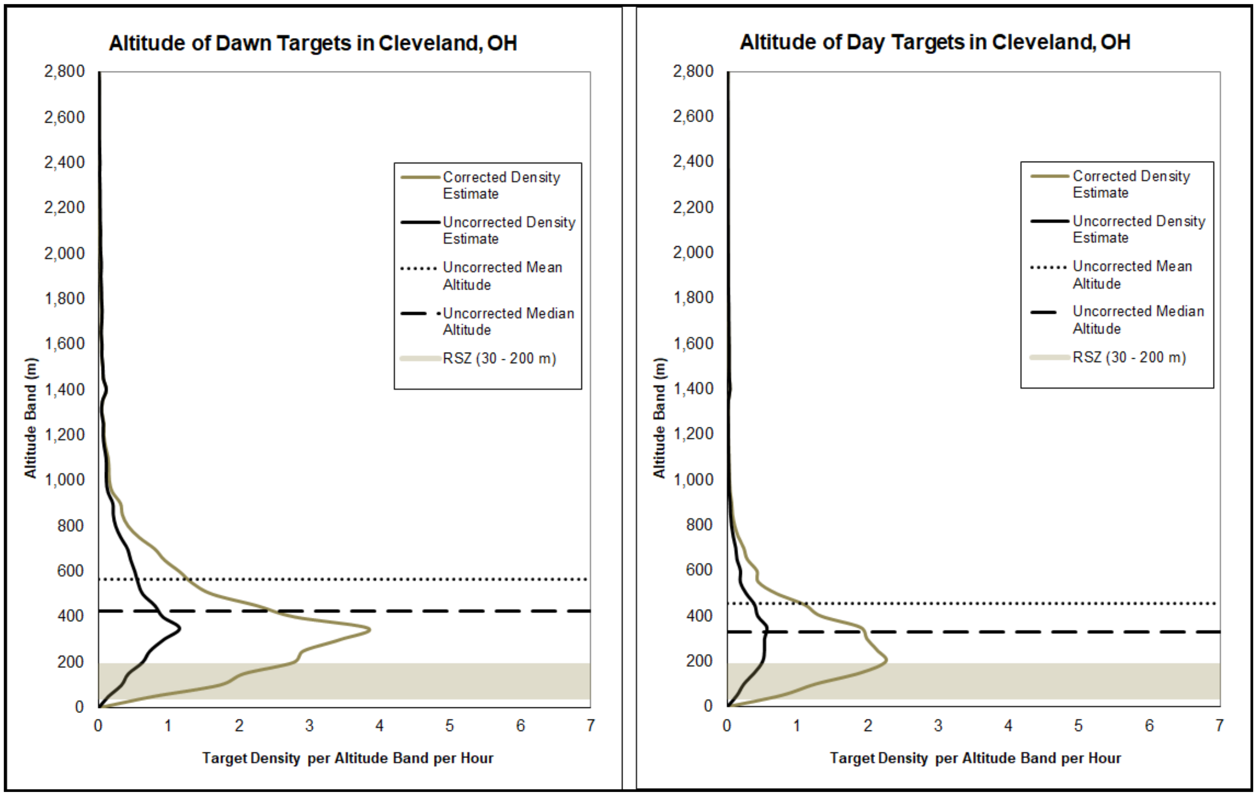

Figure-9 continued

Target Density by Altitude and Hour

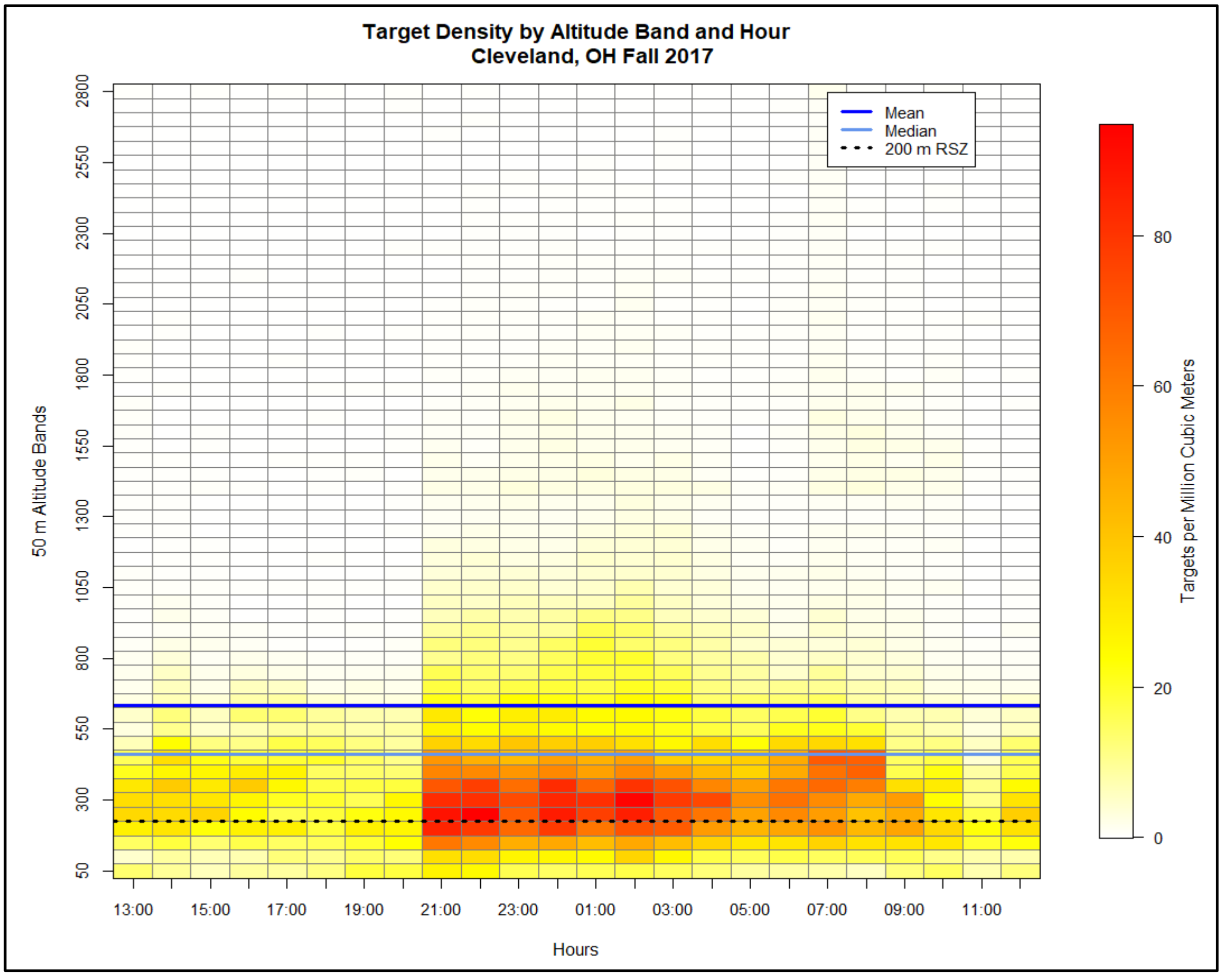

Figure 10. Hourly altitude heat map. This graph shows seasonal target density by hour and altitude. The Y-axis depicts altitude in 50-meter bands, while the X-axis shows the hour, with midnight (0:00) as the midpoint of the axis. Cell colors depict density of migrants, corrected for radar beam shape, with warmer colors indicating higher target density. Uncorrected mean and median altitudes are depicted in dark and light blue lines, respectively. A 200-m rotor-swept zone is depicted by the dotted black line.

The increase in density on the vertical radar between 21:00 and 09:00 shown in Figure 10 is consistent with strong nocturnal migrations documented throughout the Great Lakes with several unique features. First is the abrupt increase of migrant density at 21:00. This pattern is consistent with a delayed arrival due to lake crossings we documented from trackplot data (Figure 11). Second is the long tail of higher migrant density after dawn, consistent with late lake crossing, but also with waterbird movements from roosting to foraging areas. Note that these are seasonal densities, and depending on weather and other migration patterns, both densities and altitude distributions can be higher or lower. In addition, these data were collected from a coastal rather than an offshore site, and these altitude findings may not reflect the altitudes and densities of migrants at offshore sites.

Southbound Target Arrival at Cleveland

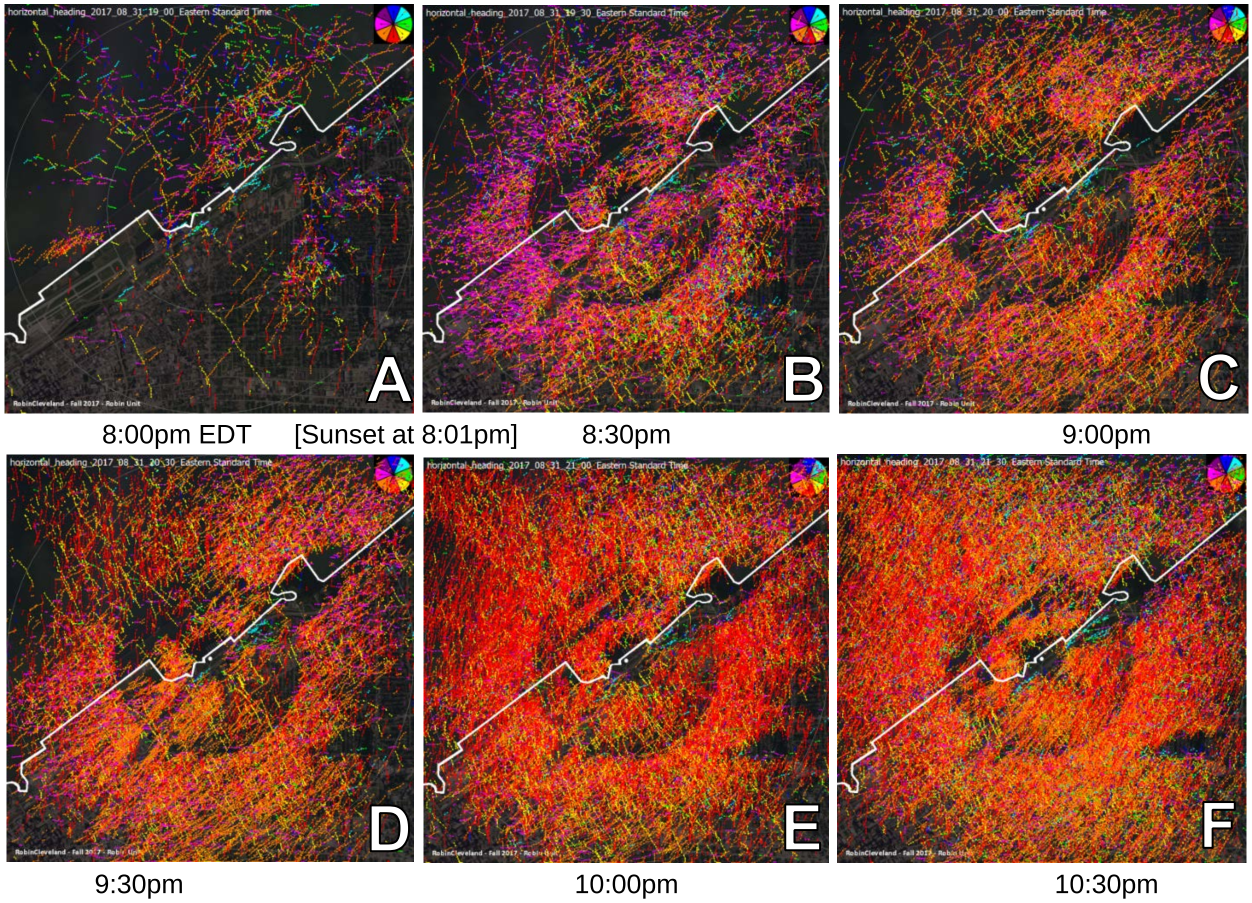

Figure 11: The plots above document the arrival of south-flying targets on the southern shore of Lake Erie (Cleveland radar site) approximately one and a half hours after sunset, and approximately one hour after the onset of migration on the night of August 31, 2017. Each plot represents 15 minutes of target tracking, beginning at the time listed. The white line represents the Cleveland shoreline and the radar location is a white dot at the center of each plot. Color indicates the direction of flight for each target, according to the color wheel at the top right of each plot: blue is north, green is east, red is south, and pink is west. Distance from our Cleveland site to the north shore of Lake Erie is approximately 80 km (50 miles). An average groundspeed of 61 kilometers per hour (17 m/s) was recorded for migrants crossing large bodies of water (Bruderer and Liechti, 1998). Thus, migrants leaving at dusk should begin to arrive on shore approximately an hour and a half later, almost exactly the time elapsed observed (panels A and D).

- **A. Low activity at the time of sunset (8:01 pm EDT)**
- **B. Migration begins in the half hour after sunset with flight to the west and southwest, and relatively low activity offshore (upper left of the plot)**
- **C. Migration continues through the next half hour, mostly to the southwest, and heavier over land.**
- **D. At 9:30, southern-moving (red) targets enter, particularly in the offshore portion of the plot.**
- **E. In the next half-hour, south-bound target activity increases dramatically.**
- **F. Heavy migration activity with predominant orientation to the south and southwest is evident throughout the plot.**

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