OBSERVATIONAL VALIDATION OF AVIAN RADAR SYSTEMS

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INTRODUCTION

At airports, avoiding collisions between birds and aircraft is the focus of both wildlife management and bird strike hazard warning systems. In the past, the tools available to airport personnel were limited to human observation, which documented species and numbers, followed by scientific analysis. With the advent of radar technologies and the availability of relatively inexpensive radar systems, a new tool was introduced to airport safety management systems. Avian radar provides an opportunity to extend observational capabilities to 24/7 time frames and the ability to expand spatial coverage in both distance and altitude.

Radar technologies are commonly used at airports for the detection and tracking of aircraft, management of aircraft and vehicles in airport operations areas, and the detection of hazardous weather conditions. Unfortunately, none of the existing radar sensors at airports can be easily modified to provide needed information on wildlife movements on and around the airport. For this reason, specific radar-based detection systems have been developed to address an airport's critical wildlife management and bird strike hazard warning requirements. The most common avian radar systems use readily available marine band radars (S-band and X-band) with scan configurations and digital processing of sensor data optimized for wildlife target detection and tracking. Unlike other radars used at airports, avian radars are a new addition to the technological capabilities of airports. As a result, few airport personnel have experience in the acquisition and use of this technology. Further, the validity of information produced by these avian radars has been questioned. Although it is clear that radars can detect bird targets, developing concepts of operation for avian radars at civil airports require very high levels of target discrimination capability and system reliability.

Beginning in 2006, the Department of Defense in association with other government organizations, private industry and CEAT undertook an assessment program to validate the performance of avian radars, the Integration and Validation of Avian Radars (IVAR). (http://www.estcp.org/Technology/SI-0723-FS.cfm) The effort evaluated avian radar systems, spanning a three-year period at four widely separated geographic locations during different seasons. Ground-truthing of the radar system was a major component of the IVAR project. At each study location, visual teams were dispersed to sites around the radar system. Radar operators then called target information to visual teams for verification that the target was a bird. Visual teams were also encouraged to call avian targets that they believed should be visible to the radar. Ground-truthing for the IVAR project encompassed seven sessions of three days each with two to three two-hour periods per day. Specifics can be found in the *IVAR Final Report, Method #3: Visual Confirmation Of Bird Targets*. Brand [1]

The IVAR project identified several problems associated with ground-truthing an avian radar system. First, study locations utilized a radar system equipped with a parabolic dish antenna generating a four degree beam. Visualizing the area of space covered by a four-degree beam is difficult with no visual reference. As a radar beam is transmitted, it increases in elevation and width as its distance from the radar system increases. For example, a visual observer 1400 m from the radar system must visualize a beam pattern where the bottom of the beam begins at ~66 m overhead and extends upwards to ~186 m. The observer must also visualize the beam width becoming wider further from the radar system or narrower in the direction of the system. Second, bird flight speeds can range from 9-20 m/s (20-44 mph). Alerstam et al [2] Visually locating specific flying birds against varying backgrounds and within a reasonable time frame is very challenging. At a speed of 15 m/s, the target will move a distance that exceeds the field of view of most binoculars in 8 seconds. Third, unless the target is overhead or very close to a visual team, judging distance in the air or over water without reference points is very difficult. Each of these problems needed to be addressed in the development of future validation efforts.

CEAT's effort in performance assessment of avian radars continued beyond the IVAR project, and innovative processes have been used to better understand and evaluate avian radar performance. CEAT validation efforts are based on an identified need for an independent assessment of avian radar systems, which can provide potential end users with a set of defined standards and requirements of performance. Nohara [3], Brand [1] A review of vendor information has failed to confirm that vendors have validated radar capabilities and, except for IVAR and CEAT studies, no independent validation has been undertaken. In the IVAR studies, short-term validation programs were used. In CEAT validation efforts, a long-term study plan has been implemented to assess avian radar system performance during seasonal changes in the local environment and species composition.

In an ongoing effort to understand avian radar physics and the system's ability to track bird-sized targets, several assessment campaigns were completed by CEAT utilizing unmanned aerial vehicles (UAV) with onboard geographic position system (GPS) technology. The use of these cooperative radar targets supported comparison of target position with radar detection position. Two configurations of UAV were utilized, a helicopter and an airplane, both approximately the size of a large bird. The use of these different UAVs allowed researchers the flexibility to control movement through the radar beam in controlled flight regimes. In conditions wherevisual tracking was marginal, these flights provided a better understanding of the system's ability to track birds.

Another validation approach used by CEAT and others has focused on visual observation of birds. Researchers have shown repeatedly that avian radar can track and monitor bird movement over a larger area than is possible using visual observation. This has been demonstrated on a local and regional level. Gauthreaux and Belser [4], Eastwood [5] and Cooper [6] Researchers utilizing radar and implementing studies to verify that detected targets are birds have also used other sensors, including acoustical and thermal systems. In general, existing studies were conducted when weather conditions were conducive to radar operations and conditions were also suitable for visual observation. Targets that could not be verified were assumed to be the target of interest only if established criteria were met. Cooper [6]

In reviewing these validation efforts, there appeared to be little work done to identify the potential for using radar to monitor bird activities and, at the same time, to evaluate the limitations imposed by the location and physics of radar operation. The CEAT observational validation effort was designed to address both issues while eliminating two of the problems identified in the IVAR ground-truthing: the CEAT validation program located a confirmed bird target and confirmed that the bird target was within the radar beam.

METHODS

Comparison of visual observations with avian radar data were conducted at Naval Air Station Whidbey Island (NASWI), Oak Harbor, Washington, located on Whidbey Island in northern Puget Sound at the eastern entrance to the Straits of Juan de Fuca. The local topography of the air station is relatively flat terrain with low hills to the north and south. NASWI is bordered by Puget Sound to the west and marsh and farmlands to the east. The area within the airfield is grasses and shrubs surrounded primarily by evergreens.

Whidbey Island is situated on the Pacific Flyway, providing a seasonal change in species and population densities. The most numerous species, year round, are gulls. Cormorants, Northern harriers, Red-tailed hawks, and Bald eagles are common all year. In summer, gull and cormorant sightings increase due to nesting areas close to the airfield. In the offshore areas, species change with the seasons. In the fall through winter, waterfowl, dominated by scoters, diving ducks, loons, and mergansers, utilize the local waters. In spring through summer, alcids, pigeon guillemots, rhinoceros auklets, murrelets and common murres are frequently seen. National Audubon Society[7], Klope [8]

The primary system/sensor collecting avian radar data for the CEAT assessment was a Furuno 8252, X-band, 25kW, marine radar outfitted with a Furuno 22 degree array antenna, set at an angle of zero degrees, and an Accipiter® avian radar system. The antenna/transceiver was mounted atop a mobile radar trailer (3.08 m AGL). On site were two additional radar systems:

- a Furuno 8252, X-band, 25kW, marine radar outfitted with an Accipiter® 4 degree parabolic dish antenna, and

- a Furuno 2155, X-band, 50kW, marine radar black box system, outfitted with a 4 degree parabolic dish antenna both equipped with an Accipiter® avian radar system.

Both parabolic dishes were set at +5 degrees elevation with the antenna/transceiver set at 3 feet above ground level. All systems were set with and antenna rotation of 24 rpm. Elevation at the radar site is 15.7 meters ASL.

Data from these systems was automatically collected 24/7 and archived on the local avian radar digital processor. Data was also downloaded onto the CEAT server at the University of Illinois. In parallel, data on bird movement on and around NASWI was collected through visual observation.

Visual observations were performed from July 2008 through September 2009. An observation period consisted of an initial qualitative survey of species present followed by quantitative assessment. At the beginning of each observation period, a qualitative species-present survey of the birds present and their behaviors in the vicinity of the observation site was conducted. This survey was not intended to be an accurate census of birds, but rather to provide a general sense of the species present and their general behaviors. Birds that could not be identified because of environmental conditions or distance were listed as unknown species. Also recorded were wind speed/direction, general weather conditions, tide level and wave conditions. Weather data was obtained from the National Weather Service Seattle, which maintains a weather station on board NAS Whidbey Island. Tide level was obtained from http://tbone.biol.sc.edu/tide/ utilizing data for Bowman Bay Washington, located 4.25 miles north of the observation site. Wave conditions were estimated based on close proximity to the waves and extensive personal boating experience in the area. When wind direction permitted, these estimates were compared against a sea-state calculator and found to be within the estimates provided by the calculator. White and Hanson [9]

A subsequent quantitative assessment was made using the 30x-power spotting scope. The observation site was located at N 48˚ 21.294' W 122˚ 40.416' on a bearing of 270˚ true and 502.0 meters from the radar unit. The spotting scope was equipped with a compass-card base-plate, which was aligned to true north prior to use. This allowed for easier comparison of visual observations with radar history files. Two samples were taken:

- a low-view scan with the horizon located near the top of the field of view to provide a low-elevation view and
- a high-view scan with the horizon located near the bottom of the field of view.

Distance to the horizon is ~ 6.4 km. View angle was adjusted as required to maintain the same field of view at each compass heading. Data was collected every 20 degrees between 200 and 080 degrees i.e. 200, 220, 240. Areas not observed were eliminated because of their proximity to aircraft hangars, buildings or a limited field of view. Observations at the selected headings were timed to 20 seconds. Spacing and timing were chosen to reduce the chances of multiple documentation of the same bird. Multiple-heading data sheets were developed to provide observations over areas of varying radar clutter and areas of significant continuous radar clutter, based on previous clutter mapping events performed by CEAT.

When a bird sighting occurred, the time was recorded to the second. Only birds in flight were documented. Other sighting-related data recorded were:

- numbers
- species, if known,
- the bird's apparent direction of travel
- relative distance (near or far)
- an estimate of elevation, if possible

Birds less than approximately 1.6 kilometers from the observation site, based on the bird's size as viewed through the spotting scope, were considered near distance. Elevation was based on the bird's size as the measure of how high it appeared above the surface, land, or water. An arbitrary figure of 6 m was used to define whether a bird was close to the surface or elevated above it. To document flight behaviors near surface of the water, the close-to-surface estimate was further defined to <2 m. During observation periods, field notes were kept that documented other bird movements, vehicle and aircraft movement, and changing weather conditions that might be useful in assessing performance.

Archived radar historical files from the primary avian radar system were used to validate the sightings made during field observations utilizing the Accipiter Track Viewer program. This viewer program allows the loading of archived data, from specific time periods, for playback and includes options for measuring distance and bearing of the target from the observation site. The display includes a Google Earth map of the local area. Radar files from the additional two radar systems, when available or appropriate, were also searched for radar tracks that corresponded to observed birds.

RESULTS AND DISCUSSION

Visual observations were conducted during daylight hours from July 2008 through September 2009. Times varied from just after sunrise to sunset and included differing tidal and weather conditions. A total of 220 samples were performed.

Numbers of bird species observed during the general census totaled 69. Numbers of bird species observed during the observation sample periods totaled 37. The difference between the two totals is explained by the requirement that birds be in-flight to be counted as part of the observation sample. In both the census and the sample periods, gulls were the most numerous species documented. Distance, lighting, and time constraints of data collection limited the observer's ability to identify gull species. At times, gull numbers conservatively exceeded 1000 individuals within view of the observer. The most significant changes in species observed occurred when the winter waterfowl species are replaced by summer alcid species, as a result of fall migration into and out of the area.

Species observed over the land areas were not as numerous and typically flew close to the ground and for short distances. This was especially true of the small Passerines. Raptors and crows moved about the airfield, foraging in different areas during the day. Family groups of crows made flights across the airfield early and late in the day and to and from roosting sites, but were dispersed during the day. A significant change in species was not observed from the observation site.

Several factors, and often a combination of two or more factors, affect whether a bird or flock is tracked by radar. Target aspect, size of the target, position relative to clutter, flight behavior, duration of flight, weather conditions and the overall clutter environment all affect the system's ability to detect and track avian targets. Eastwood [5], Cooper et al. [10]

Target aspect refers to the angle of the bird's body in relation to the sweep of the radar beam. As the bird changes position, its aspect changes and, therefore, its radar detectability changes. This is referred to as radar cross section (RCS). In association with other factors, changing RCS due to bird movement can increase or decrease the system's ability to track the target. Wing movement as the bird flies has been shown to change RCS. However, the wings themselves add essentially nothing to the overall RCS. Eastwood [5]

Position of the target in relation to clutter also affects the system's ability to detect and track bird targets. Ground and water always contribute some level of radar clutter. Eastwood [5], Cooper [11] Early in the assessment period at NASWI, it became apparent that gulls were not routinely tracked by radar when they were flying close to the surface of the water. It was noted that gulls flying less than approximately 6 m above the water's surface were not routinely tracked and gulls within 2 m of the surface were seldom tracked.

Although gulls flying close to the water's surface were not routinely tracked by radar, the Surf Scoter *Melanitta perspicillata* was. This validation effort and the IVAR validation both found that this bird species was often tracked close to the water's surface. Brand [1] As fall migrants arrived at NASWI, the Surf Scoter became common in the observation area, typically flying at elevations of less than 10 ft and, more commonly, less than 5 ft. A physical comparison of the scoters and gulls may provide some insight into this situation. The most common species of gull in the NASWI local area is the Glaucous-winged gull, which has a wingspan of 58 in, a body length of 26 in and a total weight of 1000 g. The surf scoter has a wingspread of 30 in, a body length of 20 in, and a total weight of 950 g. Sibley [12] - In this instance, it appears that the morphological, and other characteristics, of the Surf Scoter is sufficient to be detected in the close-to-surface clutter environment while the same is not true for the larger gull.

Ground clutter makes detecting and tracking targets such as birds and flocks of birds difficult in areas of high clutter. Eastwood [5], Kelly [13] and Cooper [6,10] The land area around the observation site has a significant amount of ground clutter. Figure 1 shows the normal ground clutter environment at NASWI.

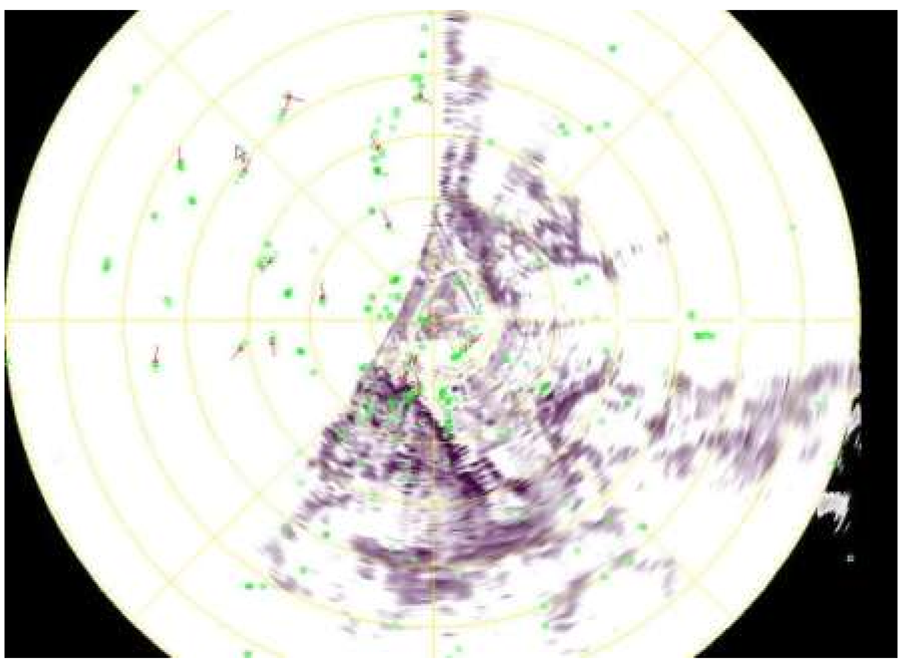

Figure 1. Ground Clutter at NASWI.

The clutter shown in Figure 1 is caused by radar reflection from the ground, buildings and vegetation in the area of radar detection. Passerines, bald eagles and other raptors were not typically tracked in these areas because of this clutter. In cases where flocks of birds and large individual birds were documented traveling across the airfield, tracking would begin in areas of low clutter, terminate as the targets entered high clutter areas and then were again tracked after leaving the clutter areas. The only tracks visible in the clutter of Figure 1 can be seen in zones of low clutter. Researchers in the past have utilized several techniques to mitigate the effects of clutter including utilizing natural radar fences and attaching adjustable fences to antennas to reduce nearby clutter and improve the radars ability to track bird targets at distance. Cooper [10] During this validation, no attempt was made to reduce the effects of ground clutter on the primary sensor beyond existing radar and software adjustments. There was a reduced level of clutter over the water off shore from the radar. The targets moving towards a central point are gulls congregating at a school of baitfish that have been forced to the surface by predators from below.

Sea clutter is a term applied to the clutter effects from water surfaces in the radar detection area. Sea clutter is present at all times but its effect is increased as weather conditions increase the size of waves in the detection area. Kelly et al. [13] During this validation study some weather conditions had the effect of generating large numbers of false tracks over the water. Figure 2 shows the effect of wave action on the primary validation radar. The two supplemental radar systems were not affected by the increased wave action because their parabolic dishes were set to an up-elevation of five degrees and the beams were not hitting the surface of the water.

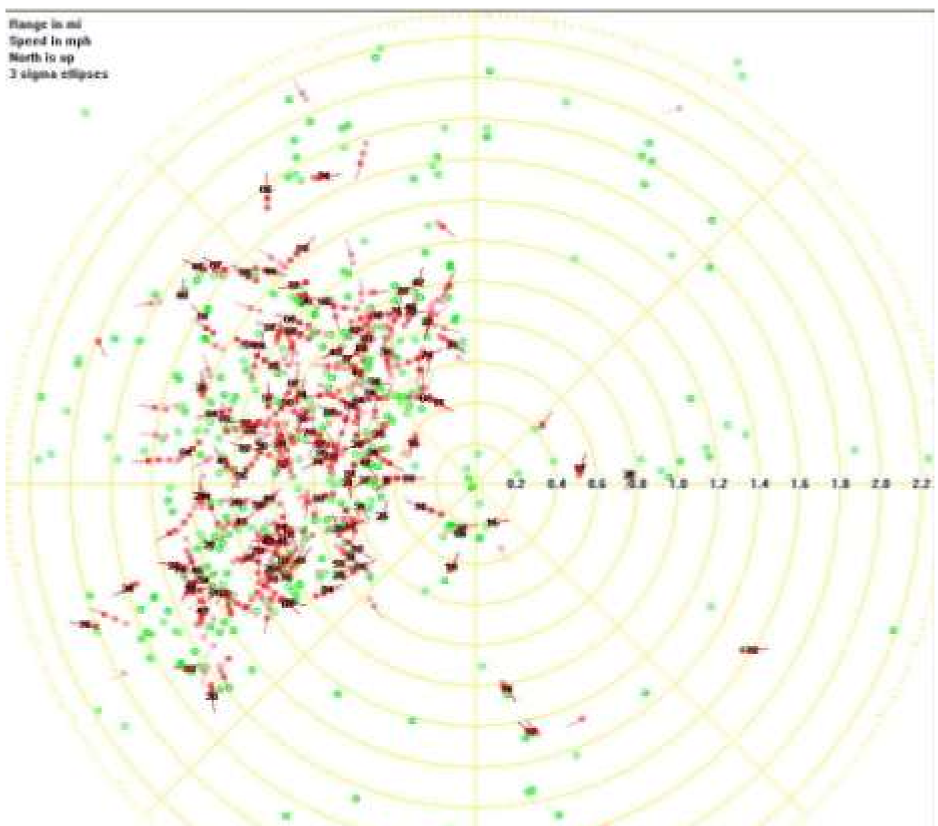

Figure 2. Sea Clutter and False Tracks.

The false tracks shown in Figure 2 were short in duration, erratic in direction, and often had speeds in excess of the speeds flown by local birds. This effect was related to wind direction at NASWI. Winds from the northeast, east and southeast had minimal effect on radar detection while winds from the southwest, west, northwest and north had the greatest effect and produced the most false tracks. Tide currents contributed to the effect when current flow was against the prevailing winds. During some periods of radar operation, the effects of clutter can be seen to increase with the increase in wind speed. When conditions created large numbers of false tracks because of increased wave size, it became impossible to detect/track the bird movement close to the surface. This clutter did not seem to affect the system's ability to track high-flying bird targets. On one occasion, when the water areas seen by radar were obscured by false tracks from sea clutter, a small group of Northern Pintails *Anas acuta* were tracked as they flew along the shoreline. They were lost from tracking after crossing over the airfield into the ground clutter.

Radar was originally developed to track aircraft and was later adapted to other uses including ornithology. The flight behavior of birds has a significant effect on a radar system's ability to detect and track bird targets. The primary NASWI avian radar system had a rotation speed of 24 rpm, resulting in a nominal detection every 2.5 seconds, although this detection rate is dependent on target speed and direction in relation to rotation where multiple detections can occur over shorter time intervals. The Accipiter® system has the capability to detect a bird target with each sweep and requires four detections before it will elevate a detection to a target being tracked. When birds are flying on a relatively constant heading, the tracking is consistent. However, birds are uncooperative targets that often turn sharply, soar in tight circles and take-off and land again after flying short distances. These behaviors present challenges to all radar systems. The physics of radar, the effects of ground clutter, and movement patterns resulted in targets such as soaring raptors being rarely tracked. Most of the small passerines observed flew erratically, close to the ground, and for short distances from one perch to another. Swallows also flew randomly in search of insects. Both were seldom tracked for the same reasons. Depending on the degree of movement and behavior after the movement, tracking was resumed when the criterion for tracking was once again met. Individual birds in flocks were not tracked. The blocking of the birds in the interior of the flock by those on the outside edge caused flocks to be tracked as a line of tracks that represented the outer edge.

From the beginning of radar development, it was noted that inclement weather conditions could have an adverse effect on tracking aircraft with radar. Meteorology was one of the early adaptations of the technology. Eastwood [5], Skolnik [14] Rain and snow both hindered detection and tracking of targets. In this study, we found that rain and snow each generated large numbers of detections and false tracks. These false tracks were short in duration and erratic in direction, and generally had speeds within the range of speeds flown by local birds.

Two screen images from the Accipiter® Track Viewer display demonstrate the process utilized to validate a target. Figure 3 is from 27 March 2009. A Surf Scoter was documented at a bearing of 300 degrees moving towards the southwest, flying within 5 feet of the surface at 17:19:41GMT. Track identification number 305 is the track generated as the radar acquired and tracked this bird. The history files show that this bird was continuously tracked for ~ 2.6 km. The

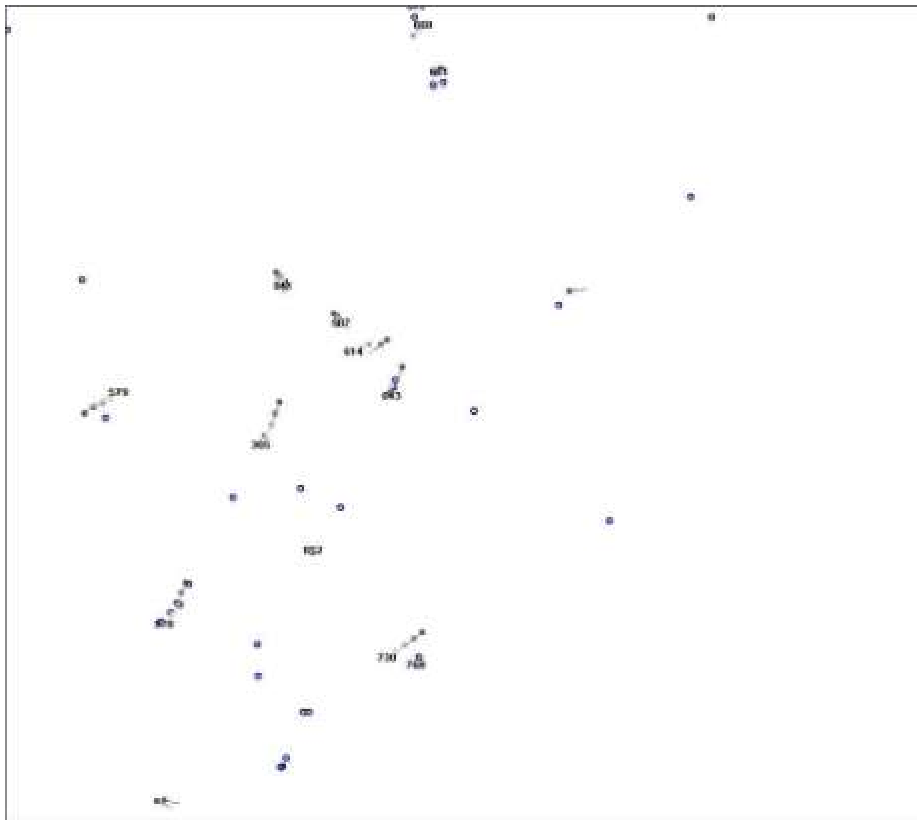

Figure 3. Surf Scoter Track Identification Number 305.

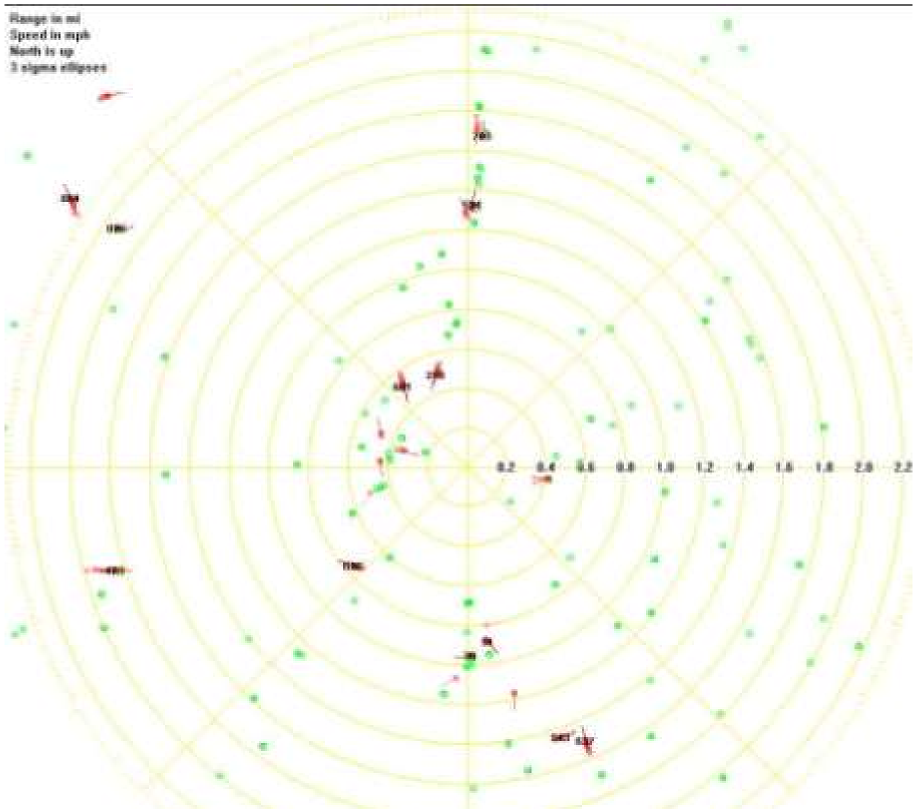

Figure 4. Bonaparte's Gull Track Identification Number 601.

movement represents the normal route taken by scoters from one feeding location to other. Figure 4 is from 2 April 2009. A Bonaparte's gull was documented at a bearing of 0/360 degrees, flying to the south elevated above 20 feet of the surface at 20:49:26 GMT. Track identification number 601 is the track generated as the radar acquired and tracked this bird. The history files show that this bird was continuously tracked for ~1.4 km. The track ends near the shoreline, where the target has either landed or was lost in the clutter.

CONCLUSIONS

Radar has been used for years to monitor bird movements and avian radar systems have shown the capabilities to accurately track bird-sized targets. Researchers have shown repeatedly that avian radar can track and monitor bird movement over a larger area than is possible using visual observation. However, research is needed to identify the potential for using radar to monitor bird activities and, at the same time, to evaluate the limitations imposed by location and physics of radar operation.

At NASWI, a comparison was made of visual observations and data collected by avian radar systems during the same time periods. Results indicate that, although avian radar systems can be used to track bird and flock movement on and around an airport, there are significant limitations to the current technology. Factors that can compromise detection include target aspect, target size, flight behavior, flight duration, target position relative to clutter, the overall clutter environment and the weather. This means that the use of avian radar systems will require some level of visual validation at every airport location; in more complex locations, such as the coastal environment of NASWI, significant visual validation will be necessary. Additionally, the location of the avian radar system within the area to be monitored will have to be carefully evaluated for the level of clutter to ensure the system can discriminate bird targets and track those targets in the desired areas.

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