DOT/FAA/TC-15/53

Federal Aviation Administration
William J. Hughes Technical Center
Aviation Research Division
Atlantic City International Airport
New Jersey 08405

Deployment and Assessment of Avian Radar Systems at John F. Kennedy International Airport

October 2015

Final Report

U.S. Department of Transportation
Federal Aviation Administration

NOTICE

Technical Report Documentation Page

1. Report No. DOT/FAA/TC-15/53	2. Government Accession No.	3. Recipient's Catalog No.

4. Title and Subtitle DEPLOYMENT AND ASSESSMENT OF AVIAN RADAR SYSTEMS AT JOHN F. KENNEDY INTERNATIONAL AIRPORT	5. Report Date October 2015
	6. Performing Organization Code ANG-E261
7. Author(s) Edwin E. Herricks and Elizabeth Woodworth	8. Performing Organization Report No.
9. Performing Organization Name and Address Center of Excellence for Airport Technology Department of Civil and Environmental Engineering University of Illinois at Urbana Champaign 205 N. Mathews, MC-250 Urbana, IL 61801	10. Work Unit No. (TRAIS)
	11. Contract or Grant No.
12. Sponsoring Agency Name and Address U. S. Department of Transportation Federal Aviation Administration Airport Safety R&D Section William J. Hughes Technical Center Atlantic City International Airport, NJ 08405	13. Type of Report and Period Covered Final Report
	14. Sponsoring Agency Code ANG-E261

15. Supplementary Notes

The FAA Airport Technology Research & Development Branch PM was Mr. Ryan King.

16. Abstract

Avoiding collisions between birds and aircraft is the focus of airport safety programs. In those programs, wildlife management is a key activity. A wide array of wildlife management tools is available to airport wildlife biologists, with avian radar systems prominent in the list. Avian radar systems are available commercially and provide new information to wildlife managers and new operational opportunities in airport safety management systems.

The University of Illinois Center of Excellence for Airport Technology (CEAT) has led a multiple-year program to assess the performance of avian radar systems at airports. This report provides a comprehensive review of avian radar system deployment at John F. Kennedy International Airport (JFK), providing a summary of installation, operations, maintenance, and data analysis. This report addresses program, project, and study objectives that were updated throughout the deployment. The deployment was completed with the installation of two avian radar systems, which were operated for more than two years. Operational experience found that avian radars are robust and reliable. CEAT personnel demonstrated support for airport wildlife hazard management through near real-time and after-the-fact studies that identified and quantified bird movement dynamics. Daily, seasonal, and inter-annual variability in bird movement and activity were characterized. The two avian radar systems deployed did not provide complete airport coverage, nor were they deployed to provide the sense-and-alert functionality needed for air traffic control. Surveillance was provided for approach and departure paths for several runways and for areas where birds were known hazards. Avian radars were shown to contribute important supplementary information on bird movement and dynamics to airport wildlife management Concept of Operations.

17. Key Words Wildlife hazard management; Avian radar; Performance assessment; Maintenance; Birds; Bird movement; Bird hazards; Wildlife; Concept of Operations	18. Distribution Statement This document is available to the U.S. public through the National Technical Information Service (NTIS), Springfield, Virginia 22161. This document is also available from the Federal Aviation Administration William J. Hughes Technical Center at actlibrary.tc.faa.gov.

19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 112	22. Price

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

ACKNOWLEDGEMENTS

The University of Illinois Center of Excellence for Airport Technology (CEAT) would like to acknowledge the invaluable guidance and assistance of John F. Kennedy International Airport (JFK) wildlife personnel, specifically Ms. Laura Francoeur, who provided support and guidance throughout the project, and Mr. Stanley Nowak, who regularly escorted field crews and provided insight on wildlife at JFK. CEAT would also like to acknowledge United States Department of Agriculture (USDA) personnel. Local USDA biologists assisted with field studies, and Dr. Brian Washburn provided maps and other reports and information from USDA studies at JFK. CEAT benefited from insights provided by the New York City Airports Wildlife Hazard Management Steering Committee. Accipiter Radar Technologies, Inc. provided radar, data management, and analytical support and assisted in event analysis. This report would not have been possible without the support of CEAT personnel, including Wendell Bunch, Professor Sidney Gauthreaux, Peter Lazar, David Mayer, and Sid Majumdar. Numerous undergraduate hourly employees assisted in data analysis while participating in CEAT research efforts.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ACRONYMS

AC	Advisory Circular
AR1	Accipiter Radar single-sensor unit
AR2-1	Accipiter Radar dual-sensor, low-beam unit
AR2-2	Accipiter Radar dual-sensor, high-beam unit
ARTI	Accipiter Radar Technologies, Inc.
CEAT	Center of Excellence for Airport Technology
CONOPS	Concept of operations
COTS	Commercial off-the-shelf
CSV	Comma-separated values
DFW	Dallas/Fort Worth International Airport
DRP	Digital radar processor
FAA	Federal Aviation Administration
GOT	Group of tracks
HVAC	Heating, ventilation, and air conditioning
IP	Internet protocol
ISP	Internet service provider
ITO	Initial track observation
JFK	John F. Kennedy International Airport
NASWI	Naval Air Station at Whidbey Island
NEXRAD	Next-Generation Radar
NY/NYC	New York/New York City
ORD	Chicago O’Hare International Airport
PANYNJ	Port Authority of New York and New Jersey
PPI	Plan position indicator
QAP	Quality Assurance Plan
RCS	Radar cross section
RF	Radio frequency
RRC	Radar remote controller
SEA	Seattle-Tacoma International Airport
SMS	Safety management systems
SFTP	SSH File Transfer Protocol
SSH	Secure Shell
TDV	Track Data Viewer
TPH	Tracks per hour
TVW	Track Viewer Workstation
UIUC	University of Illinois Urbana-Champaign
UPS	Uninterruptible power supply
USDA	U.S. Department of Agriculture

EXECUTIVE SUMMARY

This report provides a comprehensive review of avian radar deployment issues specific to John F. Kennedy International Airport (JFK) and reviews the operation and use of avian radar systems in an airport environment. The overall objective of this report is to contribute to the further understanding of strategies for avian radar deployment and use in conjunction with active wildlife hazard management programs at airports.

In 2006, the Federal Aviation Administration (FAA) Airport Safety Research and Development Section at the William Hughes Technical Center (ANG-E261) tasked the FAA Center of Excellence for Airport Technology (CEAT) with the development of a performance assessment program for commercially available avian radar systems. The comprehensive CEAT performance assessment program considers key issues such as sensor location, radar testing with known targets, data acquisition and management, and data visualization. This report is based on CEAT's experiences with the deployment, operation, and assessment of two radar systems from Accipiter Radar Technologies Inc. (ARTI) operated from January 2010 to October 2012 at JFK.

The two systems used were the AR1, a single-sensor system equipped with a slotted array antenna; and the AR2, a dual-sensor system comprising two radar sensors operating simultaneously from the same location with parabolic dish antennas. The AR2-2 was deployed from January 28, 2010 to October 29, 2012, generating 21,785 hours of data with 90% reliability. The AR2-1 was deployed from January 29, 2010 to October 29, 2012, generating 19,427 hours of data with 81% reliability. The AR1 was deployed from March 18, 2010 to August 7, 2012, and generated 20,517 hours of data with 98% reliability. Regular maintenance on the radar systems was performed including warranty service on the AR2 after early operational issues were encountered.

Throughout the deployments, both planned and opportunistic ground-truth/validation studies were conducted on both systems. Opportunistic observations revealed numerous challenges to confirming targets, such as the inherent latency between target detection and display of the target on the radar screen; the difficulty in identifying specific targets in a technology that detects many targets simultaneously; and the importance of understanding radar coverage and the influence of beam geometry and target characteristics. In the JFK setting, visual confirmation of bird targets was challenging and relied on the ability to very closely combine target location, a highly accurate time stamp, and azimuth while considering radar processing latency and the presence of multiple bird targets. Successful target validation occurred most often when the subject bird flew a consistent heading for the time needed for track identification and observer acquisition of targets. CEAT personnel were usually unsuccessful with forensic analyses aimed at determining exactly where a target was in relation to the radar track display. However, the lack of success was not due to lack of detection by the radar.

CEAT personnel conducted extensive after-the-fact analyses using data management, processing, and display reprocessing capabilities of the ARTI avian radar systems. After-the-fact analyses were not able to confirm that tracks were associated with a particular species. However, researchers were able to identify bird movement, relate groups of tracks (GOTs) with location and, with the processing and display reprocessing capabilities of the radar, were more successful in developing a sense of the birds' movement dynamics on and around the airport. Bird

movements could be characterized in terms of activity and heading, and the AR2 dual parabolic dish radar provided altitude information. These movement patterns could be related to local topographic or geographic features and researchers demonstrated the ability to relate levels of activity to timing and/or altitude.

The radars used at JFK are useful tools for migration detection and analysis. Detailed analyses focused on migration periods because they are recognized as a seasonal hazard to aircraft and due to their contrasting movement and activity characteristics. Based on researchers' findings, no single display or analysis metric provided enough information to confirm migration. However, track-history displays on the ARTI Track Viewer Workstation were useful tools for identifying periods when the data record should be reviewed to confirm migratory activity. The general assumption that there would be an increase in overall activity with migration was demonstrated using longer-term radar data records. Daily summaries of track counts did not necessarily correspond to migration movements identified in track history displays. Further, CEAT personnel noted that track counts may be influenced by rain, multipath, or other interferences that may produce false detections.

In summary, CEAT personnel completed the deployment of avian radar systems at JFK. Program, project, and study objectives were addressed and supported by a range of CEAT activities and accomplishments. Two radar systems were operated for more than two years. Records suggest avian radars are robust and reliable. CEAT personnel demonstrated support for airport wildlife hazard management through real-time and after-the-fact studies that included ground-truth/validation, and bird movement dynamics studies. The radars deployed did not provide complete airport coverage, and avian radar systems were not deployed to provide the sense-and-alert functionality needed for air traffic control. Surveillance was provided for approach and departure paths for several runways and for areas where birds were known hazards. Avian radars were shown to contribute important supplementary information on bird movements and dynamics to airport wildlife management Concept of Operations.

1. INTRODUCTION.

This report provides a comprehensive review of avian radar deployment issues specific to John F. Kennedy International Airport (JFK) and reviews the operation and use of avian radar systems in an airport environment. The overall objective of this report is to contribute to the further understanding of strategies for avian radar deployment and use in conjunction with active wildlife hazard management programs at airports. The report discusses deployment strategies, presents performance assessment results, and summarizes maintenance issues for avian radar systems used at civil airports, focusing on JFK.

1.1 AVIAN RADAR.

At airports, avoiding collisions between birds and aircraft is the focus of wildlife management and bird strike hazard warning systems [1]. A wide array of wildlife management tools is available to airport wildlife biologists, with new technologies regularly proposed for airport use. One objective of the new technologies is to extend wildlife hazard analysis beyond daytime visual observations of species and numbers, which has been the foundation for documenting wildlife hazards. One of the most prominent of the new technologies is radar. With the increased availability of relatively inexpensive radar systems, avian radar was introduced to airport safety management systems (SMS). Avian radar can provide around-the-clock observational coverage and expand spatial coverage of observations in both distance and altitude. The most common avian radar systems use readily available commercial off-the-shelf (COTS) 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 an addition to the technological capabilities of airports. As a result, few airport personnel have experience in the acquisition and use of this technology. Unlike air traffic control radars that benefit from cooperative targets, avian radars deal exclusively with uncooperative targets. In addition, avian radars have limited capabilities for species identification, reducing their value to some types of hazard assessment. Even at this stage of development, avian radars can provide a valuable asset for wildlife hazard management.

The deployment of avian radar systems at a civil airport is a complex undertaking that includes preliminary site-selection decisions, actual deployment, operations, maintenance, data analysis, management, and information dissemination. The Center of Excellence for Airport Technology (CEAT) has published a general protocol for avian radar deployment that addresses a wide range of issues associated with radar use in the complex environment of a typical civil airport in DOT/FAA/AR-09/61, "Deployment of Avian Radars at Civil Airports" [2]. Radar operation is site-specific, addressing the operations and management needs of the airport. This report is specific to CEAT personnel experiences at JFK.

1.2 THE CEAT AVIAN RADAR PERFORMANCE ASSESSMENT PROGRAM.

In 2006, the Federal Aviation Administration (FAA) Airport Safety Research Program (ANG E261) at the William J. Hughes Technical Center tasked CEAT with the development of a performance assessment program for commercially available avian radars. CEAT deployed avian radars in 2007, including the operation of avian radars at Chicago O'Hare International Airport (ORD), Dallas/Fort Worth International Airport (DFW), JFK, Portland International

Airport, Seattle-Tacoma International Airport (SEA), Vancouver International Airport, and the Naval Air Station at Whidbey Island (NASWI). In total, CEAT personnel have operated 15 radar units for periods ranging from several months to more than 6 years. The comprehensive CEAT performance assessment program considers key issues such as sensor location, radar testing with known targets, data acquisition and management, and data visualization.

The information in this report is based on CEAT personnel experiences with the deployment, operation, and assessment of two avian radar systems at JFK that operated from January 2010 to October 2012. As part of the assessment, the radars operated 24 hours a day, 7 days a week.

1.3 THE JFK BACKGROUND.

The selection of JFK as part of the CEAT Avian Radar Performance Assessment Program was based on several factors. Considering other deployment locations, CEAT personnel sought an assessment site on the East Coast. The strong support of JFK wildlife staff and the willingness of the Port Authority of New York and New Jersey (PANYNJ) to support the deployment effort was an important consideration. JFK is also a heavily used airport with a complex operational environment, and it is adjacent to a wildlife refuge. Finally, JFK had a well-developed wildlife management program and well-developed stakeholder interaction in their wildlife management efforts.

1.3.1 The JFK Wildlife Environment.

1.3.1.1 Atlantic Flyway.

As shown in figure 1, North America has four flyways for migrating bird species [3]. Each flyway features different species and different seasonal timing. CEAT avian radar assessments at ORD, DFW, and SEA provided information on the Central, Mississippi, and Pacific flyways, and JFK provided information on the Atlantic Flyway.

Figure 1. North American Flyways [3]

1.3.1.2 Jamaica Bay.

Flyway location sets a context, but local conditions define actual bird movement dynamics. JFK is located on Jamaica Bay, which stretches from Brooklyn to Long Island and has a surface area of approximately 39 sq mi. More than 9000 acres (20 sq mi) are part of the Jamaica Bay National Wildlife Refuge administered by the National Park Service. Figure 2 shows Jamaica Bay, the refuge, and the location of JFK to the northeast. Jamaica Bay is known for its habitat diversity, including salt marshes, upland field and woods, freshwater ponds, and brackish water ponds [4]. More than 325 bird species have been recorded in the refuge in the past 25 years producing seasonal wildlife management challenges for JFK biologists [5]. The Jamaica Bay refuge features wintering waterfowl, including snow goose (chen caerulescens). In other months, numerous shorebird species; various duck species, including brant (branta bernicla); and, raptors, including Cooper's hawk (accipiter coooperii) and peregrine falcon (falco peregrinus), are common. In the refuge area directly south of JFK's Runway 4L, is a laughing gull (leucophaeus atricilla) colony, which has increased from 15 nesting pairs in 1979 to more than 7500 pairs in 1990 [5].

Figure 2. Map of Jamaica Bay Showing JFK to the Northeast [4]

1.3.1.3 New York City Urban Environment.

The New York City (NYC) urban environment also provides attractants for wildlife. For instance, a sewage treatment plant near the airport on 134th Street in Jamaica, NY is an attractant for gulls. Pigeons are drawn to the waste and litter near the taxi hold area at JFK. Other attractants, including golf courses, are within the 5 nmi circle that defines the area of interest for JFK wildlife management.

1.3.2 Challenges to Avian Radars at JFK.

JFK's location presents unique challenges to avian radars. The density of buildings on and off the airport causes clutter and shadowing issues for avian radars. This produces conditions where site selection and the number of radars are critical for total airport coverage. Placing radars to cover Jamaica Bay also introduces issues of wave movement detection in the radar, termed sea clutter. JFK is also bound by major highways to the north. Slower traffic moves at velocities similar to birds, which places birds and some traffic together in detection algorithms and leads to false target issues. Because birds are regularly observed flying along roads on and off the airfield, simple masking of road corridors cannot be done without losing important bird-target information.

1.3.3 Identified Bird Hazards at JFK.

An avian radar is designed to detect and track birds. The November 2010 FAA Advisory Circular (AC) 150/5220-25, "Airport Avian Radar Systems," [6] identifies a standard avian target that is approximately the size of a crow. Although all birds are of interest, the focus of wildlife hazard management applications of avian radars is on detection of the more hazardous bird targets. With a location adjacent to the Jamaica Bay National Wildlife Refuge and major water features east and west of the airport, there is an expectation that high bird numbers and a diverse fauna will produce potential hazards to aircraft. To provide a sense of dimension to the wildlife hazard management issues at JFK, the FAA's Bird Strike Database [7] was consulted to identify bird species involved in bird strikes at JFK, table 1. The five most commonly struck species are in the size range of the standard avian target. Further, connecting species with life history and behavior provides background information on seasonality and potential use of areas on and around JFK. Although radar does not provide target identification, knowledge of commonly struck birds allowed for calibration and tuning of the radar to better support wildlife hazard management at JFK.

Table 1. Most Commonly Struck Species at JFK, 1992–2012 [7]

Species	Number of Strikes
Herring gull	296
Laughing gull	132
Gulls	72
American kestrel	112
Barn owl	99
Rock pigeon	71
Barn swallow	64
European starling	58
Mourning dove	53
Osprey	46
Snow bunting	44
Horned lark	43
Great black-backed gull	40
Peregrine falcon	39
Ring-billed gull	35
Mallard	32
Tree swallow	28
Canada goose	25
American robin	23
Northern harrier	23
American oystercatcher	22
Double-crested cormorant	22
Brown-headed cowbird	21
Brant	19
Killdeer	19
Northern flicker	19
Short-eared owl	19
Black-crowned night heron	18
Sparrows	14
Snowy owl	12
Common tern	11
Gray catbird	11
American coot	10

1.3.4 The JFK Wildlife Program.

The JFK wildlife program began in the 1970s and is among the nation's oldest airport wildlife programs. The program follows recognized procedures and includes lethal and nonlethal means of bird control. The program has successfully reduced the number of gull strikes [5]. JFK is at the forefront of wildlife hazard research and has hosted several studies, many focusing on gull species. As part of the coordinated effort with state, federal, and local agencies, a NYC Airports Wildlife Hazard Management Steering Committee was established and meets regularly to bring together stakeholders, including National Park Service and the New York Department of Environmental Protection. The committee was informed about plans for the CEAT avian radar performance assessment and received regular updates as the assessment efforts progressed.

1.4 RADAR PERFORMANCE ASSESSMENT OBJECTIVES FOR JFK.

1.4.1 Original Objectives.

Before the avian radar systems were deployed to JFK, the CEAT personnel collaborated with FAA project managers and JFK wildlife personnel to establish three types of objectives for the radar installation: program objectives, project objectives, and study objectives. Program objectives were established that supported the research goals of the FAA technical center. Then, more specific project objectives were designed to fulfill program-level objectives and key the program objectives specifically to JFK. Finally, CEAT personnel established individual study objectives that guided testing and analysis. Additional studies were requested by JFK wildlife personnel, and other studies originated from the reviews of initial radar results.

A review of the program, project, and study objectives reveals overlap between objective groups and duplication of objective intent. This is a result of separate listings of program, project, and study objectives that, of necessity, addressed efforts meeting broad to narrow assessment needs. The most important aspect of the objective development process was developing a clear understanding of intent so all parties involved supported the effort. The objectives also supported the development of study plans, which made the most effective use of limited resources.

1.4.1.1 Program Objectives.

CEAT personnel addressed program objectives with activities that included gaining operational experience with radars from the deployment and the operation of avian radar systems at several airports. These deployments were intended to improve understanding of issues related to operation, maintenance, and data management. Program objectives were primarily addressed by deploying and operating avian radars at JFK, which provided the basis for addressing validation of radar information and the development of operational procedures, i.e., concepts of operations (CONOPS), for avian radars use.

The program objectives are listed below.

- Design and execute an avian radar performance assessment program for civil airports. This program will supply technical information to help identify requirements and standards for avian radars and develop an AC.

- Compile technical data and develop an understanding of radar system components and operations to support the selection of avian radars and radar systems for deployment at civil airports.

- Deploy avian radars and radar systems representing different technologies, design approaches, and system characteristics at civil airports.

- Operate avian radars and radar systems continuously for a sufficient time to account for environmental variability and avian target variability. Assess operational characteristics and general reliability.

- Validate that the radar targets identified are birds. Investigate and validate the capability of the radar to track bird movement. Provide location and altitude data of avian targets in the airport environment.

- Identify data characteristics and information provided by avian radars and radar systems with the objective of developing a central avian radar data management capability that would provide national access to local data sets.

- Assess the use of avian radars and radar systems for reducing bird/aircraft hazards and collisions at civil airports.

- Assess the use of avian radars and radar systems for managing wildlife at civilian airports.

- Prepare reports to help develop requirements and standards for the continuous use of avian radars at civil airports and publish an AC.

1.4.1.2 Project Objectives.

CEAT personnel addressed project objectives by documenting the planning and deployment of the avian radar systems at JFK and providing information on site-specific operation and location-specific characterization of bird hazards. Initial project activities included deployment planning, deployment, tuning the radar to JFK site locations, and development of an understanding of radar coverage in relation to identified areas of hazardous bird activity.

The specific project objectives are listed below.

- Deploy an avian radar system with all applicable support systems at JFK.

- Characterize actual radar coverage in relation to airport avian radar coverage needs to identify future deployment needs.

- Determine setup, operation, and maintenance requirements for the avian radar.

- Conduct validation studies to develop criteria for assessing radar performance in tracking avian targets.

- Conduct a series of ground-truth/validation campaigns to assess the performance of the avian radar based on identified criteria.

- Evaluate horizontal and vertical tracking of birds on the airport, in the airport exclusion zone, and to a range of approximately 6 nmi from the radar.

- Develop the capability to identify hazards posed to aircraft from the movement of wildlife on and around the airport.

- Develop and implement a hazard warning system for aircraft using the airport.

1.4.1.3 Study Objectives.

Study objectives were developed after consultation with JFK wildlife management personnel and were designed to identify the location, movement, and timing of bird targets, and the variation of these characteristics over time. The specific study objectives listed below were translated into study plans where one or more objectives could be addressed with the design of specific studies.

- Design, conduct, and report on studies intended to characterize radar performance in JFK's complex and target-rich environment.

- Conduct preliminary studies to assist in radar calibration. Verify radar performance considering target range and altitude.

- Collect and process data from the avian radar system to provide information that will help identify general movement patterns of birds on and around JFK. Pay particular attention to activity near dawn and dusk.

- Collect and process data from the avian radar system to provide information that will help identify origin and destination of birds tracked by the radar. Emphasize on movements on the kilo extension and near terminal buildings.

- Collect and process data from the avian radar system to provide information that will help identify the timing of local movements of bird species on and around JFK. Pay particular attention to Thursten and Bergen basins.

1.4.2 Evolution of Objectives.

CEAT personnel used a Quality Assurance Plan (QAP) to guide the deployment and assessment of the avian radar system at JFK. A component of the QAP included a regular review of objectives. The intent of the reviews was to use project accomplishments and ongoing CEAT experiences with avian radars at JFK and other airports to refine objective statements and better support the design of individual studies. Annual reviews were conducted with airport hosts and other interested parties with the goal of improving their understanding of current project activities. Through this continuing review process, objectives were modified and the design of specific studies was refined to reflect the results of sampling and assessment activities. Study plans to address objectives were also influenced by conditions specific to JFK, including the availability of specific communication technologies and the impact of airport construction projects. Thus, objectives evolved as the deployment progressed. The following list provides a summary of the evolution of some objectives reflecting project development and, in particular, objectives changes that were made based on deployment experience.

- During the planning phase of the installation prior to the deployment, JFK program objectives were revised in response to the Miracle on the Hudson on January 15, 2009. The revision emphasized hazard reduction, rather than a relatively straightforward focus on surveillance and radar validation. Nonetheless, it was possible to use planned coverage of arrival and departure corridors and coverage of Jamaica Bay. Although not all airport runways were covered, radar placement provided good coverage over Jamaica Bay and coverage with varying levels of quality for Runways 13R/31L, 22R/4L, 22L/4R, and areas of 31R.

- In July 2010, a review of objectives and consultation with the FAA program manager and the JFK wildlife biologist further refined objectives, leading to studies emphasizing wildlife management CONOPS. (Section 1.5 provides an overview of avian radar CONOPS.)

- In a fall 2010 review of the program, CEAT personnel noted that the stakeholders at JFK, who were not radar experts, did not fully understand radar coverage and the influence of beam configuration and clutter interference. This point was reinforced by JFK wildlife biologists, who found it was difficult to interpret and integrate radar data with their visual observations. CEAT personnel then placed a priority on pioneering new methods of portraying coverage of the radar so that data, and the landscape context of the data, could be better understood by stakeholders.

- Possibly the greatest influence on how formal program, project, or study objectives were implemented was the identification by JFK wildlife staff of specific issues, which often reflected current management questions or the observation of species or conditions that could be addressed by radar analysis. Special study plans were created to address these issues. Study plans often addressed elements of more than one study or project objective.

1.5 AVIAN RADAR CONOPS.

The purpose of an avian radar system is to support airport wildlife hazard management and contribute to improved safety in an airport's operational environment. Optimizing the radar's utility requires working in the context of an airport's SMS and existing operational procedures to develop strategies and tactics aimed at efficiently and effectively disseminating and using information derived from the radar system. The more integrated an avian radar system is in the context of an airport's established CONOPS and SMS procedures, the more useful it will eventually become for airport users.

Strategic Avian radar CONOPS encompass existing wildlife management programs. When integrated into wildlife management CONOPS, avian radar technology can extend the capabilities of wildlife managers to provide better spatial and temporal assessments. JFK provided a test bed for development of strategic CONOPS procedures for avian radars.

Tactical Avian radar CONOPS have the safety of aircraft movement as a primary focus, with information reaching a varied audience from airport operations personnel to controllers to pilots. Although tactical CONOPS were considered in the JFK performance assessment, the assessment emphasis was on the strategic wildlife hazard management utility of avian radar systems.

Figures 3 through 11 show strategic wildlife management CONOPS with supporting avian radar CONOPS, required technology, and required outputs/data. This listing of wildlife management CONOPS is intended to identify elements of CONOPS appropriate to managing wildlife hazards on airports and illustrate the range of activities that might be included in any comprehensive CONOPS. The selection of wildlife management CONOPS in the following figures is intended to provide a general sense of the types of operations wildlife managers conduct and how radar technology might enhance those operations. The selection of elements is intended to be more illustrative than comprehensive, but should provide a good foundation for wildlife management CONOPS development at any airport.

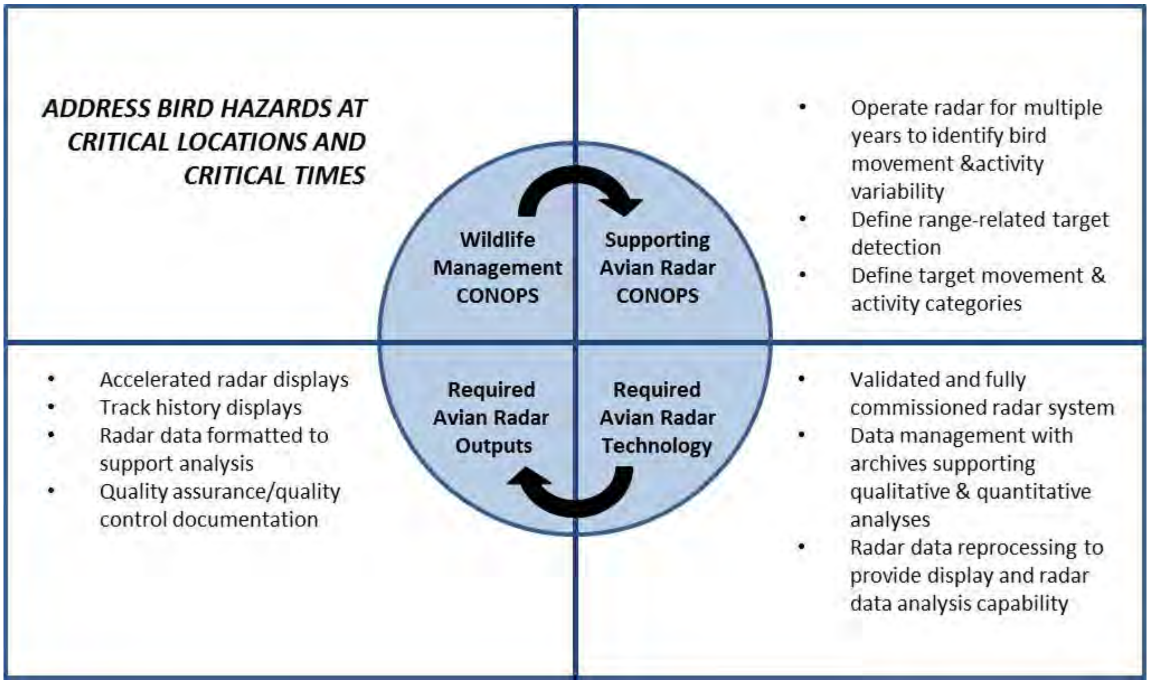
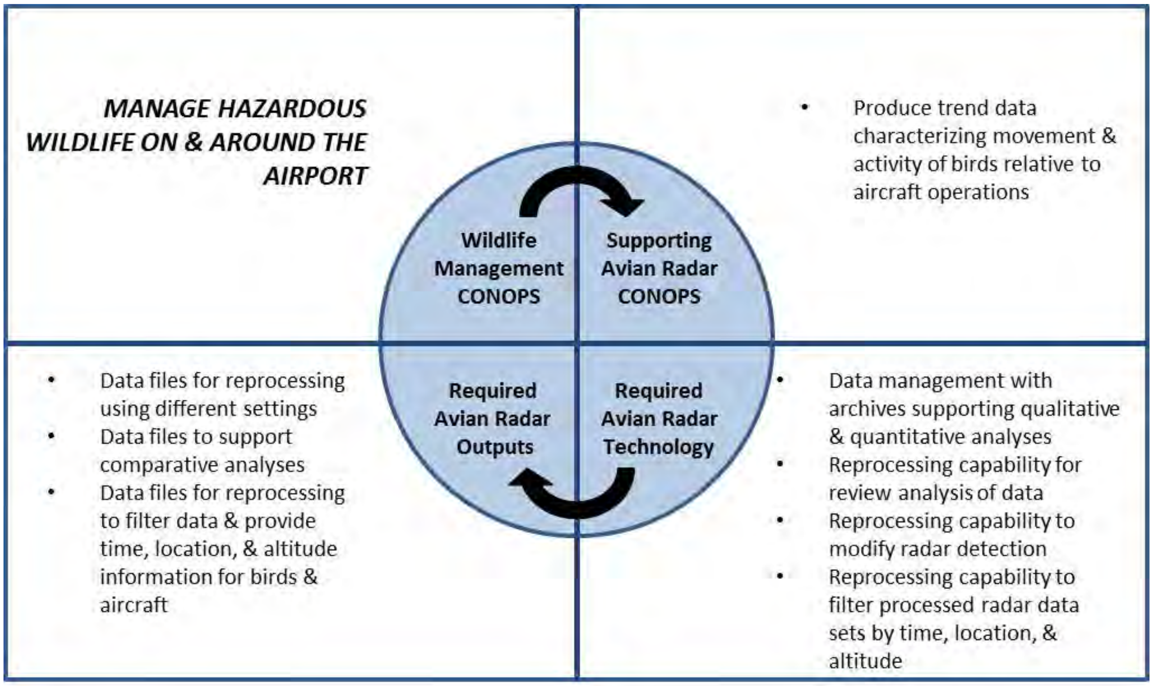


Figure 3. Avian Radar Requirements for Addressing Bird Hazards at Critical Locations and Times

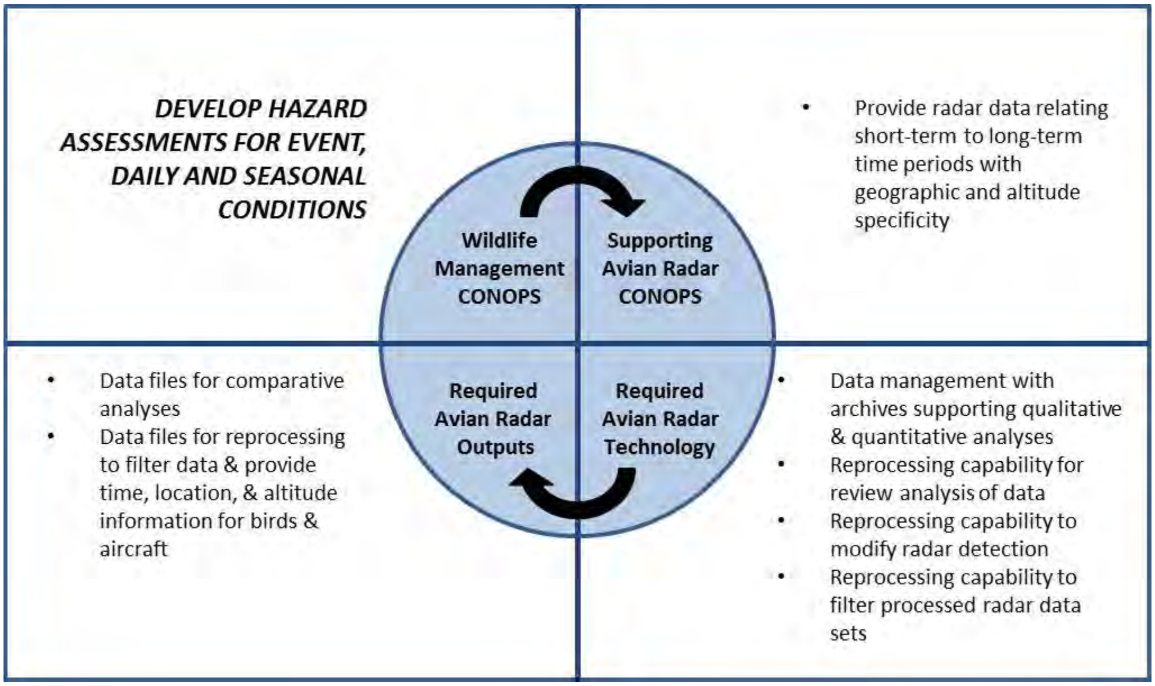


- Produce trend data characterizing movement & activity of birds relative to aircraft operations

- Data files for reprocessing using different settings
- Data files to support comparative analyses
- Data files for reprocessing to filter data & provide time, location, & altitude information for birds & aircraft

- Data management with archives supporting qualitative & quantitative analyses
- Reprocessing capability for review analysis of data
- Reprocessing capability to modify radar detection
- Reprocessing capability to filter processed radar data sets by time, location, & altitude

Figure 4. Avian Radar Requirements for Managing Hazardous Wildlife on and Around the Airport



- Provide radar data relating short-term to long-term time periods with geographic and altitude specificity

- Data files for comparative analyses
- Data files for reprocessing to filter data & provide time, location, & altitude information for birds & aircraft

- Data management with archives supporting qualitative & quantitative analyses
- Reprocessing capability for review analysis of data
- Reprocessing capability to modify radar detection
- Reprocessing capability to filter processed radar data sets

Figure 5. Avian Radar Requirements for Developing Hazard Assessments for Event, Daily, and Seasonal Conditions

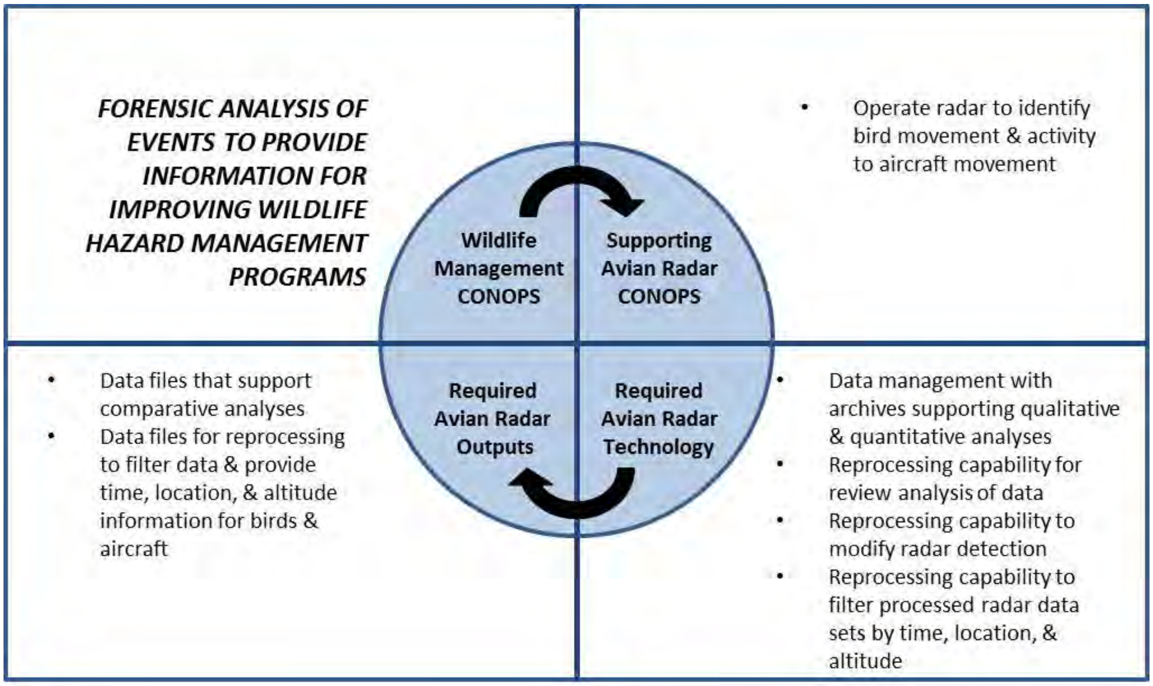


Figure 6. Avian Radar Requirements for Forensic Analysis of Events to Provide Information for Improving Wildlife Hazard Management Programs

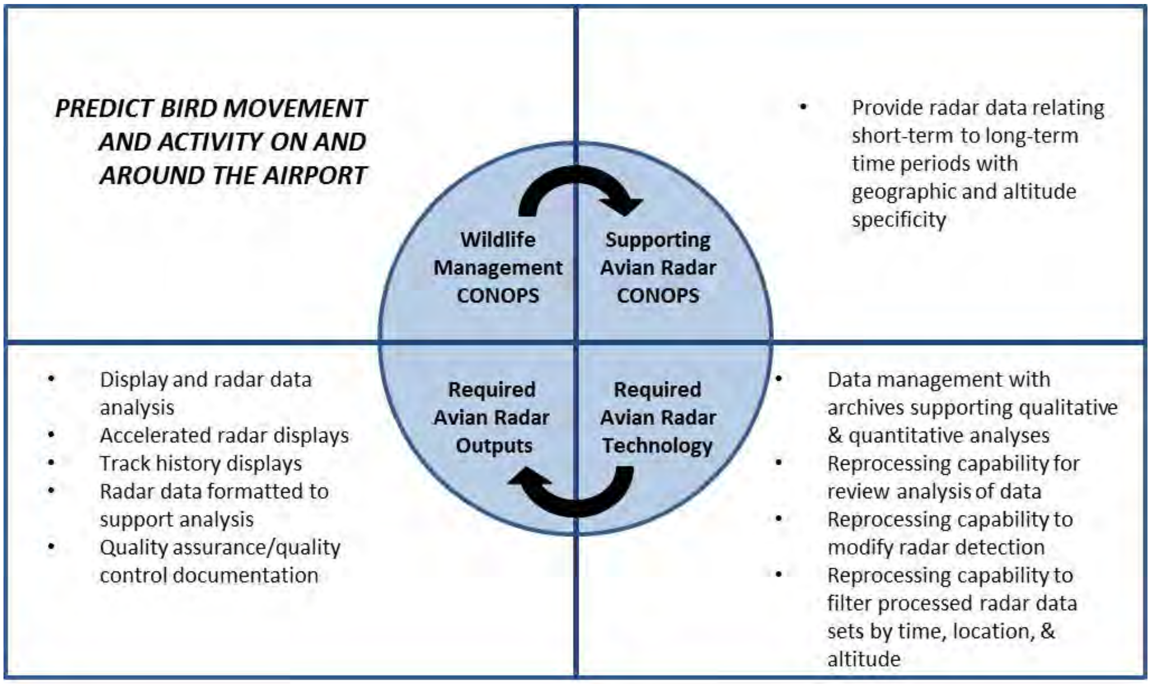


Figure 7. Avian Radar Requirements for Forensic Analysis of Events to Provide Information for Improving Wildlife Hazard Management Programs

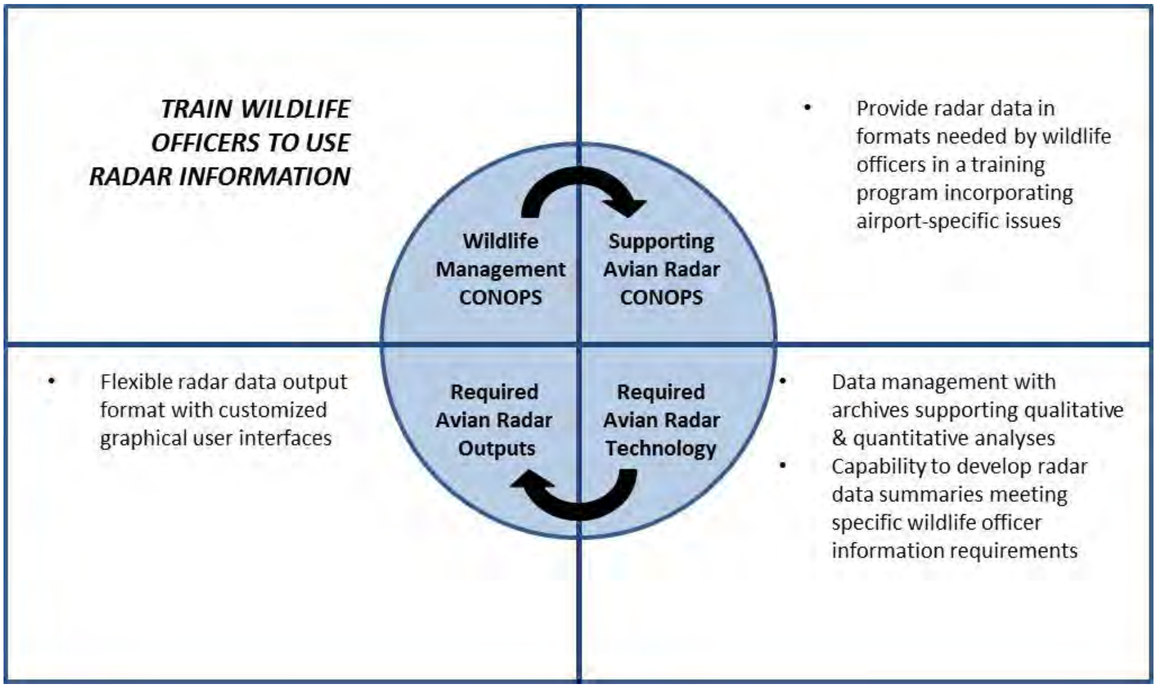


Figure 8. Avian Radar Requirements for Training Wildlife Officers to use Radar Information

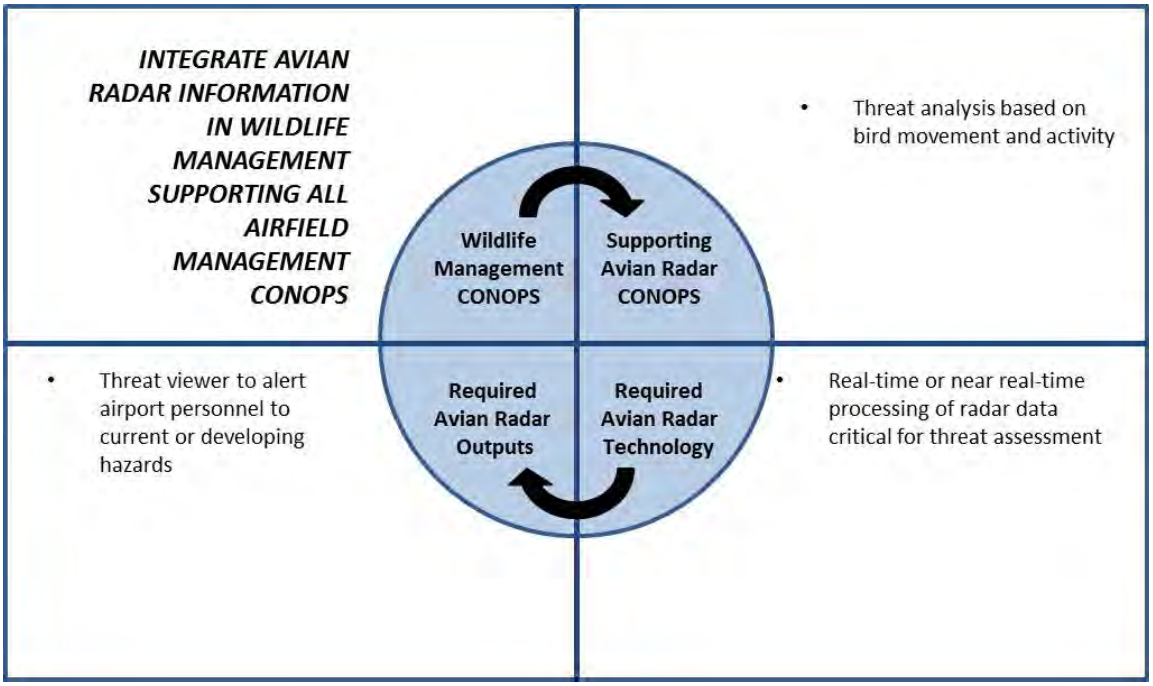


Figure 9. Avian Radar Requirements for Integrating Avian Radar Information in Wildlife Management Supporting all Airfield Management CONOPS

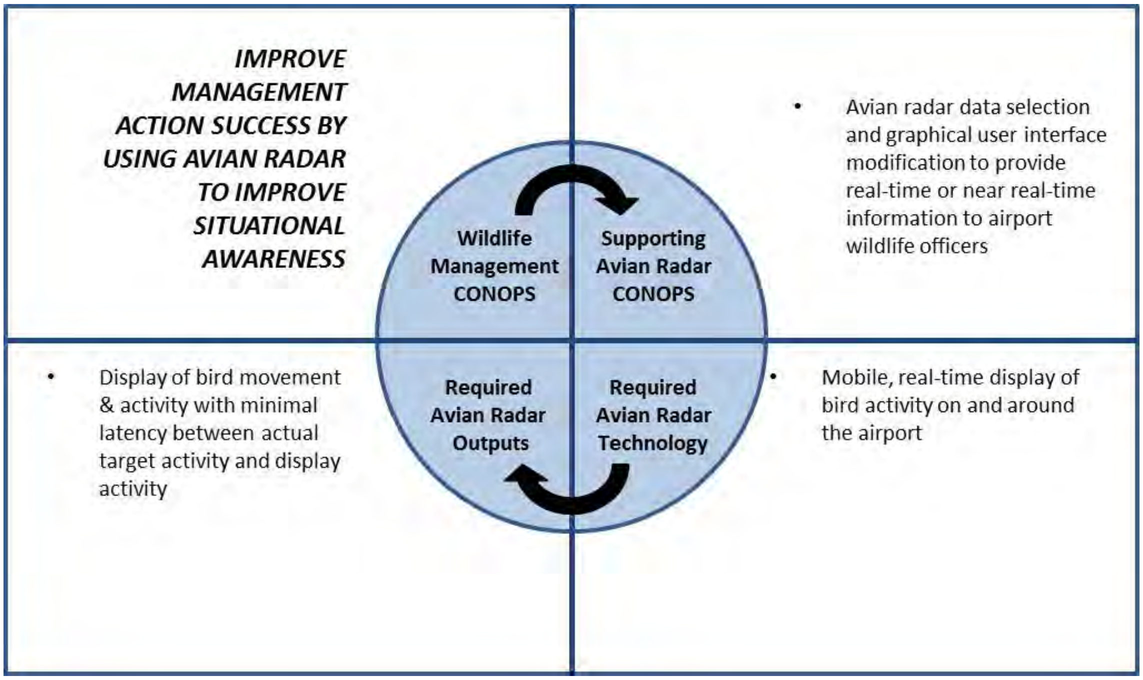


Figure 10. Avian Radar Requirements for Improving Management Action Success Based on Improved Situational Awareness

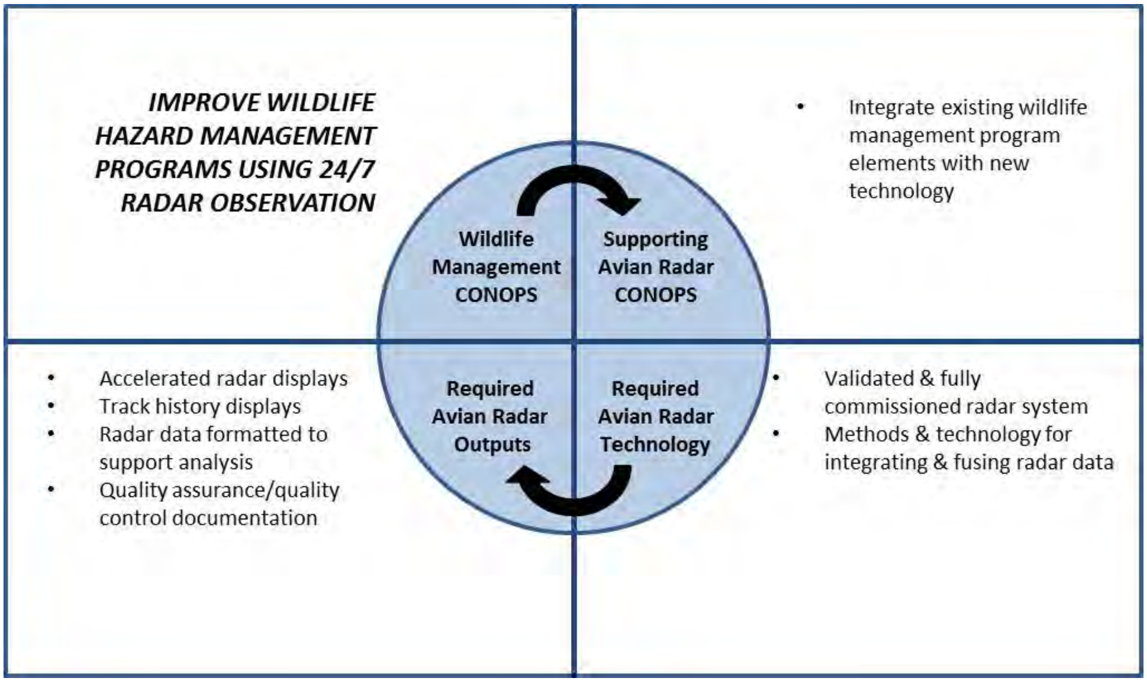


Figure 11. Avian Radar Requirements for Improving Wildlife Hazard Management Programs Using 24/7 Radar Observation

2. THE JFK AVIAN RADAR SYSTEMS.

2.1 TECHNOLOGY OVERVIEW.

2.1.1 The AR2 and AR1 Avian Radar Systems.

Two avian radar systems, AR2 and AR1, were installed at JFK in 2010. The AR2 became operational in January 2010; the AR1 in March 2010. Continuous records were available for both radar systems from those times. The systems were supplied by Accipiter Radar Technologies, Inc. (ARTI) and used Furuno 25kW FR-8252 X-band radar units. The systems included a scanner unit with an antenna, a radar control console, a digital radar processor (DRP), and supporting equipment networked for system control that included an ARTI Radar Remote Controller (RRC) unit that supported full remote control of the avian radar system. Each system was deployed in a utility trailer with heating, ventilation, and air conditioning (HVAC) climate control and work spaces.

The AR2 consisted of two radar units operating simultaneously. The AR2 scanners were equipped with parabolic dish antennas set at different angles. The low-beam radar unit was designated the AR2-1; the high-beam radar unit was designated the AR2-2. Using a wireless bridge, the AR2 was connected to an Internet service provider (ISP) in a PANYNJ building providing a high-speed connection so remote operation and data retrieval from this radar was possible. Remote operation was made possible by the RRC, as shown in figure 12.

The AR1 consisted of a single-radar unit equipped with a slotted array antenna. It was not possible to establish high-speed Internet connection to the AR1. A connection to the radar system was established using a 4G Verizon cellular connection. This supported remote operation, but it was not possible to meet requirements for full-remote utilization of the radar data.

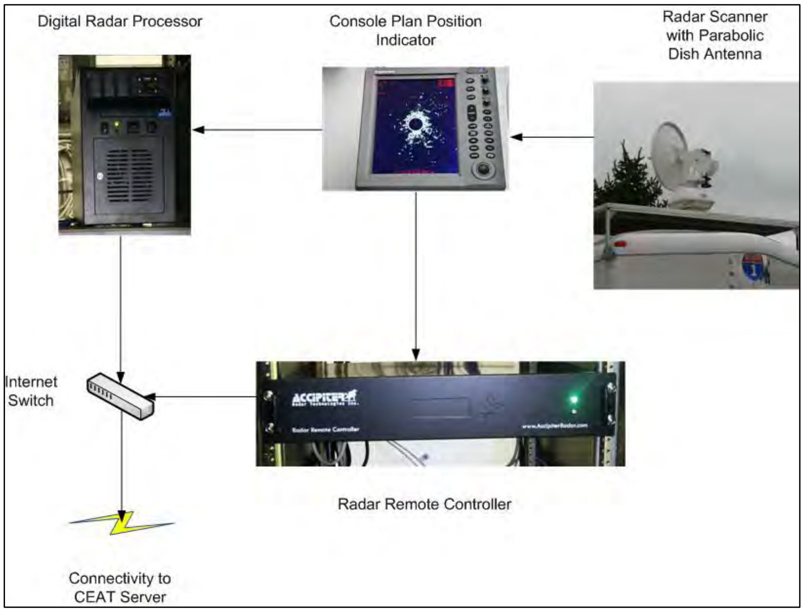


Figure 12. Data Flow Through the ARTI Systems Used in the JFK Deployment

2.1.2 Data Processing and Management.

For the ARTI systems, the radar scanner is equipped with either a parabolic dish or slotted array antenna. The radar signals are processed in a control console that has a plan position indicator (PPI) radar display. The signals from the receiver are provided as an analog input to the DRP. The DRP includes a digitizer that processes the analog data. The ARTI system utilizes B-scan data consisting of target range, azimuth, and intensity, and provides storage capability for this raw data as well as real-time processing. Next, a data processing component in the DRP identifies targets that meet processor criteria and produces a plot that locates the target in relation to the radar. Further processing of the plot data associates plots into tracks and develops target data that includes time of detection, azimuth, range, intensity, and calculated parameters, such as radar cross section (RCS), altitude, velocity, and heading. At this point, the ARTI system integrates radar data with maps or aerial photographs to display radar data in relation to local conditions to improve situational awareness. The DRP operates with settings that are optimized in the tuning process and with plot-and-track files that are related only to that DRP setting. A raw, digital data source can be recorded from the digitizer, which can be processed multiple times with different DRP settings. The plot-and-track data files provide input to two ARTI software packages, which are Track Viewer Workstation (TVW) and Track Data Viewer (TDV). The TVW supports display-based analysis and reprocessing. The TDV translates track files to a spreadsheet format for detailed data analysis.

The plot-and-track files are written to internal storage on the DRP. Data transfer between the DRPs and the Internet is secured via Secure Shell (SSH) and SSH File Transfer Protocol (SFTP). SSH is a cryptographic network protocol that allows users to run commands on a machine remotely and enables the establishment of a secure channel over an insecure network. SFTP is a network protocol that provides file access, file transfer, and file management functionalities over any reliable data stream such as SSH. The stored files can be accessed and used on the DRP via an internal TVW. However, to minimize processor overhead, plot-and-track files were copied for analysis to servers, external hard drives, or other computers with the TVW software. With full connectivity, plot-and-track files can be transferred to the ARTI server in real time. Without full connectivity, it was necessary to accept non-real-time data transfer, sometimes requiring transfer to storage media and then sending that media to ARTI for transfer to the ARTI server. In the ARTI server, track histories were automatically produced. Track histories and plot-and-track files were downloaded to the CEAT server daily. The CEAT server is located behind the firewall of the University of Illinois Urbana Champaign (UIUC) network. Another server, the ARTI Google Earth Enterprise™ server, provided real-time track displays accessible at multiple locations. The daily downloads were stored on the CEAT server and used for data analysis. Multiple TVW instances accessed the CEAT server, allowing simultaneous data analysis on several TVWs. The CEAT server also supported TDV access for data analysis. Figure 13 shows data flows for CEAT avian radars.

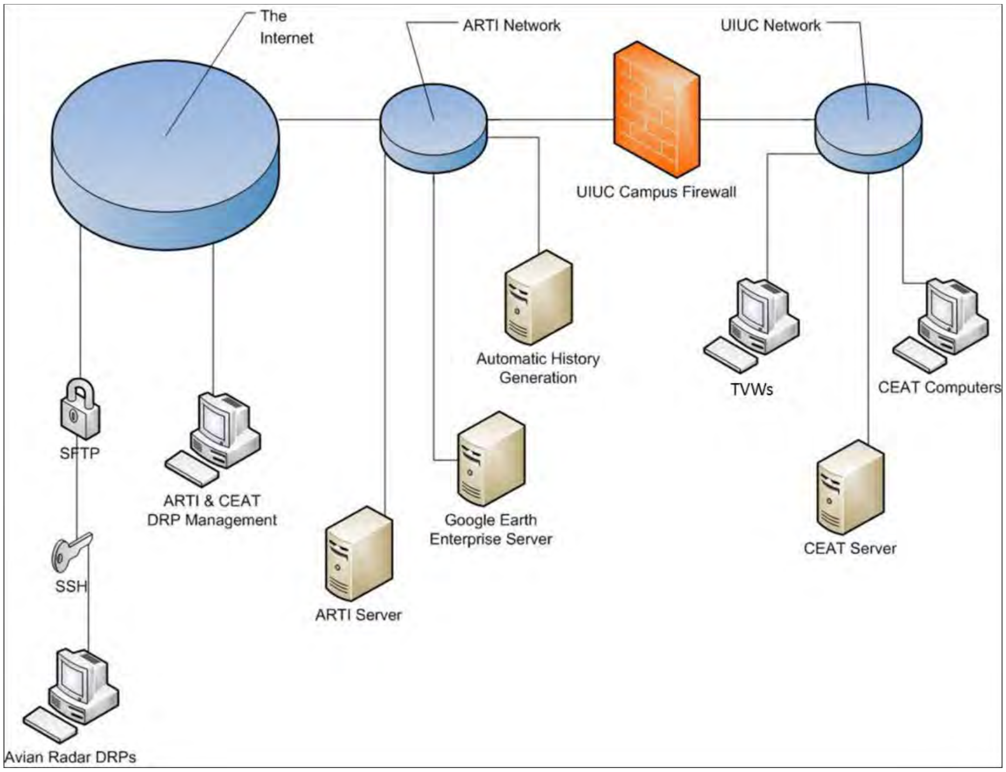


Figure 13. The Data Management System Flow Diagram

2.1.3 Radar Trailers.

The ARTI avian radar systems were deployed to JFK in utility trailers designed to support radar equipment and provide on-site working and storage space. The trailers provided HVAC systems to support installed electronic equipment, tools for maintenance, and other supplies. Each trailer had a workspace and could accommodate visitors. Radar scanners were mounted on a platform on the trailer top, and the wireless bridge was attached to the trailer side.

2.2 RADAR SYSTEMS DEPLOYMENT AT JFK.

When JFK was identified as a site for possible avian radar deployment, initial planning meetings were held with JFK wildlife staff and CEAT personnel. As planning progressed, airport facilities issues and FAA installation requirements involved a range of PANYNJ personnel specialties. A critical step in the installation was the FAA review of radar system obstruction in safety zones and frequency authorization for radar and wireless transmissions. These issues were addressed in the Form 7460 application. Critical to the radar installation was the availability of power and the access to high-speed communications for remote operation of the radars. Port personnel identified locations where power would be available. Where necessary, FAA personnel were involved when power distribution was under FAA, rather than PANYNJ, control. CEAT personnel addressed connectivity by using a wireless bridge, which required a physical location where communications hardware could be connected to an ISP. Radars were first moved to JFK in April 2009 to support clutter mapping and site selection.

2.3 SITING THE RADAR UNITS AT JFK.

Finding an acceptable site for the radar required prioritizing identified needs and then carefully analyzing competing issues. From a wildlife detection perspective, the most important criteria for site selection were providing good detection capabilities for critical habitats or known areas of bird hazards on the airport. The presence of Jamaica Bay presented the primary radar coverage issue. Jamaica Bay is large, has numerous areas that attract hazardous bird species, and is on the flight path for Runways 4L and 4R; Runway 13/31 borders the bay. Because power locations were limited on the airport, a second major challenge was to match needed radar coverage with uninterruptible power supplies (UPSs) that would support long-term deployment of the radars. The primary issue associated with radar operation is clutter and shadowing, which influence target detection capabilities of the radar. To address this issue, CEAT personnel conducted a clutter-mapping exercise prior to final selection of radar installation location.

2.3.1 Clutter Mapping.

The JFK clutter-mapping exercise required FAA approval for operation at all identified locations. The clutter-mapping exercise provided needed information to optimize radar location to provide good coverage of critical areas. Based on experience at other installations, CEAT personnel recognized that not all clutter sources are obvious to an observer. At JFK, 13 sites were used in the clutter-mapping exercise, as shown in figure 14. At each site, the radar was operated with general settings. Areas of clutter were observed, and screen images were archived. Raw, digital, radar data was also recorded at each site to support reprocessing and future radar tuning.

Figure 14. The 13 Sites Used in the Clutter-Mapping Exercise (Sites 5 and 12 were selected as radar locations.)

2.3.2 Site Selection and Radar Installation.

After the clutter-mapping exercise, sites 5 and 12 were selected to maximize coverage of known hazards (see figure 14). These sites also reflected the availability of power and potential for connectivity.

2.3.2.1 The AR2 Radar System.

The AR2 was the first avian radar system deployed at JFK; it became operational on January 29, 2010. The high-speed wireless connection became operational on May 2, 2011. The AR2 trailer was located on the south (Jamaica Bay) side of JFK near the middle of Runway 31L/13R, as shown in figure 15. The AR2 radar scanners were equipped with parabolic dish antennas tilted to 2 degrees and 6 degrees above horizontal, as shown in figure 16. The AR2 was installed to provide coverage of the approach/departure paths for Runway 31L/13R, monitor the south portions of Runways 4R and 4L, and provide coverage of Jamaica Bay.

2.3.2.2 The AR1 Radar System.

The AR1 was placed to the northwest of the departure end of Runway 4R on March 18, 2010, providing approach coverage of Runways 22L, 22R, and 31R, departure coverage of Runways 13L, 4L and 4R and coverage of the Thursten basin, a known area of high bird activity (see figure 15). The AR1 consisted of a single radar scanner equipped with a slotted-array antenna, as shown in figure 17. This radar provided a nominal 10-degree beam measured from horizontal to the top of the beam.

Figure 15. Location of Radar Systems AR1 and AR2 and Runway Configuration for JFK

Figure 16. The AR2 Trailer on Runway 13R/31L

Figure 17. The AR1 Trailer at Departure End of Runway 4R Near the Beginning of Thursten Basin

2.3.3 Securing the Radar Trailers.

JFK required a trailer tie-down system for high-wind conditions. With the assistance of JFK staff, fence posts were driven diagonally into the ground, and trailer frames were used as tie-down locations.

The methods CEAT personnel used for securing the trailers were sufficient to keep the trailers in place during Hurricane Irene and Superstorm Sandy. However, Superstorm Sandy produced local flooding at the AR2 location that damaged electronics, and the deployment was terminated in October 2012.

2.4 RADAR COVERAGE.

The antenna type of each radar sensor defined the coverage volume as the radar rotated through 360 degrees horizontal. The coverage pattern defined by beam physics finds a zone of no detection at approximately 60–100 ft, with a detection zone expanding with range based on antenna characteristics. The result is a detection volume for the AR1 and AR2 that is defined by antenna type, which increases with range from the radar.

The AR2 used two radar units equipped with parabolic dishes that operated simultaneously. Each parabolic dish had a beam width of 4 degrees. Tilting the dish antennas so the center of the beam was at 2 degrees in the low beam (AR2-1) and 6 degrees in the high beam (AR2-2) provided radar coverage from horizontal to approximately 8 degrees above the horizon. An example of beam projection for the parabolic dish antennas is provided in figure 18. The beams' coverage of the parabolic-dish-equipped radars increases with range. To illustrate coverage, figure 19 uses boxes with the beam diameter to show beam coverage change with range and also lists the expected top and bottom altitudes of the beam.

Figure 18. Example of Beam Projection for AR2 Parabolic Dish Antennas Shows the High Beam Projected by the AR2-2 (Blue) and the Low Beam Projected by the AR2-1 (Gold)

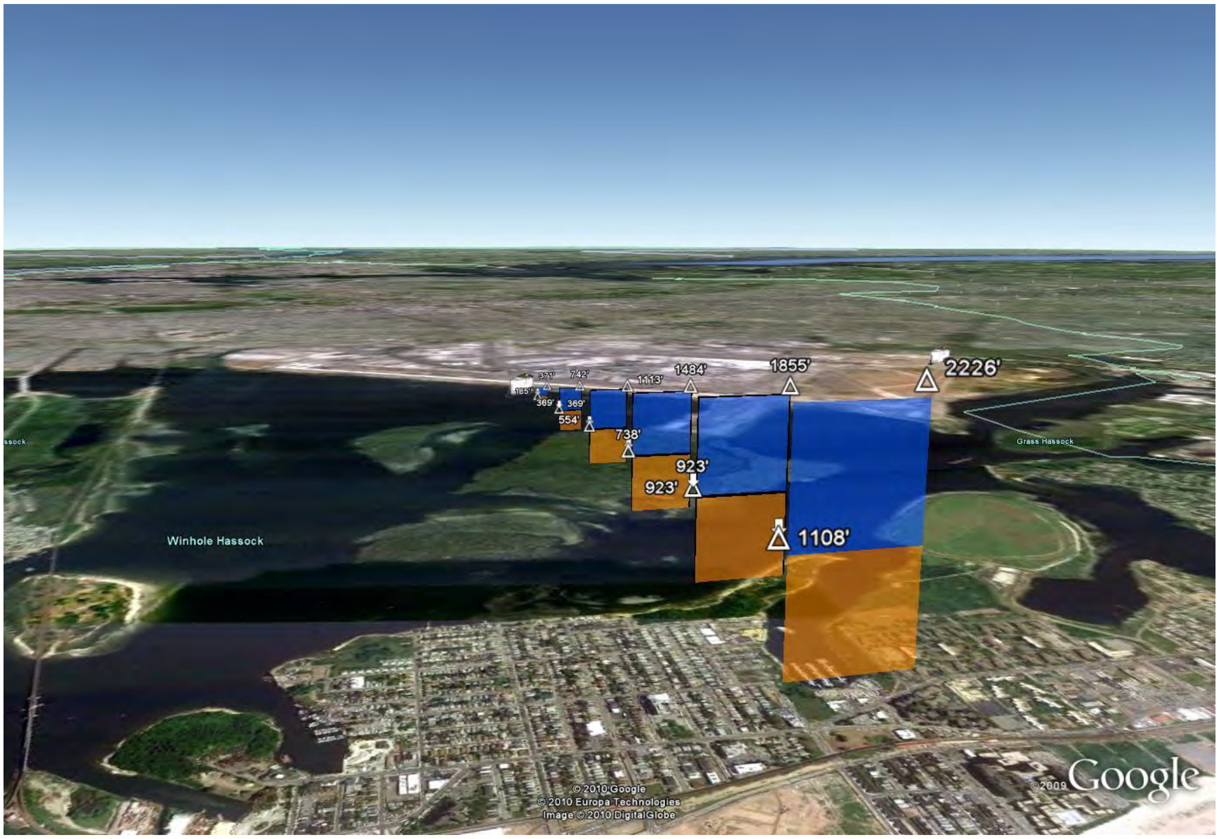


Figure 19. Changes in Coverage Diameters and Top and Bottom Altitudes Based on Range for AR2-1 (Gold) and AR2-2 (Blue) Radar Beams

The coverage of the AR1 slotted array antenna produces a vertical beam height of approximately 20 degrees; this was ±10 degrees from horizontal in the configuration used at JFK. Because the radar is located near the ground, a horizontal line from the antenna to the ground was approximately 13 ft above ground level. This means that the lower 10 degrees of the beam intersected the ground a short distance from the radar. The result is that the actual beam height of the AR1 was only 10 degrees, with a bottom-of-the-beam altitude of zero. This beam height of 10 degrees was comparable to the AR2 total beam height of 8 degrees.

In both radars, the conal-shaped volume immediately above the top of the beam is termed a cone of silence because there is no detection in this volume.

Tables 2 through 4 provide expected altitude coverage for the AR1, equipped with an array antenna, and the AR2, equipped with two parabolic dish antennas. This altitude information, combined with clutter mapping and reliability analysis, was used to define coverage and assist in all analysis of radar data.

Table 2. Expected AR1 Altitude Coverage

AR1 Array Antenna With 20-Degree Beam Centered on Horizontal		
Distance From Radar (mi)	Altitude at Bottom of Beam (ft)	Altitude at Top of Beam (ft)
0.25	0	246
0.50	0	479
0.75	0	711
1.00	0	944
1.50	0	1410
2.00	0	1875
2.50	0	2341
3.00	0	2806
4.00	0	3737
5.00	0	4668

Table 3. Expected AR2-1 Altitude Coverage

AR2-1 Dish Antenna With 4-Degree Beam Centered on 2 Degrees From Horizontal		
Distance From Radar (mi)	Altitude at Bottom of Beam (ft)	Altitude at Top of Beam (ft)
0.25	13	105
0.50	13	198
0.75	13	290
1.00	13	382
1.50	13	567
2.00	13	751
2.50	13	936
3.00	13	1121
4.00	13	1490
5.00	13	1859

Table 4. Expected AR2-2 Altitude Coverage

AR2-2 Dish Antenna With 4-Degree Beam Centered on 6 Degrees From Horizontal		
Distance From Radar (mi)	Altitude at Bottom of Beam (ft)	Altitude at Top of Beam (ft)
0.25	105	199
0.50	198	384
0.75	290	570
1.00	382	755
1.50	567	1126
2.00	751	1497
2.50	936	1868
3.00	1121	2239
4.00	1490	2981
5.00	1859	3723

Based on beam physics, radar location and beam characteristics can be related to actual JFK coverage. The AR2 unit was located approximately midway along Runway 13R/31L. This location was just over 1 mile from the end of Runway 4L. With this location, the radar provided coverage of the approach and departure paths of Runways 13R/31L, 4L, and 4R. The AR2 also provided coverage for important Jamaica Bay landmarks, as shown in figure 20 and table 5. The AR1 unit was located to the north between Runways 22L and 22 R. This radar provided coverage of Runways 22L/4L and 22R/4R. Runway 13L/31R was not effectively covered by either radar because of structures on both sides of the runway, although the AR1 did provide some coverage for approaches and departures to Runway 31R.

Figure 20. Important Landmarks in the JFK Vicinity

Table 5. Altitude Coverage for Important Landmarks in the JFK Vicinity

			AR1		AR2-1		AR2-2	
	Distance From AR1 (mi)	Distance From AR2 (mi)	Bottom of Beam (ft)	Top of Beam (ft)	Bottom of Beam (ft)	Top of Beam (ft)	Bottom of Beam (ft)	Top of Beam (ft)
Bergen Basin	3.75	2.00	0	3504	13	751	751	1497
Thursten Basin	0.75	2.50	0	711	13	936	936	1868
Southern Coast of Airport	2.25	0.00	0	2108	13	13	13	13
Head of Bay	1.50	2.00	0	1410	13	751	751	1497
Rulers Bar Hassock	4.00	1.75	0	3737	13	659	659	1312
East Bay Meadow	3.00	1.25	0	2806	13	475	475	941
Joco Marsh	3.00	1.50	0	2806	13	567	567	1126

2.5 RELIABILITY MAPPING.

A critical element of the CEAT assessment was conveying to stakeholders an accurate sense of not only radar coverage, but also the variable nature of target detection due to interferences with radar detection. To accomplish this, CEAT personnel developed a reliability mapping method that used

- analysis of clutter,
- observations of anomalies, such as multipath or indications of side lobe detection,
- track history displays, and
- field observations.

Clutter is produced when radar beams are reflected from surfaces. These surfaces may be buildings, waves in Jamaica Bay, rain, or particles in the atmosphere. CEAT personnel used clutter presence in initial clutter mapping and developed a clutter analysis for each radar site after deployment. Clutter displays were also available for each radar and were consulted in the reliability mapping process.

Multipath is produced when radar beams propagate from large reflectors, such as aircraft. Some of these reflections are detected by the radar receiver, producing false targets. Side lobes are low-energy emissions other than the main beam that are associated with the physics of radio wave propagation. The radar beam is associated with high energy levels, with the actual beam width defined when energy drops to half the maximum energy level. Side-lobe emissions will have lower energy, but reflections from side-beam emissions may be detected by the radar receiver and produce false targets. Multipath is normally identified by observing the radar screen, and side-lobe detections are revealed in validation observations.

Thus, after radar installation, it is possible to develop a better sense of the reliability of target detection. Where there is little or no clutter, targets are readily detected. Where multipath or side-lobe interference exists, target detection is less reliable. Consistent or heavy track density is an indication of reliable target detection.

CEAT personnel developed reliability maps for the AR1 and AR2 installations that incorporated an understanding of beam characteristics and an analysis of target detection reliability based on radar interference and target detection, as shown in figures 21 through 23. By adding colors to the radar coverage areas, these reliability maps assisted CEAT personnel in interpreting radar data. In the figures, black is used for areas with heavy clutter. Red is used for areas of known clutter, but where target tracks (typically vehicles and aircraft) were common. Yellow is used for areas with moderate clutter where track characteristics suggested birds or bird flocks. Green is used for areas where long tracks typical of bird targets were regularly displayed, indicating good detection. Purple is used for areas that had good bird target capability, but where multipath produced periodic interference.

Figure 21. Reliability Map for the AR1

Figure 22. Reliability Map for the AR2-1

Figure 23. Reliability Map for the AR2-2

2.6 RADAR DATA PROCESSING AND ANALYSIS.

2.6.1 Raw Data.

Radars produce large quantities of data, so data processing and analysis is a major component of avian radar systems. The radar systems at JFK utilizing ARTI equipment had data acquisition, processing, and management tools unique to this supplier; and the ARTI avian radar systems provide options for data processing and management, including the recording of raw radar digital data—range, azimuth, and target intensity for all echoes—which included clutter and other radar interference. The raw data were recorded directly from the digitizer in the DRP, which supported a full range of data processing and reprocessing needs. The primary limit to recording raw data is the large file sizes generated by this data type. In CEAT assessments, raw data files for 30 minutes of radar operation are commonly recorded as a part of initial radar calibration and tuning associated with deployment. Raw radar data are also recorded as part of CEAT's QAP.

2.6.2 Plot-and-Track Files.

The primary outputs of the DRP are plot and track files. In the ARTI system, each echo supports plotting of possible targets. Echoes that meet DRP processing criteria as targets are recorded in plot files. Further processing of plot files allows association of individual plotted targets together, producing target tracks that receive unique track identification numbers. The target tracks are contained in track files. Plot-and-track files, once produced by the DRP, cannot be changed; they serve as the input data to ARTI data processing and management tools.

2.6.3 The ARTI Data Management Tools.

The ARTI data management tools include the TDV and the TVW. The TDV is software that does not require a hardware license for use. The software supports displays the radar data in a tabular format, commonly a spreadsheet comma-separated values (CSV) file. The display of radar data in a spreadsheet format supports the exploration of data relationships and the typical iterative processes of data analysis using a well-organized data matrix. The TVW requires a hardware license and incorporates software that uses the plot-and-track files as a basic input to support a wide range of analyses. The TVW allows a user to set alarm regions and play back data to assess whether alarms are generated; support a variety of data history compilations, including track history plotting; and can be used to replay the radar record at different speeds. At JFK, TDV and TVW tools supported the assessment of bird movement and dynamics for day-to-day, week-to-week, and season-to-season time periods.

2.6.4 Detection Update Times, Tracking, and Resolution.

A number of issues must be considered in radar data analysis. Issues of beam volume, radar coverage, and clutter influence are discussed in sections 2.4 and 2.5. Issues are also associated with detection update times, tracking, and resolution.

2.6.4.1 Detection Update Times.

The radar transmit/receive antenna rotates, and the typical rotation rate for ARTI avian radar systems is 24 revolutions per minute. This means that a single scan takes somewhat more than 2 seconds, which produces a built-in time delay between the multiple detections needed for track assembly and identification. In ARTI software, formation of a track requires a minimum of three detections. Thus, the time between detection and track confirmation may be 5 to 10 seconds. This latency is important because it influences validation. An observer watching a bird target may see the bird before the radar resolves a track. A similar problem exists when the radar operator observes a target and calls that target to a visual observer. The bird target may have moved some distance from the identified radar location in the time required for track formation. Thus, confirmation of bird targets is influenced by radar processing latency. Further, birds do not fly predictable ballistic paths, so their flight paths can be irregular to erratic, with circular paths common in some species. The result is that target confirmation in validation studies requires well-developed study plans and careful execution to produce reliable results.

2.6.4.2 Track Data Record.

Once a track is initiated in the ARTI system, that track is assigned a unique number. Regular updates to the track are made as long as tracking criteria are met, producing a track data record that includes all detection updates associated with each track number. Each update contains the detailed detection data from plot files. Once a track is identified, information on target heading and speed is available. In addition, using map or aerial photographic-based screen images allows for the display of a track in relation to a geographic location or important features on or around the airport.

2.6.4.3 Resolution.

Resolution issues should also be considered in radar data analysis. Resolution issues are related to the physics of radar beams, hardware, and processing/display settings. Radar resolution is established by radar frequency and antenna configuration where greater resolution is related to bigger antennas and range from the radar. In COTS radars, such as those used at JFK, range produces larger detection volumes and, based on radar physics, it is possible to separate two targets that are close together. The result is that, depending on range, two targets detected in the same range bin may be far apart in actual altitude. The COTS radars with array antennas have no altitude discrimination. Thus, detections in these COTS radars are only plotted in two dimensions, giving rise to interpretative issues when multiple targets are plotted close to each other. Parabolic dish antennas project a circular beam, and multiple antennas set at different tilt angles allow geometric estimation of target altitudes where altitude estimates will be variable with range. Interpreting radar data is not straightforward. Birds do not carry transponders to support differentiation of targets, so it is incumbent on the analyst to consider the range of issues associated with the radar sensors in any data analysis.

2.6.5 Consistent Terminology.

As CEAT personnel developed methodologies for radar data analysis, the importance of developing a consistent terminology that supported an unambiguous interpretation of radar track data became clear. The ARTI system provides a number of analysis tools in the TVW. For example, the radar display can be easily replayed for a given time period at different speeds, providing new insight to target movements with each speed change. CEAT personnel took advantage of this capability early in the performance assessment program, providing display summary videos that compressed 8 hours of operational results into a 5- to 7-minute movie. Using the TVW, track information can also be displayed in different ways. Tracks can be accumulated over time to provide a track history display. This track history display allows the consolidation of individual movements, providing a display that illustrates track density. Track density can be related to numbers of birds tracked per unit of time, as well as concentrations around certain areas. Sections 2.6.5.1 through 2.6.5.7 define terms developed by CEAT personnel to provide consistent description of radar data. These terms apply to real-time or processed radar displays.

2.6.5.1 Track.

A track is a processed radar data product based on classification assumptions and algorithms used in the DRP. Tracks have a unique identifier that is displayed on the screen and associated with data files for tracks. Tracks are developed from target plots (unassociated target detections) and provide an indication of target movement. Track length is variable and depends on meeting criteria for plot association that can be influenced by target movement in the radar beam, target RCS, and parameter settings in the DRP. Tracks are illustrated in yellow in figure 24.

Figure 24. Example of Tracks on and Around JFK

2.6.5.2 Track Update.

In the ARTI track data files, each plotted detection in a track has a unique data set, termed a track update. Using the TDV, a spreadsheet can be developed that contains information from all plotted detections related to a single track number. Summaries of and data in track update files were used in radar data analysis. Because track updates occur in uniquely identified tracks, the number of updates in a track can provide useful information. For example, the number of track updates can be used as a measure of track length. Although tracking algorithms require three plots to form a track, CEAT personnel used only tracks with five or more track updates in track analysis. Different species exhibit different flight behaviors and flight speeds, so track updates can contribute to the analysis of species presence. This is particularly valuable in extracting information from radar detection validation studies where tracks are related to known species. Using track update totals with track length also provides a basis for estimating bird density. Longer tracks, with more updates, also assist in identifying variability in flight path and may be diagnostic of migration.

2.6.5.3 Track History Display.

Tracks can be overlaid on a single display to reveal track history. In a track history display, all tracks for a given time interval are displayed on a single screen. This produces an image that consolidates tracks and supports analysis of movement patterns and what CEAT personnel identifies as hot spots where bird activity may be concentrated. In CEAT analysis, a track history display is one of the first analysis tools used in the interpretation of avian radar data. Track history displays for defined time intervals can be created automatically. Setting the interval for track history displays depends on the level of bird activity in the area. A balance is sought where displays show track concentrations, but avoid saturation of the image with tracks. For example, at SEA, a 1-hour interval was chosen for the track histories. Lower overall levels of activity at SEA allowed interpretation of radar data with this interval. Increased bird activity at NASWI required 30-minute display intervals, and the high level of bird activity at JFK required 15-minute display intervals and, sometimes, 5-minute intervals. In addition to single-image displays, it is possible to display sequential track history displays to identify movement timing and movement patterns in relation to attractants. In all track history displays, the same scale is used temporally and geographically for comparative analysis.

2.6.5.4 Movement.

A movement is a large number of tracks, or groups of tracks, that have a similar heading. CEAT personnel determined that clarification of bird movement dynamics required definition of a movement as detected on radar. A movement is identified when multiple tracks appear on the screen moving in the same direction at the same time. Tracks may be distributed over a large area and become evident when the radar display is replayed at different speeds. Movements typically are associated with longer tracks, which make it possible to follow a movement for several minutes on the radar display. Movement patterns can be identified as tracks displayed in real time, but it is easier to identify movement in accelerated replay of the radar display. Short-interval use of the track history function is also used to support movement identification.

2.6.5.5 Activity.

Activity is related to levels of movements over a defined time period (hours to years). In activity analysis, track history displays are used. High activity is assigned to displays that show a high track density with activity ratings related to track saturation for different track history time intervals. Thus, high activity is associated with track history plots that are saturated over short time intervals. Low activity is assigned to track history plots that have few tracks or track history displays that do not become saturated over long time intervals. Accelerated replay of screen videos can also be used to assess activity. CEAT personnel used activity determination to identify hot spots with attractants or landscape conditions that influenced bird activity. In more detailed analysis, the TDV supports the development of data matrices that allowed the summarization of track counts for defined time periods. In this more quantitative analysis, track counts can be normalized based on time intervals. In CEAT analysis procedures, activity is related to both time and location using qualitative and quantitative analysis procedures. This analysis strategy helps identify recurring patterns in radar displays that can characterize movement dynamics over short to long time periods and for periods when specific activities occur (e.g., migration).

2.6.5.6 Initial Track Observation.

The initial track observation (ITO) is a new term CEAT personnel developed specifically to address issues radar beam characteristics and interpretation of track data. With the recognition that the initial tracking of a target is related to beam characteristics and operational settings of the radar, rather than origin from geographic features, the ITO was defined to identify the time and location of the first appearance of a target track on the radar display. The term ITO is intended as a reminder that beam geometry must be considered when analyzing radar data. The appearance of tracks on the display is not necessarily related to target origin. This is because the altitude coverage of the beam at any range supports only the fact that a target was detected at a particular location. ITOs provide a useful tool for radar analysis. Most importantly, the ITO defines the beginning of the track, which helps focus detailed data analysis. ITO determination in validation assists in confirming the volume of coverage when target position and altitude are available from observations. ITOs also assist in defining latency in the radar. CEAT personnel consensus is that use of an ITO designation reinforces the notion that radar coverage is limited by beam and environment characteristics.

2.6.5.7 Group of Tracks.

A group of tracks (GOT) is another term CEAT personnel developed to identify movement elements. A GOT is identified when a number of tracks that are close together exhibit the same heading and velocity. GOTs are particularly apparent in the association of ITOs that appear on the radar display at approximately the same time and moving in the same direction. A GOT can be related to a movement or simply define a small association of tracks in a movement analysis. The GOT was developed to help identify flocks, where a flock is identified when four or more tracks have a similar movement pattern. Identification of GOTs follows preliminary analysis and associated detailed track information with all tracks in a group. GOTs may, or may not, indicate the presence of a flock. However, they do define associated ITOs in radar display analysis and provide direction to analysis of data tables to incorporate RCS, velocity, or other measures to better defining group characteristics. The identification of GOTs is an important next step in CEAT radar data analysis, following subjective assessments based on general display analysis.

2.7 OPERATION, MAINTENANCE, AND DATA MANAGEMENT.

2.7.1 Operation.

Throughout the course of the performance assessment, the JFK avian radar systems were operated 24 hours a day, 7 days a week. CEAT personnel maintained records of all maintenance performed on the radars, and used data records to develop metrics of operational performance. High-speed connectivity supported remote operation of the radars.

2.7.2 Maintenance.

Maintenance to JFK radar systems was both planned and ad hoc. Planned maintenance included a daily evaluation of operational status and a radar health assessment that reviewed operational results. Ad hoc maintenance was on-demand, related to an identified fault or an operational failure.

2.7.3 Data Management.

Data management was based on ARTI data management systems, which were regularly backed up and updated to take advantage of new capabilities. In each radar, the DRP was able to store data. The stored data were ARTI plot-and-track files, although it was possible to store raw data for short time intervals. With high-speed connectivity, data was transferred to ARTI and CEAT servers. Servers supported a range of data analysis programs and data displays. TDV and TVW workstations used stored plot-and track files for analysis. TVW capabilities were used to generate time-accelerated radar displays and track-history plots. ARTI used a server to provide real-time displays in a Google Earth environment that were broadcast on the web. Full archives of all recorded data were maintained on both CEAT and ARTI servers.

3. RESULTS AND DISCUSSION.

The CEAT avian radar performance assessment program at JFK was designed to address identified program, project, and study objectives. Because the implementation of the program remained flexible, experience was gained, while the changing needs or interests of the host airport were addressed. Further, the CEAT performance assessment program broke new ground in avian radar systems operation, analytical methodologies, and data management. To reflect the range of issues addressed in the performance assessment, and provide general organization, results and discussion are divided into two sections: section 3.1, radar operation; and section 3.2, radar application.

3.1 RADAR OPERATION.

A critical component of the performance assessment at JFK was the analysis of operational issues, which included radar reliability and maintenance. Because radars produce large quantities of data, data management issues were also important.

3.1.1 Radar Reliability.

The operational performance of the JFK avian radar systems is summarized in table 6. Total deployment time varied between the AR1 and AR2 systems, with the AR2 systems being the first installed. Operation time was influenced by maintenance and weather conditions, which caused power interruptions beyond the approximately 30-minute capability of the UPSs used in the system. In total, the AR1 operated for 20,932 hours, the AR2-1 for 24,080 hours, and the AR2-2 for 21,120 hours.

Table 6. Operational Performance of JFK Avian Radars

Radar	Uptime (hours)	Uptime (%)	Deployment Start	Deployment End	Deployment Time (hours)
AR1	20,517	98.02	3/18/10 19:49	8/7/12 00:03	20,932
AR2-1	19,427	80.68	1/29/10 16:16	10/29/12 00:22	24,080
AR2-2	21,795	90.36	1/28/10 00:13	10/29/12 00:18	24,120

Before establishing high-speed connections to the radars, CEAT personnel downloaded data to external hard drives and transferred that data to ARTI and CEAT servers. The data downloads took place on a biweekly schedule as could be accommodated by CEAT and JFK personnel. In total, 21 visits were made to the radars to download data.

3.1.2 Maintenance.

The regular maintenance performed on the JFK radars included daily checks of system function. During the period when no high-speed connectivity was available, CEAT personnel made biweekly visits to the radars. During these visits, CEAT personnel checked the equipment function of interior and exterior hardware, checked the parabolic dish angles, and downloaded the data to a portable drive. On an ad hoc basis, JFK personnel checked the three radars to ensure that the antennas were spinning, indicating normal function.

Once connectivity was achieved, CEAT personnel made occasional site visits on an approximately quarterly schedule. Once AR2 connectivity was achieved, the track histories were created automatically, sent to an ARTI server, and JFK and CEAT personnel had access to this web application. CEAT personnel used this capability to supplement ARTI daily checks on system function.

In spring 2011, CEAT and ARTI personnel worked together to develop a regular radar health check. This health assessment compared radar output along with general function. The intent was to determine if radar performance was at expected (healthy) levels. A monthly radar health assessment was initiated in April 2011 and continued on a monthly basis. No anomalies were identified in these checks.

ARTI personnel upgraded software on the DRPs during the performance assessment. Software upgrades were generally performed remotely by ARTI personnel.

The actual maintenance performed varied by radar unit. Maintenance included replacement of a Radio Frequency (RF) board in one unit, UPS battery replacement, repair/upgrade of radar remote controllers, and replacement of a DRP power supply. Other maintenance included adjustment of HVAC settings, replacement of tie-downs for the trailers, and a number of equipment restarts after power failures.

ARTI software updates also influenced total system operation. In December 2011, ARTI released new side-lobe and multipath-rejection algorithms. The algorithms were installed on the JFK radars in stages so that changes in performance could be monitored. On January 23, 2012, multipath-rejection algorithms were installed on the AR2-1. On May 3, 2012, the side-lobe rejection algorithms were enabled on the AR2-1. Both the side-lobe detection and multipath-rejection algorithms were enabled on the AR2-2 on February 27, 2012. On April 4, 2012, the multipath-rejection and side lobe rejection algorithms were enabled on the AR1.

3.1.3 Data Management.

The data management capabilities provided by ARTI personnel were used in the JFK deployment. Local storage of radar data was used throughout the assessment to provide a data backup. Before connectivity was established, local data archives were transferred to portable hard drives on a regular basis. This data was then uploaded to ARTI and CEAT servers. Data on these servers supported CEAT and ARTI data analysis. Two types of high-speed connectivity were used at JFK. A wireless bridge from the AR2 to a PANYNJ facility allowed connection to an ISP, supporting a dedicated connection to the AR2 radars. Connectivity to the AR1 was established using a Verizon Wireless™ 4G data card. This was a high-speed connection, but it would not support full, two-direction data transfers for all data management functions on the AR1. The major limitation was an inability to create a static Internet protocol (IP) address similar to the dedicated connection. ARTI provided a resolution that allowed data transfer to their server, but CEAT personnel did not have direct access to the AR1 through this connection procedure. Beginning July 11, 2011, the data feeds for the AR1, AR2-1, and AR2-1 to ARTI were available to view on a live display using the Google Earth environment. CEAT personnel used this feed to drive displays in the CEAT office at the University of Illinois. JFK personnel did not have access to this data feed until December 2, 2011, when the PANYNJ Internet firewall protocols had been addressed and feeds could be used on PANYNJ systems.

3.2 RADAR APPLICATION.

The deployment of avian radar systems to JFK was intended to address wide-ranging program, project, and study objectives. In all CEAT avian radar performance assessment efforts, the application of radar technologies and the characterization of avian radar system capabilities is the foundation for the avian radar system deployments. In radar application, radar validation activities are an underlying issue in all studies. Throughout the JFK assessment, CEAT personnel conducted radar validation observations and studies. Whenever field personnel were able to observe birds concurrent with radar operations, CEAT personnel took advantage of opportunistic observations to correlate bird observations with radar target data in real-time comparisons. CEAT personnel also designed ground-truth/validation studies where observers followed reviewed study plans. Two general procedures were used in these observation-based validation efforts. One approach used field observations of birds to determine if identified birds appeared as targets on the radar. The second approach used displayed radar targets to challenge field observers to verify that the target was a bird. Study designs for ground-truth/validation campaigns originated from opportunistic observations by CEAT staff or requests from JFK wildlife biologists to address species-specific interests or developing situations. One observer-based approach used regular point-count observations conducted as part of the JFK Wildlife Hazard Management Program to determine if radar targets correlated with time- and location-specific observations of birds. Validation also used a variety of methods to analyze radar data to determine consistency with observed or reported bird movement. These studies were typically developed in response to requests from JFK biologists to better understand the radar's contribution to the characterization of bird movement dynamics.

3.2.1 Identification of Known Areas of Bird Activity.

As part of the general preparation for radar deployment to JFK, CEAT personnel consulted with JFK wildlife biologists to learn more about wildlife hazards and known locations of bird activity. Based on years of observation and management intervention, JFK biologists provided information used in radar site planning, as shown in figure 25. CEAT personnel also worked with JFK wildlife biologists to better understand regional wildlife hazard issues. JFK wildlife biologists identified regional locations where birds had been observed or where habitat was known to attract birds. These regional locations are provided in figure 26. Reviewing these efforts is useful because this information was used to site radars and focus attention in radar analysis to areas of highest known hazard.

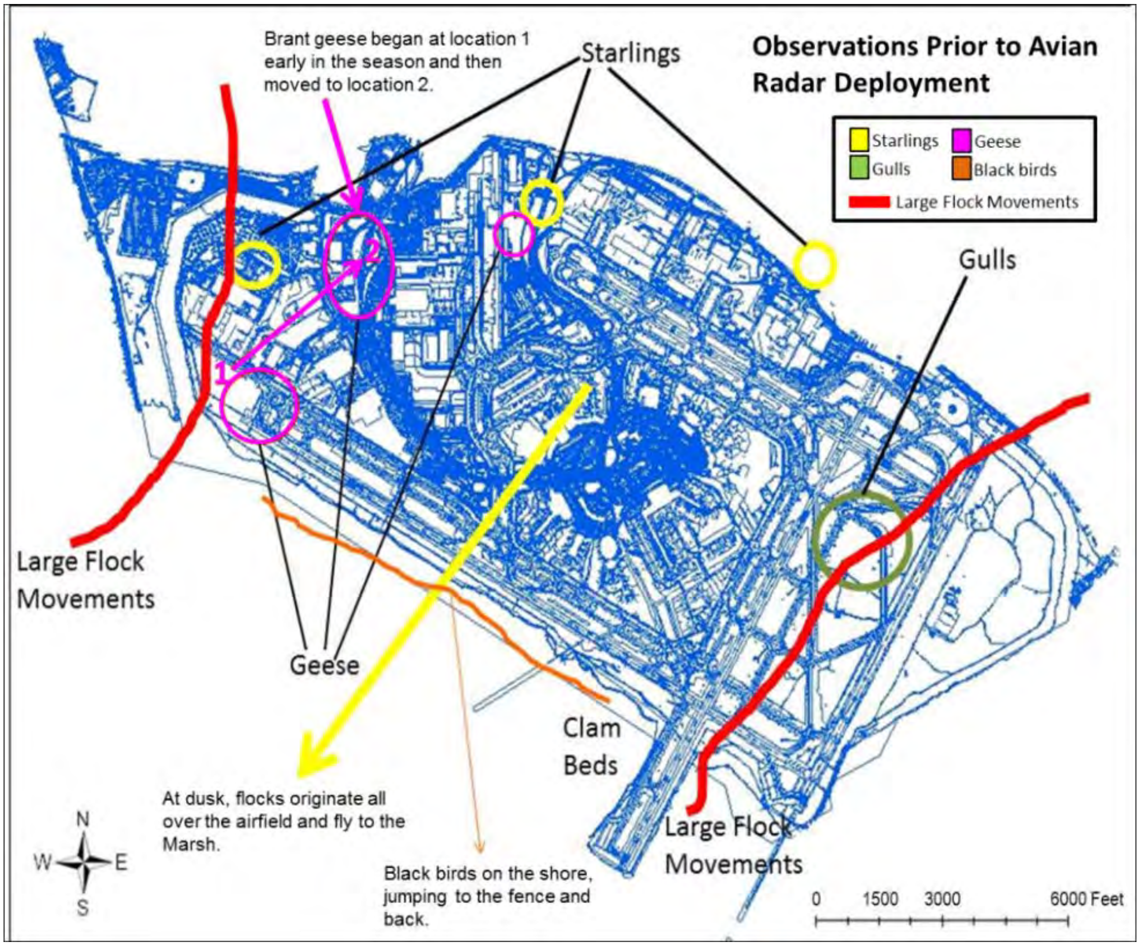


Figure 25. Locations Where JFK Wildlife Biologists Observed Specific Bird Hazards

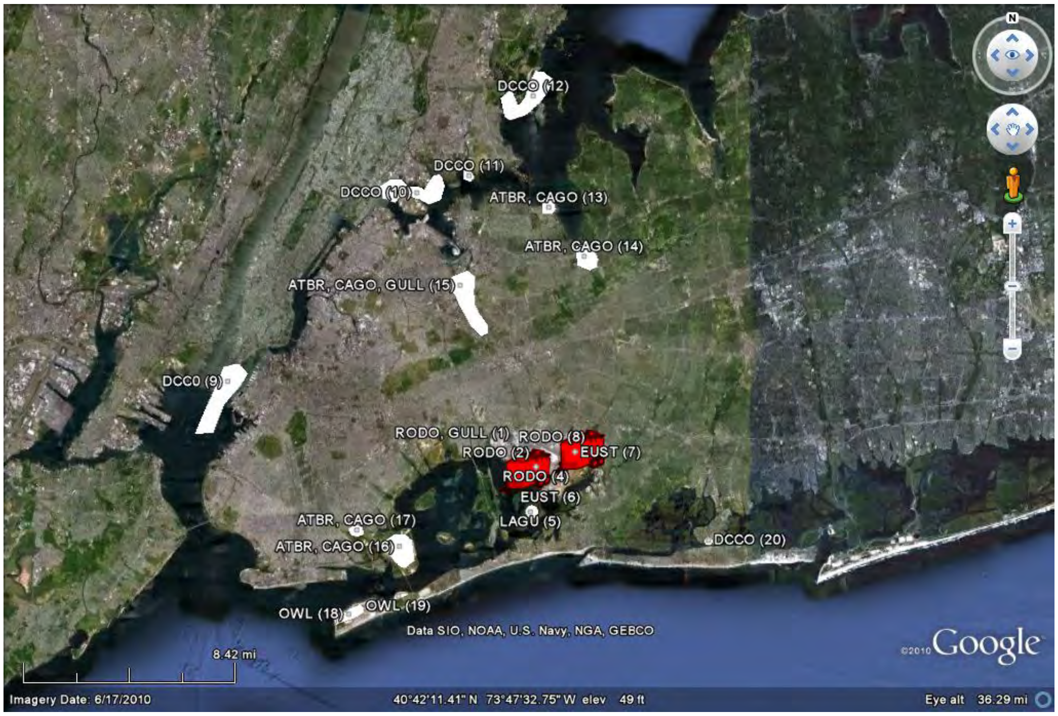


Figure 26. Regional Wildlife Hazard Locations (white) Identified by JFK Wildlife Biologists

Known seasonality is also associated with bird presence at JFK. So that CEAT personnel could better understand seasonal issues, JFK wildlife biologists provided information on seasonal hazards, which was used as radar data analyses progressed, shown in figures 27 through 29.

Figure 27. Fall Avian Hotspots (orange) Identified by JFK Wildlife Biologists

Figure 28. Winter Avian Hotspots (purple) Identified by JFK Wildlife Biologists

Figure 29. Summer Avian Hotspots (yellow) Identified by JFK Wildlife Biologists

3.2.2 Opportunistic Observations That Correlated Birds With Radar Targets.

On several occasions, unusual bird movement activity was observed. Because these movements were often large and accompanied by time-specific observations, radar records were reviewed to determine if the event could be found in the radar record. When found, these documented events provided an initial validation of radar detection of bird targets. This section provides examples of these opportunistic observations and correlative radar records.

One of the first opportunistic observations occurred during clutter mapping. CEAT personnel and JFK wildlife biologists observed a brant flock passing over their location. A review of the radar record is provided in figure 30. This figure shows the tracks (in red) displayed by the radar at a time consistent with observations of the brant flock.

Figure 30. Brant Flock Recorded on the AR2 During Clutter Mapping

This confirmation of radar tracking of known bird movements encouraged additional opportunistic analyses during the initial radar setup and tuning period. On March 21, 2011, at 15:25, JFK wildlife biologists observed a large flock of brant passing over the middle of the airfield and the General Aviation Terminal. The flock heading was from northeast (NE) to southwest (SW). CEAT personnel reviewed records from radars. Possible tracks for this flock were identified in both radar systems, but CEAT personnel were unable to relate specific tracks to the time of the observations. Such uncertainty about track confirmation using opportunistic observations was initially related to time stamps for the observations. For example, on July 19, 2010, several observations were submitted to CEAT personnel. These observations, supported by map annotations, were detailed, "1420: 4 birds (2 terns and 2 laughing gulls) cross 13R-31L from the bay side and turn back and fly in between the 3,000-4,000 ft to go markers." Although a time stamp was provided, the time stamp and a 1-minute time interval did not adequately narrow the search time for corresponding radar tracks. CEAT personnel identified track possibilities, and singled out one track for confirmation from the multiple possibilities displayed. Another issue was related to the perspective of the observer. The observer saw only one bird moving at that time in the direction indicated by the radar. In this instance, an observation was related to the radar display. CEAT personnel had confidence that birds were being tracked; but again, it was not possible to confirm which track was the bird the observer saw.

From these experiences, CEAT personnel identified issues associated with opportunistic observations. Records of observation time were critical. Unless time stamps were specific to location and synchronized with the radar time, relating specific tracks to observed targets was problematic. Track updates were available at very short time steps. Again, because of the quantity of data generated by the radar and multiple targets commonly present at JFK, it was difficult to relate a specific track update to an observed target. Even with observations synchronized to radar time, the processing latency of radar tracking produced uncertainty. Added to time issues, CEAT personnel came to understand that beam configuration and volume introduced other issues. Simply, observation of birds other than those flying overhead produced unreliable target location information because of the difficulty of locating an observed bird exactly over a landmark. This location estimation issue had variable impact on ground-truth/validation efforts based on range from the radar and size of the target. For example, figure 31 shows two tracks (circled in yellow) that were related to birds moving at the correct time direction. In this example, tracks are distinctive and isolated from other tracks, providing confidence that the tracked targets were the observed birds.

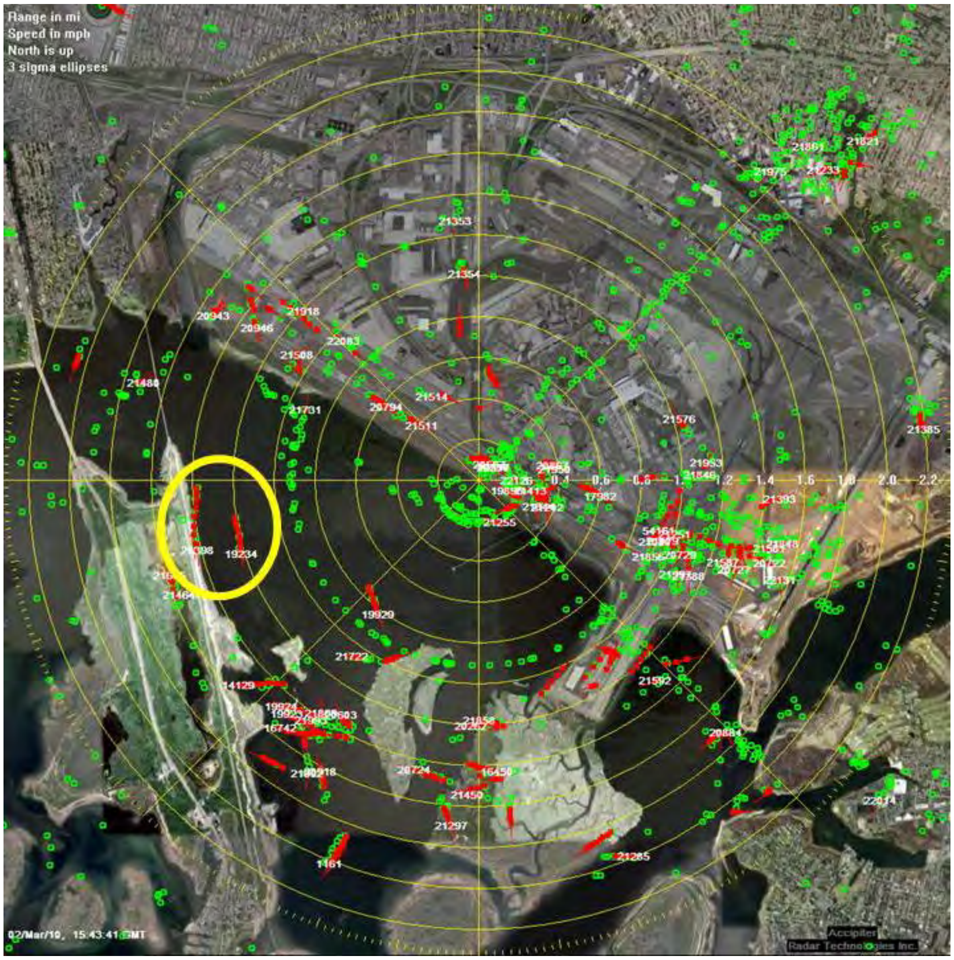


Figure 31. Bird Tracks Noted During Ground-Truth/Validation Campaigns

Another opportunistic approach used by CEAT personnel began with targets on the radar display. When a target was identified on the radar, the radar operator would "call" the target, providing range and azimuth information to observers. Observers then would attempt to identify the target. This technique was only partially successful. CEAT personnel determined that the inherent latency associated with target tracking was the major factor producing validation variability. If the target was at short range, a relatively fast-moving bird could be far from the position called by the radar operator and would be missed by the observer. If the target was at a greater range and flying across the observer's field of view, the observer was typically able to verify the bird target and even match sighting to the continuing track on the radar. This approach was particularly valuable for confirming radar coverage, especially for larger targets, such as boats or aircraft, where the confirmed sightings were used in coverage mapping. The technique was also used when long tracks were noted on the radar, providing more time for observation and verification of display issues such as latency.

A final opportunistic approach was event related. On August 9 and 13, 2010, JFK personnel asked CEAT personnel to review radar records for times of reported bird strikes. Specific tracks could not be related to a bird/aircraft collision in either case. To address time issues, an extended radar record was reviewed and TVW settings were modified to show aircraft tracks so that the movement of both birds and aircraft could be reviewed. The results of these analyses were inconclusive. CEAT personnel determined that, without an exact location of the strike, it was not possible to determine if the radar was actually providing coverage at the time of the incident. Timing issues made it impossible to confirm if nearby bird target tracks were for the bird that collided with the aircraft. It was possible to relate general activity levels and provide other information to JFK wildlife biologists, but it was not possible to provide specific information on the strike.

The results of opportunistic approaches were mixed. Although it was assumed that ground-truth observations and validation efforts would be relatively simple, that was not the case. Radar is a technology that operates on high-frequency radio transmissions. Although time to detection is short, the confirmation of targets introduces latency between detection and display on the radar screen. Basically, the radar is operating in a time domain specific to the radar. When making observations of bird targets, CEAT personnel assumed that it would be a relatively straightforward exercise to match the observation time domain with the radar time domain. The opportunistic observations showed both the importance of exact time stamps and the difficulty in identifying specific targets in a technology that detects many targets simultaneously. CEAT personnel were able to confirm many targets, such as those with long tracks, but not always able to confirm targets identified by observers. The opportunistic studies also revealed the importance of understanding radar coverage and the influence of beam coverage and target characteristics in target confirmation.

3.2.3 Ground-Truth/Validation Studies.

A number of ground-truth/validation studies were designed to assess radar capabilities and learn more about bird movement dynamics. A common method of wildlife hazard assessment is the point count, an observational method where all birds visually observed in a given time period are recorded. Point counts are the foundation for wildlife hazard assessments and the basis of observation programs in wildlife hazard management plans. CEAT personnel took advantage of regular point count studies performed by the United States Department of Agriculture (USDA) at JFK to develop a validation study for the radars.

Point counts were made at 24 locations around the JFK airport. At each point, the observer identified birds for 3 minutes. CEAT personnel accompanied the wildlife biologist conducting the point count so observations could be related to radar information. Time at the beginning of the observation was recorded to the second. The observer recorded the species of all birds observed whether moving or stationary. CEAT personnel recorded only moving birds and added a time stamp, bearing, and direction of movement to the data record.

After a field session, CEAT personnel examined the radar record to determine its consistency with point-count observations and provide additional information on bird density and general movement. This study identified additional issues with opportunistic observations. CEAT personnel found that the radar detected and tracked multiple bird targets during point-count observation time stamps at locations 1 through 5 shown in figure 32. The locations identified in point-count observations could be related to tracks on the radar, but it was not possible to confirm that radar tracks corresponded to the birds observed due to slight location differences or the presence of multiple tracks. Another issue is related to point-count methodology. Point-count observations count all birds observed, whether moving or stationary, and at all altitudes;

there appears to be a bias to lower altitudes where birds are more easily observed. CEAT personnel noted that few birds were counted at higher altitudes and above trees or buildings where the radar might be expected to detect and track birds. CEAT personnel also noted that birds were often counted in shore areas. Locations 1, 2, and 3 in figure 32 had shore areas below the radar beam. Although there were limits, there were also successful studies. A steady stream of gulls was noted during a dawn survey period at Bergin Basin on November 22, 2010. The tracks in the radar record did not exactly match observations, but the movement was consistent with the point-count summary.

Figure 32. Trends and Ground-Truth/Validation Observations From USDA Point-Count Surveys

3.2.4 Analysis of Radar Data to Determine Consistency With Observed or Reported Bird Movement.

3.2.4.1 Species Identification.

JFK wildlife biologists asked CEAT personnel if the radar could be used to identify species. Cormorants were regularly observed at JFK and, because of the hazard this species presented, information was requested from the radar on location and movement patterns. JFK wildlife biologists also noted that brant were present in the spring, and there was an interest in developing a better understanding of seasonal occurrence. To accommodate these interests, CEAT personnel assessed potentials for species identification in the radar. Radar target characteristics can be diagnostic of species, but without visual confirmation, radars are generally ineffective for species identification. CEAT analyses focused on areas where target species were known and on whether radar displays and radar tracks could provide sufficient diagnostic information to confirm species. CEAT personnel determined that the existing radar installation provided insufficient data to confirm species identification. As in other CEAT studies, radar added to an understanding of bird movement and movement dynamics, but it was not possible to associate specific movement or dynamics with a species of interest.

3.2.4.2 Initial Analysis of Radar Targets.

In February 2010, CEAT personnel initiated a series of studies that sought to identify patterns in tracks. Radar displays and track history summaries were used for this analysis. An initial focus was on tracks that would be free from nonbird target contamination from vehicles or multipath and on Jamaica Bay, where target velocity, track heading, ITOs, and track termination supported identification of targets as birds. CEAT personnel identified movement timing and characteristics. At dawn, there were movements to the north, over Jamaica Bay, which occurred from approximately 30 minutes before sunrise until approximately 30 minutes after sunrise. Typically, tracks ended at the Jamaica Bay shore between the middle and the northwest end of Runway 13R/31L, as shown in figures 33 and 34. Note that track ends are not necessarily based on bird landing, but could indicate movement out of the radar beam. In the late afternoon and evening, the movement trend was different, suggesting movement from Bergen Basin, as shown in figure 35. Evening activity levels were generally lower than observed near dawn. CEAT personnel also identified evening and night movement patterns in Jamaica Bay that indicated movement between islands, as shown in figure 36.

Figure 33. Tracks Indicating Morning Movements of Birds Between Jamaica Bay Islands

Figure 34. Arrows Illustrating Morning Movements of Birds Between Jamaica Bay Islands

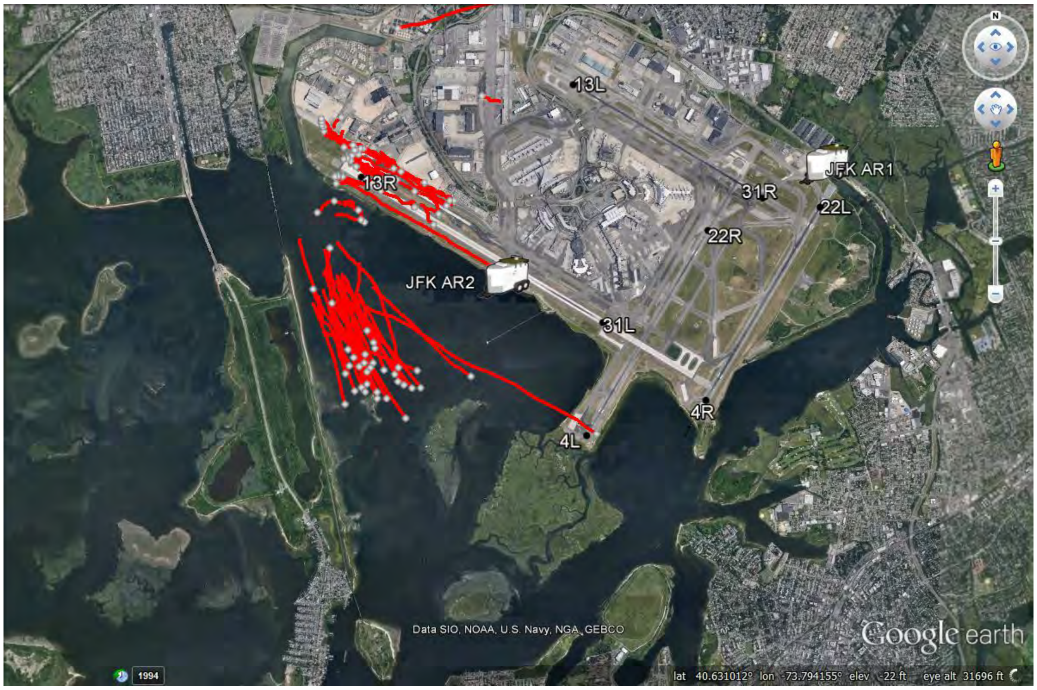


Figure 35. Tracks Indicating Evening Movements of Birds Between Jamaica Bay Islands

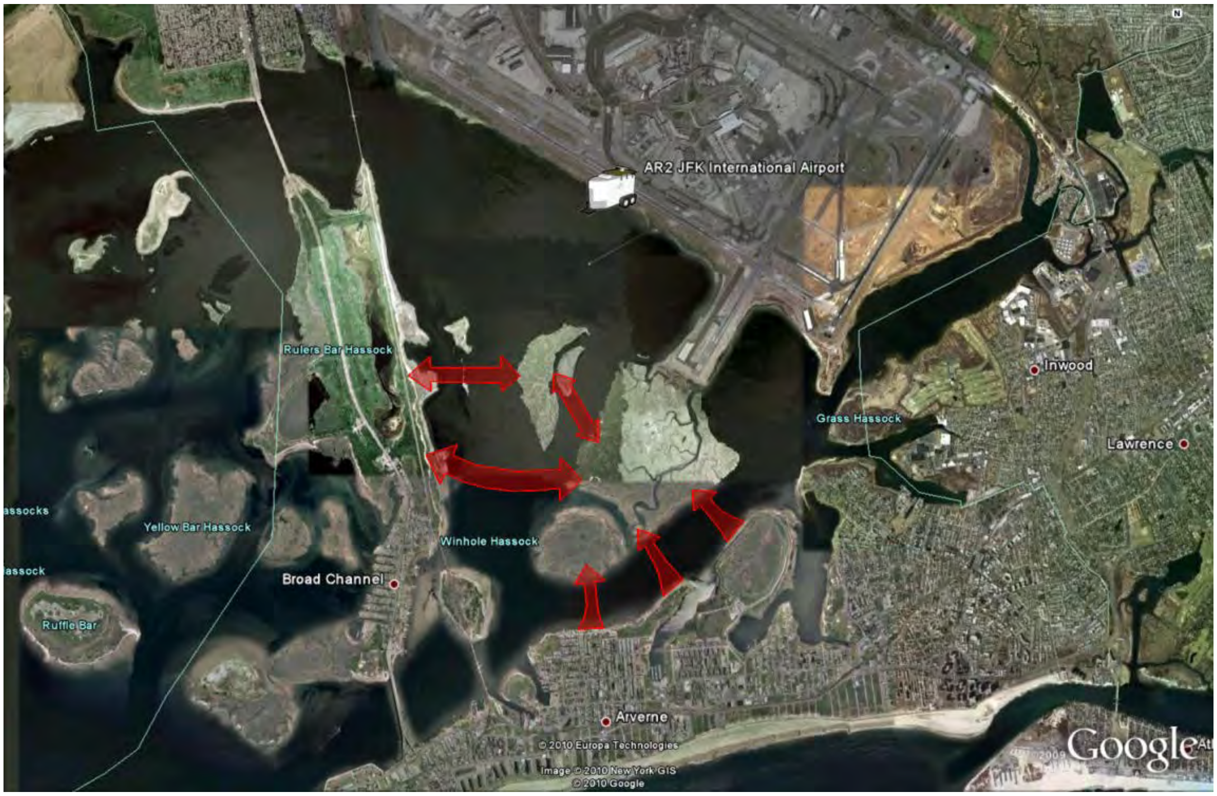


Figure 36. Arrows Indicating Evening Movements of Birds Between Jamaica Bay Islands

During nighttime hours, long tracks were also present beyond airport boundaries, shown in figure 37. These tracks were long, with a heading consistent with migrating birds. Although CEAT personnel recorded a migration possibility, they were unable to confirm species. These results demonstrate the capacity of the radar to track birds for long distances at long range. The tracks identified in these analyses were approximately 2.5 miles from the radar with a track length of almost 3 miles (see figure 37). The yellow circle highlights the tracks of interest.

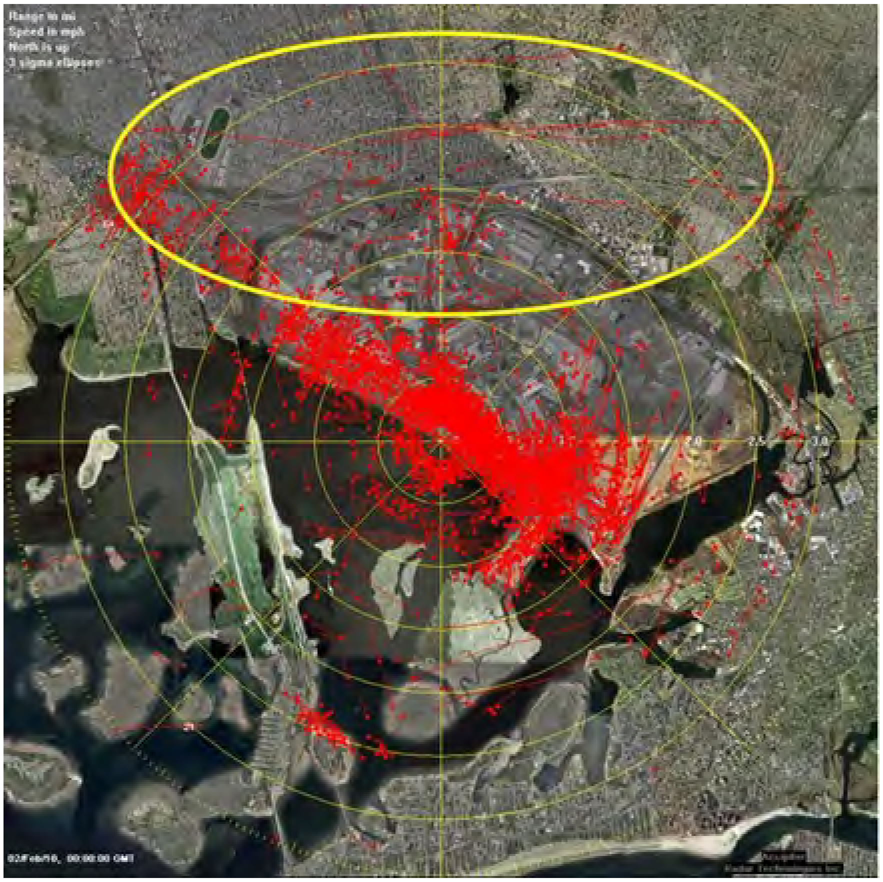


Figure 37. Long Tracks Noted at 21:00 After Sunset on February 2, 2010

3.2.4.3 Bird Movement Studies.

As CEAT personnel gained JFK radar experience, they initiated studies based on radar display details. A major element of the CEAT assessment effort was gaining an appreciation of what information could be provided by an avian radar system. This required regular review of radar data where recorded displays and track history plots were used to identify movement timing and location; track details including length, location, and timing; and other radar display aspects. This resulted in the identification of movement patterns and dynamics, as well as events or patterns that could benefit from detailed studies. These detailed studies were for forensic, after-the-fact analysis, so it was not possible to confirm movements with actual observations. However, it was possible to relate identified movements to hazard issues identified by JFK wildlife biologists.

Observations recorded by the AR1 in the winter of 2010-2011 identified a movement that originated daily near sunrise (06:55) from the northwest corner of the terminal complex near terminal 5, as shown in figure 38. Using replays of the radar record, CEAT personnel identified a common movement period that occurred approximately 10-15 minutes before sunrise and was common from mid-November 2010 through January 2011. Confirming the track origin on the radar display was not possible due to clutter associated with terminal structures. However, it was possible to confirm track locations; so the radar results were summarized noting the presence of tracks near the northeast corner of the terminal complex. Because this was an after-the-fact analysis, it was not possible to make observational studies to confirm these movements.

Figure 38. Tracks Recorded by the AR1 That Began at the Terminal Complex Near Sunrise on November 25, 2010

CEAT personnel also found that evening radar records for the same record period produced consistent movements. CEAT personnel observed movements toward the terminal complex following two routes, as shown in figure 39. The first route moved from the area north and northeast of the airfield, across the marsh that is northeast of the airfield, to the terminals. The second route moved from the east, around Head of Bay, to the terminal complex. The movements began about 30 minutes before sunset and ended close to sunset. The evening activity levels were less than the morning levels.

Figure 39. Direction of Tracks Recorded by the AR1 Moving Toward the Terminal Complex in the Evening

CEAT personnel observed birds flying in the eastern area of the airport and near the terminal at the same time. Figure 40 illustrates the general direction of flight observed near dawn summarized from display analysis. The dawn movements were to the north from the terminal area (yellow lines) as well as from Head of Bay and Thursten Basin (red lines). Evening activity followed a southerly path on the east side of the airport (red lines) and southeasterly and easterly paths toward the terminal complex (yellow lines), shown in figure 41.

Figure 40. Movement Summary of AR1 Tracks for December 2010 Near Sunrise

Figure 41. Movement Summary of AR1 Tracks for December 2010 Evenings

The near-terminal movements identified in this analysis were reviewed with JFK wildlife biologists, and efforts were made by JFK staff to confirm the identified movements. Because CEAT personnel's radar display analysis results were completed after the fact, designing an observational study to confirm radar displays was not possible. Although the JFK staff recorded point-count and general observations for their records, they were unable to confirm these movements. JFK observations have the advantage of long time periods and a variety of weather and bird movement activity conditions. Unfortunately, CEAT personnel found that JFK observations rarely coincided with event timing. So, a review of JFK records did not confirm bird movement in the terminal area, nor did periodic observations intended to confirm radar findings observe birds at the identified locations. This is not an unusual finding. Radar is very effective at detecting birds, and radar displays use symbols that can be readily seen on the display. Although the radar detects multiple separated targets, the display may suggest a dispersion front with high density of tracks when the actual movement is more dispersed. Further, dawn and dusk are periods of changing lighting conditions that make visual observations more difficult, particularly at low altitudes with terminals or buildings providing little contrast to distinguish bird targets. These results indicate the capability of an avian radar, but not necessarily fidelity to an observational reality.

CEAT personnel also discussed the bird movement along Thursten Basin with JFK wildlife biologists; this movement was confirmed from general observations. Movement along this corridor is unlikely to create a conflict with aircraft because the birds do not fly routes that intersect with aircraft.

3.2.4.4 Bergen Basin Study.

Bodies of water located on three sides of JFK are wildlife attractants. To the west of the airport is the Bergen Basin, a location where hazardous birds, such as gulls, were often observed. Using this information as a basis for selecting locations to develop analytical methodologies, CEAT personnel designed a study that examined detailed data from November 22, 2010 for the Bergen Basin area. The TDV was used to access and process radar data from the AR2 installation, which was approximately 2 miles from the study area. The first step of the study was to extract spreadsheet data from the plot-and-track files using the TDV. An initial filter selected data only from locations in the study polygon. This limited data set was then used to create the tracks for each track number. The location of each track update was plotted, producing a track display, shown in figure 42. The next step in the analysis considered the average number of track updates in a track per unit of time. This analysis was intended to provide an indication of track length related to time, which could be used to characterize activity levels or identify migration when long tracks were common. Then, the number of tracks per hour was calculated to provide a general sense of activity. Finally, velocity and heading were determined for each target.

Figure 42. All Tracks Within the Area of Interest (green polygon) on November 22, 2010, From 06:00–08:00

The results for track update analyses did not reveal a useful relationship between track update number per hour and activity definitions. The analysis of tracks per hour did identify differences between altitude and level of activity, with a generally higher number of tracks per hour recorded in the AR2-2. Activity levels were also different temporally. Activity in the AR2-1, had two high values at approximately 02:00 and 09:00, but the general activity level was consistent and moderate through the day, as shown in figure 43. Activity in the AR2-2 was low during the day, but increased to high levels at night, as shown in figure 44. This increase in nighttime activity levels may be due to migration. The velocities determined for targets were within the expected range for birds. CEAT personnel recommend using caution when generalizing these results because data are available for only one day.

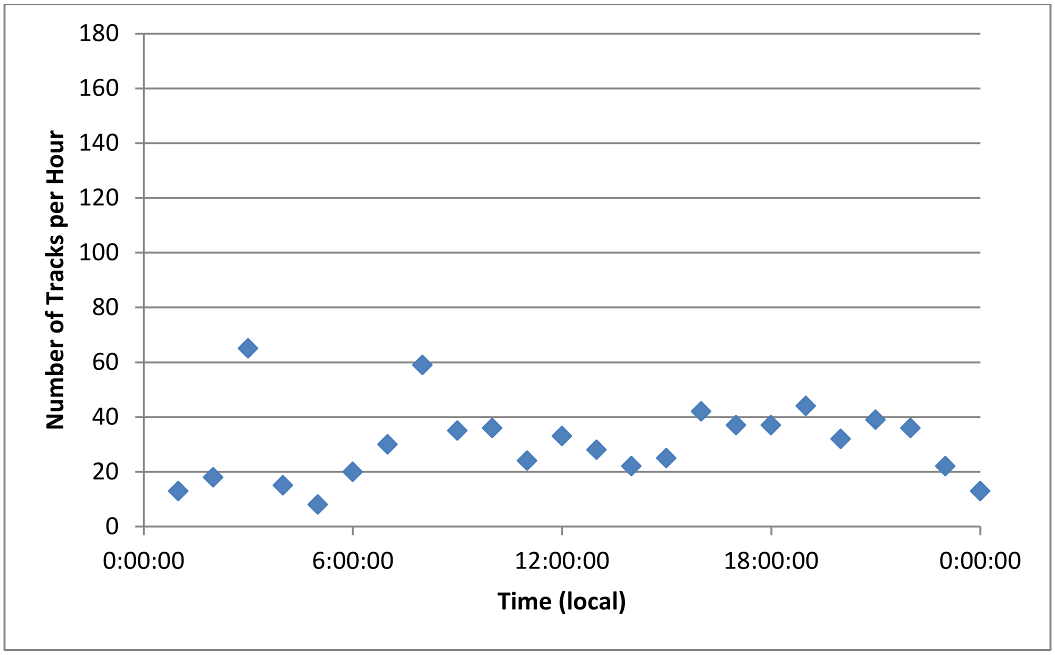


Figure 43. Number of Tracks Identified From the AR2-1 for the Bergen Basin Polygon

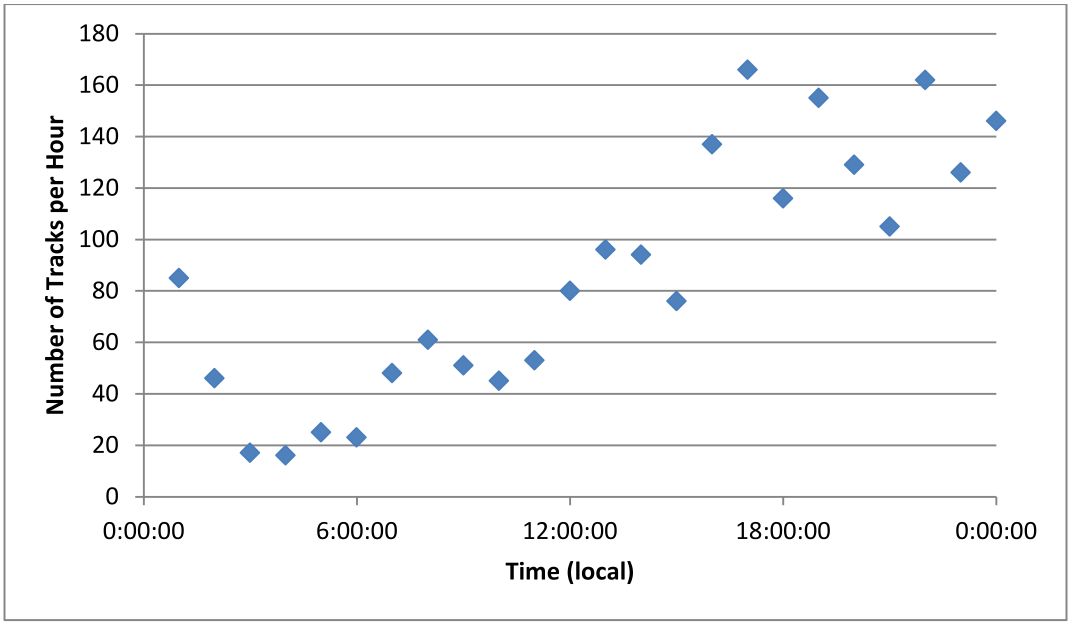


Figure 44. Number of Tracks Identified From the AR2-2 for the Bergen Basin Polygon

3.2.4.5 Comparison of Strike and Radar Records.

Another issue related to bird movement on and around an airport is the assessment of activity in critical areas and how that activity may change due to seasonal activities such as migration. In this study, CEAT personnel examined the record of reported bird strikes for 2010. An initial analysis suggested high numbers of strikes in October and November 2010. Table 7 shows that 40% to 60% of the reported 2010 strikes for Runways 13L/31R, 13R/31L, and 4R/22L occurred in October or November.

Table 7. Number of Strikes in 2010 for Each JFK Runway

Runway	2010 Strikes	October 2010 Strikes	October Percentage of 2010 Strikes (%)	November 2010 Strikes	November Percentage of 2010 Strikes (%)
13L/31R	19	8	42	3	16
13R/31L	25	9	36	2	8
4R/22L	87	21	24	15	17
4L/22R	44	5	11	3	7

Runways 4R/22L and 4L/22R were of particular interest, because they have an approach path over Jamaica Bay. A study was designed to identify seasonal changes in bird strike hazard in the approach path to these runways. Two time periods were chosen for detailed radar data analysis: September 23-25, 2010, and October 31-November 1, 2010. Using techniques that allowed track counts in a defined polygon, the area shown in figure 45 was studied. Radar data from the AR2-1 and AR2-2 were used to provide information for different altitudes. The tracks per hour (TPH) are illustrated in figure 46 for September and figure 47 for October. The major difference between the months is shown on the Y-axis where maximum track counts were nearly 10 times greater in October than September. Clearly, activity levels were greater in October. September AR2-1 TPHs were generally consistent over the time period. September AR2-2 TPHs illustrated a tendency to higher activity levels around dusk or later in the night.

The TPH for September 23-25, 2010 and October 31-November 1, 2010 were computed (see figures 46 and 47). Both time periods showed relatively consistent AR2-1 TPH values. In contrast, the AR2-2 showed higher TPH values during nighttime hours for both time periods; the TPH values during nighttime in October was almost an order of magnitude greater than in September. These results suggest that the peak activity levels occurred at higher altitude.

CEAT personnel made a preliminary hazard assessment that found the target altitude in the AR2-2 beam were at 600 ft to 1400 ft, which is above the glide slope altitude for the runways. Although there is some separation between birds and aircraft, the high activity and movement patterns indicate increased hazard to aircraft. This is substantiated by the strike records where an increased number of strikes on Runway 4L occurred duration periods of increased bird movement activity associated with migration.

Figure 45. Area of Interest (Highlighted) is the Approach to Runway 4L

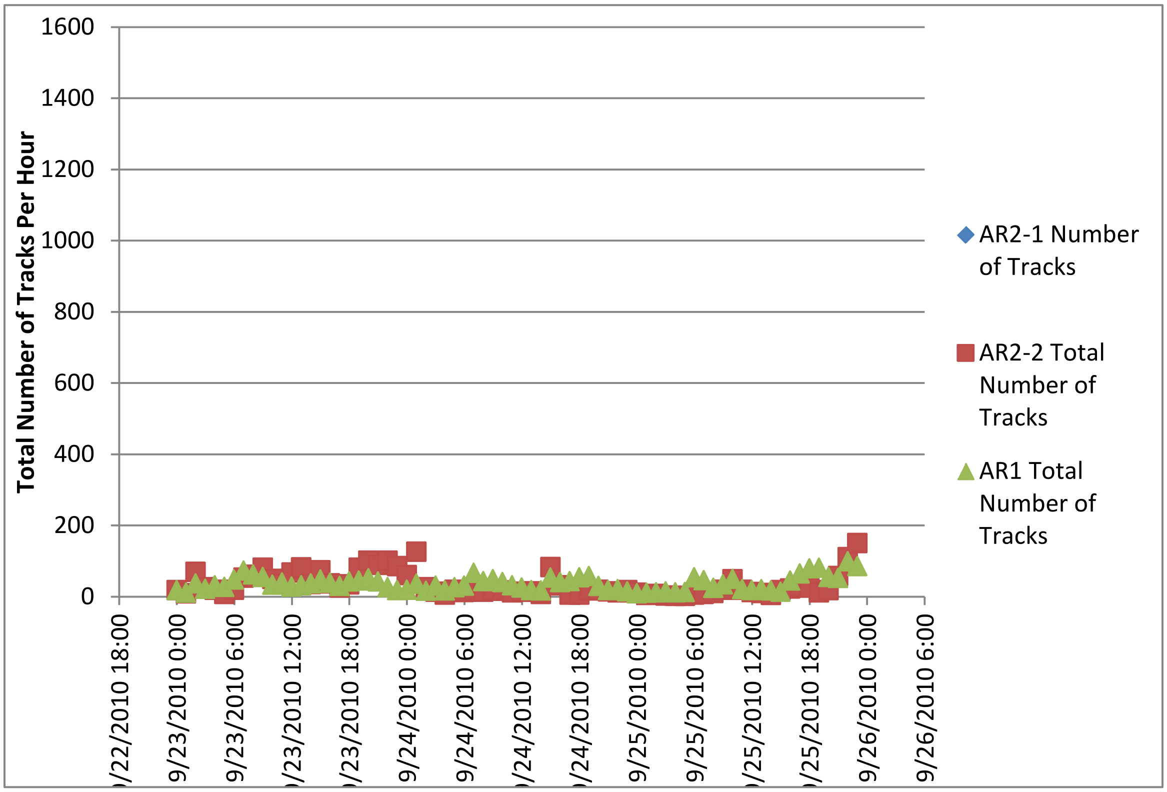


Figure 46. Tracks per Hour in the Approach to Runway 4L on the AR1 and AR2 for September 23–25, 2010

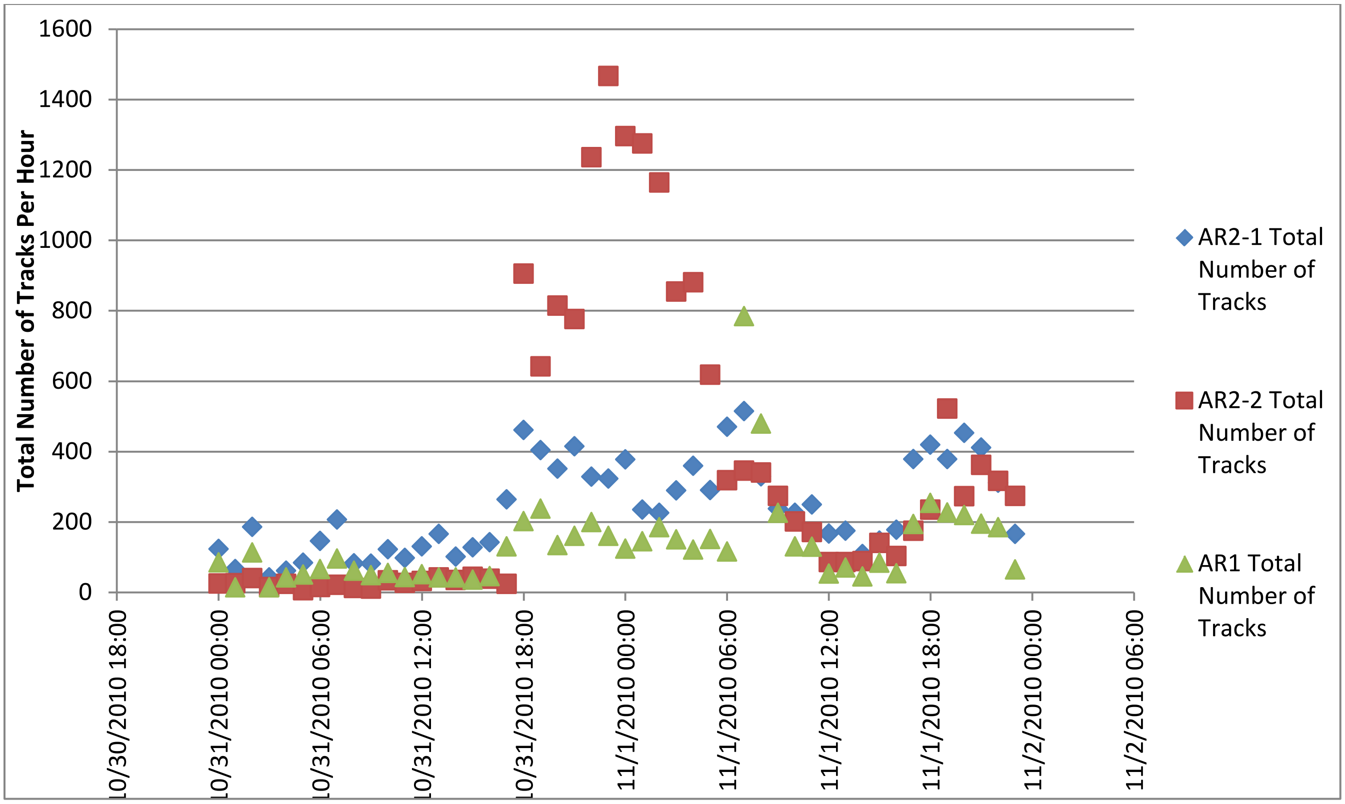


Figure 47. Tracks per Hour in the Approach to Runway 4L on the AR2 and AR1 for October 31–November 1, 2010

3.2.4.6 Heading Analysis.

Heading is the direction of track movement. In radar data, sequential track updates define the direction of movement. Heading information is important in radar data analysis because it indicates direction of movement that, when combined with ITOs, landscape features, and other information, provides critical information on bird movement dynamics. The spreadsheet files generated with the TDV provide a heading for each track update; more general heading assessments can be made from long tracks using the radar display. CEAT personnel have investigated methods of heading analysis and display. The major difficulty in heading analysis of radar data is the relative abundance of heading data. With rapid updates, the radar potentially provides multiple headings for each track. In fact, the TDV provides the start time, speed, altitude, and heading for each track update. Determining an average heading for a track from this data may be misleading and does not work for reciprocal (0/360 degree) headings.

To address this problem, CEAT personnel identified Oriana™, a software package designed specifically for working with directional data. CEAT personnel use Oriana analytical and display features in heading analysis. For example, it is possible to generate a scatterplot of the mean vector of tracks for a given time period. A scatterplot for data from the AR2-2 for May 1, 2010 is provided in figure 48. This figure suggests that targets have different headings during the day, with daytime targets moving at headings between 270 and 360 degrees, suggesting a northward movement. Oriana also supports other display options. Figure 49 displays the May 1, 2010 data as a circular histogram that more clearly defines the range of northward movements.

CEAT personnel have used these new heading analysis capabilities to improve understanding of bird movement dynamics.

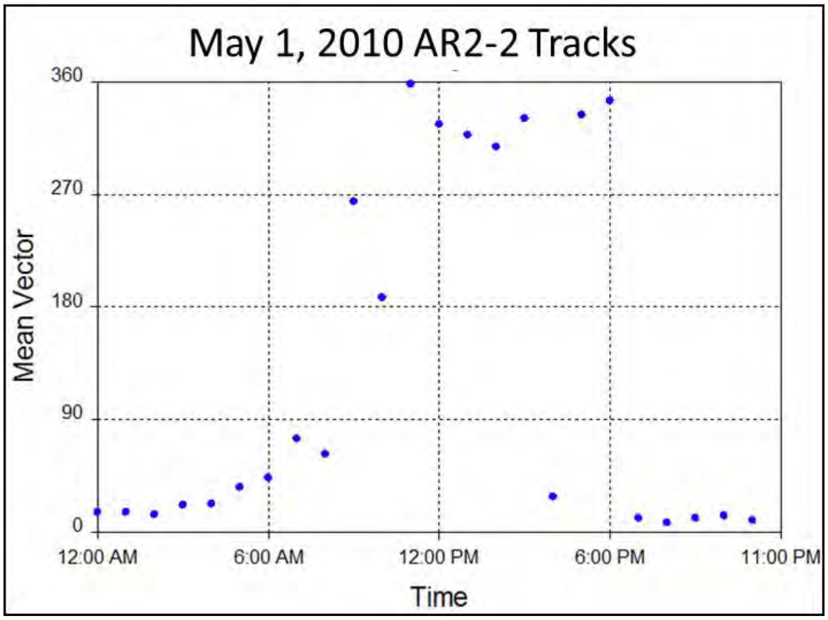


Figure 48. Scatterplot of AR2-2 Average Track Vector (Heading) for May 1, 2010

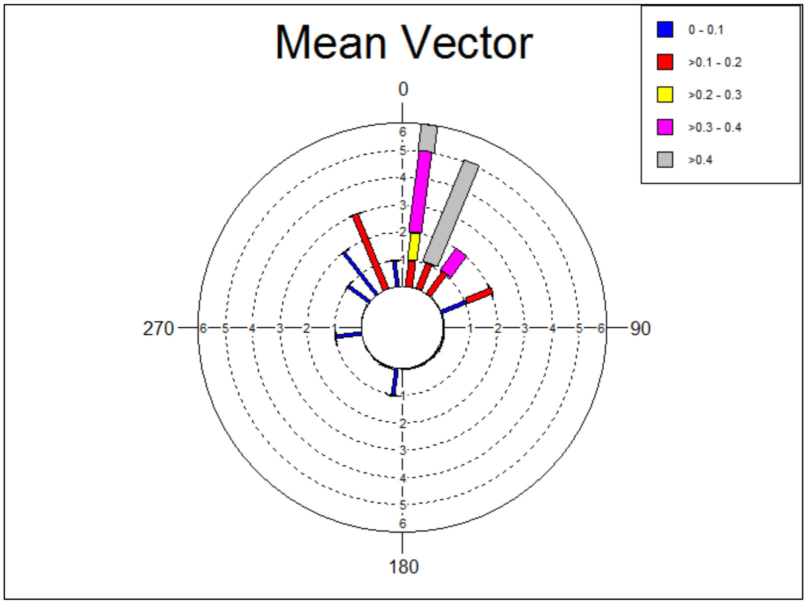


Figure 49. Circular Histogram of AR2-2 Average Track Vector for May 1, 2010

3.2.4.7 Altitude Studies.

The configuration of the ARTI radars deployed in the CEAT avian radar performance assessment at JFK was selected to provide broad area coverage with a slotted array antenna and altitude discrimination using co-located parabolic dish antennas with different tilt angles. The AR2 radar was equipped with dual parabolic dish antennas, the AR2-1 and AR2-2. The AR2-1 had a low beam tilt (0-4 degrees) and the AR2-2 had a high beam tilt (4-8 degrees). Altitude determinations were based on a geometric estimate based on range and antenna tilt angle above horizontal. As discussed in section 2.4, beam expansion with range produces a greater altitude variation from the top to bottom of the beam. Thus, in altitude studies, estimates become less exact with range from the radar. Note that the range value is a slant range. Depending on tilt angle, the horizontal distance to target will differ from the slant range. As with any radar, targets are only detected when they are in the beam, so radars provide only a sample of the actual distribution of birds in the atmosphere. Finally, target discrimination in any radar is related to the strength of the target echo, so larger birds may be detected at ranges greater than those where small birds are detected.

The altitude of targets within the atmosphere changes seasonally. This study focused on September 23-25, 2010, and October 29-31, 2010. No precipitation was noted in the weather data for either set of days. The period of focus was 21:00-23:00, a time when migratory movements would be expected.

Table 8 summarizes track data listing total counts and average altitude. Activity, as indicated by track numbers, was greater in October than September. Figures 50 through 52 provide plots of altitude for September 23, October 29, and October 30. These figures illustrate a difference in the distribution of targets on these days. For September 23, activity peaked at over 1000 tracks, with moderate levels of activity, between 300 ft and 700 ft. For October 29, overall activity was high, between 200 ft and 1100 ft, with track numbers between 500 and 1500. On October 30, aside from high activity at 200 ft with 1000 tracks, overall activity at higher altitudes was low, with maximum track number near 400.

This data shows that the activity at altitude changes daily and may reflect seasonal influences, such as migration. Activity below 500 ft reflects local bird movement, while activity at higher altitudes can be attributed to migration, particularly during these months.

Table 8. Track Data Listing Total Counts and Average Altitude From 21:00–23:00

Date	Number of Tracks	Average Altitude of Tracks
9/23/2010	8,122	385
9/24/2010	7,240	387
9/25/2010	8,185	490
10/29/2010	12,474	628
10/30/2010	3,825	507
10/31/2010	11,685	628

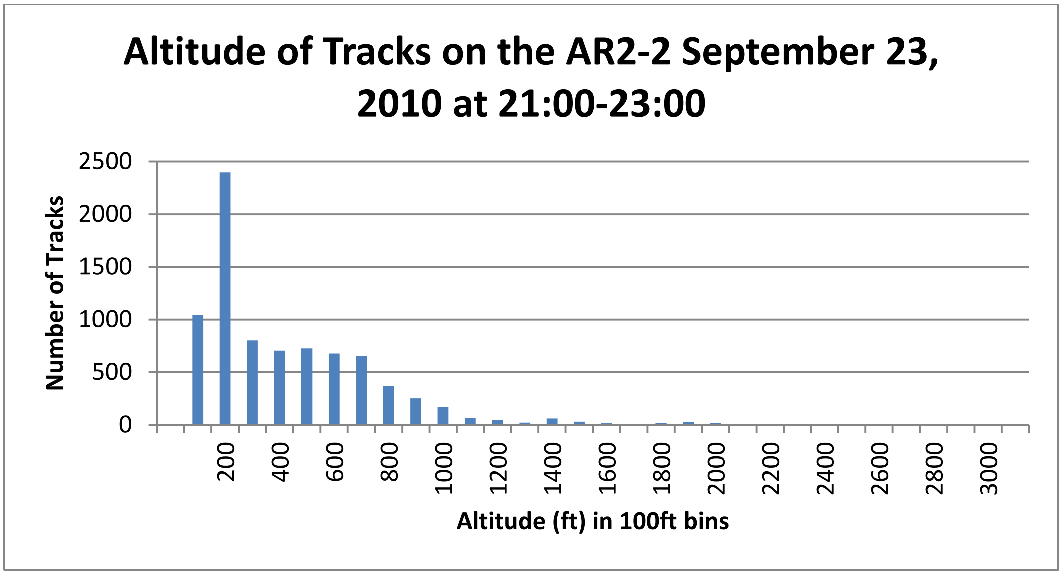


Figure 50. Altitude of AR2-2 Tracks on September 23, 2010

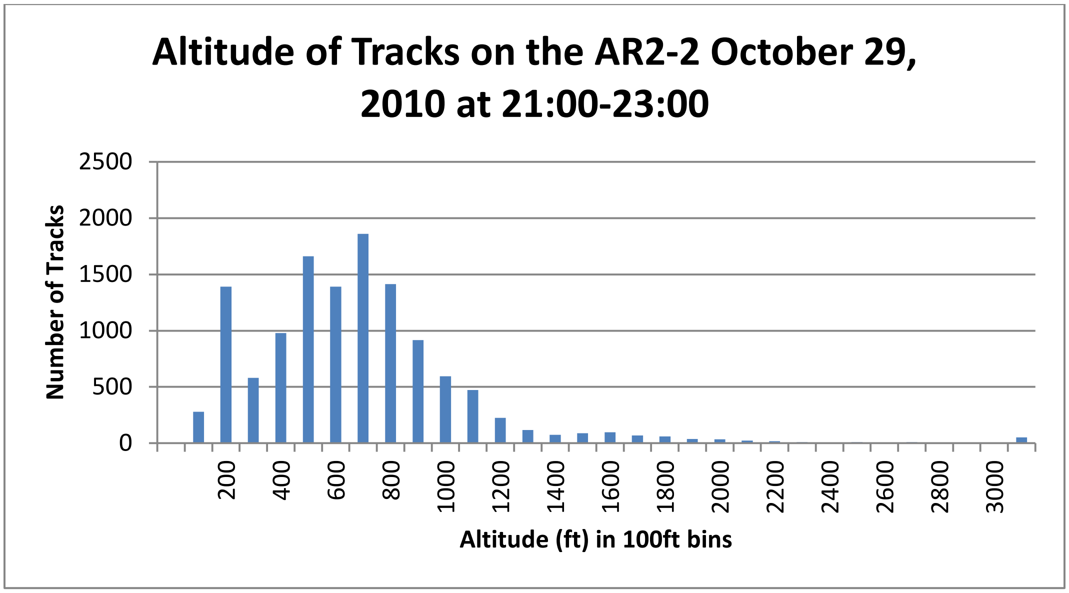


Figure 51. Altitude of AR2-2 Tracks on October 29, 2010

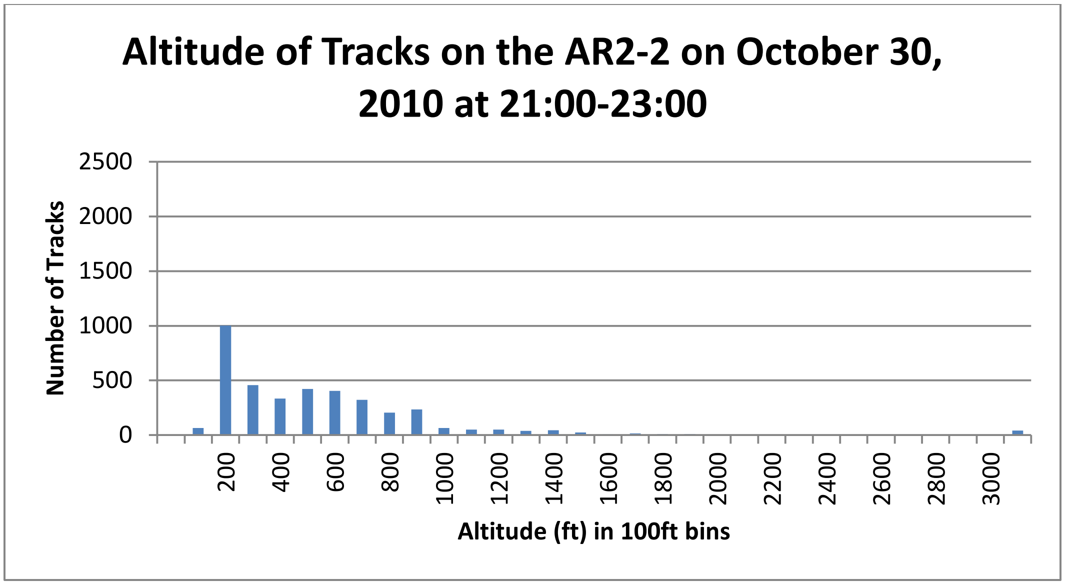


Figure 52. Altitude of AR2-2 Tracks on October 30, 2010

3.2.4.8 Migration Activity.

Migration has been a focus area for radar analysis for decades. As part of the project objectives' focus, CEAT performed a series of migration studies during the avian radar performance assessment program. The use of Next-Generation Radar (NEXRAD) is well described in the literature [8]. Avian radar systems, such as those used at JFK, can contribute to a better understanding of migratory activity at airports. Because migrations typically occur at higher altitudes, the AR2-2 radar data was used in this study. Of particular importance is the long-term record of radar data developed in the JFK performance assessment. This extensive record supports analysis of short- and long-term data.

The primary focus of the CEAT migration study was characterizing the difference between periods of no expected migration and periods of expected migration. To simplify the analysis, data was used from 21:00 to 23:00, a time period identified in the literature when high migration activity might be expected [9 and 10]. During June 2010, activity was generally consistent with peak track numbers in the range of 8000 tracks per day, as shown in figure 53. For September 2010 to November 2010, the daily track values were in the same range as summer except for several days in October when track numbers often exceed 12,000 tracks per day, as shown in figure 54. Because migration introduces birds not familiar with an area and the overall number of birds is higher than during nonmigratory periods, CEAT personnel examined bird strike records and included this information in the figures. Different colors are used on figures 53 and 54 to indicate days with reported bird strikes. Yellow squares indicate days with one to two strikes, and red indicates days with three or more strikes.

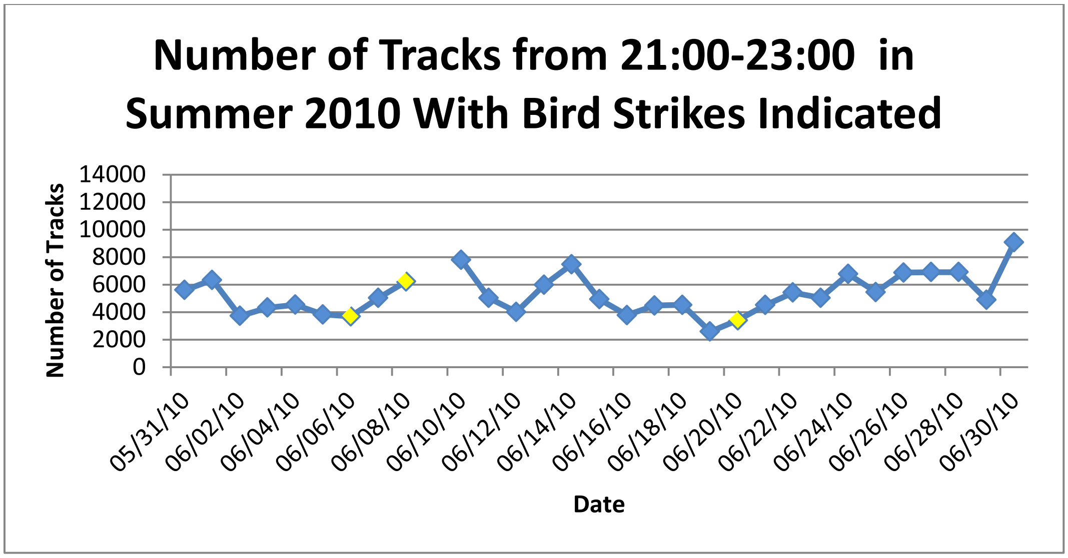


Figure 53. Number of AR2-2 Tracks From 21:00–23:00 in Summer 2010 (Yellow indicates days with 1-2 bird strikes.)

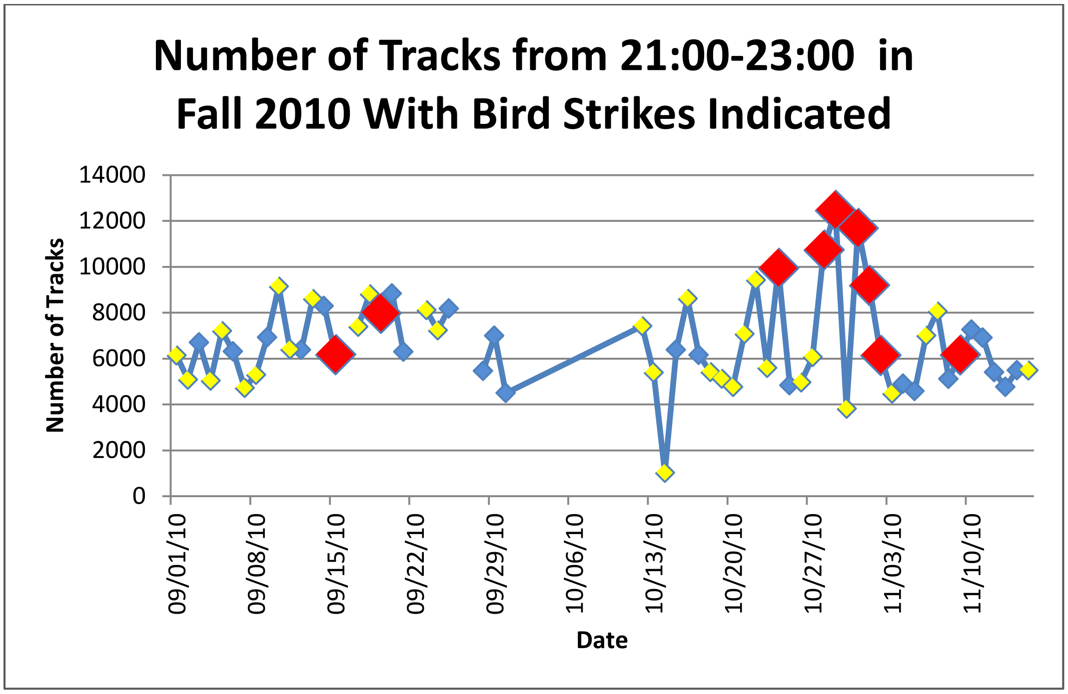


Figure 54. Number of AR2-2 Tracks From 21:00–23:00 in Fall 2010 (Yellow indicates days with 1-2 bird strikes, and red indicates 3+ strikes.)

Another migration study focused on spring 2010. CEAT personnel had identified that longer tracks could be diagnostic of migratory activity in the track histories developed with TVW. Data records were developed using the TDV for days that featured long tracks moving in the same direction. Three days were selected: April 2, May 1, and May 8, 2010. For these days, an assessment of track counts over a 24-hour period was used to identify features that could be related to migration. Figures 55 through 57 show track counts for the three days, respectively.

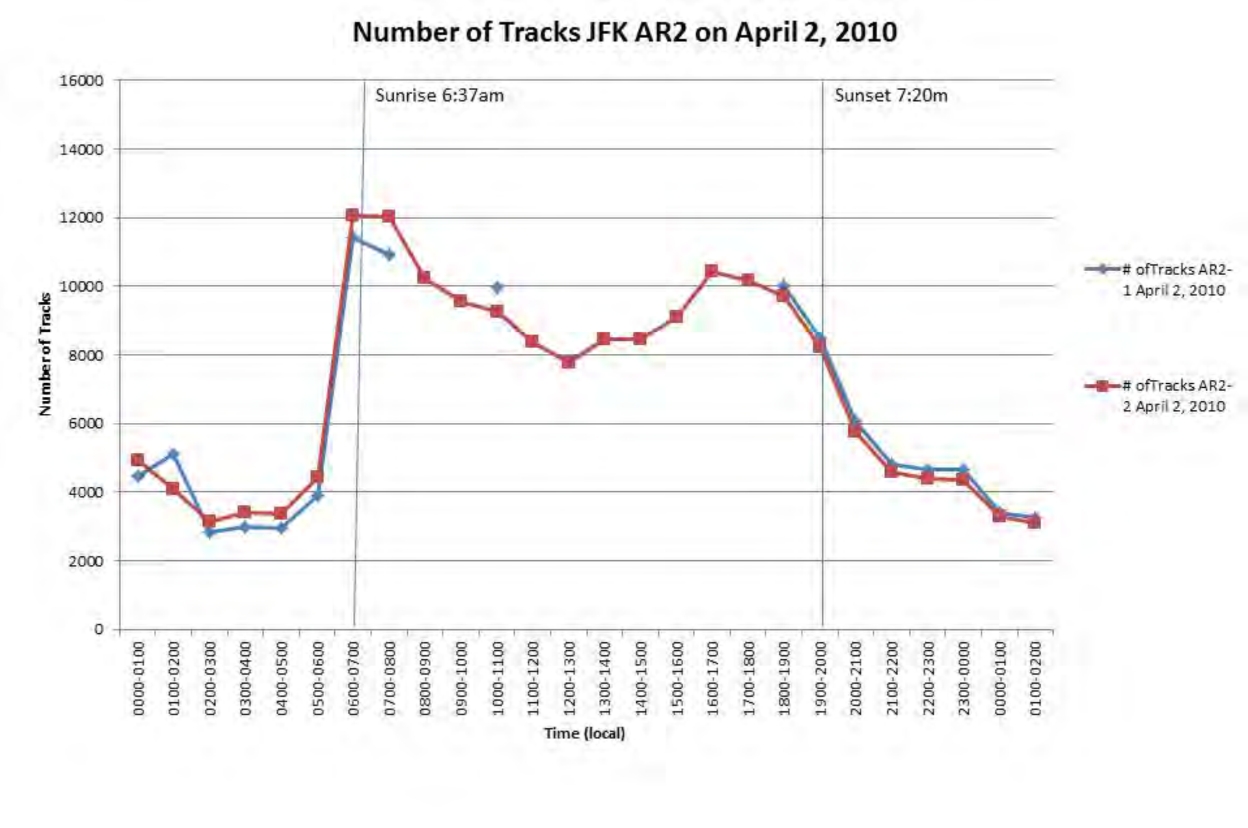


Figure 55. Number of Tracks on AR2-1 and AR2-2 on April 2, 2010

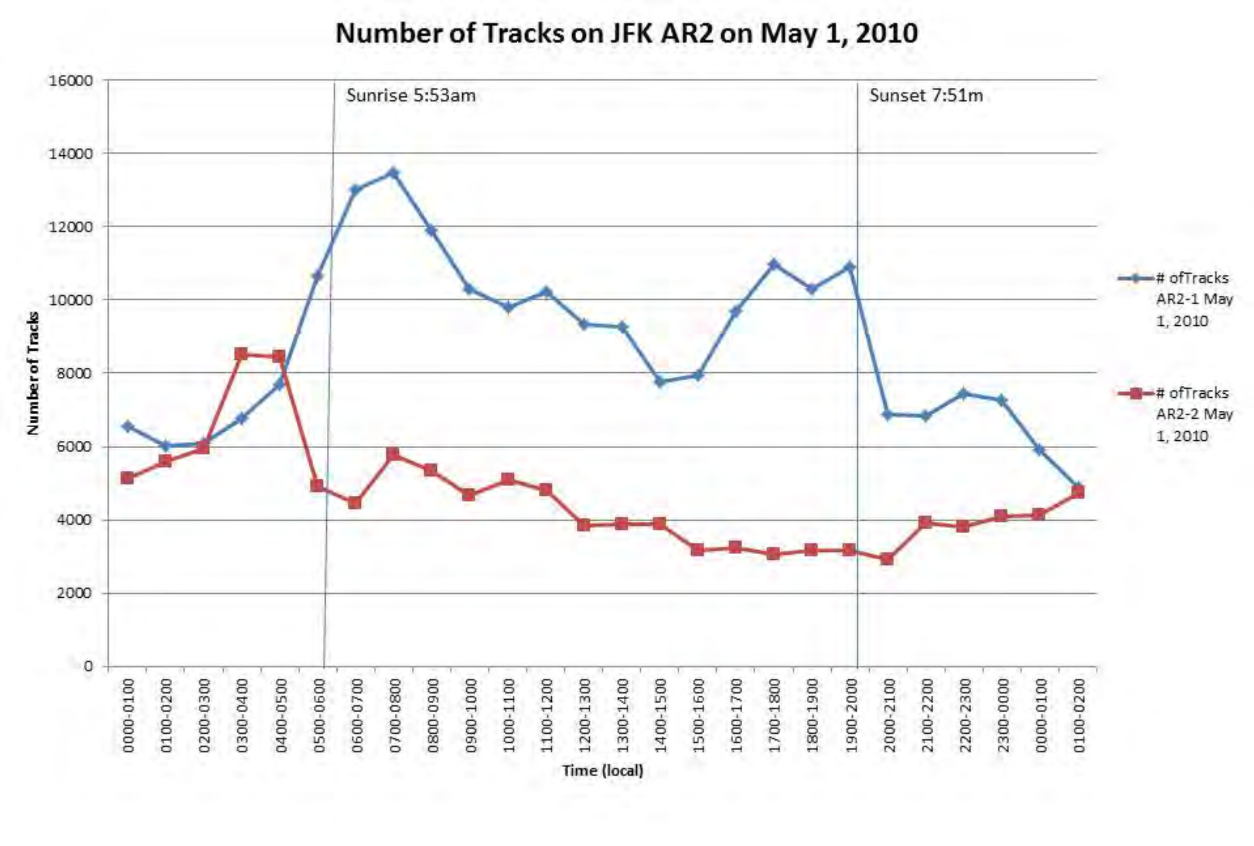


Figure 56. Number of Tracks on AR2-1 and AR2-2 on May1, 2010

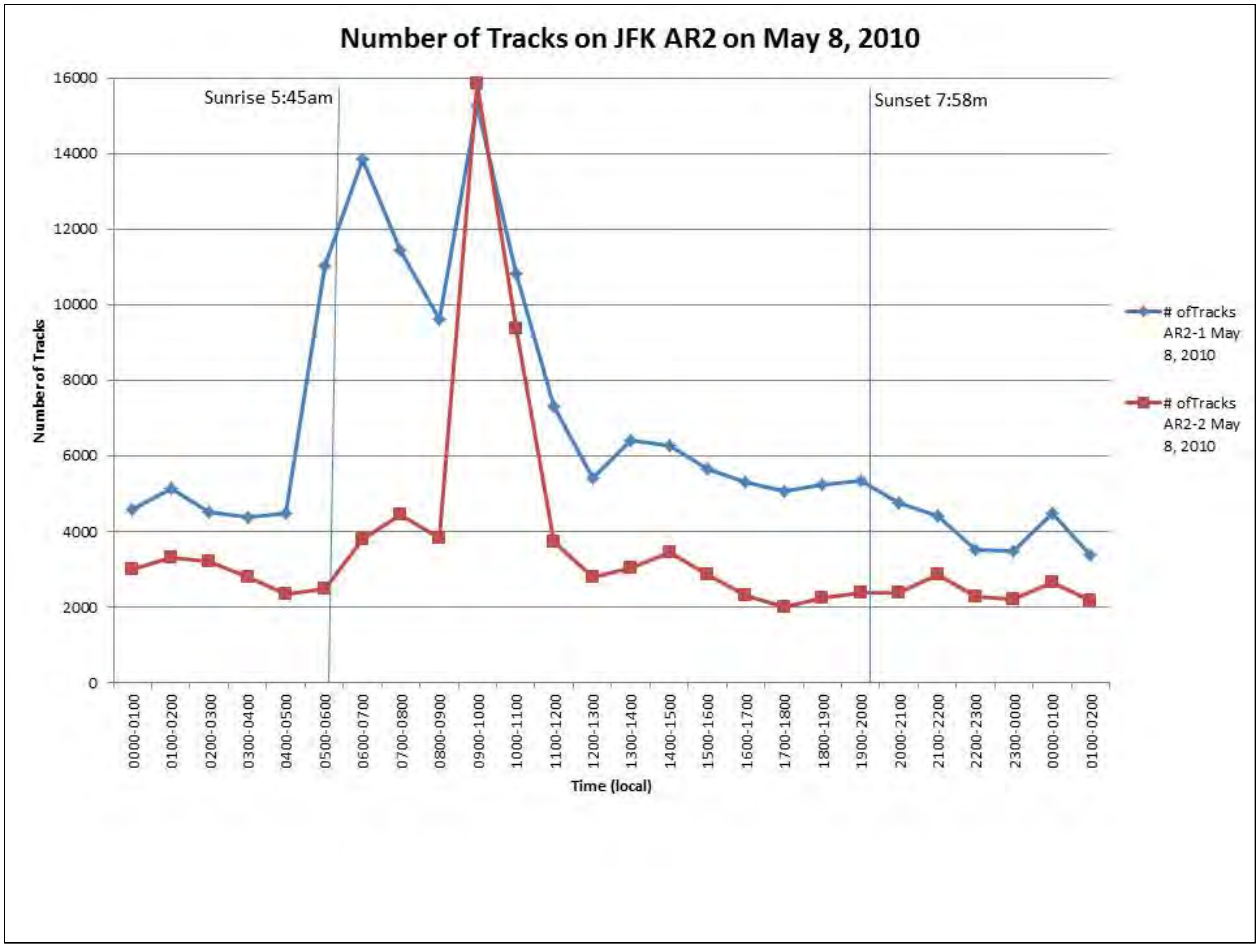


Figure 57. Number of Tracks on AR2-1 and AR2-2 on May 8, 2010

In this analysis, the AR2-1 had higher track counts than the AR2-2. This may be attributed to the detection of vehicles and false tracks produced by multipath and side-lobe interferences. Weather conditions could also influence track numbers, with precipitation producing false tracks. The peak on May 8 is likely due to rain.

When timing and the higher levels of activity expected during major migration are considered, the track distribution over time on April 2 suggests migration as indicated by a peak in activity between 22:00–24:00. The distribution of tracks on May 1 shows high activity near dawn and dusk in the AR2-1 and a small peak in activity near 03:00 in the AR2-2. The low activity at higher altitude is repeated on May 8 with a dawn peak in activity in the AR2-1. The peak in track counts on May 8 at 10:00 corresponds to recorded rainfall. Interpretation of these results from multiple days suggests migration and diurnal movement of birds to and from nighttime roosts. This analysis illustrates the variability in radar data and the difficulty in interpreting results in after-the-fact analyses. In this instance, rain data (i.e., time and duration of the event) was limited but was sufficient to identify possible rain influence on track numbers. It was possible to relate activity to likely behavior of birds. CEAT personnel found that radar information was useful in confirming general patterns of movement and activity, but any cause-and-effect interpretation required planned studies that would provide measures of environmental factors, radar data, and field observations.

In addition to detailed analysis keyed to days with more strikes or days with longer track lengths, CEAT personnel used radar display replays to identify events or conditions that could be related to migratory activity. Through this analysis, CEAT personnel identified different patterns in different seasons. In Spring 2010, the number of tracks observed increased around 22:00. CEAT personnel observed that the location and number of tracks became more consistent from one night to the next in late April through early May 2010. This is consistent with migration studies conducted by Professor Sidney Gauthreaux on Long Island between 2001 and 2005 [11]. When translating these results into hazard potential, a greater hazard may occur in the spring with low-altitude bird movement across the northwest portion of Runway 31R and movement from East High Meadow to the intersection of Runways 31L and 4L, circled in yellow in figure 58.

Figure 58. Track History From 21:15–21:20 on May 1, 2010

Another common pattern during spring migration was a movement with an easterly heading across Joco Marsh, which is south of Runway 4L, circled in yellow in figure 59. The radar beam at this location would provide coverage below the expected approach altitude to Runway 4L.

Figure 59. Track History From 22:45–22:50 on April 6, 2010

In the fall, radar displays suggested higher levels of activity throughout Jamaica Bay. The movements tended to the southeast and crossed over Joco Marsh, which is in the approach to 4L, circled in yellow in figure 60.

Figure 60. Track History From 21:25–21:30 on October 31, 2010

3.2.5 General Analysis of Radar Targets.

The definition of ITO and the characterization of GOT were organic developments related to observation and analysis of the radar data record, sections 2.6.5.6 and 2.6.5.7. To address objectives related to bird-movement characterization and analysis of time-related variability, CEAT personnel initiated reviews of the recorded radar displays. For each day within the study period, the TVW was used to replay the radar display at faster than real time. The display acceleration varied from 5 to 7 minutes for 8 hours of record to much slower display rates that were adjusted to target activity levels. The TVW also allowed changes in display rate for a study session. Using the display and pause method, studies were performed on GOTs. When a GOT was observed, the display replay was paused and data were recorded. The recorded data included date, time, approximate size of movement, and approximate latitude and longitude of the movement ITO. For selected GOTs, a screenshot was made and the GOTs enumerated. With the date and time information, CEAT personnel related GOTs to daily variability;

associated environmental factors, such as tides; considered weather, lighting, dawn, and dusk issues; and developed data sets for assessment of longer term variability in activity and movement. GOTs were also related to topographic features. A typical GOT screenshot is provided in figure 61. The GOTs in this study included approximately 4 to 30 tracks. Generally, the GOTs in the AR2-2 display contained fewer tracks than in the AR2-1 display.

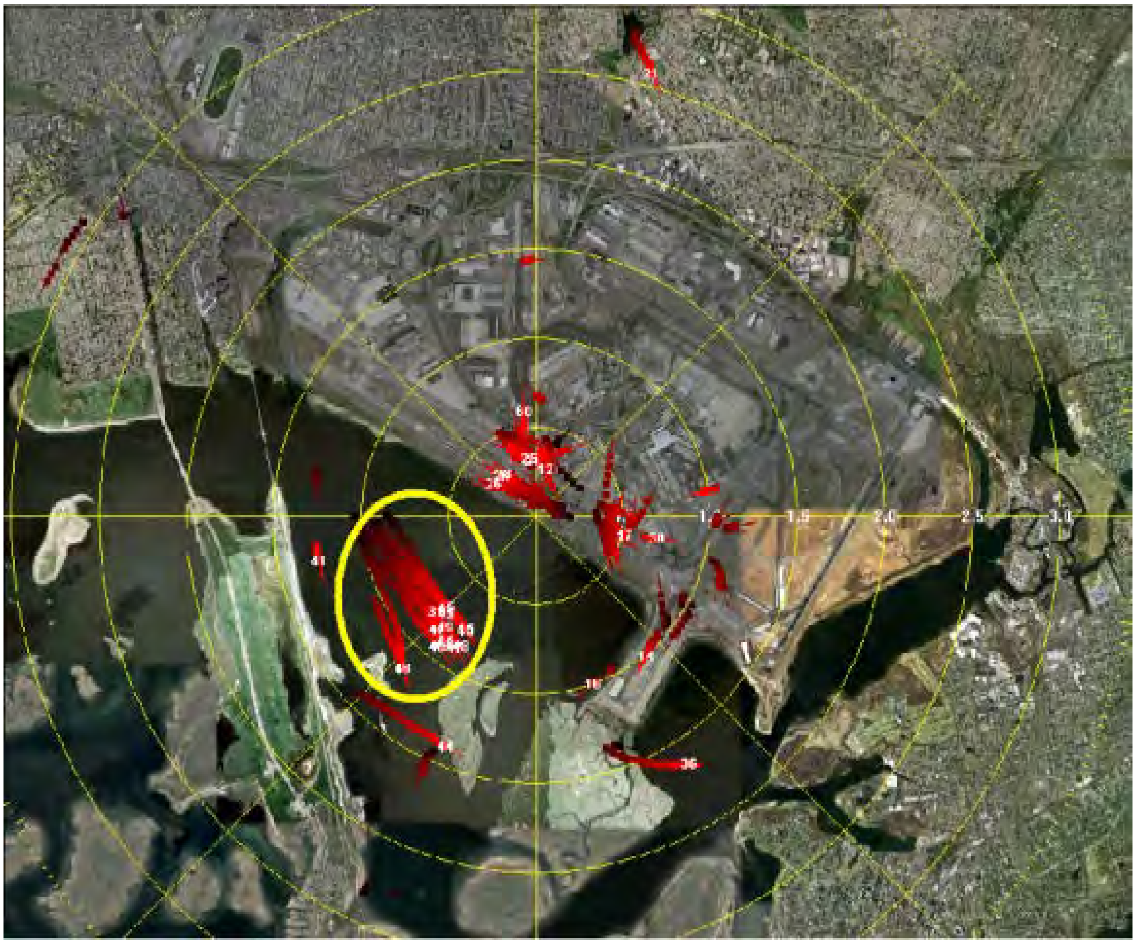


Figure 61. Screenshot From the AR2-2 on May 16, 2010 at 19:33

CEAT personnel developed methods to quantify display track information. In these methods, a GOT was selected in the paused screen. The TVW ruler tool was used to measure the North-South and East-West axes of each GOT. The display was restarted and again paused. The GOTs measurements were repeated three more times on paused displays, generally selecting at the beginning, middle, and end of each GOT. The measurements were used to estimate area, and the four measurements were compiled to provide a final GOT area estimate. In an example from May 2010, the AR2-2 had an average area for GOTs between 0.002 mi^2 (1.28 acres) and 0.217 mi^2 (140 acres). The area of most GOTs was less than 0.068 mi^2 (44 acres), shown in figure 62.

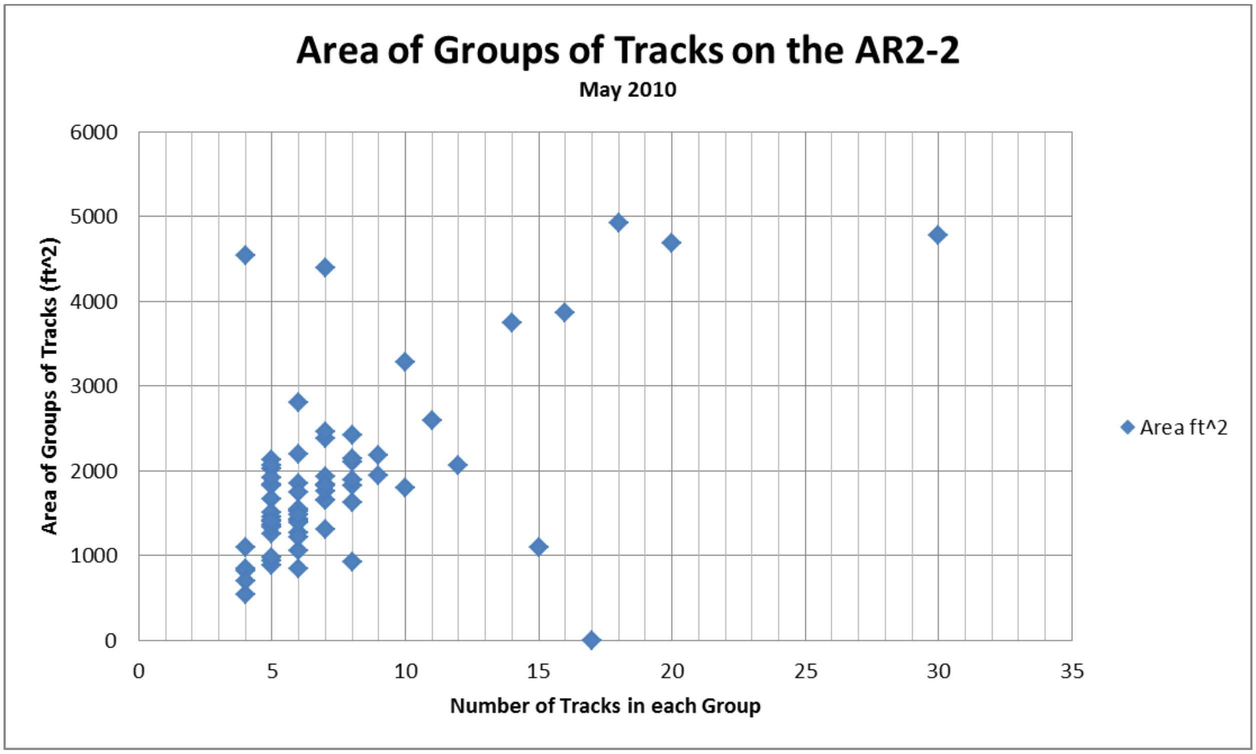


Figure 62. Average Area for AR2-2 GOTs Observed and Number of Tracks per Group

It was also possible to estimate the approximate latitude and longitude of a GOT on a paused screen and, with additional display pauses, determine heading. From this type of analysis, CEAT personnel identified areas of increased activity related to the number of GOTs in a display. Figure 63 provides an example of the interpretation of GOTs location using AR2-1 and AR2-2 data.

Figure 63. Common GOT Locations Based on AR2-1 (red) and AR2-2 (yellow) Data

CEAT personnel examined the location data for useful information. Using ITO location for identified GOTs suggested different movement patterns at lower and higher altitudes. To address the potential bias associated with activity at altitude, a simple metric was developed to provide an indication of activity for data from the AR2-1 and AR2-2. The percentage of GOTs in a display originating from different locations was calculated using the following formula:

[(total number of GOTs from specific area)/(total number of GOTs for that radar)]*100%

This provided a location specific activity estimate. A compilation of the results from this study in May 2010 is shown in figures 64 and 65. The ITOs for the GOTs in the AR2-1 were most common at Joco Marsh and at East High Meadow. In fact, nearly half the GOTs identified in the AR2-1 entered the beam near Joco Marsh. The AR2-1 at this location covered altitudes from near the horizon to approximately 600 ft. In comparison, on the AR2-2, covering altitudes from approximately 600 ft to 1200 ft, only 8% of the GOTs entered the beam near Joco Marsh. Thirty percent of the GOTs entered the AR2-1 near East High Meadow, where altitudes covered were from the horizon to 435 ft. Twelve percent of the GOTs entered the AR2-2, where altitudes covered were from 435 ft to 860 ft. Both Joco Marsh and East High Meadow are reported locations of nesting colonies.

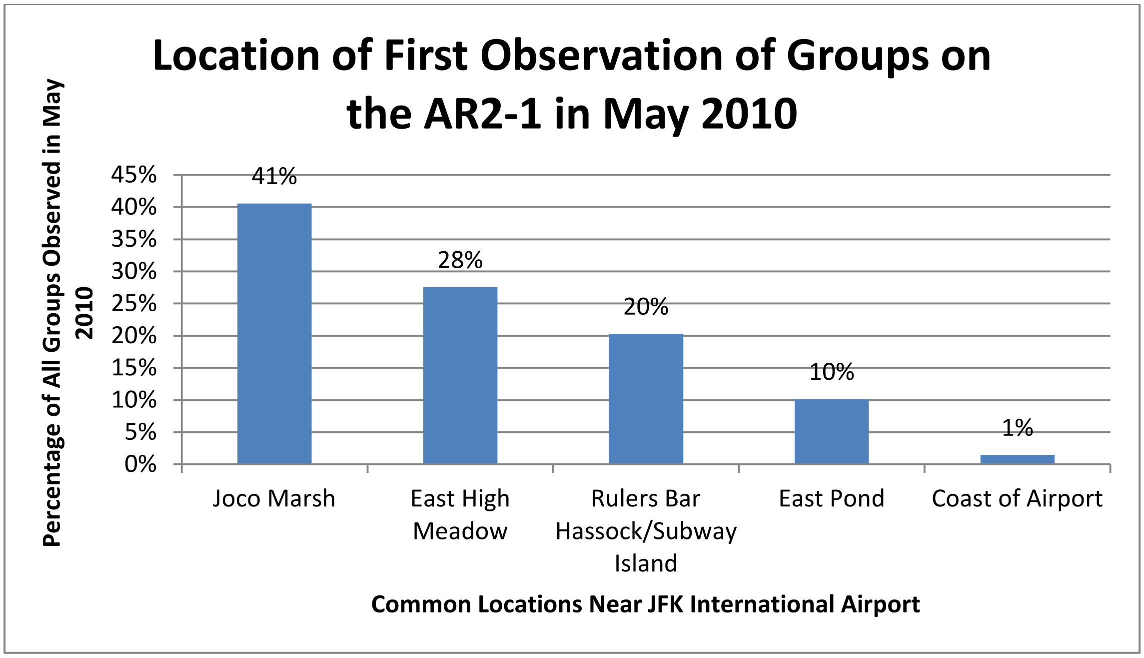


Figure 64. Locations GOTs Were First Observed on the AR2-1

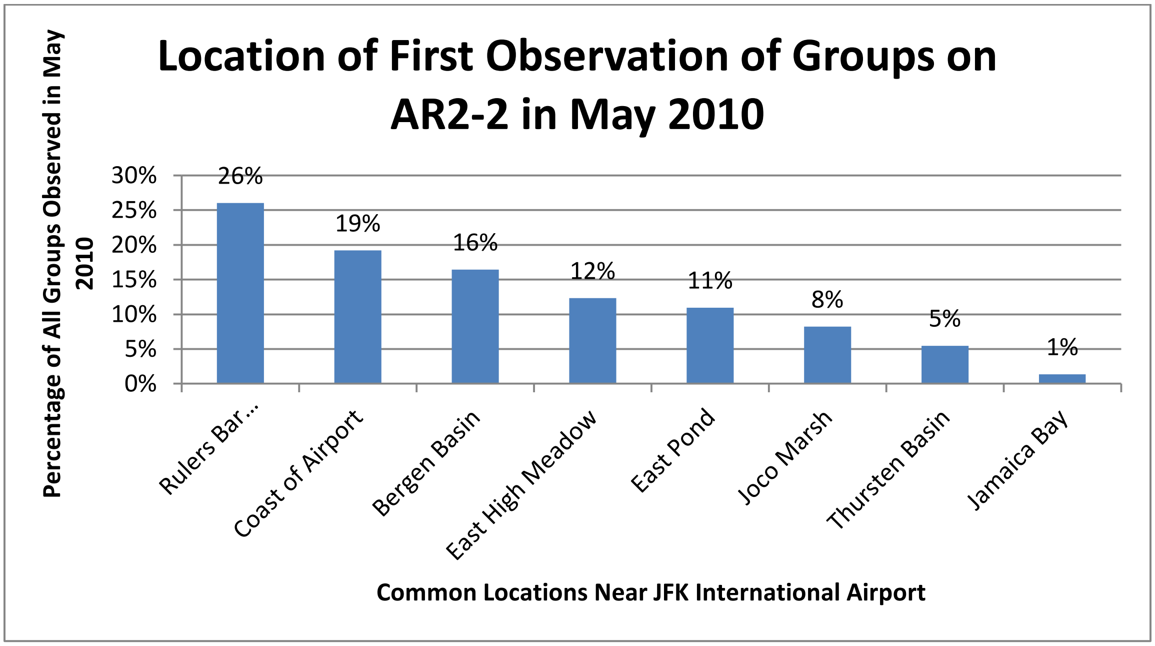


Figure 65. Locations GOTs Were First Observed on the AR2-2

The AR2-2 had 26% of GOTs originating in the beam near Rulers Bar Hassock/Subway Island, while the AR2-1 had 20%. Both of these features are large landforms. The north end of Rulers Bar Hassock is 1.6 miles from the radar; the south end is 2.3 miles from the radar. The AR2-1 covered altitudes from the horizon to 600 ft on the north end of Ruler Bar Hassock and to 850 ft on the south end. The AR2-1 covered from 600 ft to 1200 ft on the north end of Ruler Bar Hassock to 850 ft to 1700 ft on the south end. East Pond, which is 1.75mi from the radar, is located approximately in the middle of Ruler Bar Hassock. Approximately 10% of GOTs entered both the AR2-1 and the AR2-2 near East Pond where the AR2-1 covered altitudes from the horizon to 650 ft and the AR2-2 covered altitudes from 650 ft to 1300 ft.

CEAT personnel also used this display analysis to identify heading, and found no trends in the AR2-1, as shown in figure 66. In fact, the tendency observed was for GOTs to head in all directions, with some emphasis on headings toward the center of Jamaica Bay. For the AR2-2, GOTs movement headings were identified. ITOs near Subway Island tended to have north or northeast headings towards the shore, the runway, or east towards Thursten Basin. The GOTs near Bergen Basin tended to have headings south or southeast towards Rulers Bar Hassock or Joco Marsh in Jamaica Bay. GOTs near the South Coast of Airport tended to head south to the Rulers Bar Hassock, Joco Marsh, or East High Meadow. These general display analyses provided an initial means to quantify display data, and CEAT personnel began to develop a better understanding of bird movement dynamics on and around JFK airport. Movements and activity are clearly greater at low altitudes, although CEAT personnel observed some influence of ground vehicles and multipath at surface locations on or near the airport. Over water and at higher altitudes, movement and activity were less than observed near the ground. Movement and activity patterns in Jamaica Bay identified by the radar tended not to be at locations that presented immediate hazard to aircraft, with the exception of movement patterns that crossed the Runway 4L flight path.

Figure 66. Direction of Movements Shown on the AR2-2 (yellow) and AR2-1 (red)

CEAT personnel also used display analysis to identify timing of movements and activity. The time recorded for each GOT was noted in the general display analysis. The criterion for identification of GOTs was a display with 4 to 30 or more tracks in a movement. The time GOTs occurred was plotted, producing multiple GOTs for some days and fewer to none on other days. Using these plots, the time of GOTs observations was correlated with diurnal changes in light and daily tides in Jamaica Bay. The expectations for movement and activity are tied to a long history of bird observations. Bird activity is related to diurnal lighting conditions with peaks of activity at dawn and dusk and generally lower activity at night than during the day time. This characteristic behavior pattern can be modified by weather and other environmental factors, and overall movement and activity patterns can change seasonally, particularly during migration where activity tends to increase. The time-related counts of GOTs are provided in figures 67 and 68. These figures provide daily GOT counts for May 2010, with sunrise and sunset indicated. For each day, the GOT time is shown by the blue diamond. Some days have multiple GOTs and other days have none. The time of day is noted on the y-axis, and the date for each day in the period of study is on the x-axis. For example, on May 1, 2010 on the AR2-1, four GOTs were observed at approximately 01:00, 09:00, 12:00, and 14:00.

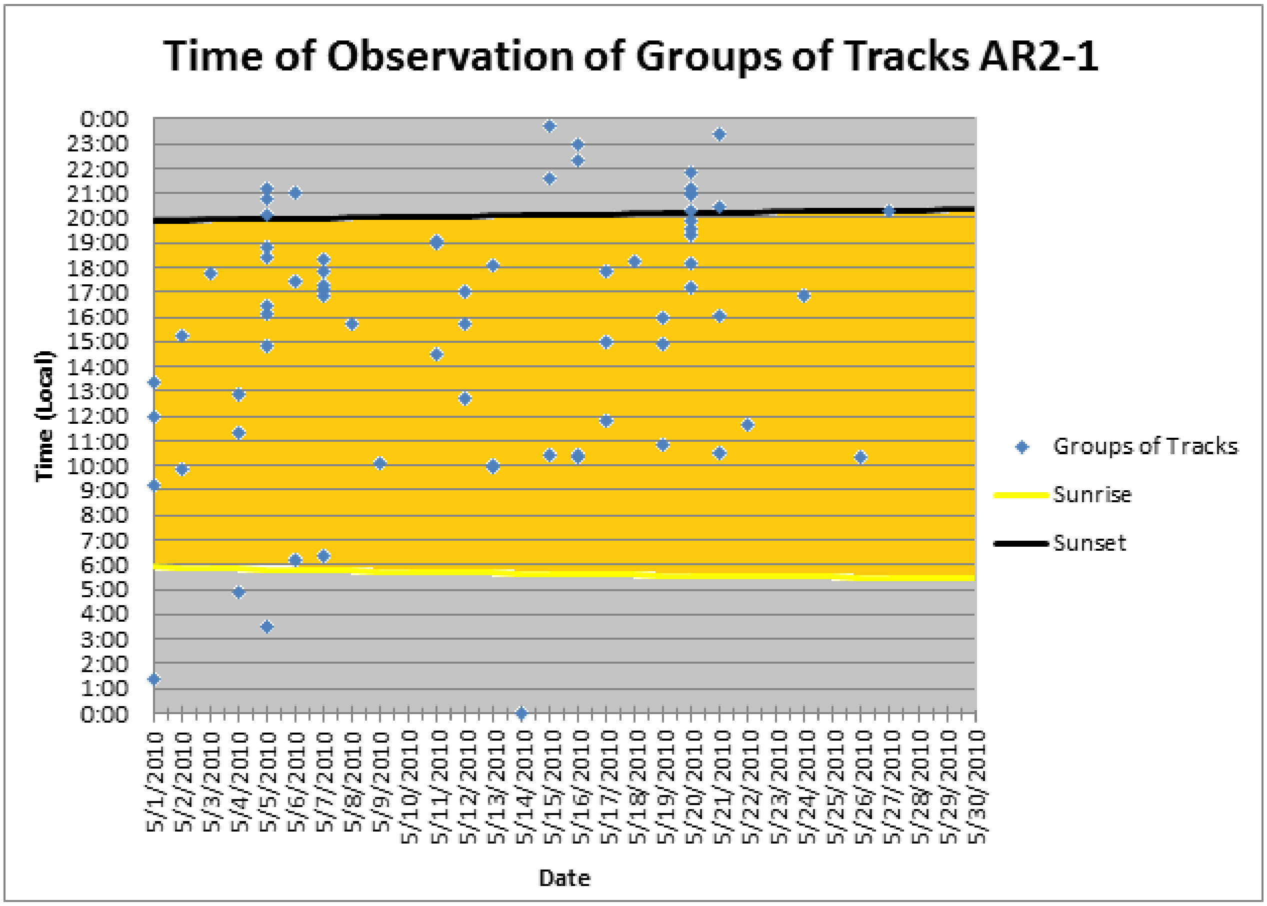


Figure 67. Time of Observation of GOTs, AR2-1

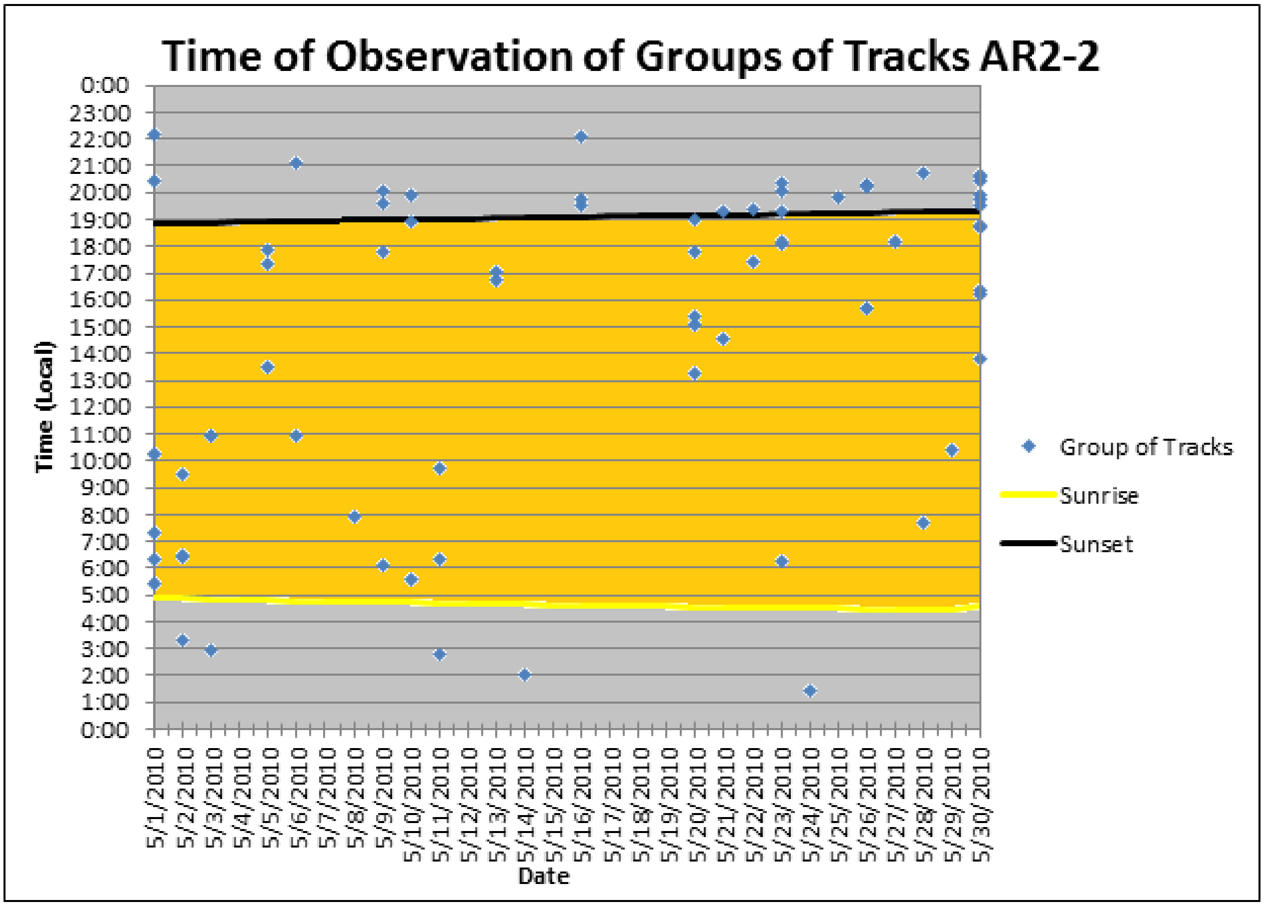


Figure 68. Time of Observation of GOTs, AR2-2

CEAT personnel used TDV spreadsheet data to confirm observations made from display GOT analysis. In this check, the TPHs were developed from the spreadsheet data. Only tracks with more than five updates were included in this analysis. Track number was then plotted in a bar graph, providing hourly compilations of the total tracks present. Figures 69 and 70 provide this compilation for May 15, 2010. Overall variability was low in the AR2-1, ranging from approximately 4000 to 6000 TPH. In the high beam (AR2-2), there was a distinct activity signal with greater activity levels at night.

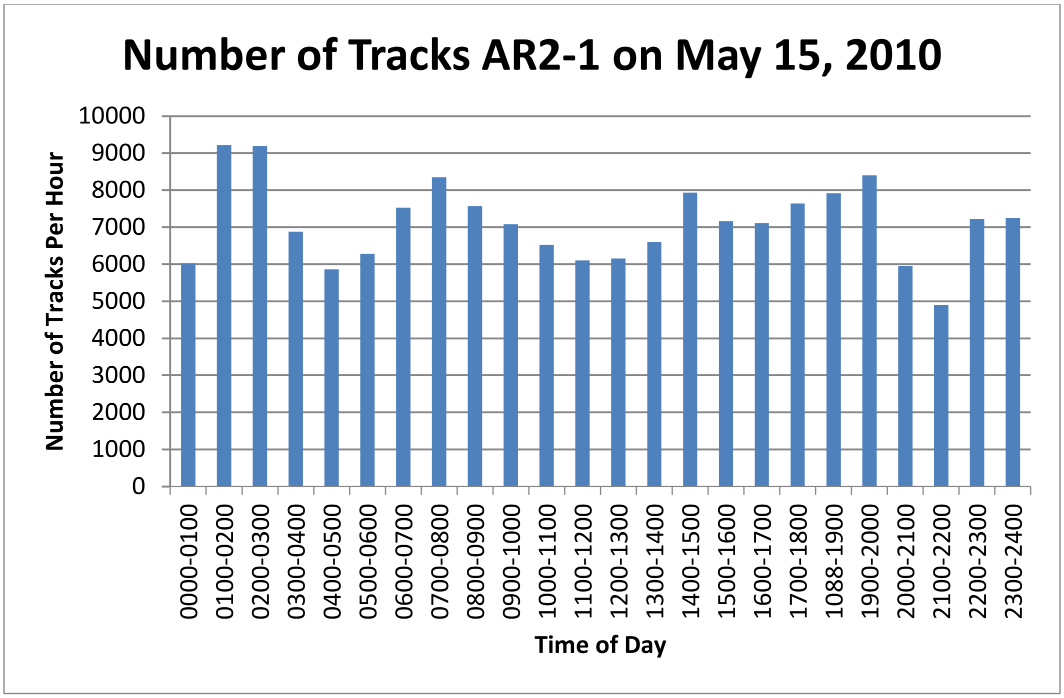


Figure 69. Hourly Track Counts for the AR2-1 on May 15, 2010

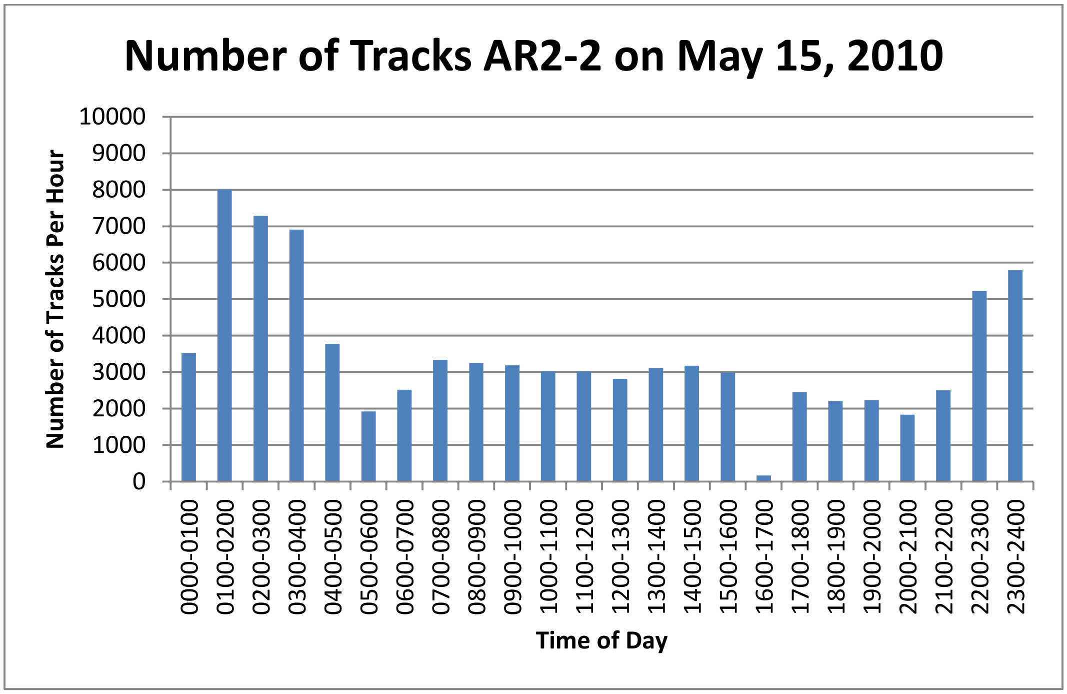


Figure 70. Hourly Track Counts for the AR2-2 on May 15, 2010

With JFK's location on Jamaica Bay, tidal change has an influence on habitat availability, and tides are known to influence bird activity. To assess potential tidal influence on bird activity on or near JFK, CEAT personnel related the observed times of GOTs to time of high and low tide. Plots of GOTs by time for May 2010 are provided in figures 71 through 74: figures 71 and 73 for the AR2-1 and in figures 72 and 74 for the AR2-2. No consistent pattern is evident in these figures. There are times where GOT time is related to high or low tide on both the AR2-1 and AR2-2, but there is a greater tendency for GOTs around 18:00, which is near dusk. Although this analysis is only for a single month and cannot be considered conclusive, it does not appear that the tidal change in Jamaica Bay is a major influence on bird activity.

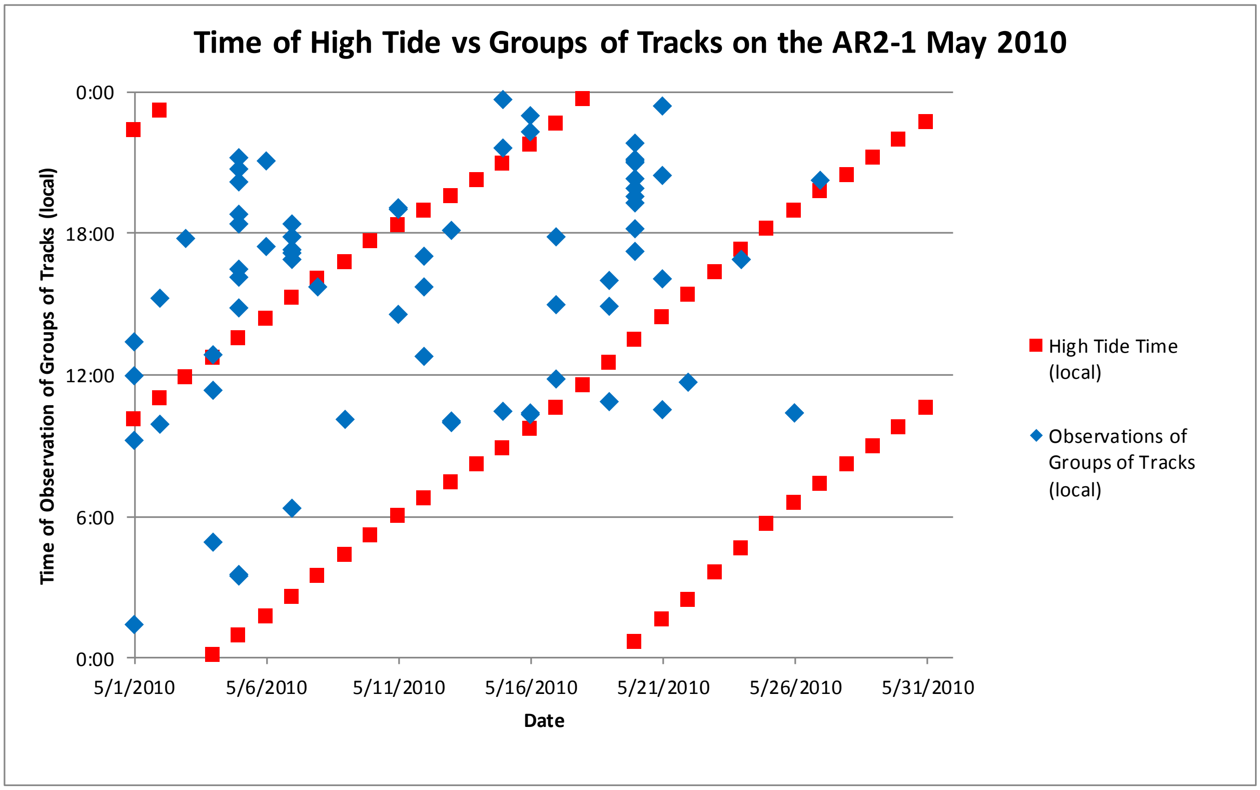


Figure 71. High Tide Related to GOTs on the AR2-1

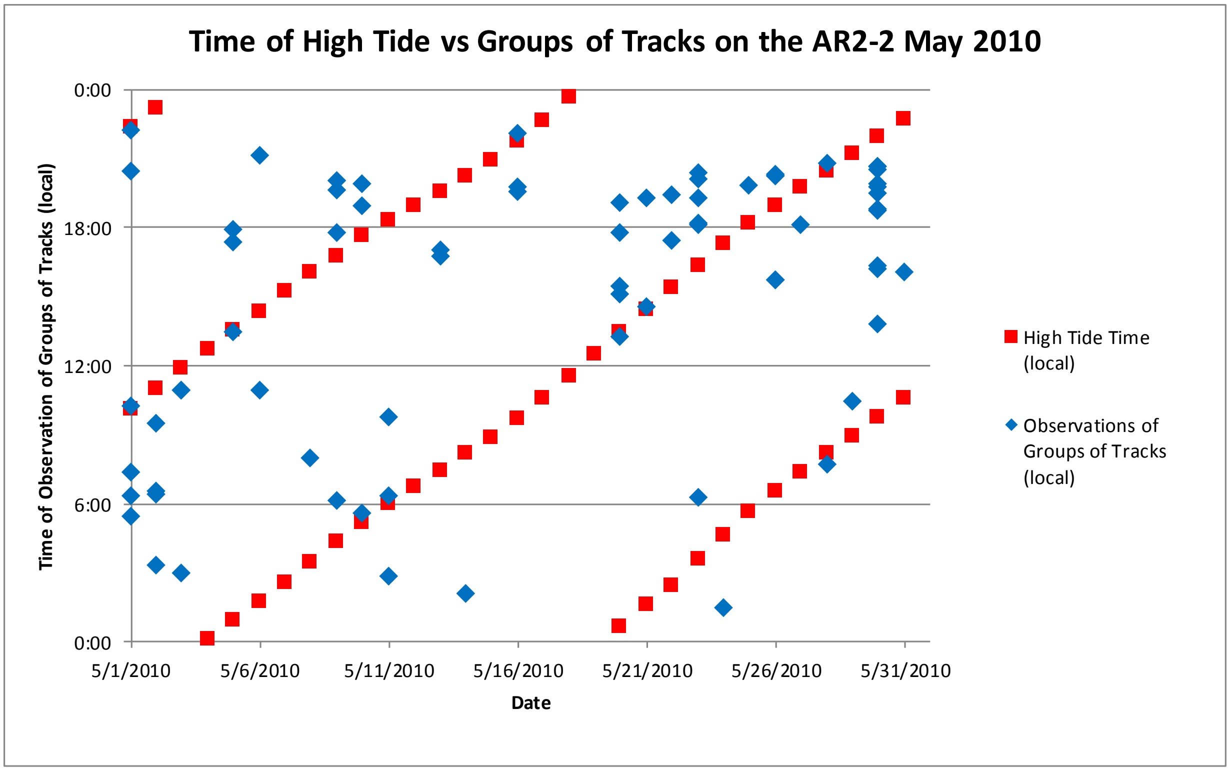


Figure 72. High Tide Related to GOTs on the AR2-2

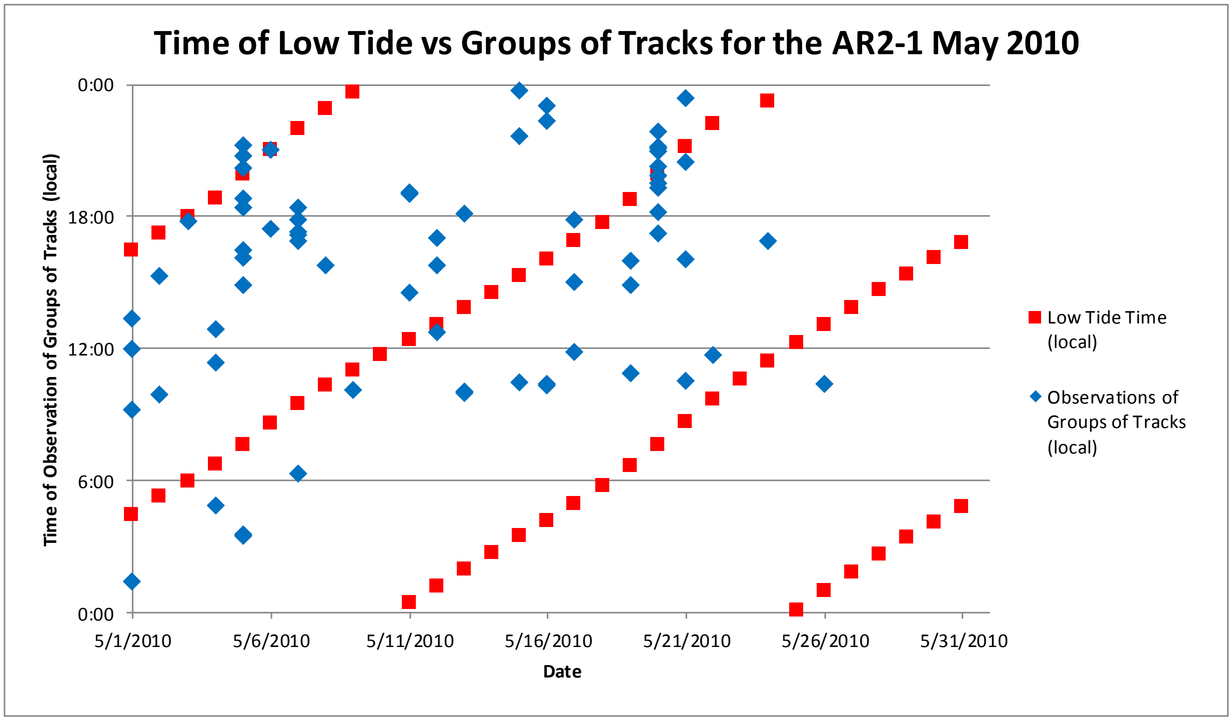


Figure 73. Low Tide Related to GOTs on the AR2-1

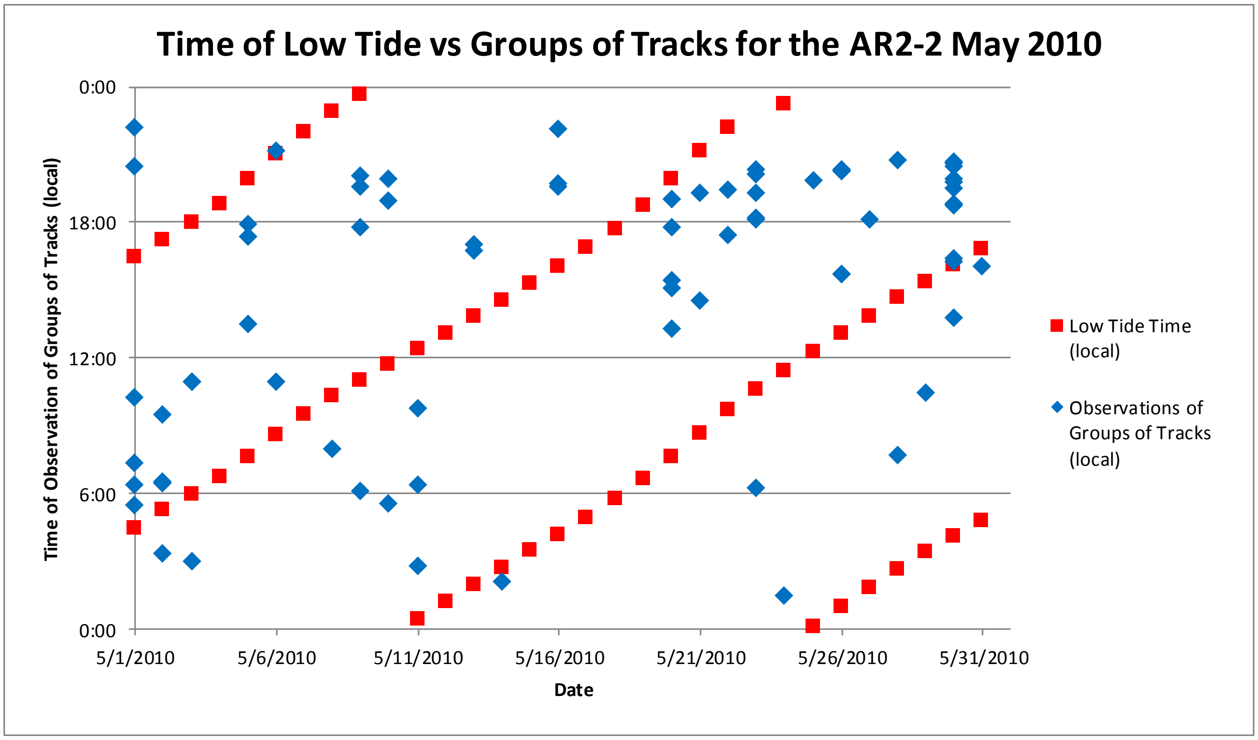


Figure 74. Low Tide Related to GOTs on the AR2-2

3.2.6 Migration Over and Around JFK.

The long-term operation of multiple-radar units provides additional utility in migration studies. Further, the detection and analysis of movements and activity related to migration address assessment objectives to help identify daily to interannual dynamics of bird movement. This section addresses questions of migration movement and activity and provides examples of data analyses that illuminate how airport avian radars can contribute to wildlife management and, potentially, air traffic control.

CEAT personnel investigated whether avian radar systems of the type deployed at JFK can identify migratory activity. Because migratory activity typically occurs at higher altitudes, the AR2-2 radar was the main radar data source for these analyses, with the AR1 and AR2-1 radars providing comparative results for lower-altitude movements. First, CEAT personnel reviewed track histories generated by the TVW. High-altitude movement patterns can be characterized as long tracks with the same heading. Figures 75 and 76 provide track histories for the AR2-2 radar for May 1, 2010 and October 31, 2010. Long tracks moving at a uniform heading are easily identified in these figures. The track heading, estimated from the track display (the white box followed by the red track) indicate a northerly movement in the spring (May) and a southerly movement in the fall (October), identifying seasonal heading differences.

To confirm that the tracks displayed were associated with migration, radar data were analyzed. To obtain this radar data, the TDV was used to select radar data for May 1, 2010 and export it to a spreadsheet. The data were then analyzed using spreadsheet functions and graphical capabilities. The results for this analysis found that a plot of track altitude for May 1 showed tracks at higher altitudes at night. This plot supported a rough correlation in timing between the track history display and high-altitude tracks, as shown in figure 77.

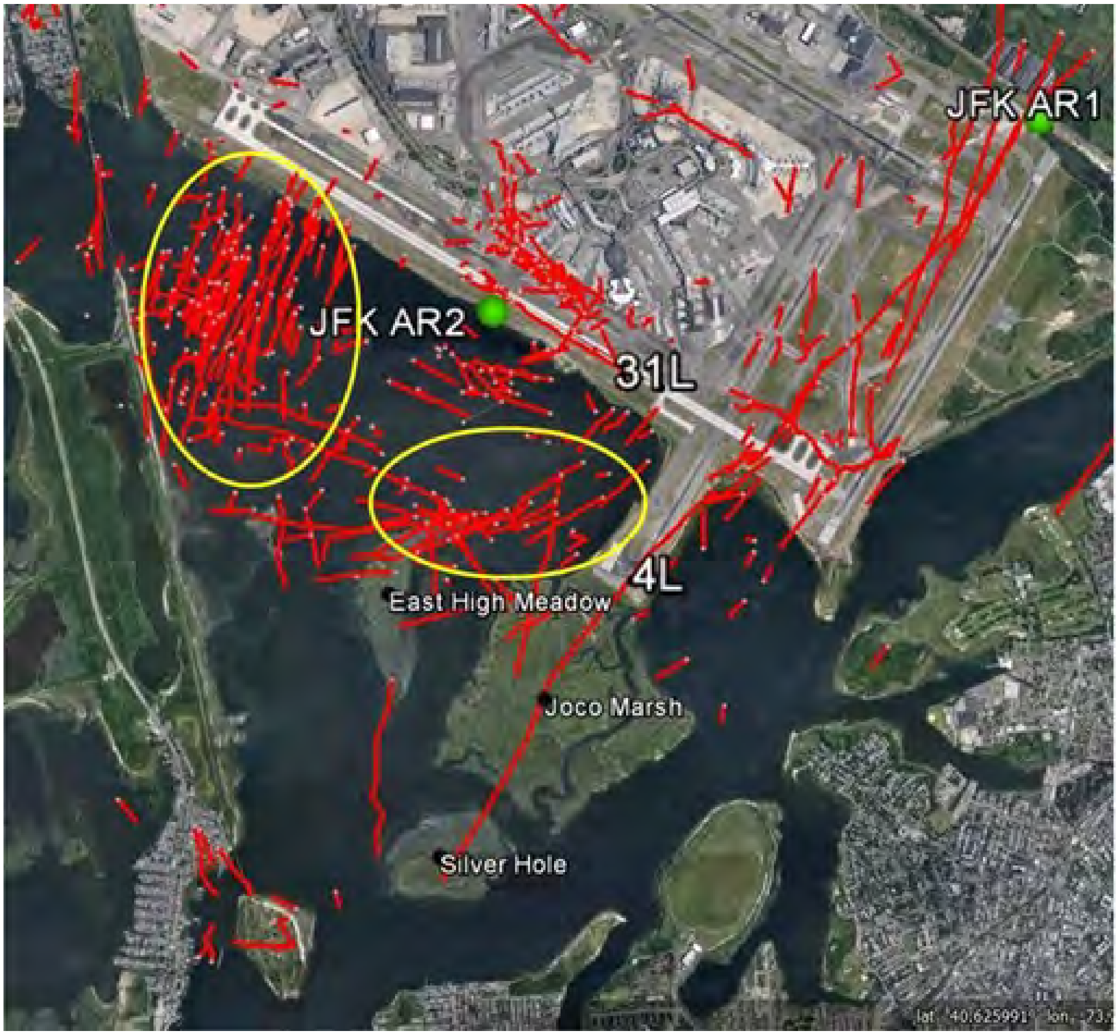


Figure 75. Example of Spring Migration: AR2-2 Track History From 21:15–21:20 on May 1, 2010

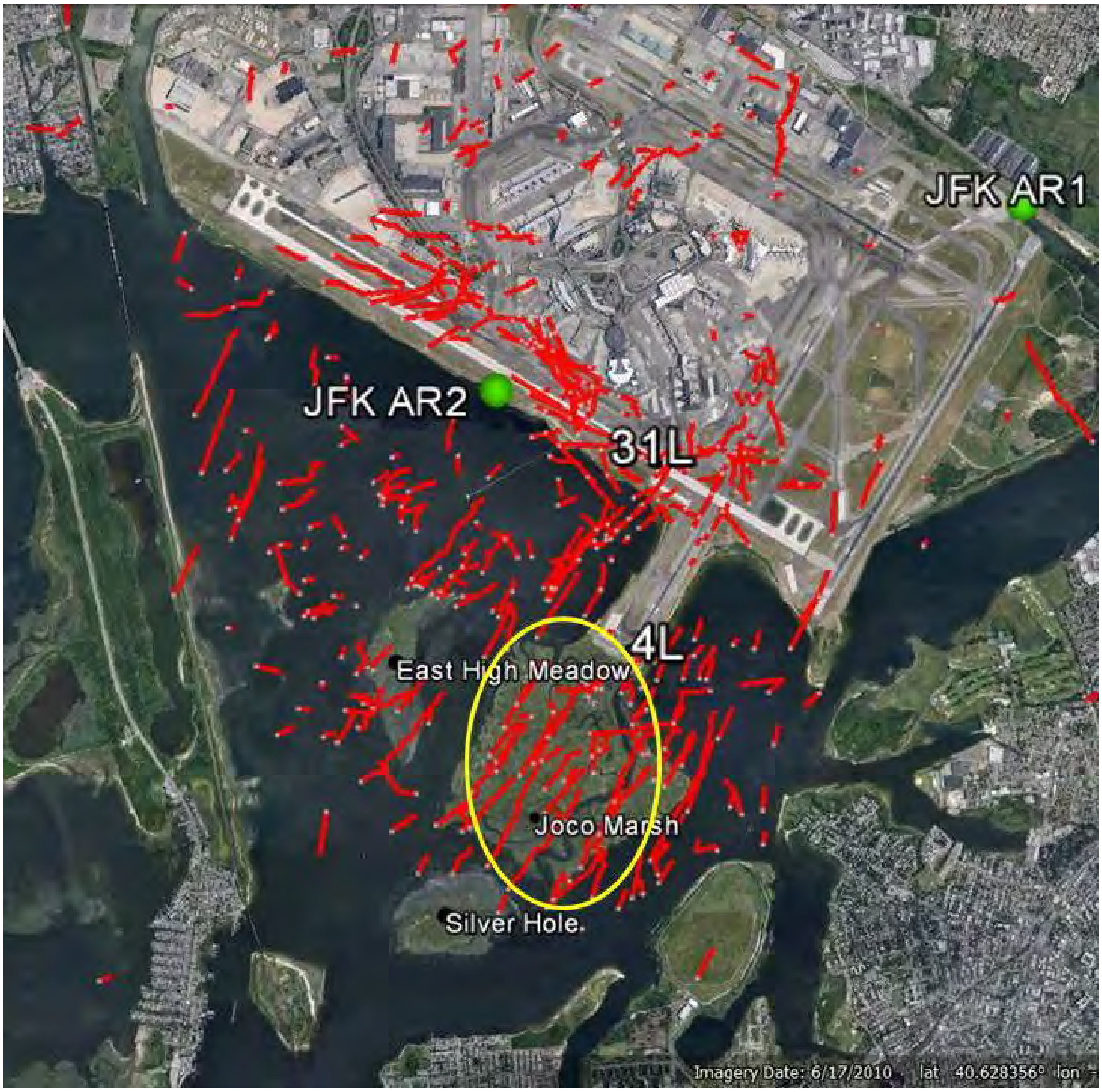


Figure 76. Example of Fall Migration: AR2-2 Track History From 21:25–21:30 on October 31, 2010

Figure 77. The AR2-1 and AR2-2 Altitude Plots for May 1, 2010

Velocity is another useful metric in determining migration. The general expectation is that higher velocities will be maintained by migrating birds. Figure 78 provides a plot of the 1-hour track velocity from AR2-2 data for May 1, 2010. This plot is consistent with migration because higher velocities are present at night. The availability of AR2-1 and AR2-2 data shows a consistent velocity pattern in both radars, with higher velocities at night and lower velocities during the day, and the AR2-1 indicating generally higher velocity during the day than the AR2-2. The velocity data set does not support migration determination as strongly as altitude, but patterns are consistent with migration and may provide wildlife biologists with an indicator of potential migration that they could seek to verify by other means such as optical sensors.

Figure 78. The AR2-1 and AR2-2 Velocity Plots for May 1, 2010

The final radar data set analyzed for May 1, 2010 was number of tracks, shown in figure 79. The general expectation would be that the number of tracks in the AR2-2 would be greater at night when migration activity is high. It would also be expected that AR2-1 activity would be less at night, reflecting reduced activities, such as feeding. Figure 79 shows activity peaks for the AR2-1 at dawn and dusk. Overall activity levels at lower altitudes are greater than at higher altitudes, and no peak in higher altitude track counts correlates with the track history display.

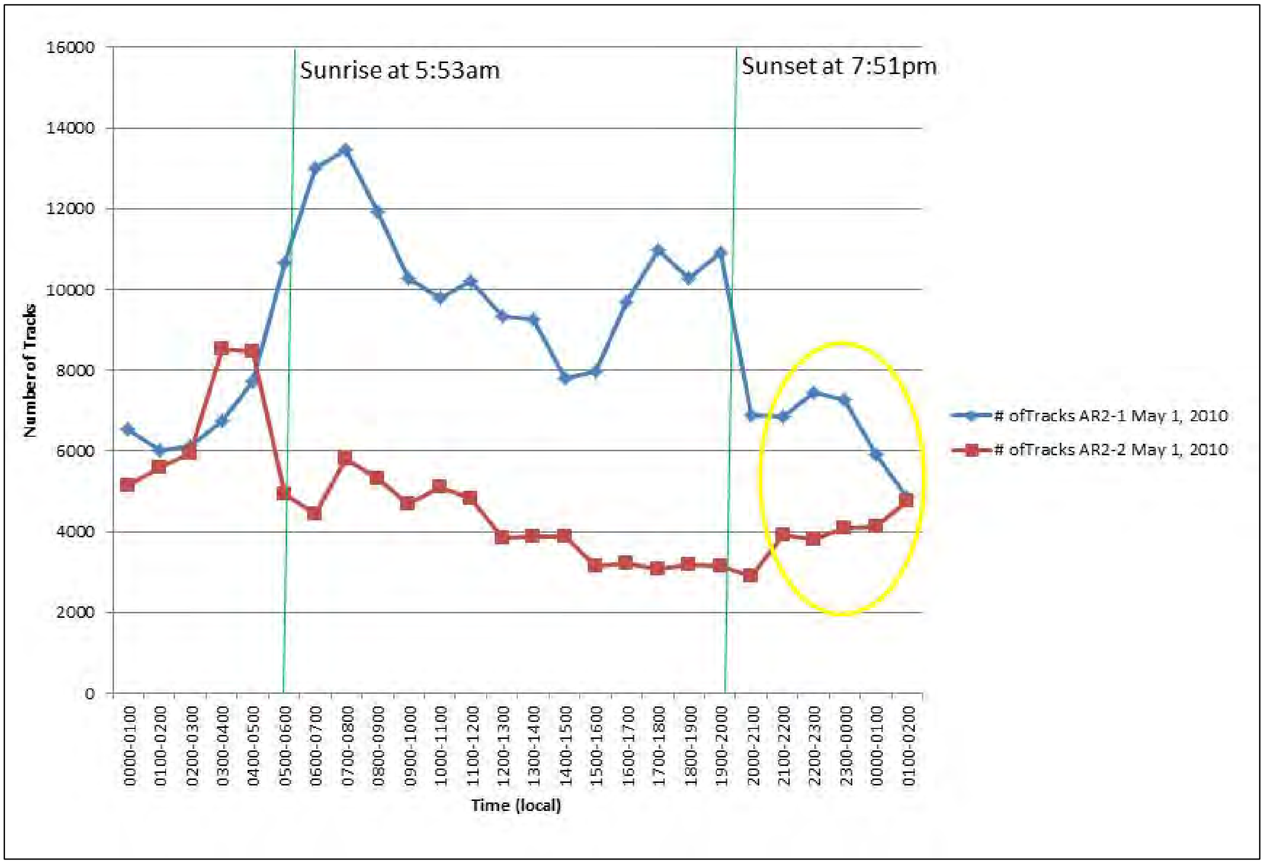


Figure 79. The AR2-1 and AR2-2 Track Counts for May 1, 2010

The absence of a correlation between display track history and track count encouraged further study to examined track data for periods when track history displays featured long tracks moving in the same direction. Three days were selected for this study: April 2, May 1, and May 8, 2010. Data from the AR2-1 and AR2-2 were used in the analysis. Plots of tracks for April 2 and May 8, figures 80 and 81, can be compared with May 1, figure 79. The AR2-1 generally had higher track counts than the AR2-2, a result that suggests generally higher movement activity at low altitudes. This is consistent with visual observations and expectations based on bird behavior in the vicinity of the wildlife refuge where feeding, roosting, and nesting (all occurring at low altitude) are common. The higher AR2-1 counts may also be due to detection of vehicles and slow moving aircraft in this low beam and the presence of false targets due to multipath or side-lobe interference associated with ground targets. The peak in activity on May 8 in the middle of the day is likely due to rainfall-induced high track counts. These results do not clearly define migratory movements, but they do provide examples of some difficulties associated with interpretation of radar data. Although displays and analyses of altitude and velocity suggested migration, examination of 24 hours of track counts did not produce the same strong migration signal. Further, activity at altitude may be tied to general levels of activity, which can be interpreted from figure 80 for April 2. Peak counts are not always due to bird movement, as shown on figure 81 when rain was related to high track counts.

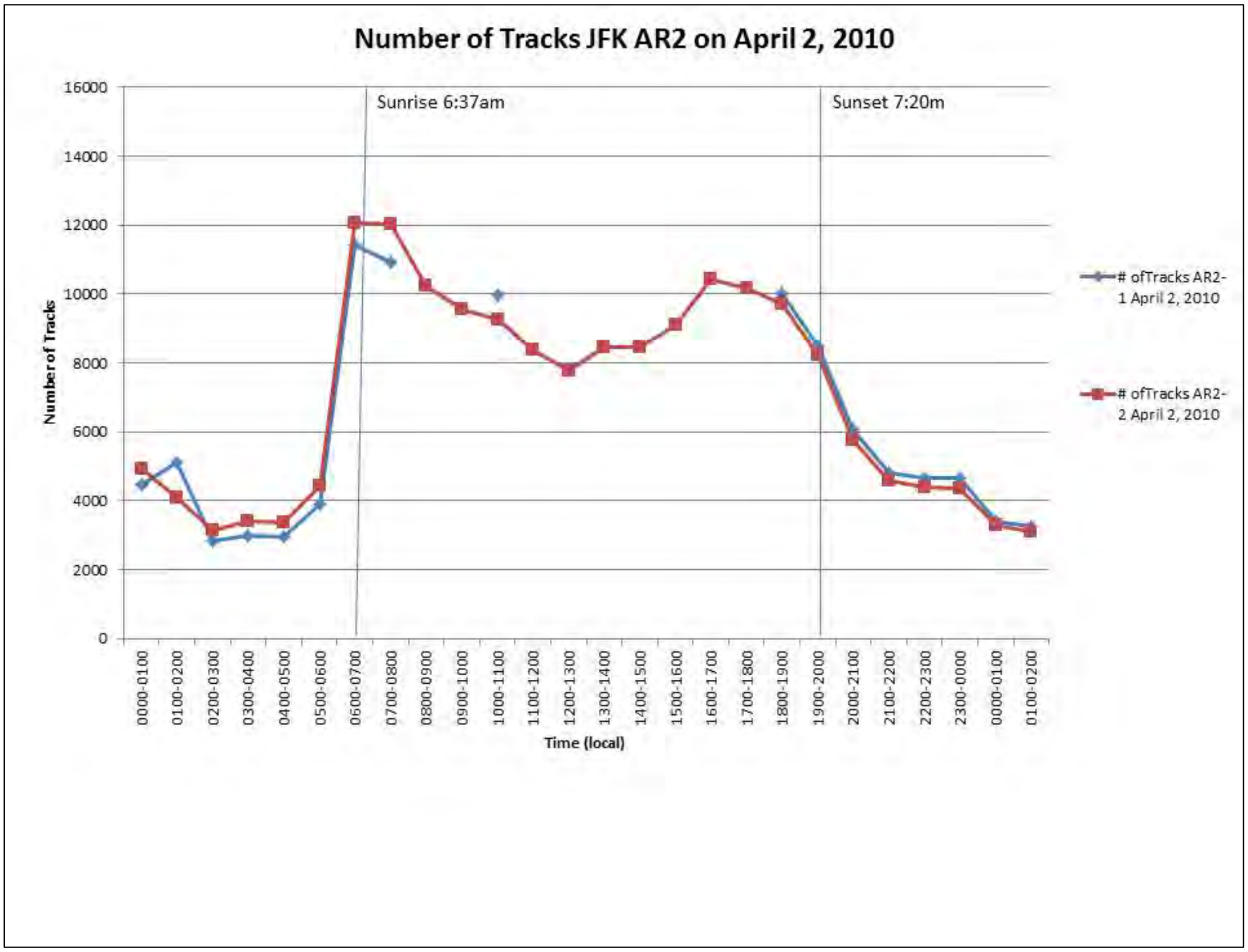


Figure 80. Number of Tracks on AR2-1 and AR2-2 on April 2, 2010

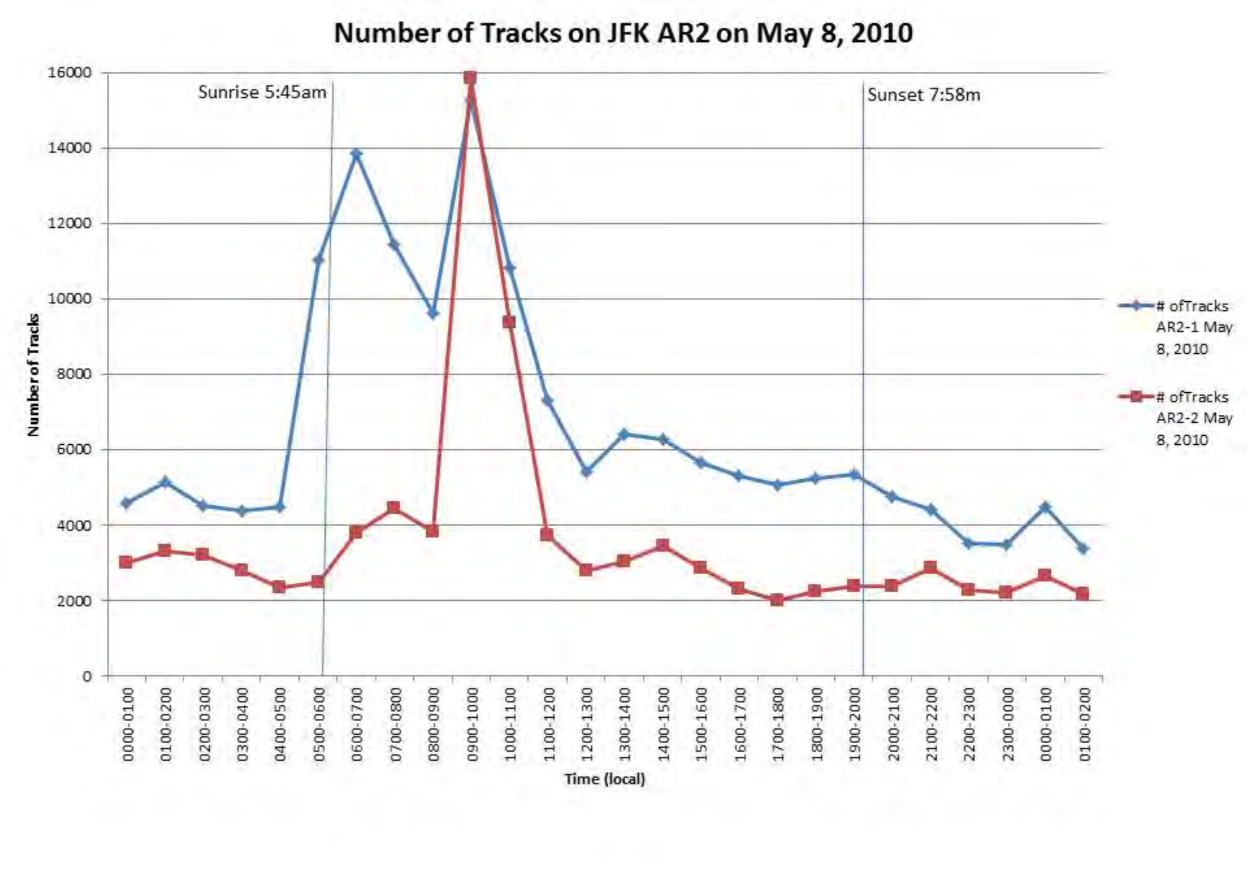


Figure 81. Number of Tracks on AR2-1 and AR2-2 on May 8, 2010

With identification of radar display and data characteristics typical of migration, CEAT personnel sought to further confirm radar utility for migration detection and analysis. This was accomplished by determining if the radar record differed between periods when no migratory activity is expected and periods when migration would be expected. May and June 2010 and September through November 2010 were selected for periods with expected differences in migratory activity. Track counts for 21:00 to 23:00 were totaled from the TDV-based spreadsheet. In May and June, daily track counts varied between 6000 and 8000, as shown in figure 82. In September and October, daily track counts varied between 5,000 and 13,000, with highest counts in late October, shown in figure 83. These results suggest generally higher activity in the fall. A review of the plots for May and June show a pattern with no extreme values and a generally consistent, while somewhat variable, pattern. A review of the plots for Fall 2010 finds count variability around a value of 8,000 counts and several peaks in counts in late October with the number of tracks exceeding 12,000. For comparison, figure 84 shows the number of tracks for a nonmigratory period. These results suggest that, over a long data record, periods of increased activity coincide with expected migratory periods. The analysis also revealed that the highest levels of activity occur on a few days and that those days of high activity tend to be grouped together.

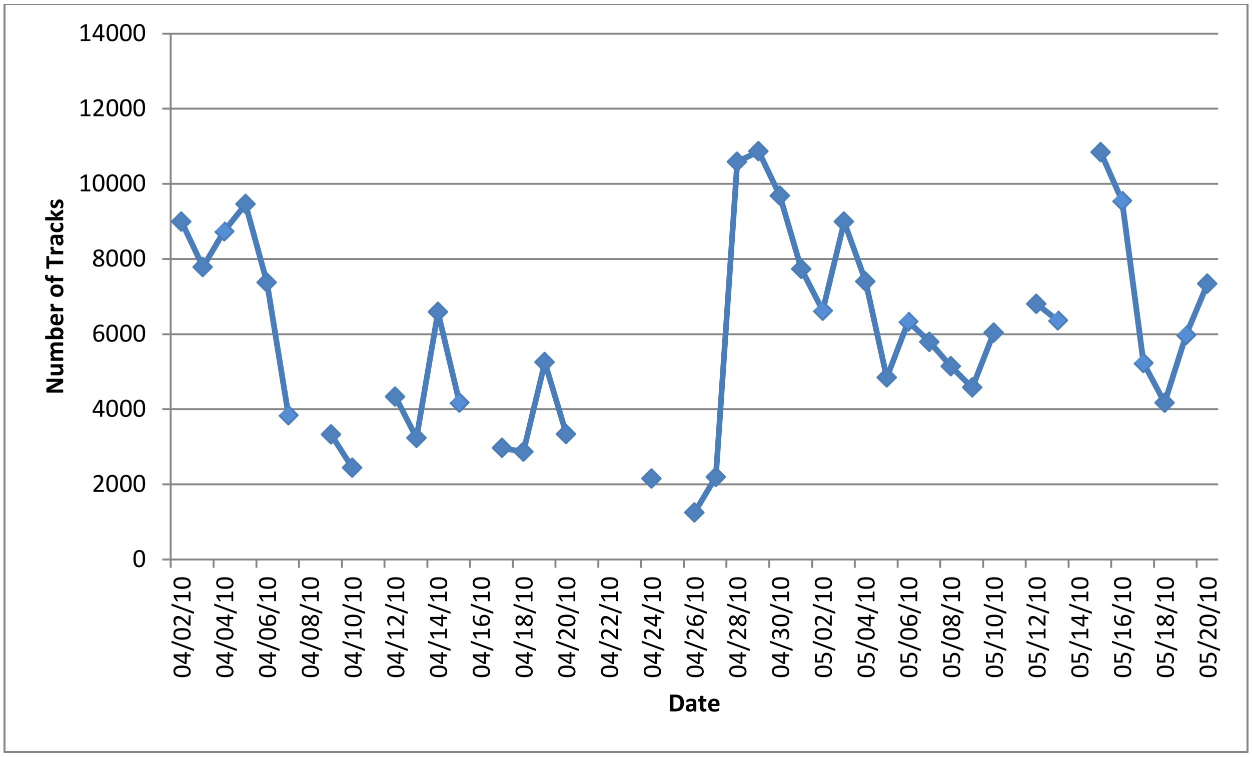


Figure 82. Number of Tracks From 21:00–23:00 on the AR2-2 in April and May 2010

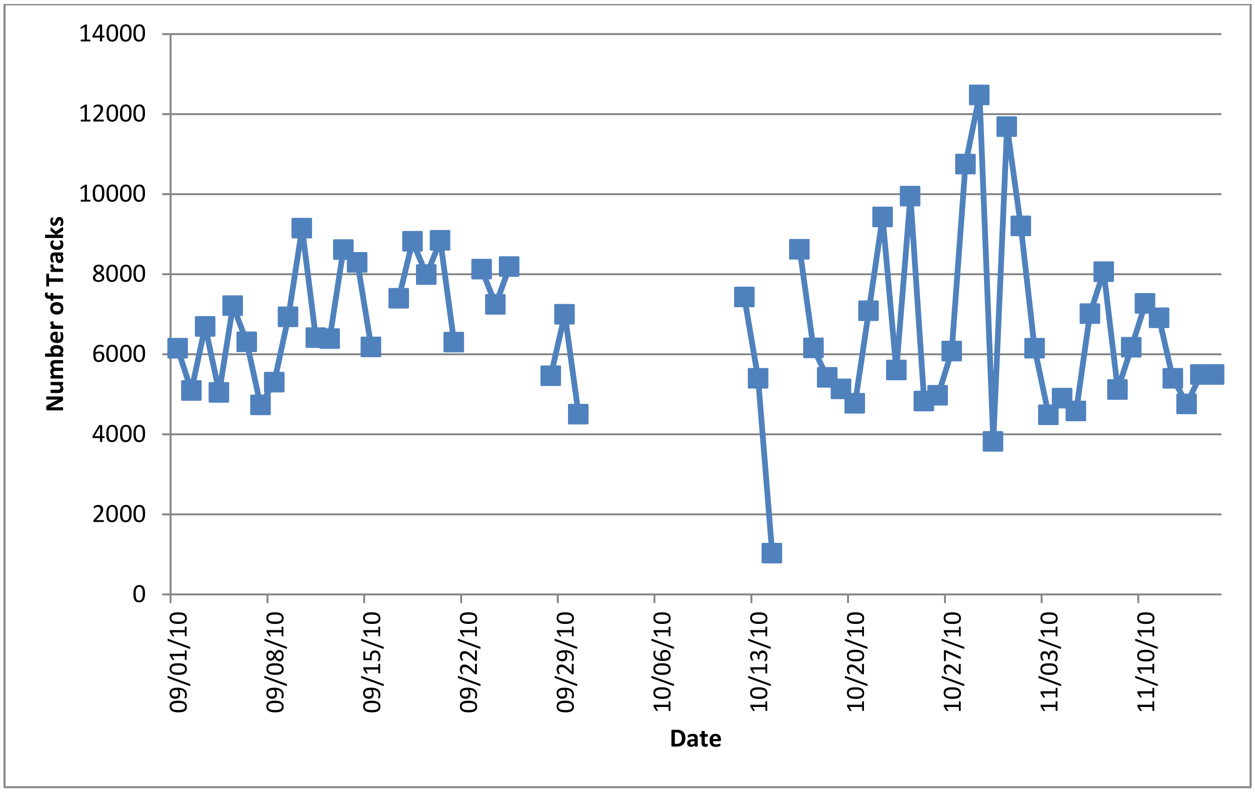


Figure 83. Number of Tracks From 21:00–23:00 on the AR2-2 in Fall 2010

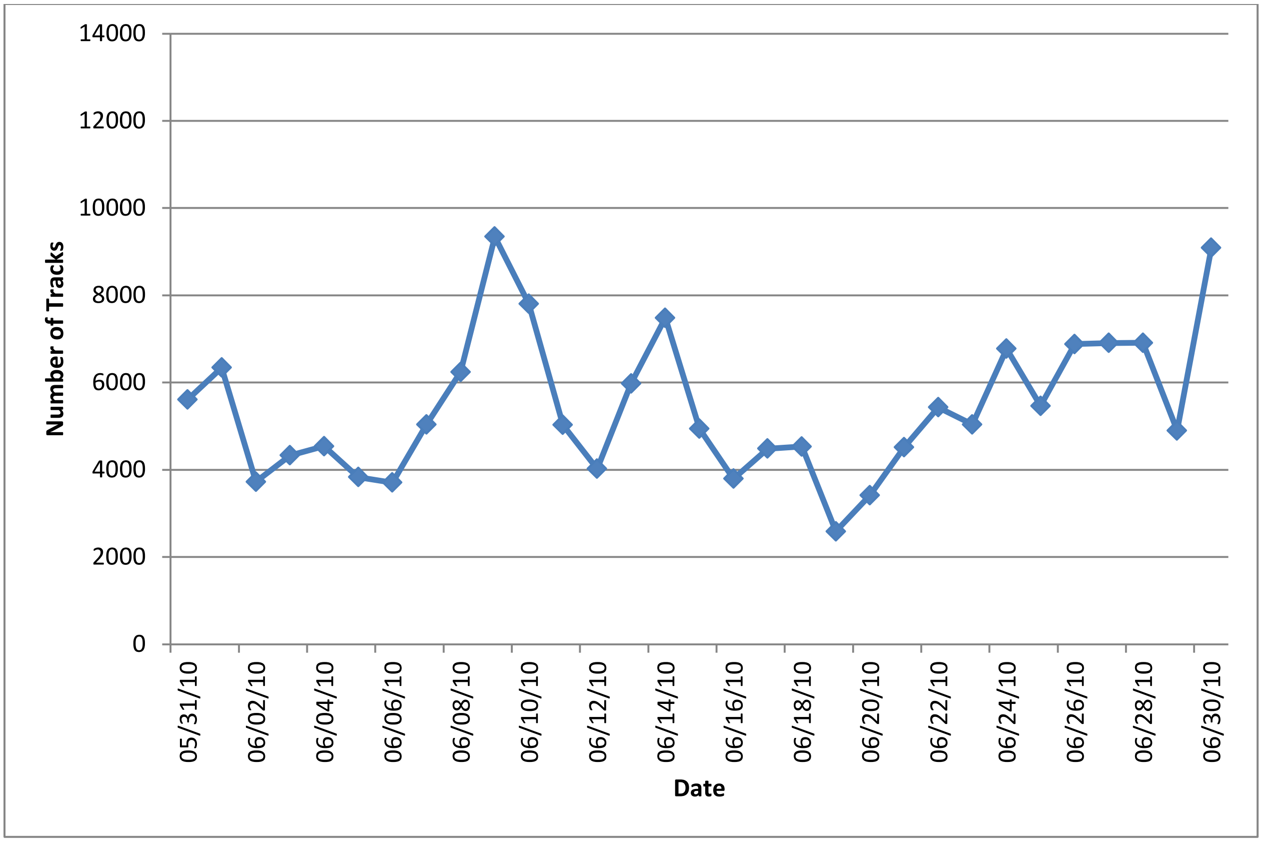


Figure 84. Number of Tracks From 21:00-23:00 on the AR2-2 in Summer 2010

In summary, the radars used at JFK are useful tools for migration detection and analysis. The radar display and track data serve as useful resources for identifying periods when bird migration occurs on and around JFK. Based on these findings, no single display or analysis metric provided enough information to confirm migration. However, TVW track-history displays were a useful tool for identifying periods when the data record should be reviewed to confirm migratory activity. The general assumption that there would be an increase in overall activity with migration was demonstrated using longer-term radar data records. However, track counts over a 24-hour period, as on April 1, 2010, did not necessarily correspond to migration movements identified in track history displays. Further, track counts may be influenced by rain, multipath, or other interferences that may produce false detections, as on May 8, 2010.

By using the full set of tools provided for radar data analysis, the study of JFK bird radar utility for migration analysis provided the foundation for developing migration analysis procedures. The studies associated with confirming the use of the JFK radars for migration analysis provided the foundation for the developing migration analysis procedures that used the full set of tools provided for radar data analysis. CEAT personnel identified the following steps for migration analysis:

a. Use the track history function in the TVW to produce plots for the suspected migration period. For JFK, analysis-abundant observational data was available from the Jamaica Bay Wildlife Refuge for identifying migration species and timing.

b. Use the TVW and TDV to select data for migration periods.

c. Prepare spreadsheet data sets for analyses that will assess activity and track characteristics for long time periods (weeks to months) and for short time periods (days and peak migration times of 21:00–23:00).

d. Conduct statistical analyses of radar data to provide range, average, and standard deviation of the number of tracks, track velocity, range-to-track, altitude, and RCS.

e. Plot radar data to support comparisons of migratory activity: (1) between daytime and nighttime periods, (2) between days, and (3) between weeks and months.

f. Analyze data to identify typical migration patterns as well as event-specific characteristics.

These analysis steps were applied in a study designed to identify the variability or consistency in bird movement activity over short and long periods. Although CEAT personnel addressed these objectives in other studies, migration was highlighted because of the water landing of the Miracle on the Hudson (U.S. Airways Flight 1549 on January 15, 2009) and the desire of JFK wildlife staff to better understand migration issues in support of wildlife hazard management planning and airport wildlife hazard management.

Two periods of migration occur annually along the Atlantic Flyway. In the fall, migratory birds move south and in the spring they move north. The CEAT avian radar performance assessment at JFK supported analysis of migrations in 2010 and 2011, providing an opportunity to assess differences in spring and fall migration periods and differences in migration dynamics in different years.

The first issue was to select periods when migration could be expected. CEAT personnel used several methods to make that selection in addition to radar display and data analysis. Information from the Jamaica Bay National Park Service and the Internet were reviewed. Bird strikes at JFK by month were reviewed using the FAA National Wildlife Strike Database. CEAT personnel also received a personal communication from Professor Sidney Gauthreaux, who conducted studies of migration using NEXRAD data for 2001-2005 [11]. His input suggested migration in April with a peak in early May. Professor Gauthreaux also noted that migration activity is often greater in the fall than in the spring and high migration activity occurs around 23:00.

Based on assessment of the JFK radar data record and other information sources, CEAT personnel selected April and May (spring) of 2010 and 2011 and September and October (fall) of 2010 and 2011 as the focus for migration analysis. Not all migratory movements occur in these months and early and late migrations may be associated with both species behavior and weather patterns. However, reducing the time period for analysis was necessary for reducing data sets to a manageable size.

In spring 2010, the AR2-2 radar was not operating on April 8 and April 21–23. In fall 2010, the radar was not operating on October 1–3. In spring 2011, the radar was not operating on April 14. The radar was operating throughout the fall 2011.

Rainfall was noted in spring 2010 on April 25, May 11, and May 14. Rainfall was noted in fall 2010 on September 16, 22, 26, 27, and October 15. In spring 2011, rainfall was noted on April 6, 11, 12, 16, 24, and May 14 and 18. In fall 2011, rainfall was noted on September 6, 7, 23, 30; October 19, 29; and November 15, 16, 21, 22, and 29.

The CEAT personnel's comparison of migrations was initiated by analysis of track numbers. Table 9 provides summaries of the number of days with track counts exceeding 8000 per day and days with track counts below 3000. Note that all track counts were for the 21:00–23:00 study period, indicating interannual variability.

Table 9. Daily Track Count Summary for Spring and Fall 2010 and 2011

Season	Days With Track Counts Above 8000	Days With Track Counts Below 3000
Spring 2010	9	6
Spring 2011	5	0
Fall 2010	15	1
Fall 2011	3	1

Track counts from the spring and fall of 2010 and 2011 are illustrated in figures 85 and 86. The spring track counts indicate both interannual variability and daily variability, with peak track counts over 10,000 per day in the 21:00–23:00 study period. The interannual and daily variability was also evident in the fall of both years, with daily peak values reaching counts of 12,000 per day in the 21:00–23:00 study period. Heavy migration was noted on April 29, 30, May 1, and October 29, 30. The daily variability was greater in spring 2010 than spring 2011. Spring 2010 had 9 days with more than 8000 tracks; spring 2011 had 5 days with more than 8000 tracks. Similarly, there were 6 days with fewer than 3000 tracks in spring 2010 and none in spring 2011. Fall 2010 had 15 days with more than 8000 tracks with several consecutive days between October 24 and 31. Fall 2011 had only 3 days with more than 8000 tracks. Fall 2010 and fall 2011 both had 1 day with fewer than 3000 tracks.

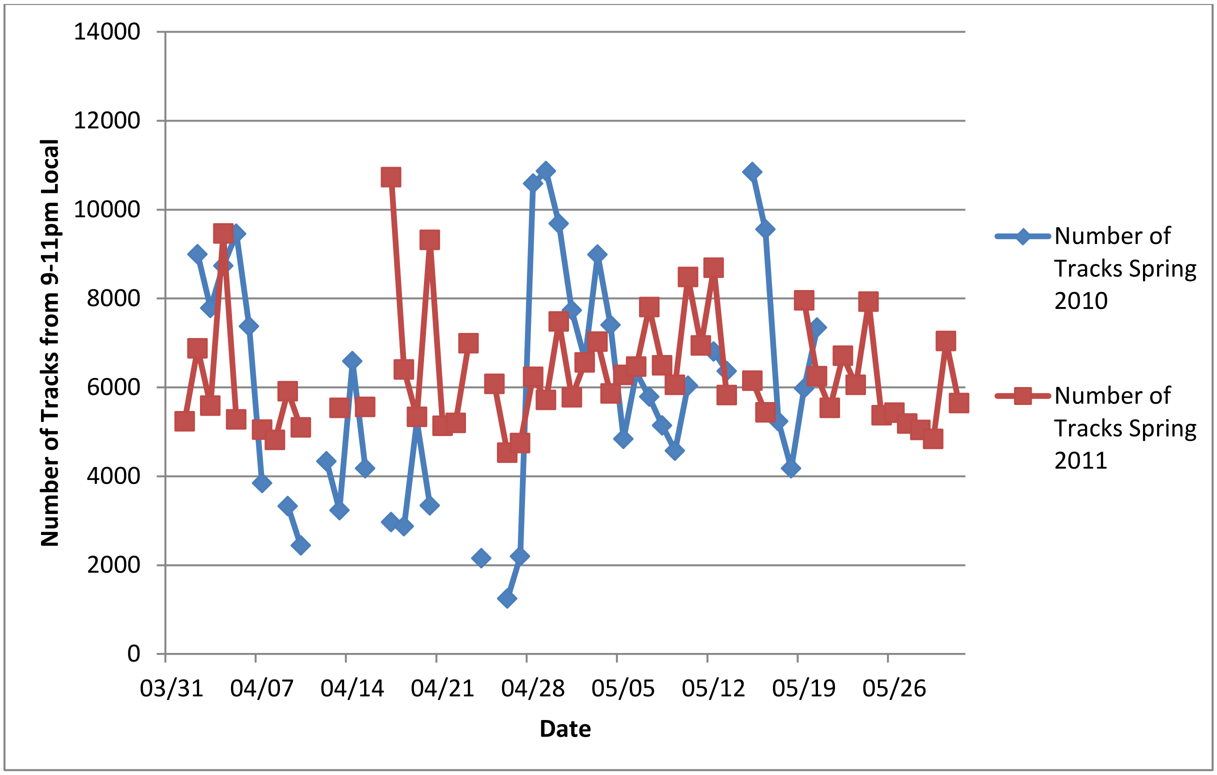


Figure 85. Daily Track Counts for Spring 2010 and 2011

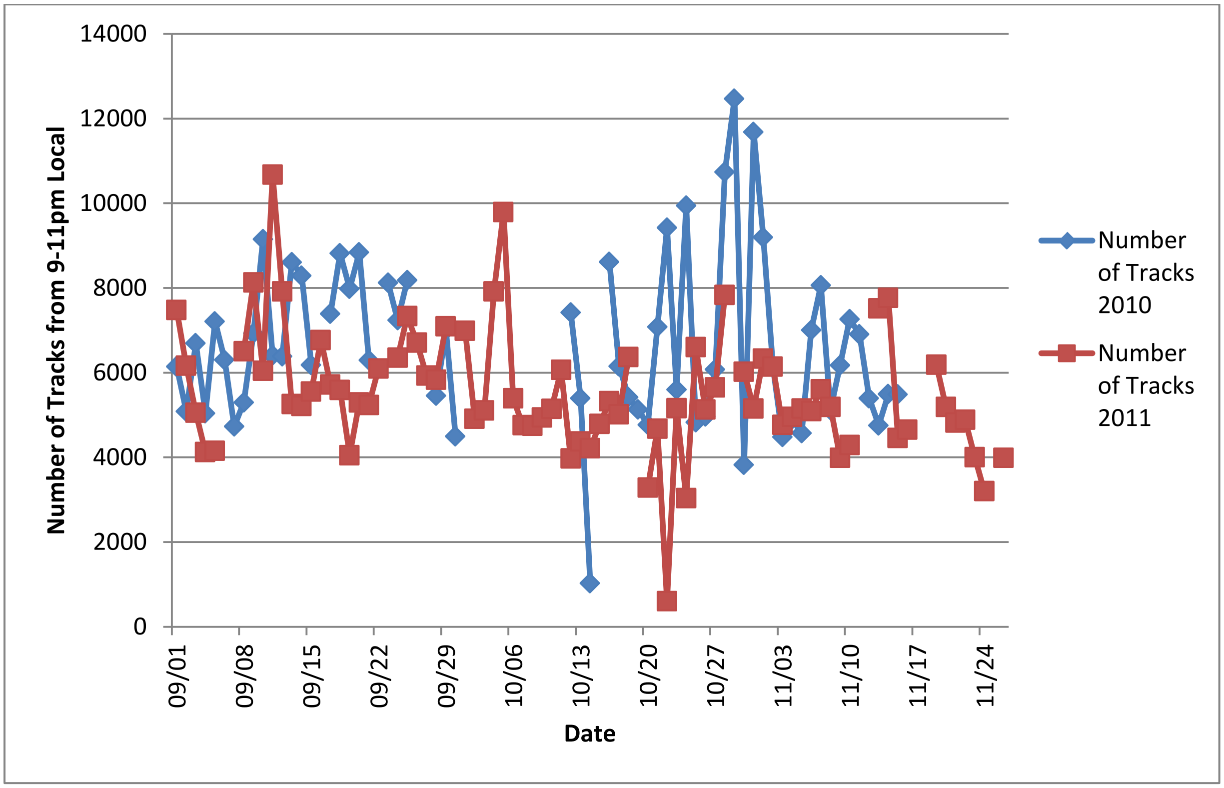


Figure 86. Daily Track Counts for Fall 2010 and 2011

Track altitude was also examined. Table 10 lists the number of days in the spring and fall where altitude was greater than 800 ft or below 200 ft. Daily altitude plots are provided in figures 87 and 88. Altitude plots again illustrate interannual and daily variability, suggesting a greater variability in the spring than in the fall.

Table 10. Days in Spring and Fall Altitudes Above 800 ft or Below 200 ft

Season	Days With Average Track Altitude Above 800 ft	Days With Average Track Altitude Below 200 ft
Spring 2010	7	2
Spring 2011	2	2
Fall 2010	0	10
Fall 2011	0	6

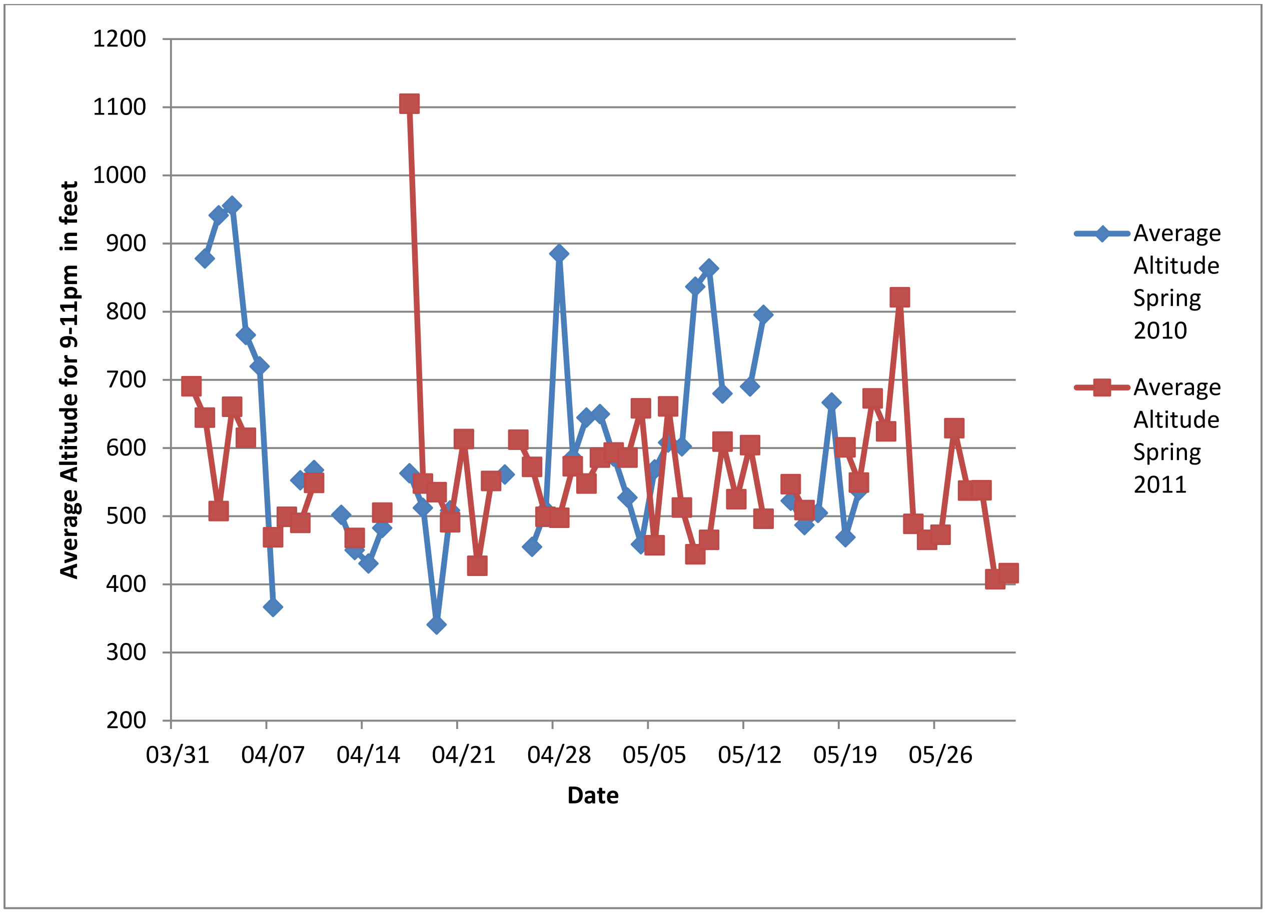


Figure 87. Daily Altitude Summary for Tracks in Spring 2010 and 2011

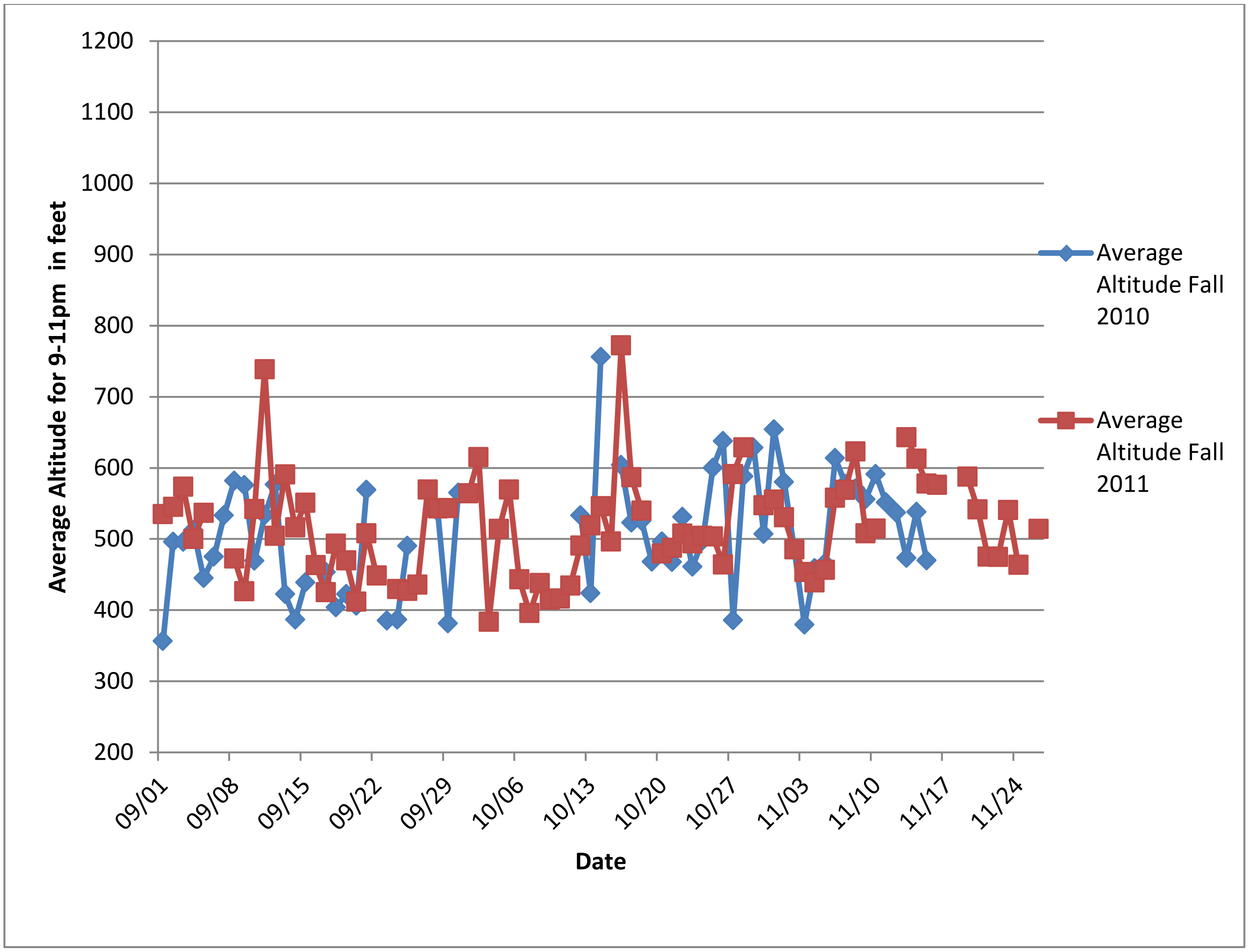


Figure 88. Daily Altitude Summary for Tracks in Fall 2010 and 2011

The comparison of seasonal migrations in spring and fall 2010 and 2011 identified a migration event in late October 2010. High track numbers and other indicators of migration were observed on October 31, 2010. That event was analyzed, and examples of that analysis assist in better defining migration movements. Figures 89 and 90 provide 5-minute track history plots (shown in red) for 21:25–21:30 and from 22:25–22:30 . A 5-minute track history was selected to retain definition of tracks. Longer track histories in this period of high activity would have produced a map with red clusters with indistinguishable tracks. The figures further illustrate variability; in this case, variability over very short time intervals.

Identifying movement characteristics is possible through sequential analysis of track history plots. Figure 91 provides a summary of fall migratory patterns near JFK airport from the fall 2010 data. The red arrows indicate locations where track numbers were highest, and orange arrows indicate areas where track presence was consistent but not with the high numbers found in the areas with red arrows.

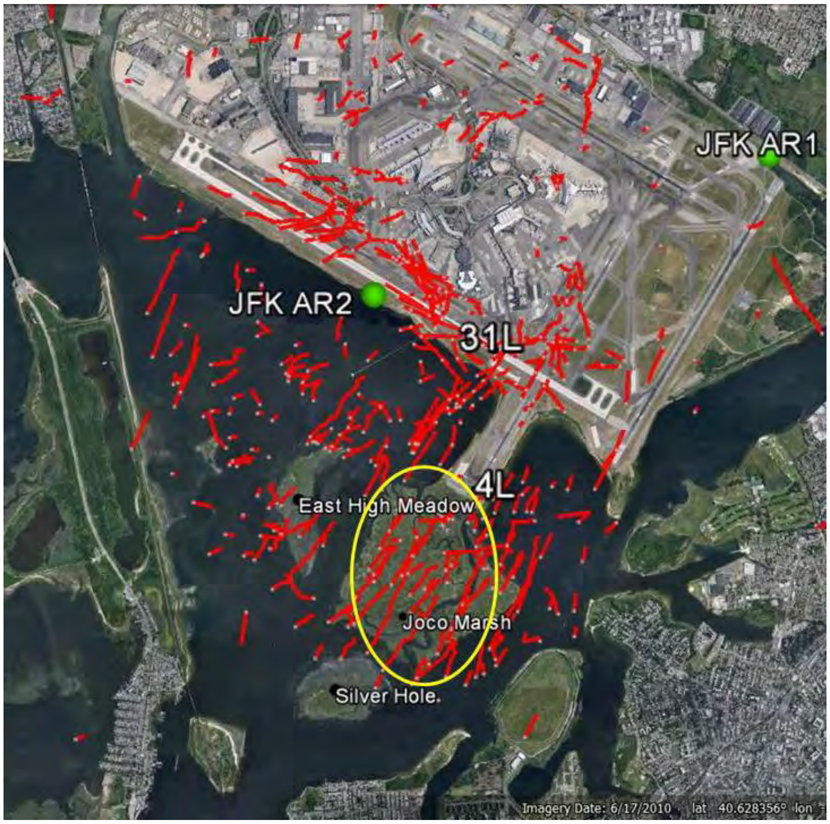


Figure 89. Track History Summary for 21:25–21:30 on October 31, 2010

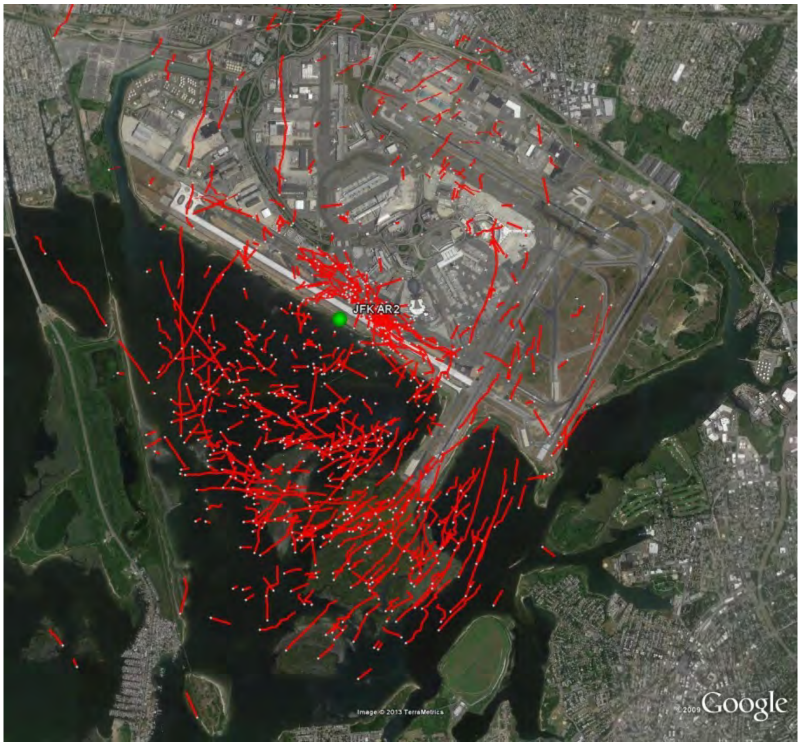


Figure 90. Track History Summary for 22:50–22:55 on October 31, 2010

Figure 91. Fall 2010 Migration Movements Near JFK Airport Summarized From Track History Plots

In summary, the avian radar systems deployed to JFK as part of the CEAT avian radar performance assessment program provided information on migration and clearly demonstrated the variability of migratory events and migratory patterns. There was a clear interannual variability between 2010 and 2011. There is variability between spring and fall migration periods. There is also daily variability with movement activity peaks often occurring on single days or a small number of days. Analysis also finds that daily variability can be great and even shorter term (such as minute-to-minute) variability occurs.

3.3 SUMMARY OF RESULTS AND DISCUSSIONS.

3.3.1 Deployment.

The JFK radar deployment followed a series of steps that began with defining program, project, and study objectives. The site selection and installation approval process was time consuming because of requirements for matching deployment location with power and data connectivity, regulatory approvals, and actual installation and operational factors. The AR1 was deployed from March 18, 2010 to August 7, 2012, for a total of 20,932 hours. During that time, the AR1 generated 20,517 hours of data with 98% reliability. The AR2 experienced early operational issues that were addressed in warrantee service. The AR2-1 was deployed from January 29, 2010, to October 29, 2012, for a total of 24,080 hours. During that time, the AR2-1 generated 19,427 hours of data with 81% reliability. The AR2-2 was deployed from January 28, 2010 to October 29, 2012, for a total of 24,120 hours. During that time, the AR2-2 generated 21,785 hours of data with 90% reliability.

Regular maintenance on the systems was performed, and operations were influenced more by power interruptions than mechanical failures, with excellent reliability of the hardware.

Radars were tuned to the JFK operation site, and those settings were maintained through the deployment. ARTI personnel provided software updates, including a major update in late 2011 that was designed to address multipath and side-lobe issues. Radars were managed remotely with high-speed data connections using a cellular broadband connection to the AR1 and a wireless bridge to the AR2. ARTI personnel provided a display using an Google Enterprise server, which supported broadcast of real-time displays of JFK radars over the internet supporting use at CEAT and JFK.

3.3.2 Radar Analysis Terminology.

CEAT personnel developed definitions and methods useful in radar data analysis. Early on, the importance of carefully presenting radar data in relation to radar coverage and the reliability of radar sensors in the JFK setting was understood. Indicators of target activity over time were used to confirm radar coverage in addition to clutter mapping. Then, those indicators were used to develop reliability maps for JFK. Another critical element for data analysis was to use consistent and appropriate terminology. Bird movements were defined in terms of tracks, track number, and consistent track heading. CEAT personnel identified the importance of an initial target observation as a reminder of beam coverage and as a starting point for detailed analysis of track characteristics.

3.3.3 Opportunistic Studies.

The validation of avian radars included opportunistic studies throughout the deployment of the radars. The results of opportunistic approaches were mixed. The assumption that ground-truth observations and validation efforts would be relatively simple proved to be false. Radar is a technology that operates on high-frequency radio transmissions. Although time to detection is short, the confirmation of targets introduces latency between detection and display on the radar screen. Basically, the radar is operating in a time domain specific to the radar. Matching the time domains of the radar with the observers during bird target observations was more challenging than originally anticipated based on a combination of factors.

Successful matching of a bird target with a radar track was possible when the flight paths of birds provided longer tracks at longer distances from the radar. Because of inherent processing times for track identification, successful validation occurred when the bird flew a consistent heading for the time needed for track identification and observer acquisition of targets. CEAT personnel were unsuccessful with forensic analyses determining exactly where a target was in relation to the radar track display. Lack of success was not due to lack of detection. The need for exact matching of target location, a highly accurate time stamp, and azimuth, combined with radar processing latency and the presence of multiple bird targets to prevent confirmation in these studies. The opportunistic observations showed both the importance of exact time stamps and the difficulty in identifying specific targets in a technology that detects many targets simultaneously.

Targets identified by observers were not always able to be confirmed by the researchers. The opportunistic studies also revealed the importance of understanding radar coverage and the influence of beam coverage and target characteristics in target confirmation.

3.3.4 After-the-Fact Analyses.

The researchers were not able to confirm that tracks were associated with a species in after-the-fact analyses. The radar and subsequent analysis did enable identification of bird movement, relating of GOTs with location and, through track history plots, development of a sense of movement dynamics on and around the airport. However, it was not possible to confirm that a particular track was a particular species.

Developing a sense of movement dynamics of birds on and around the airport was more successful. Movements were characterized in terms of activity and heading. The dual parabolic dish (AR2) provided altitude information and repeated patterns of bird movement were identified. Such movement patterns could be related to local topographic or geographic features, and levels of activity with relationships to timing and/or altitude was demonstrated. The researchers demonstrated that activity levels could be related to bird strikes when longer term records tended to have more strikes on days with higher activity indicated by track counts. More detailed analysis of runway-specific conditions was demonstrated. Again, a relationship between activity and bird strikes was shown, although detailed analysis of movement altitude did not necessarily intersect with aircraft flight path.

The radars used at JFK are useful tools for migration detection and analysis. Detailed analyses focused on migration periods that provided contrasting movement and activity characteristics, and represented a seasonal hazard to aircraft. Based on the findings, no single display or analysis metric provided enough information to confirm migration. However, TVW track history displays were useful tools for identifying periods when the data record should be reviewed to confirm migratory activity. The general assumption that there would be an increase in overall activity with migration was demonstrated using long-term radar data records. However, daily summaries of track counts did not necessarily correspond to migration movements identified in track history displays. Further, track counts may be influenced by rain, multipath, or other interferences that may produce false detections.

CEAT personnel found that radar information was extremely valuable in identifying general movement and activity patterns when visual observations were not possible. The radar also helped identify events, although it should be noted that there is a high variability in bird movement and activity over short and long time periods. It was often clear that seasonal or environmental factors were likely related to movements and activities identified in radar data, but any verification of cause and effect required planned studies. A reality of planned studies, when control of the study conditions is not possible, is that results are more descriptive than definitive.

4. CONCLUSIONS.

The Center of Excellence for Airport Technology (CEAT) personnel completed the deployment of avian radar systems to John F. Kennedy International Airport. Program, project, and study objectives were addressed and supported by a range of study activities and accomplishments.

Two radar systems were operated for over 2 years. Records suggest avian radars are robust and reliable. CEAT personnel demonstrated that through real-time and after-the-fact studies using avian radar, including ground-truth/validation and bird-movement dynamics, avian radar can provide support for airport wildlife hazard management. The radars deployed did not provide complete airport coverage, nor were avian radar systems deployed to provide sense-and-alert functionality needed for air traffic control. Surveillance was provided for approach and departure paths for several runways and for areas where birds were known hazards. Avian radars were shown to contribute important supplementary information on bird movement and dynamics to airport wildlife management concepts of operation.

5. REFERENCES.

1. Herricks, E.E., and Key, G., "Avian Radar Systems," *International Airport Review*, Vol. 6, pp. 56-59, 2007.

2. Herricks, E.E., Woodworth, E., and King, R., "Deployment of Avian Radars at Civil Airports," FAA report DOT/FAA/AR-09/61, February 2010.

3. http://www.ducks.org/conservation/where-we-work/flyways (date last visited January 2014)

4. http://www.nps.gov/gate/planyourvisit/map_jbu.htm (date last visited January 2014)

5. Dolbeer, R. A., Belant, J. L., and Sillings, J. L., "Shooting Gulls Reduces Strikes with Aircraft at John F. Kennedy International Airport," *Wildlife Society Bulletin*, Vol. 21, No. 4, Winter 1993, pp. 442-450.

6. Federal Aviation Administration, "Airport Avian Radar Systems," Advisory Circular (AC) 150/5220-25, November 2010.

7. Federal Aviation Administration, "Wildlife Strike Database and Reporting System," http://wildlife.faa.gov/ (date last visited September 2015).

8. Ruth, J.M. (ed.), "Applying Radar Technology to Migratory Bird Conservation and Management: Strengthening and Expanding a Collaborative," USGS Open File Report 20071361, 2007.

9. Lowery, G.H., JR., *A Quantitative Study of the Nocturnal Migration of Birds*, University of Kansas Publications, Museum of Natural History, Vol. 3, No. 2, pp. 361-472, 1951.

10. Lowery, G.H., and Newman, R.J., "Direct Studies of Nocturnal Bird Migration" in *Recent Studies in Avian Biology*, A. Wolfson (ed.). University of Illinois Press, Urbana, USA, pp. 238-263, 1955.

11. Gauthreaux, S., personal communication, 2012.