MANAGING DATA FROM AVIAN RADAR SYSTEMS

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PRESENTED FOR THE
2010 FAA WORLDWIDE AIRPORT TECHNOLOGY TRANSFER CONFERENCE
Atlantic City, New Jersey, USA

April 2010

INTRODUCTION

Avian radar systems have been deployed to several airports in a performance assessment program developed by the University of Illinois Center of Excellence for Airport Technology Airport Safety Management Program (CEAT) for the Federal Aviation Administration Research and Development Branch, AJP63. As part of the CEAT Performance/Capability Assessment Program for Avian Radar Systems at Civil Airports, avian radar deployment began in 2006 with the acquisition of radar units and completion of initial calibration testing and licensing. The deployments were intended to assess this new technology at civil airports, exploring a wide range of technical and operational issues, including issues of data and data management.

Data generated by avian radar can support airport safety management systems by improving the understanding of the movements and the timing of movements of birds on and around an airport. Even when avian radar cannot be monitored in real-time, the analysis of archived data can support directed management efforts to reduce or eliminate bird hazards through such applications as evaluating avian risks on or around the airport or predicting hazardous events at specific locations. Thus, the ability to review such archived data is essential to the successful use of avian radar as a tool for improved airport safety. However, the magnitude of data produced by the radar can create an obstacle to achieving this goal. Under normal operation, a single radar will produce approximately 150 gigabytes (GB) of processed data a year, consisting of plots-and-tracks files that support a range of post-processing options. In addition, records of raw radar data, which provide maximum opportunity for post-collection analysis, can require many GB of data storage in a very short time.

After the initial deployment of an avian radar system at the Naval Air Station Whidbey Island, Oak Harbor, WA (NASWI) and a second system at the Seattle Tacoma International Airport (SEA), radar data was generated, and data analysis and management became a major and continuing effort in the performance assessment program. Although the basic data products of avian radars are well understood, the format and complexity of the data stream and the methods for management of high-frequency and long-term data were not well-defined for this technology and for application in an airport environment. Beginning with the acquisition of the first radar units, data issues were explored by CEAT and procedures were developed to acquire, process, analyze, and interpret radar data. Based on this experience, CEAT developed a comprehensive data management system that has evolved from on-site recording of radar data to a networked system that automatically processes and displays data, including a real-time display of radar detections.

This paper will review the general characteristics of radar data generation with particular focus on plots-and-tracks information used in post-processing. Post-processing will be reviewed, illustrating the information products developed by CEAT.

DATA GENERATION

Data is generated by radar systems operating at airports. The typical CEAT radar system is deployed in a trailer that supports self-contained operation. Figure 1 shows the AR-1 radar deployed at SEA. This radar is located between Runway 2 and Runway 3, approximately mid-field. From this location, connectivity for data management is achieved through a wireless bridge (the grey dish antenna, pictured) to the SEA terminal where connectivity to the internet is achieved. Lines power is supplied to this unit by the Port of Seattle from an instrument installation seen in the background.

Figure 1. Radar installation at SEA.

The data is generated using a radar unit that is equipped with an antenna specific for identified monitoring objectives. The data from the radar passes though a control console and is processed by a digital radar processor (DRP) that is connected to the internet for data transfer and management. The Accipiter Radar Technologies Inc. (ARTI) systems being assessed by CEAT have a radar remote controller that supports remote control of the radar system. CEAT's avian radar data generation system is shown in Figure 2.

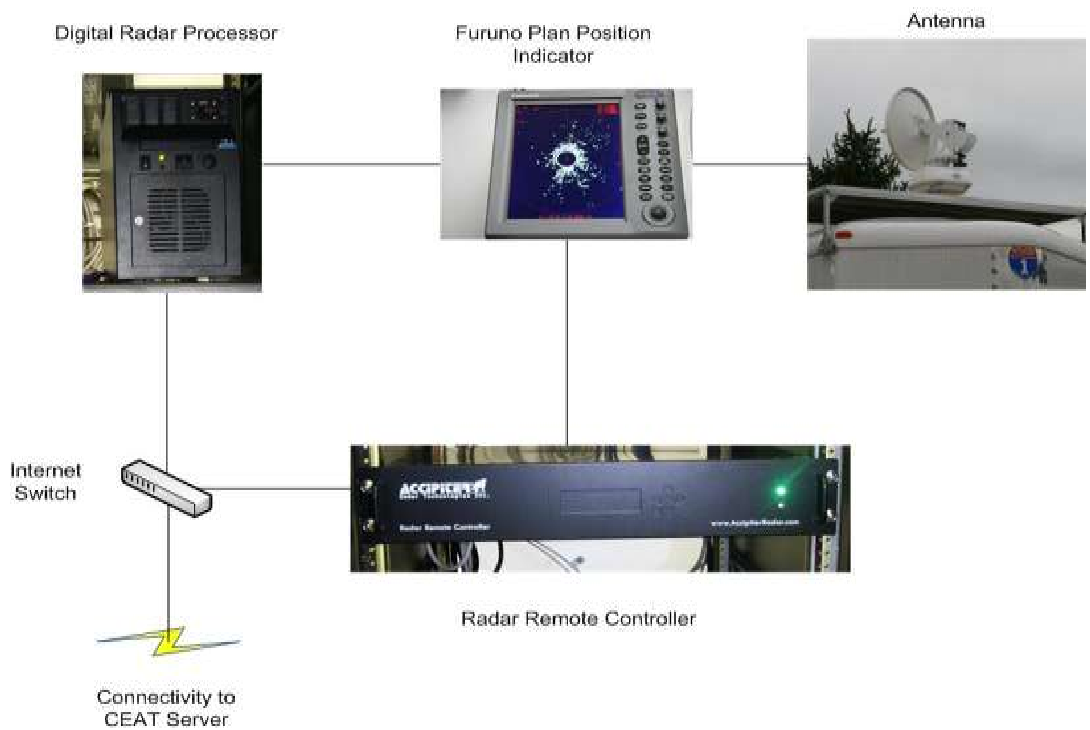

Figure 2. Data Generation System of CEAT Avian Radars.

To understand data processing and management, it is useful to quickly review radar function. A radar signal with a defined frequency and/or waveform is generated and transmitted through an antenna. The antenna is designed to spatially form a directive beam, which can be rotated mechanically or steered electronically to scan around the sensor location. This produces the WWII-style conventional plan position indicator (PPI) image of a radar screen with a rotating line and targets revealed by bright spots (echoes). Today, the PPI image is represented as a scan-converted image on CRTs or LCD displays, as shown in Figure 3. The echoes are produced by the radiated signal as it impinges on objects along a line of sight directed by the antenna and is reflected from them and returns to the radar's receiver via the receive antenna. Normally, the transmit and receive antennas are the same (monostatic operation), but they can be separate (bistatic operation). The received "raw radar signal" is composed of signal elements that can include targets, clutter, interference and noise.

Figure 3. A Furuno® Radar PPI.

In modern radar systems, the raw radar signal is received in analog form and then digitized, producing raw radar data that is then further processed, as shown in Figure 4. In the avian radars used in the CEAT performance assessment, digitization is accomplished using a commercially available digitizing board in a special-purpose computer, or radar signal processor. Because of this configuration, the first step in radar signal processing is an initial digitization of the analog signal that extracts target range, azimuth, and intensity as the rawest data product. This form of raw radar data is referred to as B-scan data. An alternative data product is a scan-converted data set obtained from the B-scan data by a range-azimuth: *x-y* coordinate conversion process. Scan-converted data is typically much lower bandwidth than raw radar data, but involves an irreversible loss of data.

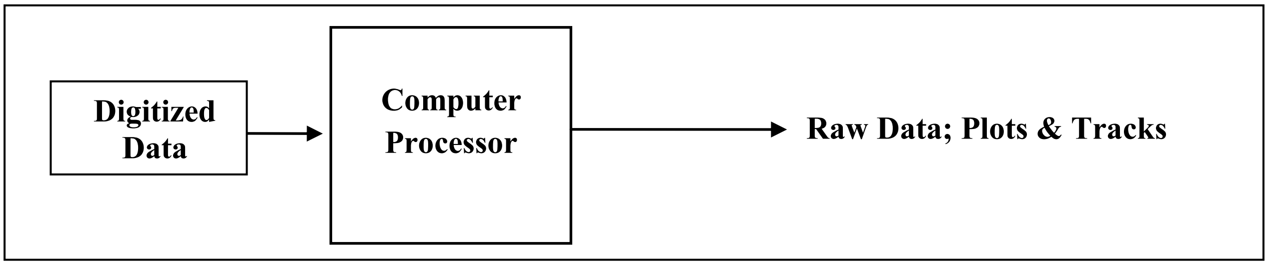

Figure 4. Flowchart of Radar Raw Data Processing with Digital Radar Signal Processor.

Two fundamental signal processing steps need to be performed in the digital radar signal processor: plot extraction (also called detection) and tracking. The simplest plot extractors involve setting a global threshold on intensity, below which everything is considered noise, clutter, and interference, and above which everything is considered a target plot or detection. Sophisticated plot extractors use a variety of adaptive thresholding schemes to optimally manage noise, clutter and interference spatially and temporally, improving the reliability of the target plots extracted. The extracted plots themselves can carry local information such as time, azimuth, range, intensity, RCS, height and other parameters. Target tracking typically carries out further processing on extracted plots over time to build trajectories for each target and to extract additional target parameters such as speed, heading, and smoothed estimates of intensity, RCS, altitude, etc. Sophisticated track generation uses algorithms specifically designed for the targets of interest and can also provide rejection of plots extracted as potential bird targets but determined by the track filtering not to be from birds. Depending on the radar system, the sequence of these steps may vary and some or all of this processed data (i.e., plots and tracks) is made available. Some tracks will be formed from targets or scatterers that are not birds, and downstream processing and filtering can be used to identify and further reject these.

Assessment issues associated with avian radars include consideration of these radar characteristics and focus on the validity of targets using analysis of basic sensor and processed data. Radar data will vary based on radar frequency (L-Band, S-Band, X-band), method of radio frequency generation (magnetron vs. solid state signals), power, range and volume covered. The radar systems presently deployed by CEAT directly acquire only range, azimuth, and intensity data from the radar echo signal; they determine altitude based on beam configuration and beam geometry analysis during plot extraction and/or tracking operations. (Future assessments will include radar systems that provide altitude using different antenna configurations and may include Doppler capabilities for clutter rejection and direct radial velocity measurement and target description, such as wing beat frequency.)

Recording raw radar (B-scan) data and/or scan-converted data in the avian radar system is an essential requirement because recording supports reprocessing, which is needed for radar calibration, sensitivity analysis, tuning, and final site commissioning. At the frequencies involved with all radar sensors, these data sets quickly become very large. Unless vendors provide specialized compression algorithms and/or data storage with the capacity for quickly storing and retrieving large data sets, the cost and practicality of recording and archiving basic input data for long periods of time can be prohibitive. (Recently, data storage has experienced major drops in unit prices, so storage issues are not as critical.)

Because it is generally cost prohibitive to store raw data continuously, radar systems designers have developed methods of data volume reduction and/or substitution that supports reprocessing-related requirements. Volume reduction is achieved by data compression or by reducing the range over which raw data is acquired and stored. It is also possible to substitute processed data, such as raw system data, that is designed for easy storage and reprocessing. Digitizing systems can be purchased off-the-shelf from companies including Rutter Technologies (Rutter), Curtiss Wright, Cambridge Pixel and National Instruments. For example, Rutter's digitizer provides hardware and software that interface with standard radars. To date, the radar systems assessed by CEAT use a Rutter digitizer and two different avian radar signal processors. One radar signal processor uses the raw B-scan data to drive its signal processor and includes a specially developed raw-data storage and reprocessing system. It also includes scan-conversion, along with scan-converted, data storage and replay capabilities. The second radar signal processor utilizes scan-converted data, which can also be archived, to drive its processing. The choice of input data product has implications for storage needs, but also relates to data fidelity. (In the CEAT assessment, the effect of the use of different digitization products is an area of continuing assessment.)

In some radars, returns from the receiver are immediately digitized. The raw digitized data is then processed by the digital signal processor and, subsequently, by a general purpose embedded processor. Data is then written to a display that is often a general purpose computer display. Digital data at various stages of processing can be collected and stored as desired. The volume of data generated depends on the point in the processing at which data is collected. As processing stages move from raw data to scan-converted data to detection data to track data, less data and more refined information are generated.

The characteristics and length of the basic raw data record are an important consideration in the development of data management schemes. Recording basic raw data provides a primary data resource that will support the most flexibility in reprocessing. The process of recording raw data should not interfere with active, real-time radar signal processor operation. Although it is possible to reprocess data to fill a missing data set, the ability to record while not interrupting ongoing radar data processing is essential. Exploiting the usefulness of stored basic raw data requires that users be able to selectively retrieve data. Thus, data management in the radar system should include an archive for basic raw data that supports rapid retrieval of recorded data based on date and time of record.

To make the high-volume data sets generated by avian radar systems useful, they must be converted from analog to digital form and placed into a more intuitive coordinate system. Metadata must be preserved to ensure that the correct context is applied to the data. To extend the usefulness of the system beyond that of a real-time device, the systems must be able to recombine data (information specific to detected targets of interest) and metadata (general information about the conditions in which data was collected) for later playback.

In the avian radar systems used in the CEAT performance assessment, the data collection and analysis process begins by establishing a base map of the average energy return. Subsequent scans are then compared to the base map, and any energy returns that exceed the base are potentially targets of interest (i.e., detections). Detections are then fed into a radar data processor that catalogs successive scans and their detections and uses pattern identification to predict the next scan's detections. Successful predictions result in upgrading detections to targets of interest, which are then catalogued and monitored until they are no longer detected. These targets records are saved in a way that enables them to be played back at a later date with full knowledge of the behavior of the target as well as the conditions in which it was monitored. With each successive step of processing and analysis, some ability to reprocess the data using alternate settings is lost. Thus, it is important to keep future applications in mind when deciding how to record data.

Any physical object is capable of reflecting energy back to an avian radar, and the he variability in factors such as bird activity, wind, human activity and precipitation can affect how radar perceives its surroundings. Thus, it is essential that any set of data include some capacity for reprocessing. All avian radars include the means to alter settings from the beginning of digitization to target resolution. The earlier in the process data is recorded, the more flexibility is available for reprocessing at a later date. For example, if data is recorded at the detection level, then alternative parameters for target resolution can be implemented. However, if the goal is to alter the sensitivity used to determine what detections are, then data must be recorded immediately after digitization.

THE CEAT DATA MANAGEMENT SYSTEM

The CEAT data management system provides connectivity and data transfer from radar units to a server environment that supports data management and data post processing, as shown in Figure 5. The data generation begins at the radar unit where the local digital radar processor (DRP) is connected through the internet. This connection is secure and data from the DRP is encrypted. Connectivity through firewalls is achieved and data is then stored in a local server. From this server data is made available to workstations for processing, analysis, and interpretation.

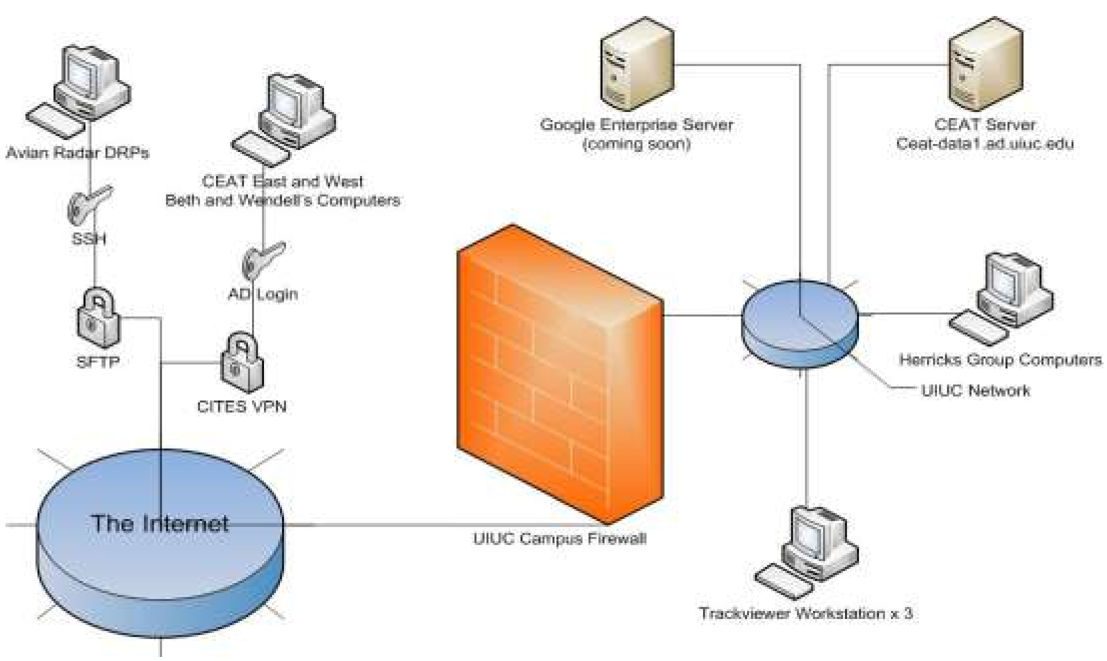

Figure 5. The CEAT Data Management System.

A useful feature of the data management system is the bidirectional transfer of data that supports remote operation of the radar systems. Using virtual network computing (VNC) procedures it is possible to achieve near-real-time control of radar units at remote locations. The control is limited by connection speed, but it is possible to achieve a video stream from the radar display, Figure 6, and execute commands through a radar remote controller. The VNC access provides cross-network compatibility and has a low requirement for system resources. CEAT has established cellular broadband connectivity to all radar units to support remote control and provide local management of data on the DRP.

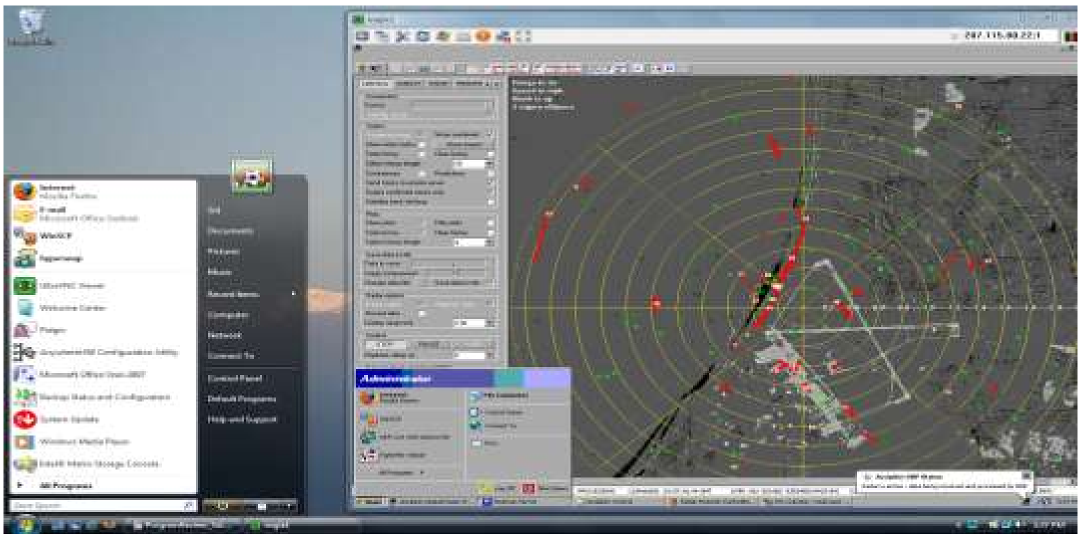

Figure 6. Image of Radar Display with VNC Connection Controls.

Investing in a coordinated and comprehensive data management system is vital to the successful use of any avian radar in an airport environment. CEAT has developed an evolving data management system to more effectively use avian radar data in airport safety management systems. Key factors in creating a solid data management system are:

- constructing a secure and reliable data storage system,
- automating or streamlining the process by which a data storage system receives and shares its data, and
- establishing a timely and efficient system for processing stored data into products that are both accessible and useful to airport personnel and other interested parties.

Creation and monitoring of a storage space for radar data can either be done “in-house” or by contracting to an external entity for server hosting. The construction and management of a server environment for radar data is time consuming and requires a certain skill and familiarity with information technologies (IT). CEAT has taken advantage of an institutional IT capability at the University of Illinois–the Campus Information Technologies and Educational Services (CITES) IT services–as a foundation for our data management systems. This service provides CEAT with a dynamic storage space, which is important to meet the needs over time of an expanding data archive from avian radar systems. Initially two terabytes (TB) of storage were reserved, but that storage capacity has since been expanded to six TB. CITES services guarantee daily backups and a uninterrupted power supply for hardware in a controlled and monitored environment. These environmental safeguards and scheduled backup reduce the risk of data loss.

Optimal placement of an avian radar systems requires installation at locations on an airfield where power and data connectivity are problematic. For this reason, careful attention must be given to site selection, considering the availability of power and connectivity at radar locations. The amount of data generated by an avian radar system will be entirely dependent on the selection of data stored (e.g., B-scan vs. plots and tracks) as well as the number of target activities detected by that system. Increased numbers of detected targets will result in larger amounts of plots-and-tracks information that must be stored. The avian radar systems tested by CEAT have, on rare occasions, generated more than one gigabyte per day of data. Because the radars are located at remote sites, this data must be transferred to locations where analysis and interpretation of the data take place. In cases where an internet connection has sufficient bandwidth for data transfer, the movement, processing and archiving of data can proceed in near-real-time. If high-bandwidth connectivity is not available, then alternate methods of data transfer are needed, including the transfer of data to storage media, physical transfer, and loading onto a local server to support processing. CEAT has conducted assessment campaigns of different lengths using transfer to local servers or even mailing storage media to server locations.

CEAT has found that connectivity to the airfield radars of 1-2 megabyte per second supports remote control of radars, and supports the systematic transfer of data to a central server. The core server capability at the University of Illinois provides a 12 GB per second network to support external radar systems.

The avian radar systems currently deployed at NASWI and SEA take advantage of the system and server capabilities of Accipiter Radar Technologies, Inc (ARTI) to provide continuous transfer of real-time detections and transfers of daily plots-and-tracks data during off-peak hours. This system supports the capability of live detection displays in multiple locations and takes advantage of reduced usage periods for bulk data transfers for daily updates of data. Transferred data is organized into folders, first by location, then by year, by month, and by day; each data file's name includes a timestamp to note time of creation time. To avoid confusion between multiple radar locations, the timestamp uses GMT. Keeping data consistently organized simplifies the use of data in any post-processing application.

Once a comprehensive dataset is collected, it is useful to process that data from general archive type files into something that can be more quickly analyzed. Furthermore, the data generated by the radar is often only readable by proprietary software made by the radar developer and is not easily shared among many people. For these reasons, radar data should be processed into data products that are quickly understood and easily shared. CEAT has used several methods to provide such data products. Initially, a cadre of workers accessed on-site data storage, downloaded daily data, and then processed the data to provide products such as images of 3-hour track histories or movies of the processor display that accelerated 8 hours of operation into a 7- to 10-minute movie. With these data products, recent bird movement activity could be quickly reviewed to determine if any events required further analysis of the daily data. Such track summaries (an example of an hourly track summary is shown in Figure 7) make it possible to identify daily timing and dynamics of bird movements and to conduct analyses relating bird activity to environmental conditions. Track data is also useful for identifying migratory events.

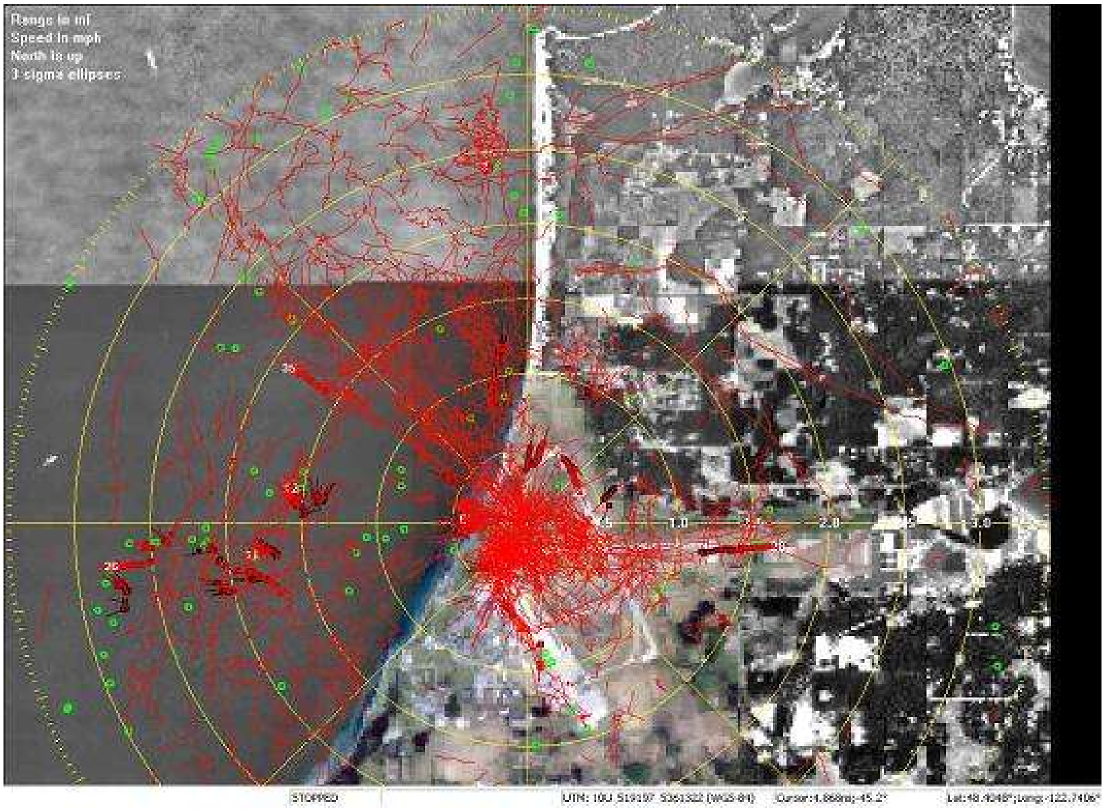

Figure 7. Example of an Hourly Track Summary at NASWI.

The processing scheme for these products is shown in Figure 8. Data is transferred from the radar DRP to the CEAT server. The data is processed on an Accipiter® Track Viewer Workstation (TVW). The data products are then stored on a Sharepoint server and made available to program cooperators.

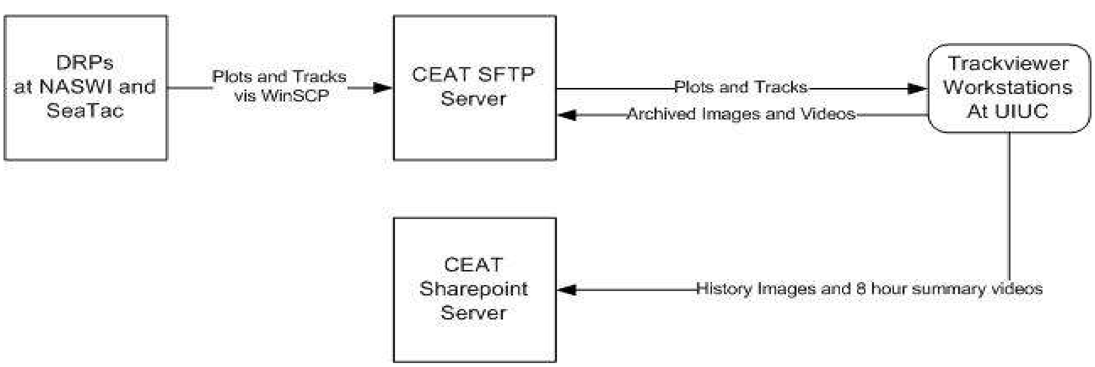

Figure 8. Data Stream for Radar Data Products.

Beginning in August 2007, CEAT began making these data products available for NASWI and SEA. In December 2009, as experience was gained and ARTI services expanded, a revised daily data management procedure was implemented. The images and movies of track histories and radar screens were replaced with a Google Earth™ (GE)-based system. Rather than provide time-sequenced images, the new system produces hourly track histories in a kml format for use in the GE environment. Initially, these files were generated manually. Then, in January 2010, the kml file generation was automated following a daily download of data from the radar sites. The GE environment also supports a live view of radar detections with the capability of playback of the previous hour of data and control of track length in the playback. These products are made available on a web server, allowing easy access via the internet to the centralized data by airport wildlife management personnel or any other interested parties.

In addition to live displays and automation of data processing, CEAT and ARTI have partnered in the use of local and remote server environments to assure data integrity and support further analysis of a site's radar data. One critical feature of this capability is the ability to review and reprocess historical data. The ability to review archived data has already demonstrated its usefulness in evaluating avian risks on an airport, as well as predicting a hazardous event at a specific location. For example, CEAT personnel recently noticed an unusual series of tracked objects departing from the main terminal at SEA. Local wildlife officers investigated and determined the cause to be starlings leaving their roosts. By reviewing archived data, CEAT was able to characterize this specific movement pattern over a 90-day period. The movement pattern was confirmed and timing of the movement determined. CEAT was able to model this movement based on the primary environmental factor–sunrise–and develop a prediction of future movement. The predictive model was verified and is used by SEA wildlife managers to address the problem and determine the success of management efforts. CEAT has also used this functionality to:

- review noteworthy events on airfields, such as suspected and confirmed bird strikes,
- investigate the effect of nearby landscaping on the performance of an avian radar and
- quantify the tracking ability and characterize the radar beam for several avian radar installations.

CONCLUSIONS

Data generated by avian radar can improve the understanding of the movements and the timing of movements of birds on and around an airport, and the analysis of archived data can support directed management efforts to reduce or eliminate bird hazards. Thus, the ability for airport wildlife personnel or others to review such archived data and to have it presented in an accessible format is essential to the successful use of avian radar as a tool for improved airport safety. However, the magnitude of data produced by the radar can create an obstacle to achieving this goal.

Based on experience with the acquisition, processing, analysis and interpretation of radar data produced by avian radar systems at NASWI and SEA, CEAT has developed a comprehensive data management system that has evolved from on-site recording of radar data to a networked system that automatically processes and displays data, including a real-time display of radar detections. This system has been used effectively in evaluating and managing avian risks at SEA.