Final Report: Coastal Ohio Wind Project
(Award Number: DE-FG36-06GO86096)

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Project Start Date: 09/01/2006
Project End Date: 11/01/2013

Executive Summary

The Coastal Ohio Wind Project intends to address problems that impede deployment of wind turbines in the coastal and offshore regions of Northern Ohio. The project evaluates different wind turbine designs and the potential impact of offshore turbines on migratory and resident birds by developing multidisciplinary research, which involves wildlife biology, electrical and mechanical engineering, and geospatial science.

Firstly, the project conducts cost and performance studies of two- and three-blade wind turbines using a turbine design suited for the Great Lakes. The numerical studies comprised an analysis and evaluation of the annual energy production of two- and three-blade wind turbines to determine the levelized cost of energy. This task also involved wind tunnel studies of model wind turbines to quantify the wake flow field of upwind and downwind wind turbine-tower arrangements. The experimental work included a study of a scaled model of an offshore wind turbine platform in a water tunnel.

The levelized cost of energy work consisted of the development and application of a cost model to predict the cost of energy produced by a wind turbine system placed offshore. The analysis found that a floating two-blade wind turbine presents the most cost effective alternative for the Great Lakes. The load effects studies showed that the two-blade wind turbine model experiences less torque under all IEC Standard design load cases considered. Other load effects did not show this trend and depending on the design load cases, the two-bladed wind turbine showed higher or lower load effects. The experimental studies of the wake were conducted using smoke flow visualization and hot wire anemometry. Flow visualization studies showed that in the downwind turbine configuration the wake flow was insensitive to the presence of the blade and was very similar to that of the tower alone. On the other hand, in the upwind turbine configuration, increasing the rotor blade angle of attack reduced the wake size and enhanced the vortices in the flow downstream of the turbine-tower compared with the tower alone case. Mean and rms velocity distributions from hot wire anemometer data confirmed that in a downwind configuration, the wake of the tower dominates the flow, thus the flow fields of a tower alone and tower-turbine combinations are nearly the same. For the upwind configuration, the mean velocity shows a narrowing of the wake compared with the tower alone case. The downwind configuration wake persisted longer than that of an upwind configuration; however, it was not possible to quantify this difference because of the size limitation of the wind tunnel downstream of the test section. The water tunnel studies demonstrated that the scale model studies could be used to adequately produce accurate motions to model the motions of a wind turbine platform subject to large waves. It was found that the important factors that affect the platform is whether the platform is submerged or surface piercing. In the former, the loads on the platform will be relatively reduced whereas in the latter case, the structure pierces the wave free surface and gains stiffness and stability. The other important element that affects the movement of the platform is depth of the sea in which the wind turbine will be installed.

Furthermore, the wildlife biology component evaluated migratory patterns by different monitoring systems consisting of marine radar, thermal IR camera and acoustic recorders. The types of radar used in the project are weather surveillance radar and marine radar. The weather surveillance radar (1988 Doppler), also known as Next Generation Radar (NEXRAD), provides a network of weather stations in the US. Data generated from this network were used to understand general migratory patterns, migratory stopover habitats, and other patterns caused by the effects of weather conditions. At a local scale our marine radar was used to complement the datasets from NEXRAD and to collect additional monitoring parameters such

as passage rates, flight paths, flight directions, and flight altitudes of nocturnal migrating species. Our work focused on the design and development of custom built marine radar that used *t*-bar and parabolic dish antennas. The marine radar used in the project was Furuno (XANK250) which was coupled with a XIR3000B digitizing card from Russell Technologies for collection of the radar data. The radar data was processed by open source radR processing software using different computational techniques and methods. Additional data from thermal IR imaging cameras were collected to detect heat emitted from objects and provide information on movements of birds and bats, data which we used for different animal flight behavior analysis. Lastly, the data from the acoustic recorders were used to provide the number of bird calls for assessing patterns and peak passage rates during migration.

The development of the geospatial database included collection of different data sources that are used to support offshore wind turbine development. Many different data sets were collected and organized using initial version of web-based repository software tools that can accommodate distribution of rectified pertinent data sets such as the lake depth, lake bottom engineering parameters, extent of ice, navigation pathways, wind speed, important bird habitats, fish efforts and other layers that are relevant for supporting robust offshore wind turbine developments. Additional geospatial products developed during the project included few different prototypes for offshore wind farm suitability which can involve different stakeholders and participants for solving complex planning problems and building consensus. Some of the prototypes include spatial decision support system (SDSS) for collaborative decision making, a web-based Participatory Geographic Information System (PGIS) framework for evaluating importance of different decision alternatives using different evaluation criteria, and an Android application for collection of field data using mobile and tablet devices .

In summary, the simulations of two- and three-blade wind turbines suggested that two-bladed machines could produce comparable annual energy as the three-blade wind turbines but have a lighter tower top weight, which leads to lower cost of energy. In addition, the two-blade rotor configuration potentially costs 20% less than a three blade configuration that produces the same power at the same site. The cost model analysis predicted a potential cost savings of approximately 15% for offshore two-blade wind turbines. The foundation design for a wind turbine in Lake Erie is likely to be driven by ice loads based on the currently available ice data and ice mechanics models. Hence, for Lake Eire, the cost savings will be somewhat smaller than the other lakes in the Great Lakes. Considering the size of cranes and vessels currently available in the Great Lakes, the cost optimal wind turbine size should be 3 MW, not larger. The surveillance data from different monitoring systems suggested that bird and bat passage rates per hour were comparable during heavy migrations in both spring and fall seasons while passage rates were significantly correlated to wind directions and wind speeds. The altitude of migration was higher during heavy migrations and higher over water relative to over land. Notable portions of migration on some spring nights occurred parallel the shoreline, often moving perpendicular to southern winds. The birds approaching the Western basin have a higher propensity to cross than birds approaching the Central basin of Lake Erie and as such offshore turbine development might be a better option further east towards Cleveland than in the Western basin. The high stopover density was more strongly associated with migration volume the following night rather than the preceding night. The processed mean scalar wind speeds with temporal resolutions as fine as 10-minute intervals near turbine height showed that August is the month with the weakest winds while December is the month, which typically has the strongest winds. The ice data suggests that shallow western basin of Lake Erie has higher ice cover duration many times exceeding 90 days during some winters.

Project Goals

The particular tasks of the project are:

- to determine the feasibility of different wind turbine designs in offshore environment using different computational tools and model analysis for reducing constructional and operational costs;
- to determine migratory patterns and potential impact of wind turbines across the northern shore of Lake Erie, using custom-built monitoring system consisting of marine radar, IR cameras and acoustic recorders; and
- to establish a geospatial database for supporting robust offshore wind turbine development which meets important environmental and economic criteria.

Technical Barriers

The Coastal Ohio Wind Project coordinates with the goals of the DOE Wind and Hydropower Technologies Program as identified in the Wind Energy Multi-Year Program Plan for 2007-2012 by addressing key challenges to the Near- and Long-Term Vision, specifically

- Higher cost of wind energy
- Challenging regulatory and policy environment
- Increasing environmental scrutiny
- Public acceptance

Summary of Project Accomplishments

Overall, the project met its primary goals and objectives and established new ideas for future research directions:

- Design and performance data on the NASA Mod5B wind turbine was acquired. The data catalogued on a CD is readily available for examination. Two two-blade wind turbine models, one on a monopole and the other on a floating platform, were developed. These models were used along with the NREL 5MW wind turbine as a benchmark turbine to determine the configuration with the lowest cost of offshore wind energy in the Great Lakes.

- Wind turbine load studies based on the IEC standards were conducted to ascertain that the turbine designs considered can safely operate in the Lake Erie environment. A cost model was developed and implemented in Matlab. The cost analysis tools were used to compute the levelized cost of energy for the three wind turbine configurations. Wind tunnel wake studies were conducted to study velocity fields of upwind and downwind configurations. Both hot wire anemometry and flow visualization were used.

- A scale model study of a floating wind turbine was conducted in a water tunnel equipped with a wave generator. A numerical model of the same flow was also developed. By comparing the test data with numerical prediction of the simulated platform motion in the tunnel, it was shown that scale model tests in a water tunnel are adequate for predicting the motion of a wind turbine platform impacted by large waves.

- One of the main accomplishments is the design and the development of functional inexpensive integration of marine radar for acquisition of biological targets. The system that was integrated and used here consisted of a marine radar with different antennas (*t*-bar and parabolic), a digitizing card for capturing radar data, and an open-source software (radR) for acquisition and analyses of the biological targets from the data.

- We developed new geospatial tools that are aimed to increase public acceptance and awareness of offshore wind farms. The GIS tools support multi-criteria evaluation analysis for collaborative decision-making and public participation in the planning process.

Specific Accomplishments

Wind Turbine Generators (WTG)

- Conducted simulations of two- and three-blade wind turbines
- Determined loads and performance (annual energy production) for a Lake Erie Site
- Developed a cost model and a computer code for computing offshore wind turbine systems
- Used the model to determine cost of energy for various turbine configurations
- Conducted wind tunnel studies of wind turbine tower and rotor blade flow fields
- Measured velocity field downstream of the tower and rotor blade to estimate wake flow dissipation to provide experimental data for developing or validating turbine wake flow
- Developed a wave model and validated the model using experimental data to estimate the hydrodynamic forces produced by large waves
- NASA Mod5B wind turbine data were obtained from NASA Glenn Research Center
- Two wind turbine models were developed. A two blade-rotor wind turbine model was developed using the NREL 5 MW reference wind turbine. Modifications to this design were made to make the design more suitable for the wind environment of Lake Erie. The resulting 3 MW turbine was used in two configurations: (1) a monopile design and (2) a floating platform design

Perform Computational Analysis of WTG Model

- A cost model was developed to estimate the capital cost, the installation cost and the operating and maintenance costs of an offshore wind turbine. The model estimates the capital cost from the available data on system components and their expected life. The installation costs were determined using the information available in the open literature. The operating and maintenance costs were appraised using both scheduled and unscheduled (random) maintenance
- The turbine design was evaluated based on the IEC standards load cases. Turbine rotor and tower forces and moments were computed under the random wind and wave loading environment of Lake Erie. Both two- and three-bladed wind turbine systems were studied. The annual energy produced by the wind turbine systems was also computed
- The cost model was implemented in Matlab. The resulting tool permits parametric studies of cost using various scenarios and system configurations with ease. A cost analysis was conducted using the turbine models developed in the study. The results

showed that for the Lake Erie environment considered, a two-blade wind turbine installed on a floating platform results in the lowest overall cost

Perform Design Comparisons and Validation

- Wind tunnel studies of a model tower-turbine rotor combination were conducted. Smoke flow visualization was performed to qualitatively explore the tower-turbine rotor flow. Hot wire velocity measurements of the wake flow were also conducted for an isolated tower and upwind and downwind turbine rotor configurations
- Wake flow measurements and visualizations were scrutinized to determine the effect of configuration factors on the wake development
- A numerical model was developed to predict the motion of a wind turbine platform from the impact of wind and water waves. The model used the WAMIT code to determine added mass, damping and exciting force coefficients for the platform and the FAST code to determine the forces transmitted by the wind turbine to the platform (mass, stiffness and damping matrices)
- A scaled model of the offshore wind turbine floating platform was studied in a water tunnel equipped with a wave maker. The wave maker was used to produce waves of desired frequency and amplitude. Measured forces on the platform were compared with the numerical results to validate the method. Factors affecting the motion of the platform were studied, and it was determined that whether the platform is submerged or surface piercing has a profound effect on its motion
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Weather Surveillance Radar and Marine Radar
- Developed radar mounting cart capable of lifting, rotating in vertical and horizontal directions
- System is capable of lifting and rotating under joy stick or computer control
- Developed radar tracking algorithms for processing of data
- Developed radar data acquisition system for collection and processing of data
- Processed four migratory seasons of data (Spring 2011, Fall 2011, Spring 2012, Fall 2012)
- Produced results according to needs of wildlife biologists
- Developed NEXRAD data processing technique for bird migration

Thermal IR camera

- Developed camera movement system for rotating of IR camera for 180 degrees
- Developed IR and radar remote data collection system
- Developed IR video data processing algorithm
- Processed IR video data for Spring 2011 data set
- Algorithm is able to show bird and bat tracks
- Produced results in a form that will be useful for wildlife biologists
- Developed ant clustering algorithm for separating birds, bats and insects in IR data

Acoustic Recorders

- Developed various feature extraction and classification algorithms for processing bird and bat calls.
- Acquired software and hardware for recording bird/bat calls
- Processed bird and bat calls for spring 2011 and fall 2011 migration season and obtained various results
- Produced results in a form that will be useful for wildlife biologists

Geospatial Datasets and Modules

- Design and implement a geodatabase structure to support offshore wind turbine development
- Identify, collected and rectify existing pertinent data from different sources
- Processed wind data for the area with temporal resolutions as fine as 10-minute intervals
- Collected ice data from NOAA Great Lakes Environmental Research Laboratory (GLERL)
- Developed a prototype for spatial decision support system (SDSS) for collaborative decision making
- Developed a prototype for Participatory Geographic Information System (PGIS) framework for evaluating importance of different candidate sites for offshore wind development
- Implemented a prototype module for field data collection using mobile and tablet devices

Project Narrative

Overview

As the nation pushes further towards production of green energy, more and more wind turbine developments are being considered. Offshore environments are thought to be ideal places to set up wind turbines because of continuous and plentiful winds. Despite immense potential, there are no full-scale offshore wind projects that are operational or under construction in the United States. Moreover, there are no offshore wind turbines near windy, freshwater areas like the Great Lakes. The goal of the Coastal Ohio Wind Project is to establish the viability of wind turbines on the coastal and offshore regions of Northern Ohio. The project evaluates the potential impact of a turbine on avian life in this region, performs an assessment of the efficacy of avian surveillance strategies, and provides an engineering analysis of potential design/operational alternatives for offshore wind turbines. The project also develops a geospatial database that supports the managerial development of offshore wind turbines.

Approach

Develop WTG Model. In this subtask, the NASA Mod-5B wind turbine design documentation was obtained from NASA Glenn Research Center. The documentation, placed on a CD for ease of access, was studied in order to incorporate the relevant design features. The Mod-5B's steel rotor blades were not desirable because all current large wind turbines use composite blades. Using composite blades will impact the weight and dynamics of the system significantly. Hence, an alternative design, the NREL 5 MW wind turbine was selected as the baseline design. The NREL 5MW turbine is a 3-balde rotor design. For two-blade rotor studies, this design was modified to construct a two-bladed wind turbine model. To compute turbine loads, the IEC 61400-1 guidelines on load cases were adopted. Accordingly, the IEC standards specify site limited load cases. For this purpose, the Lake Erie environment near Cleveland, Ohio was selected as the wind turbine site in this study. For this site, however, a more suitable power rating for the wind conditions of the site (average wind speed 6.4-8.2 m/s) is 3 MW. Therefore, all wind turbine studies in this work focused on a 3 MW version of the NREL reference wind turbine.

Computational Analysis of WTG Model. To determine the loads on the turbine models considered in this study, FAST was used to compute the wind turbine aerodynamic and structural loads. The wave loads were determined making use of the WAMIT software. Using the information obtained from these two codes, the motion of the platform was computed by solving the equations of motion using a customized computer program developed for this task. The solution strategy is shown graphically in the accompanying figure.

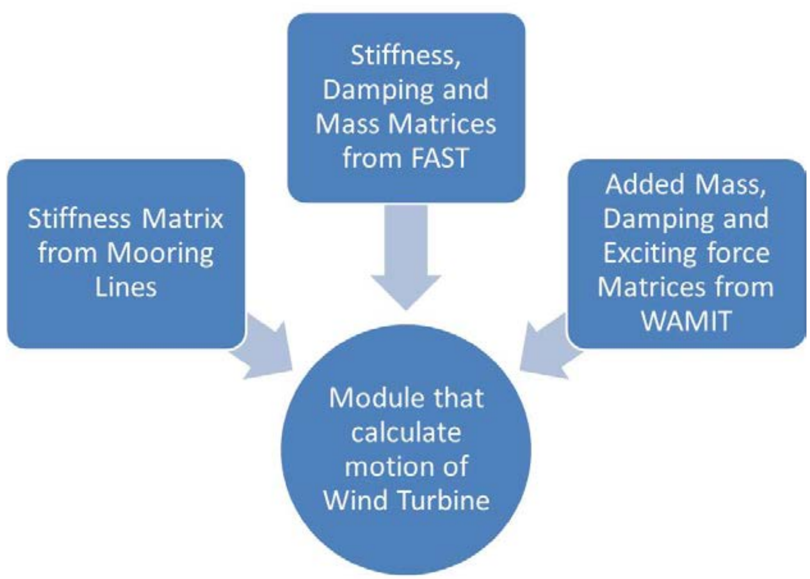

Figure 1. Schematic overview of simulation

A cost model was developed to determine the cost of energy produced by the turbine systems used in the study. This model, implemented in a program using Matlab, adopted and extended existing methods. To facilitate comparison with other systems, the computed costs are presented per one unit of energy, kWh. The costs were categorized into three areas: (1) capital costs, (2) transportation and installation costs, and (3) operating and maintenance costs. In each category, the costs were computed by identifying the cost of individual constituents contributing to that cost. This approach allows various configurations to be readily analyzed and improved estimates of the component costs, when available, can be easily incorporated. For maintenance cost, both the deterministic and Monte Carlo approaches were used. In the Monte Carlo approach, only the unscheduled turbine and balance of system maintenance estimates were randomized. The scheduled maintenance, bottom lease, plant operations, and administrative costs were assumed to remain the same as the deterministic estimate.

Design Comparisons and Validation. Wind tunnel studies were conducted in a closed-loop wind tunnel. The tunnel has a test section of 34" (height), 35" (width) and 53" (length). The flow in the test-section is relatively uniform, with a turbulence level of about 0.5% outside of the wall boundary layers. Hot wire anemometry (TSI, Inc.) and smoke flow visualization were used to study the wake of various tower-turbine configurations. A quasi-steady approach was used in which the rotor blade was stationary relative to the tower. The airfoil profile (NACA 64) at 70% span of the blade of the 5MW NREL turbine was chosen for the blade model. Experiments were conducted with the tower and blade models being arranged in different configurations that simulated various wind turbine operating conditions. Parameters of interest were the relative axial positions of blade and tower, sweep angle between the blade and tower axis, and blade angle of attack. The aerodynamic forces and moments acting on the test articles were measured using a six-axis load cell. National Instruments data acquisition and a customized LabView [10] program to position the hot wire probe and acquire and record the velocity signal from the probe were used.

The motion of an offshore wind turbine platform model was studied in a water tunnel equipped with a simple wave generator. The tunnel is 18" deep, 12" wide, and 100" long. A honey comb was placed upstream of the test area to minimize undesired flow disturbance. The test section of the flume had a transparent side wall for model viewing. A video camera was used to capture the side images of the waves in the tunnel; the images were used to quantify the wave heights incident at the platform. The wave maker was located about 30" upstream of the models. The wave maker generated waves with periods ranging from about 0.1 – 1 second, and peak-to-peak wave heights from approximately 0 - 4 cm. A six-axis force and moment measurement sensor was used to measure the water forces and moments acting on the model platform.

Development of Avian Monitoring Data Acquisition System. An embedded computer, sitting on the onshore or offshore wind turbine tower will be able to capture video data from the infrared camera and radar. The data is recorded to files on the hard drive using application software based on the DirectShow.NET library. A desktop PC located in a field station on-shore automatically connects to the wind tower computer via File Transfer Protocol (FTP) software, and transfers and displays the video files. An interface is also provided to rotate the infrared camera with commands sent to the tower by Transmission Control Protocol / Internet Protocol (TCP/IP). The redesigned system was constructed and tested in the laboratory. The system's functionality was verified to be within specification, and a recommendation is made to utilize the constructed system for laboratory demonstrations and continue development to produce a field prototype.

Improvements were made to previously developed on-shore/ off-shore wind turbine avian monitoring system. The system's purpose is to track and record how birds are affected by wind turbines, and to use this data to minimize bird-turbine collisions. Our objectives for the project included stabilizing the IR camera positioning, synchronizing the incoming video feeds, replacing the existing laptop with an embedded system, and testing the wireless transfer of data.

Stabilizing the IR camera positioning was accomplished through the use of a stepper motor which had a higher holding torque. Software was written to control the motor over the internet using a User Datagram Protocol (UDP) library. Synchronization of the video feed was closely tied to replacing the laptop with an embedded system. Synchronization was accomplished by purchasing capture cards (Epiphan VGA2USB for the radar and Winnov Videum 4100AV for the IR camera) and connecting them to the same embedded system. An embedded system was assembled in a small form-factor case. Since both capture cards are connected to the same system, we can use the system's clock to accurately timestamp and synchronize the feeds. Since both devices implement DirectShow, a filter could be made to save both videos side-by-side. To transfer data wirelessly from the off-shore embedded system to an on-shore remote computer, a 3G connection was used and a simple File Transfer Protocol (FTP) client was written.

The Remotely Controlled Radar and IR Monitoring System for Avian Wildlife improved on a previously existing, less capable, system designed for the same task. The fusion of the Radar and IR camera shall be used for detecting and monitoring birds/bats near wind turbines. This project will accomplish two goals. The first goal is to rotate the base of the radar 180º around a fixed axis. Radar positioning through this system shall be capable through both remote control and local control. The second goal is to rotate an IR camera in four directions (N, S, E, W) both locally via a joystick and remotely through software commands. The IR camera and its associated hardware should be field deployable (capable of set up and tear down by an individual and weather protected). Our improvements shall impact the data collection and the object detection capabilities of the system.

Design of X-band Marine Radar Mounting System. The main purpose of this part was to design and build a new cart and mounting system for marine X-Band radar to be used to monitor and study the effects of wind turbines on bat, bird, and raptor migration habits. There were several constraints taken into account. First was the limited size of the trailer, 5 feet by 10 feet with a door height of 4 feet 6 inches, used to transport all of the monitoring equipment. The second was the need for the cart to be robust enough that it can safely withstand the rough terrain often experienced while still being light enough to maneuver easily. One of the primary objectives was to have the ability to rotate the radar between 0º zero and 180º. Due to the need to alter the angle from 0° to 90° and the size of the trailer, the system needed to be capable of compacting to a smaller size in order to fit in the trailer. The radar needed to be raised from its compacted "traveling" position in order to rotate 90° without the 6'9" antenna hitting the ground.

The design team used the Hydraulic Boom Lift Design and the Center of Gravity Friction Lock Bracket. The team performed kinematic analysis, stress analysis, and FEA (Finite Element Analysis) to check the strength and safety factors of the system. All analyses have shown the system to be safe and robust. The original mounting system that was connected to the radar system on the first generation worked well and is to be included in the second generation cart; however the raising and lowering mechanism, that allowed the cart to be compact during traveling, needed to be attached to a motor that will rotate the original mounting system and be more stable. The final design consisted of a beam with a hinge that could be raised from a horizontal to a vertical position using a linear actuator. After the house of quality inspection was performed, the design team ultimately chose to use the final design of the locked vertical position design.

Bird and Bat Call Acoustic Recognition System. The purpose of this part of the project was to design a system that can effectively identify the avian species present within the vicinity of the wind turbines, through digital signal processing. This is important because with an effective system, endangered species of birds or bats could be identified, and steps could be made to protect the animals in the area. Interaction of birds with wind turbines has become an important public policy issue. Acoustic monitoring of birds in the vicinity of wind turbines can address this important public policy issue. The identification of nocturnal bird flight calls is also important for various applications such as ornithological studies and acoustic monitoring to prevent the negative effects of wind farms, human made structures and devices on birds. Wind turbines may have negative impact on bird population. Therefore, the development of an acoustic monitoring system is critical for the study of bird behavior.

Acoustic data were collected using acoustic detectors (SM2 and SM2BAT). Data were preprocessed to convert the recorded files to standard wave format. Acoustic monitoring involves preprocessing, feature extraction and classification. A novel Spectrogram-based Image Frequency Statistics (SIFS) feature extraction algorithm were developed and compared against traditional feature extraction techniques such as Discrete Wavelet Transform (DWT) and Mel Frequency Cepstral Coefficients (MFCC). Unlike traditional MFCC, signals were first cleaned with wavelet-denoising during the preprocessing stage. Additionally, a mixed MFCC-SIFS (MMS) technique was also developed. Features extracted from proposed algorithms were then combined with various classification algorithms such as k-NN, Multilayer Perceptron (MLP) and Hidden Markov Models (HMM) and Evolutionary Neural Network (ENN). SIFS and MMS algorithms, combined with ENN and MLP, provided the most accurate results. Proposed algorithms were tested with real data collected during the spring migration, around Lake Erie in Ohio, of five nocturnally migrating bird species native to Northwest Ohio. Also, sparrows, warblers and thrushes passing over the University of Toledo, the Ottawa National Wildlife Refuge and Ohio State University’s Stone Lab were calculated. Quantification of class level migratory bird were presented in the quarterly reports. The developed bird/bat flight call recognition system is suitable for deployment for both on-shore & offshore wind turbine locations. This system would be suitable for 24/7 remote sensing.

IR Video Processing. This study aimed to design a robust and efficient monitoring system for analyzing the bird migration data for wind farm applications. This system is able to process thermal image sequence data and output accurate results suitable for interpretation by wildlife biologists. An IR video processing algorithm was proposed which meets the IR video processing requirement for this project.

Infrared videos were collected using thermal IR camera (FLIR SR 19). Pre-processing was performed to convert infrared videos to frames. Three different background subtraction techniques were applied to detect moving objects in IR data. Thresholding was performed for binarization using extended Otsu Threshold. Morphology was performed for noise suppression and filtering. Results of three different techniques were then compared. Selected technique (RA) followed by thresholding and filtering is then used for tracking and information extraction. The proposed algorithm consists of background subtraction and consecutive frame subtraction, frame selection, 3-D region labeling and breakpoint recovery. Ant Clustering Algorithm (ACA) based on Lumer & Faieta with its three different variations including Standard ACA, Different Speed ACA and Short Memory ACA are implemented over extracted features and are compared in terms of different groups created for detected avian data. Fuzzy C means is implemented and used to group the targets.

The developed IR video processing algorithm has been simulated for performance evaluation. It is then used to process spring 2011 bird migration data that has been collected in Ottawa National Wildlife Refuge in Ohio. Results from this study will be useful for wild life biologists to make intelligent decision for siting of wind turbines.

Radar Data Processing. Marine radar data were collected to study the behavior of birds towards wind turbines. Radars employ target tracking for identifying the targets (birds) accurately and efficiently. Several methods of tracking were developed to improve the tracking efficiency of the radars over the years. Most widely used tracking techniques are Kalman filter and particle filter. These filters use data with random errors and estimate accurate values for the current state of the system. Kalman filter is a linear estimator, which does not depend on a set of past observations and hence efficient in real time applications. The particle filter also known as sequential Monte Carlo method is a nonlinear estimator, which uses a set of particles with various weights for estimation. However, particle filters have high computation time. Kalman and particle filters were developed over the years creating various models for various types of systems. A block version of Compressive Matching Pursuit (CoSaMP) algorithm used in signal reconstruction called BCoSaMP was employed in tracking. It was seen to give a similar or better performance than particle filter with less computation time. The BCoSaMP algorithm with Kalman filter estimation was developed which reduces the mean square error as compared to other models in certain cases.

This part of the work focuses on developing tracker models in radR. Kalman filter tracking model based on linear data and Gaussian noise that operates over a variety of target motions and velocities is developed. Particle filter is designed for nonlinear target motion with non-Gaussian noise. BCoSaMP model that assumes data as sparse is applied for target tracking and a modified BCoSaMP which replaces least square estimation with Kalman filter estimation are also implemented. These models were tested with different data sets and a comparative analysis is performed. The algorithms are tested on simulated data and marine radar data in radR to compare the effects of the developed tracker models with the conventional methods in radR. The hybrid algorithm showed to have better performance over the other models in the case of simulated track for some targets. Particle filter has the highest detection rate with marine radar data.

This project development used marine radar and open source software called radR and generated results comparable to commercially available radar systems. Generally two kinds of studies are conducted, pre deployment and post deployment of wind turbines. In this project pre deployment study over Lake Erie was implemented. The primary goal here was to collect information on the migration characteristics of nocturnally migrating birds, during the Fall and Spring migration period. Specifically, the objective of this study was to collect baseline information on migration characteristics (i.e., flight direction, migration passage rates, and flight altitudes) of nocturnally migrating birds.

Radar data were collected using Furuno marine radar (XANK250) and *t*-bar antenna and parabolic dish. The target detection is processed using radR which is open source platform available for recording and processing radar data. This platform was used to remove clutter and noise, detect possible targets in terms of blip, and save the blips information. The tracking algorithm was developed based on estimation and data association, independent from radR. Estimation is performed using Sequential Importance Sampling-based Particle Filter (SIS-PF) and data association is performed using the Nearest Neighbors (NN).

Develop an Environmental GIS Database. Multiple sources of data were collected in both digital and hard copy formats during the project. The hard copy data were processed and converted to geographic information systems (GIS) shape files. The data provides information sets that are used in GIS and spatial databases for purposes of geospatial analysis and spatial decision support system for mapping and decision-making. During the timespan of project, we collected many different layers of mapping data associated with our region. Some of the geographical layers that relate to both onshore and offshore environments included physical data such as wind speed, elevation, ridge line locations, and slope. In addition, new geospatial data layers were derived by implementing different algorithms and image processing techniques.

The Great Lakes region experiences significant diurnal and seasonal variability in wind speeds, which means shutting down wind turbines to protect birds would have different impacts on electricity generation depending on the time of day and time of year. Thus, we have obtained and are processing several sources of wind data for the area with temporal resolutions as fine as 10-minute intervals. Figure 2 shows one of these sources, the NCEP North American Regional Reanalysis, for the month which typically has the weakest winds at our study site (August), and the month which typically has the strongest winds at our study site (December).

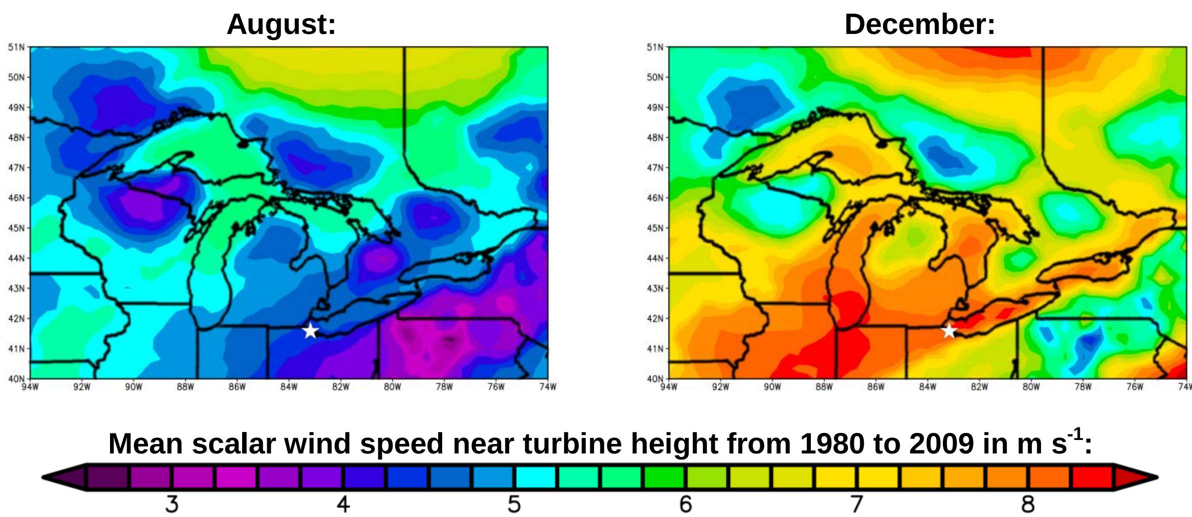

Figure 2. Wind Speed near from NCEP North American Regional Reanalysis

Analysis of seasonal and diurnal variability in power output at the study site (indicated by the star above) utilized data from MESO Inc.’s Mesoscale Atmospheric Simulation System (MASS) version 6.8 in a nested grid scheme driven by NCEP/NCAR Global Reanalysis data, which provided output at a 2 km horizontal resolution for child grids. Wind speeds from MASS for a 100-meter turbine hub height were then converted to power output by averaging the power curves for the GE 1.5xle and Gamesa G90 turbines using AWS Truepower’s SynOutput. Figure 3 shows expected production losses for a wind plant fitting this description located near the study site, from setting various shutdown rules for cumulative thresholds of bird concentrations during the fall migration period, based upon detections of birds with the parabolic radar antenna from this project’s 2011 field operations.

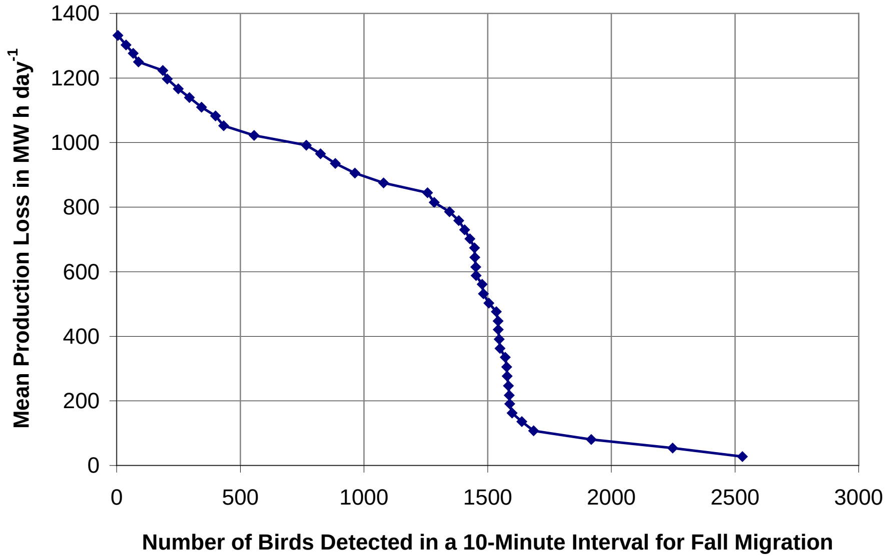

Figure 3. Expected production losses

The environmental data includes land use, open water bodies, wetlands, endangered species habitats, and migratory bird habitats. The land use data is a 200 meter-resolution raster file from the USGS 2001 National Land Cover Dataset. The open water body layer was obtained from Environmental Systems Research Institute (ESRI), and the wetlands data was acquired from the United States Fish and Wildlife Service.

The human-impact category includes data on urban areas, cities and towns, railroads, highways and interstates, roads, airports, and transmission lines. The urban areas data is from the 2000 Census and displays regions of contiguous census blocks that meet a minimum requirement of 500 to 1000 people per square mile, along with adjacent census blocks that together encompass at least 50,000 people. Data on cities and towns was acquired from The National Atlas of the United States. This dataset uses the 2000 Census to represent areas of varying populations, split into seven categories ranging from less than 10,000 people to 1 million. A layer depicting railroads was developed by ESRI from data compiled by the Federal Railroad Administration. ESRI also developed the data layer showing interstates and U.S. highways and the data containing information on roads. The transmission line data was digitized from a map created by AWS Truewind showing the locations and capacities of transmission lines in the state of Ohio. The lines are classified by kilovolt power and include; less than 100 kV, 100-161 kV, 345 kV, or 735 kV and greater.

Some of the layers associated with Lake Erie include Ice Coverage, Commercial Fishery Effort, Distance from Shore, Fish Habitat, Navigable Waterways, Sport Fishery Effort, and Utilities. Some data examples are shown below in the Figure 4 where fish habitat is used as an indicator for larval and young-of-year fishes (NREL, 2010). The fish habitat map in a vector data format was acquired from ONDR (2012) that is classified into four classes as walleye nursery, adult walleye, walleye/perch, and dead zone. The sport fishery effort is a common activity in the Lake Erie that is compiled by the average hours targeting walleye and yellow perch using an area of 10-minute quadrangle from 2000 to 2006. The spatial data layer for was acquired from ODNR (2012). The sport fishery map was grouped into four classes as 0-4,000, 4,000-25,000, 25,000-106,000, and 106,000-700,000 hours. The classes are based on the total hours spent by people in the areas. The commercial fishery effort indicates fish productivity of an area which is measured based on the amount of fish harvest which is measured in trap net lift (GLWEC, 2009). ODNR (2012) provided the vector map showing total number of commercial fishery effort trap-net lifts by 10-minute quadrangle, from 2000 to 2006. The map was classified into four classes as 0-32, 32-250, 250-600, and 600-2900 trap net lifts. Therefore, suitability decreases from the first class, 0-32 traps, to the fourth class, 600-2900 traps.

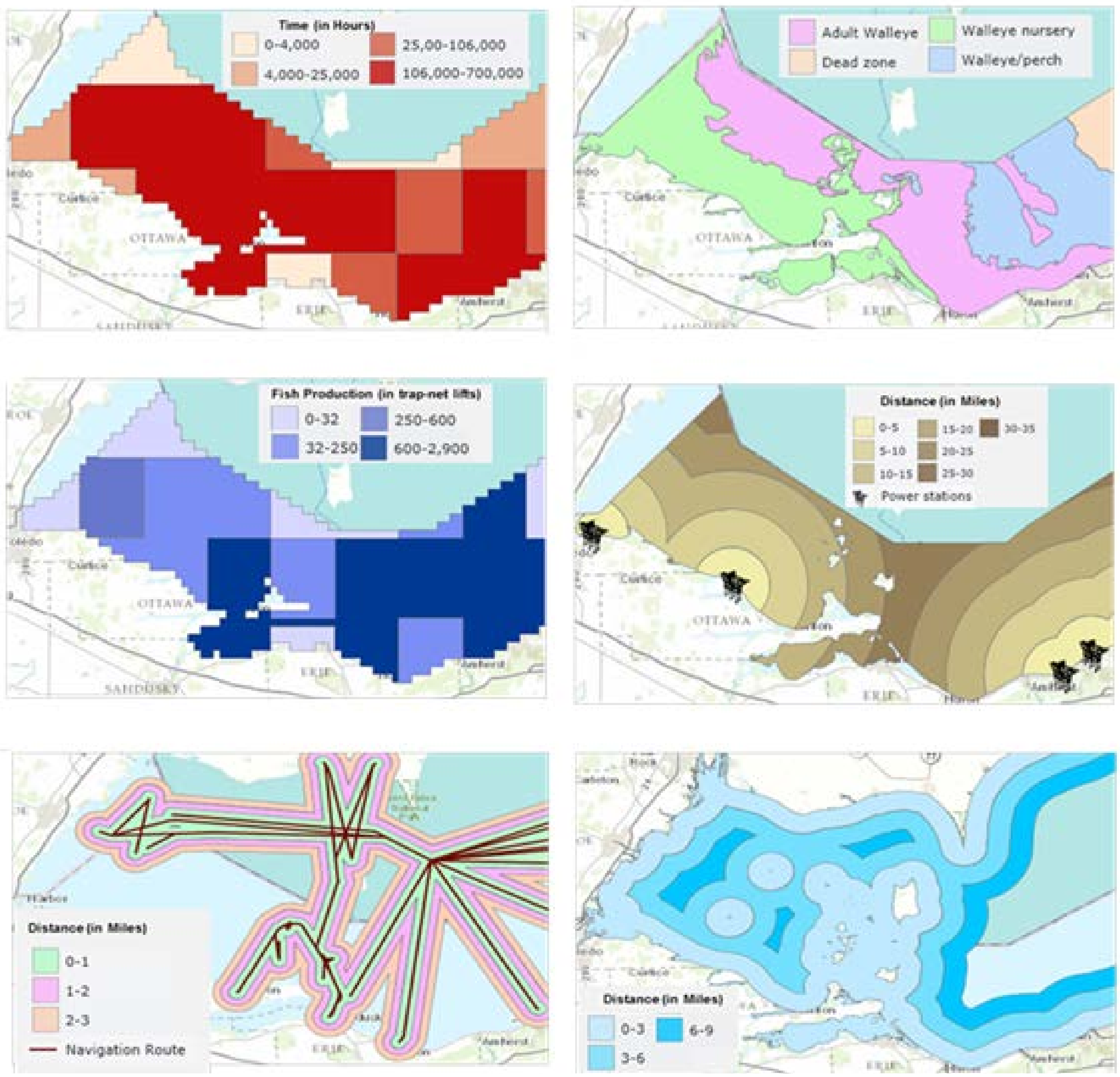

Figure 4. Sport Fishery Effort , Fish Habitat, Commercial Fishery Effort, Distance from Utilities, Distance from Navigable Waterways, and Distance from Shore

The surface water temperature and ice cover are derived from NOAA polar-orbiting satellite imagery obtained through the Great Lakes CoastWatch program at the NOAA Great Lakes Environmental Research Laboratory (GLERL) in Ann Arbor. Lake surface temperatures are updated daily with information from the cloud-free portions of the previous day's satellite imagery. When no imagery is available, a smoothing algorithm is applied to the previous day's map. Ice information will then be added, using the most recent Great Lakes Ice Analysis produced by NIC, nominally twice per week during the ice season. The Ice cover product was integrated in our GIS database.

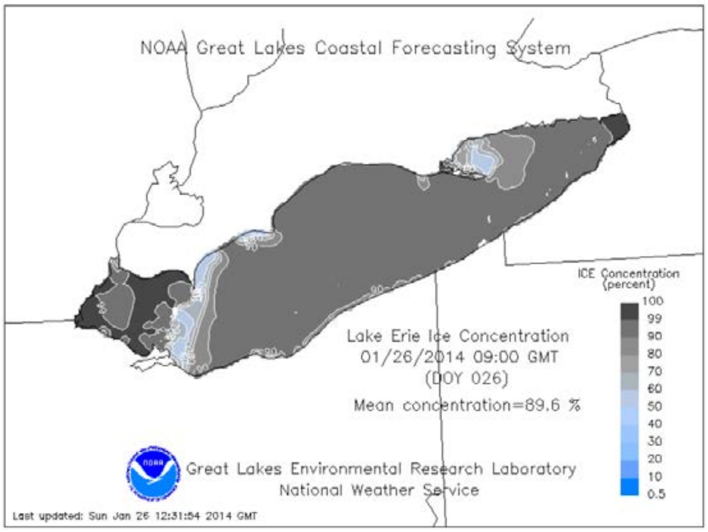

Figure 5. Ice Concentration

Results

Develop WTG Model. A 3 MW wind turbine is suited for the Lake Erie wind environment as the following results demonstrate. The Figure 6 shows the wind distribution over a range of the site's wind speeds. The rated wind speed is also shown on the graph. A 3MW wind turbine reaches rated power at 9.31 m/s. A 5 MW wind turbine reaches rated power at 11.04 m/s. A wind turbine is most efficient at or below rated wind speed. Beyond rated wind speed the control system bleeds off wind energy to keep the wind turbine at rated power capacity. As it can be seen, the wind speed reaches close to rated wind speed for a 5 MW wind turbine less frequently than it does for a 3 MW turbine. As a result, the difference in annual energy production (and the generator cost) makes the 3 MW wind turbine more cost effective than the 5 MW for Lake Erie. Figure 7 shows a comparison of annual energy production for 3 MW and 5 MW wind turbines using the wind speed range of the possible Lake Erie site. As it can be seen, the 3 MW turbine is more cost efficient most of the time. Accordingly, the study presented in this report focused on a 3 MW design. The rotor radius and the hub height were retained as 63 m and 100 m, respectively.

Three turbine configurations were studied. The baseline design is the NREL blade. The Optimal Two-Blade (2BOpt) model is a two-bladed wind turbine based on the baseline wind turbine. Along with removing one blade from the rotor, the chord and twist distributions of the blade were changed to accommodate the higher RPM of a two-bladed rotor. The Floating Turbine (2BFlt) model uses the optimal blade model installed on a floating platform.

Computational Analysis of WTG Model

Levelized Cost. The cost model developed in this study was applied to the three wind turbine models. The results are summarized in Table 2. The corresponding annual energy production is shown in Table 2. The two-blade floating platform offers the lowest LCOE at $0.0748/kWh. In order to account for the cost of unscheduled (random) maintenance, the Operation and Maintenance part of the cost analysis was done using both a deterministic method and a Monte Carlo approach. It was found that the largest difference between the deterministic and Monte Carlo LCOE estimates was the levelized replacement cost. For all three models, the randomized replacement costs increased. The baseline and optimal models saw increases of 104% and 88%, respectively. The floating model saw an increase of 5.6%.

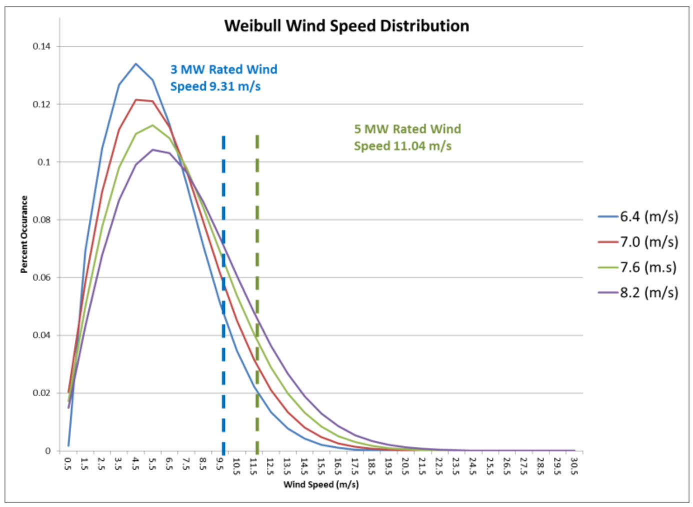

Figure 6. Weibull wind distribution of Lake Erie wind range

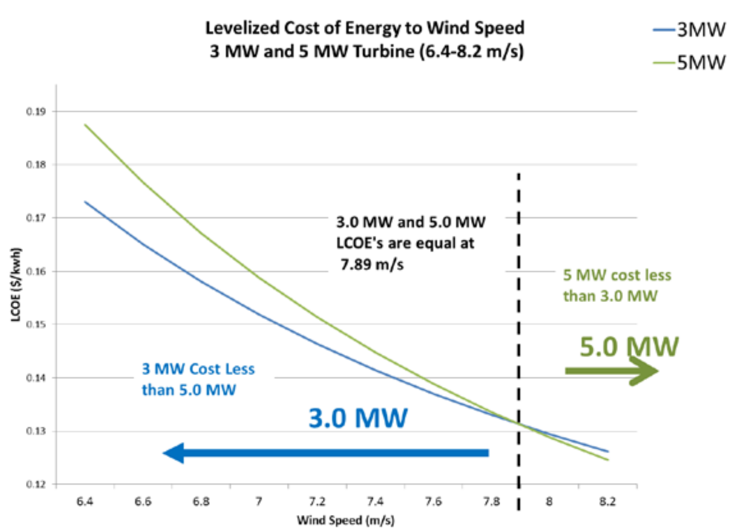

Figure 7. LCOE to Wind Speed of 3 MW and 5 MW Turbines

The large increase in the cost of the baseline and optimal models is from the gearbox. In the deterministic method, the baseline turbine had two gearbox replacements and the optimal model one replacement. However, the randomized replacement approach predicted three and two gearbox replacements for the turbine models, respectively. The blade and generator cost differences were modest for the baseline and optimal models, ranging between 0.18% and 2.13%.

Table 1 Levelized Cost of Energy Results Deterministic ($/KWH)

Levelized Cost of Energy ($/kWH)	Baseline	2bOpt	2bFlt
Turbine Capital Costs	0.0474	0.0432	0.0348
Balance of System Costs	0.0361	0.0331	0.0162
Operation and Maintenance	0.0231	0.0217	0.0169
Levelized Replacement	0.0191	0.0090	0.0069
Levelized Cost of Energy	0.1256	0.1070	0.0748

Table 2 Annual Energy Production Results Deterministic

Annual Energy Production	Baseline	2bOpt	2bFlt
AEP Gross (Turbine)	14193.86	14119.84	14119.84
Total Losses	0.18	0.18	0.18
Total Days Down	11.87	11.09	8.35
System Availability	0.97	0.97	0.98
AEP Net (Turbine)	11222.03	111.88.09	11274.64
Capacity Factor	0.43	0.43	0.43

Load Effects. Wind turbine models were studied to predict shear force, bending moment, axial force, and torsional moment at the tower base, tower top, blade root, low-speed shaft (LSS), as well as torque values at the high-speed shaft (HSS) and generator. These results are summarized in Table 2. For comparison, load effects of the NREL 5 MW reference turbine are also included. These turbine systems use different pitch control strategies and reach the rate power at different wind speeds.

Many maximum load effects of the 3MW two-bladed wind turbine model were greater than those of the 5MW wind turbine model. Most of the average load effects of 3MW machines are equal to or lower than the load effects of the 5MW machine except load effects at the blade root. All torque values of the 3MW machines are lower than the torque values of the 5MW machine.

Table 2. Load effect differences compared to baseline results.

		Load Effect Values		**Difference compared to baseline (%)**							
Location	Load Type	5MW Baseline		3MW 3-Bladed				3MW 2-Bladed			
		Maximum	Average	Maximum		Average		Maximum		Average	
Tower Base	Shear Force	1615kN	685kN	▼	-19.7	▼	-30.5	▲	33.2	▼	-30.7
	Bending Moment	129203kNm	53934kNm	▼	-20.6	▼	-31.3	▲	28.3	▼	-29.6
	Axial Force	-5961kN	-5788kN	▼	-0.3	▼	-0.2	▼	-1.8	▼	-3.3
	Torsional Moment	31380kNm	3800kNm	▲	24.4	▼	-46.1	▲	4.8	▼	-13.8
Tower Top	Shear Force	1572kN	712kN	▼	-20.4	▼	-30.6	▲	29.3	▼	-30.9

	Bending Moment	12176kNm	5018kNm	▼	-18.6	▼	-19.6	▲	3.6	▼	-34.0
	Axial Force	-3652kN	-3489kN		0.0	▼	-0.3	▼	-2.6	▼	-5.5
	Torsional Moment	31380kNm	3800kNm	▲	24.4	▼	-46.1	▲	4.8	▼	-13.8
Blade Root	Shear Force	706kN	300kN	▼	-11.9	▼	-6.0	▲	1.9	▲	2.5
	Bending Moment	21458kNm	10101kNm	▼	-14.8	▼	-25.6	▲	11.8	▲	3.1
	Axial Force	1287kN	632kN	▼	-13.1	▼	-24.4	⬆	52.2	▲	25.6
	Torsional Moment	224kNm	194kNm	▲	40.6		0.0	⬆	79.9	▼	-30.7
LSS	Shear Force	2450kN	1140kN	▲	19.7		0.0	▲	26.5	▼	-20.1
	Bending Moment	16990kNm	4671kNm	▲	22.9	▼	-18.9	▼	-19.1	▼	-15.4
	Axial Force	1334kN	790kN	▼	-20.2	▼	-26.9	▼	-2.1	▼	-29.5
	Torque	7231kNm	4186kNm	▼	-18.6	▼	-30.9	▼	-25.6	▼	-45.7
HSS	Torque	75kNm	43kNm	▼	-18.6	▼	-30.9	▼	-25.6	▼	-45.7
Generator	Torque	47kNm	43kNm	▼	-30.8	▼	-30.9	▼	-45.7	▼	-45.7

Design Comparisons and Validation

Wind Tunnel Study. Smoke flow visualization was used to study the near wake flow. Figure 8 shows an example. It can be seen that the wake in the upwind configuration is noticeably narrower compared with the downwind configuration. The flow with the downwind blade is very similar to that of the tower alone.

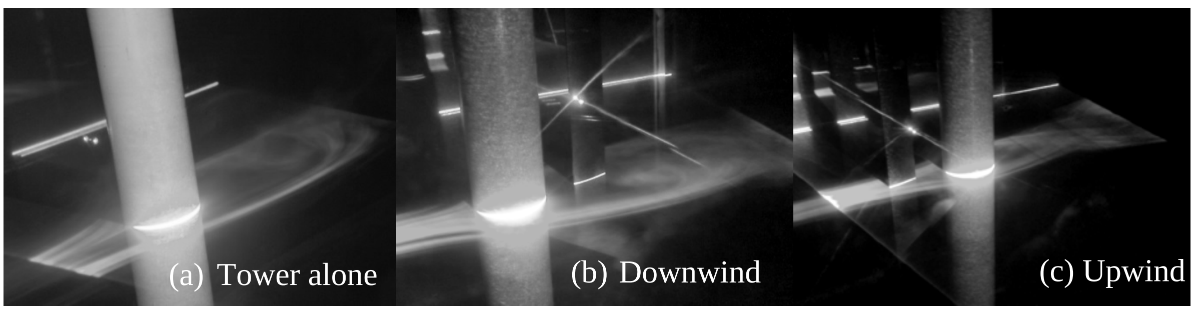

Figure 8. Visualization of the flow with the turbine blade at 10 degree angle of attack and 0 sweep angle. Distance between the blade and the tower is 1 tower diameter

Flow field measurements were conducted using a constant-temperature hot-wire anemometer and a computer-controlled 3D traverse to position the hot-wire probe during measurements. The Figures 9 and 10 show mean and rms velocities in the near wake of a turbine blade with an upwind and a downwind tower. The results show that the flow is dominated by the tower when the rotor blade is downwind, confirming the visualization results. When the rotor blade is upwind, the mean velocity shows a narrowing of the wake compared with the case of the tower alone. Correspondingly, the rms velocity peaks increase in magnitude and move in-board. These characteristics indicate the presence of a narrowed wake and stronger vortex street, which agrees with the flow visualization results. This behavior likely causes an increase in the oscillatory force on the tower.

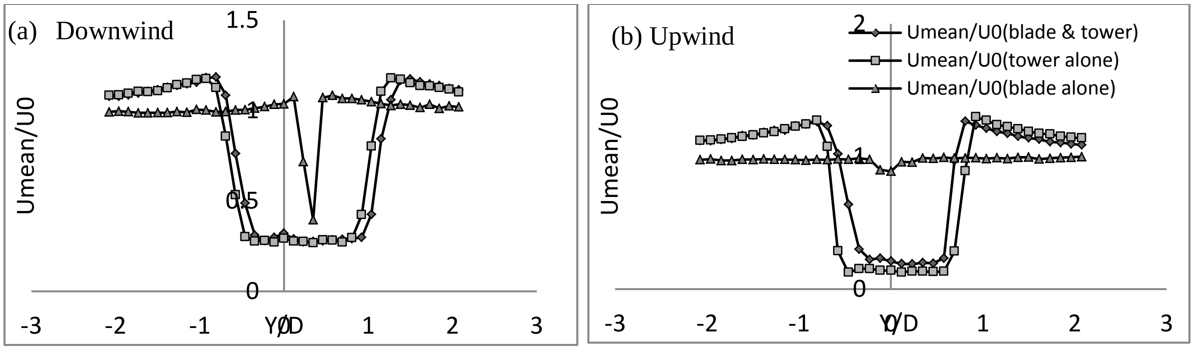

Figure 9. Mean velocity distribution with turbine blade at 10 degree angle of attack and 0 sweep angle. Distance between blade and tower is 1 tower diameter

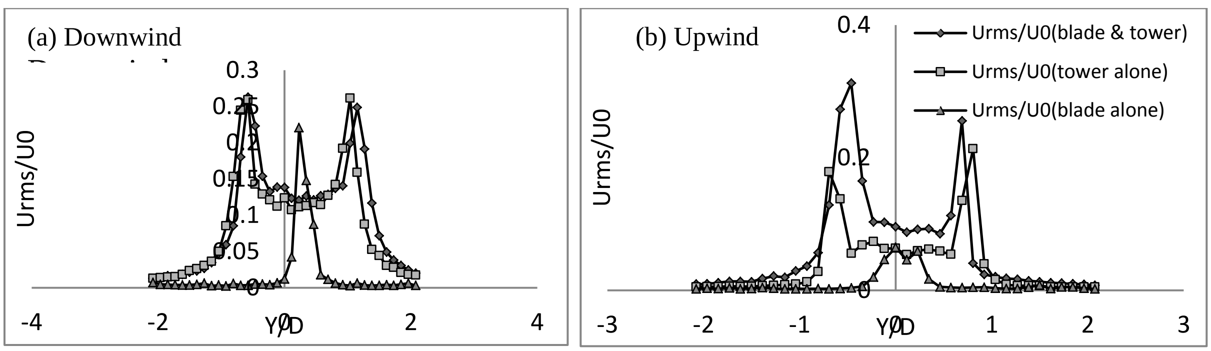

Figure 10. Rms velocity distribution with turbine blade at 10 degree angle of attack and 0 sweep angle. Distance between blade and tower is 1 tower diameter.

The far wake flow was also investigated. The results for the case when the distance between the tower and the blade is 0.75 tower diameter are shown below. Results for the downwind rotor blade was similar to that of the tower alone case (not shown), indicating that a downwind rotor blade has very little influence on the dissipation of the wake. The presence of an upwind blade, however, noticeably accelerates the rate of wake dissipation.

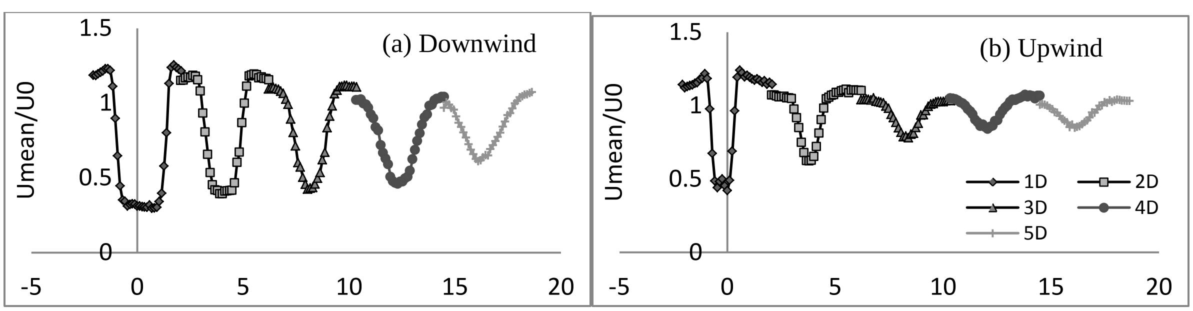

Figure 11. Downstream development of mean velocity distribution with turbine blade at 0 degree angle of attack and 0 degree sweep angle at Z=0.5L. Distance between blade and tower is 0.75D.

Numerical results and the corresponding scale model test data of a floating platform is shown in Figure 12. There is good agreement between the experimental and numerical results, which indicates promise for both approaches.

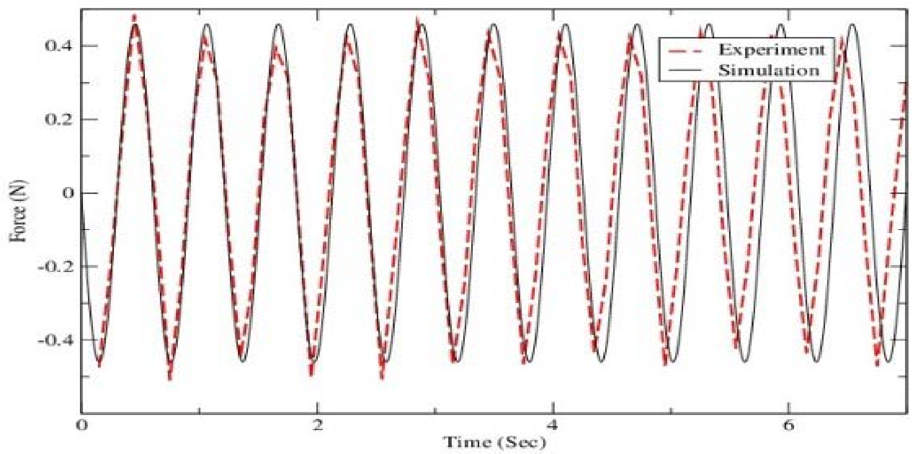

Figure 12. Wave force on single cylinder

Two platforms in three different depths, 60 m, 150 m, and 450 m were numerically studied. The response showed that when subjected to the same wave amplitude and frequency, the platform motion is strongly influenced by water depth for the three cases studied.

Findings from monitoring system. The schedule of when the *t*-bar configuration versus the parabolic dish setup was used reflected different questions we were trying to assess on the same nights during migration. Specifically, we were interested in ascent characteristics during the post-sunset period (spring only), orientation and volume during the middle of the night, and descent characteristics during the pre-dawn period. The deployment protocol was therefore as follows:

- *t*-bar antenna in sidecast configuration from 30 min after sunset until 3 hrs after sunset (spring only)
- Parabolic dish antenna rotationally sampling 15° above horizon from 3.5 hrs after sunset until 2.5 hrs before civil twilight
- *t*-bar antenna in sidecast configuration from 2 hrs before civil twilight until full sunrise

The lag period between *t*-bar and parabolic dish data collection reflects the approximate time period it took to switch the antenna configuration and recalibrate the system. Analysis of parabolic dish data stipulated that in order for targets to be considered as part of the same track they were to be consistent in size, speed and heading within certain specified thresholds and the track was to be composed of at least 4 target/blip detections from different radar sweeps. Many of the size, speed, and heading thresholds were set within the radR analysis software, but as an extra post-processing evaluation we also considered the gap between sequential points within a putative track. If these points were separated by greater than six seconds (i.e., approximately 2.5 radar rotations), then the connection was considered unsupportable and the track was split in two at this point.

One should note that our approach as well as the limited window of airspace detected by the parabolic dish meant that the tracks reported represent a relative measure of migration volume that is consistent across nights, but is not an absolute count of the number of birds or bats passing overhead on any given night. Following the radR analysis and subsequent post-processing we were able to isolate hundreds of thousands of tracks during each migratory season of 2012 (Table 3).

Table 3. Total tracks and hourly passage rates by season, antenna configuration, and time period during 2012 migratory periods.

Season	Configuration	Time Period	Total Tracks	Passage Rate (Tracks/hr) Mean (±s.d.)	Range
Spring	Parabolic	Mid-night	204,222	1350 (± 962)	172 - 3955
Spring	T-bar	Sunset	103,768	1361 (± 1274)	37 - 4604
Spring	T-bar	Sunrise	63,228	1079 (± 1083)	24 - 4038
Fall	Parabolic	Mid-night	218,092	1151 (± 932)	99 - 4031
Fall	Parabolic	Sunset	59,685	810 (± 671)	101 - 2922

Nightly passage rates (tracks/hr) varied by season, time of night, and the antenna configuration used (Table 1). Migration volume was consistently higher during Spring, with approximately 25% more tracks detected per hour in the middle of the night period relative to passage rates observed during Fall. In contrast, the maximum passage rate on any given night was approximately equal between seasons. This suggests that either the radar in parabolic configuration becomes saturated at any passage rate above ~4000 or that exceptional migration events are comparable across seasons.

Parabolic dish configuration (15° above horizon). The course heading of target tracks detected by the parabolic dish was evaluated using Oriana 4.01 (Kovachs Computing Services 2011). The mean course direction across all tracks during the Spring migration was 2.51° (Figure 13), though a large amount of variation was observed (circular s.d.= 75.44°).

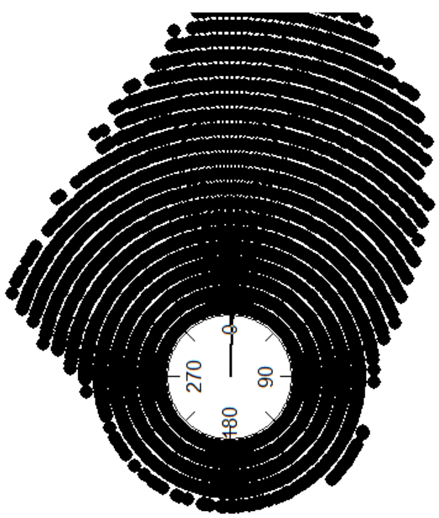

Figure 13. Circular plot of clustered track course directions for Spring 2012. Each dot represents sixty-five tracks. A line originating from the center of the compass indicates the global mean course direction.

Mean flight direction appeared to differ over water (6.2°; 99%c.i.: 5.5-6.9°) versus land (357.8; 99%c.i.: 357.1-358.6°). A Mardia-Watson-Wheeler test corroborated this (W=187.0, p<0.0001). However, a non-parametric Watson's U2 test did not indicate that the difference in overall mean course direction (U2=-33.43, p>0.50), and indicates that the significant difference is without a significant effect. The slight differences between land and water are driven in part by an increased proportion of tracks over land paralleling the coast (~310°) and an increased proportion of tracks over water heading east-to-northeastward (Figure 14).

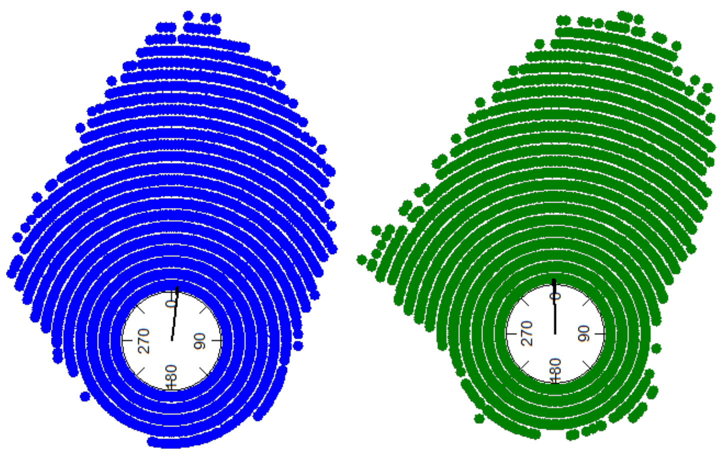

Figure 14. Overlays of relative abundance of tracks along the same heading over water (blue) and over land (green). Note that the number of tracks represented by the dots are unequal (over land green dots = 29 tracks, over water blue dots = 36), therefore the number of tracks represented by a single dot will differ accordingly.

Track groundspeeds in Spring 2012 showed a pattern similar to that observed in Spring 2011; slower tracks more generally paralleled the Lake Erie coast (~310°) than those with faster realized groundspeeds (Figure 15). This pattern is particularly pronounced in tracks over land, which suggests that an avoidance behavior may be causing migrants to change course prior to encountering the hard shoreline boundary. Significant circular-linear correlations were found both over water (r = 0.180, p<0.0001) and over land (r = 0.127, p<0.0001).

Over Water

Over Land

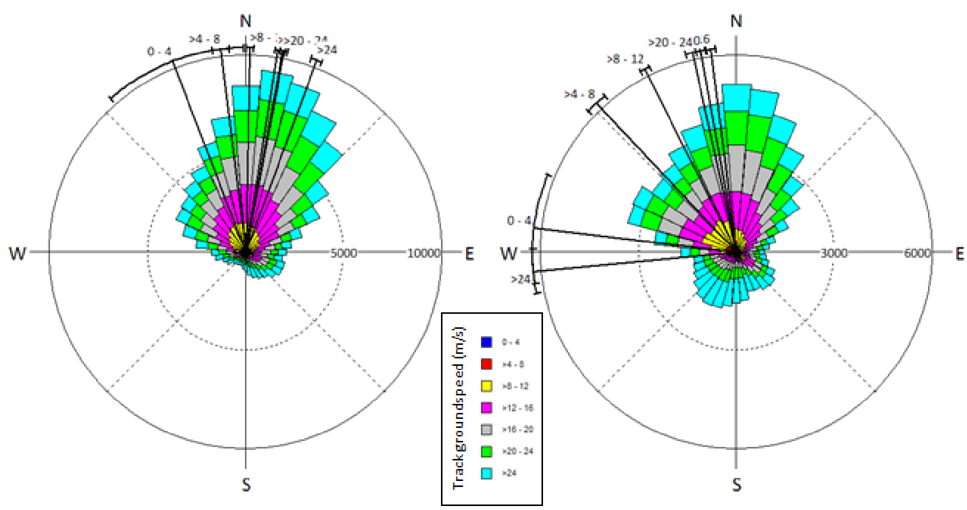

Figure 15. Bivariate rose-diagrams showing course direction and groundspeed of over water (left) and over land (right) tracks. Mean course directions (plus 95% c.i.) within bins 4m/s wide are indicated.

Figure 16. Circular plot of clustered track course directions (black dots) for Fall 2012 overlaid on a schematic of the western Lake Erie region (dark red lines). Each dot represents fifty-eight tracks. A line originating from the center of the compass indicates the global mean course direction.

Mean flight direction appeared to differ over water (174.9°; 99%c.i.: 174.1-175.7°) versus land (188.8°; 99%c.i.: 188.3-189.3). A Mardia-Watson-Wheeler test corroborated this (W=9479.5, p<0.0001). However, a non-parametric Watson's U2 test did not indicate that the difference in overall mean course direction (U2= -266.7, p>0.50), and indicates that the significant difference is without a significant effect. The slight differences between land and water are driven in part by an increased proportion of tracks over land heading more southwestward and an increased proportion of tracks over water heading southeastward, westward, or out over Lake Erie (Figure 17). The apparent narrowing of the bimodal heading of fall migrants as they pass onto land is interesting as it may reflect these animals reorienting to a more southerly heading after they have crossed the Lake Erie barrier.

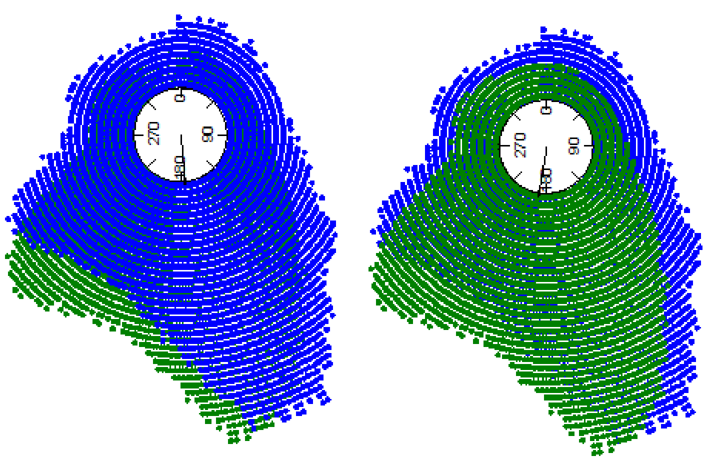

Figure 17. Overlays of relative abundance of tracks along the same heading over water (blue) and over land (green). Note that the number of tracks represented by the dots are unequal (over land green dots = 37 tracks, over water blue dots = 30), therefore the number of tracks represented by a single dot will differ accordingly.

The orientation data in fall 2012 were distributed in a bimodal distribution (Figure 16) and this general pattern is consistent over water versus over land (Figure 17). The larger mode occurred around 160° while a reduced, but still prominent, mode occurred around 230°. What these two modes potentially illustrate is that migrants are arriving from two major directions. These directions happen to correspond, respectively, to known areas of elevated migratory activity: (1) the north-northwest and the Detroit River corridor and (2) the western Lake Erie island chain that runs from Point Pelee, Ontario to Sandusky, Ohio. Further analyses will be used to determine if the nightly prominence of migratory direction alternates between these modes or according to climatic conditions.

The passage rates during mid-night periods of each night of the spring and fall migratory seasons were classified into quartiles within the respective seasons. During Spring 2012 the mean passage rate among nights of the first quartile, spQ1 (2746 targets/hr), could be extrapolated to account for 50.8% of the total seasonal migratory flow. The spQ2 mean passage rate (1404 targets/hr) accounts for another 26.0% of the seasonal flow, meaning that 76.8% of migration apparently happened on half the nights. Quartiles spQ3 (841 targets/hr) and spQ4 (411 targets/hr) accounted for the remaining 15.6% and 7.6% of migratory volume, respectively. During Fall 2012 the mean passage rate among nights of the first quartile, fpQ1 (2457 targets/hr), could be extrapolated to account for 53.4% of the total seasonal migratory flow. The fpQ2 mean passage rate (1383 targets/hr) accounts for another 30.0% of the seasonal flow, meaning that 83.4% of migration apparently happened on half the nights. Quartiles fpQ3 (538 targets/hr) and fpQ4 (227 targets/hr) accounted for the remaining 11.7% and 4.9% of migratory volume, respectively.

The altitudinal distributions of blip tracks during both spring and fall apparently differed by passage rate quartile (Figure 18). The relative abundance of tracks during Spring 2012 indicated that on heavy migration nights of spQ1 a large portion of the migration volume was distributed at relatively low altitude. As migration volume decreases between spQ1 to spQ4 the relative distribution of tracks appears to shift toward a more gradual relationship between altitude and apparent declines in track abundance. Fall, on the other hand, indicates the opposite pattern, with high migration volumes of fpQ1-2 having relatively higher track volumes at higher altitudes (Figure 18).

The apparent shift of high-volume migrations between seasons could reflect the influence of Lake Erie on migratory behavior. Much of the low-level migration during Spring may either be rising in altitude as they cross the lake or a substantial portion is reorienting shortly after encountering the barrier and moving around the lake. Under each scenario, the fall migrants detected over the Ottawa NWR shoreline are passing overhead at higher altitudes than in Spring. Our evidence tends to suggest that reorientation at the shoreline is a distinct possibility, since a notable subset of tracks appear to parallel the coastline. However, this does not negate another hypothesis that migrants are responding to the coast by rising in altitude.

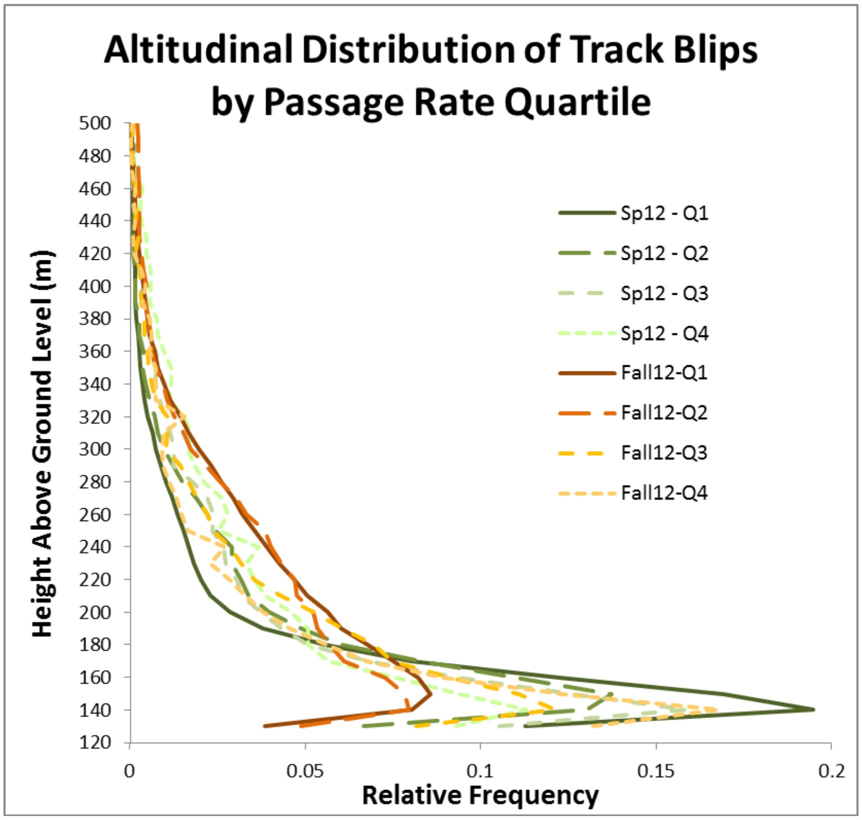

Figure 18. Relative frequencies of track altitudes between 130-500m within migratory-volume quartiles of Spring and Fall 2012.

Sidecast *t*-bar configuration (20° beamwidth oriented 19.5° east of true North). The sidecast configuration provided a means to gather data about shifts in flight altitudes at the shoreline interface by of individual migrants. During Spring 2012 the data collected provided us the further opportunity to compare climb rates (positive or negative) between lakeward-headed versus landward-headed tracks as well as during three different time periods of the night: sunset, mid-night (limited sampling), and sunrise.

Climb rates were calculated as a mean value of altitude change between each successive points of a track relative to time. Tracks were classified as headed "lakeward" or "landward" and occurred within the timeframes for each period of the night previously outlined (sunset/mid-night/sunrise). Climb rates were binned into 1m/s iterations centered on 0m/s. Rates beyond -20 or 20m/s were excluded from analysis as these likely represent erroneous tracks as such rates would largely fall outside the realm of biological possibility.

Mean, kurtosis, skew relative to mean, and skew relative to zero were calculated for climb rate data within each heading category within each time period. The latter measure is designed to test the assumption that climb rates will be equally distributed around zero in a population that shows no directed response to the shoreline boundary. Landward and lakeward climb rates plotted onto circular arrays scaled between -10 to 10m/s illustrate any departures from equality as well as the apparent shifts between time periods in the climb rates observed in Landward-headed tracks.

Results from Spring 2012 indicated that climb rates were deviating from zero, even during the mid-night period, and the rate means and variance differed across time periods and according to general heading. During the sunset period the climb rate was positive for both lakeward and landward tracks and significantly departed from zero (Table 4). The distribution of climb rates significantly differed between landward and lakeward-headed tracks during all time periods. For tracks headed the same general direction, all significantly differed among time periods except landward tracks during sunset versus mid-night (Table 4).

Table 4. Summary statistics for climb rates observed at sunset, mid-night, and sunrise in targets headed landward versus lakeward. All comparisons of means were significant between landward and lakeward tracks of the same time period. Comparisons of targets headed in the same direction (landward/lakeward) all significantly differ across time periods except where indicated. All skews relative to zero were significantly large except where noted.

				Skew (<=|20|)		
		Mean	99% C.I. (+/-)	Rel to mean	Rel to zero	Kurtosis
Sunset	Landward	0.201 ┐	0.149	-0.061	0.014	0.145
	Lakeward	0.668 ├ ns	0.046	0.160	0.541	3.742
Mid-Night[1]	Landward	0.196 ┘	0.265	-0.001	0.104 ns	2.582
	Lakeward	1.796	0.253	0.054	0.878	1.703
Sunrise	Landward	-0.408	0.107	0.055	-0.160	2.661
	Lakeward	0.366	0.057	0.304	0.763	5.115

[1]limited sampling; ns = non-significant

Kurtosis, a measure of concentration around the mean, was almost uniformly indicative of narrow distributions (i.e., values above 1). The exception was landward tracks at sunset, which had a broad distribution (Figure 19). Levels of skewness indicated that in most cases the distribution was evenly distributed around the mean, the exeptions being lakeward-headed tracks during both sunset and sunrise periods. Relative to expectations that tracks will be distributed evenly around zero most distributions appear to be skewed. For lakeward-headed tracks this skew was consistently strong and positive. For landward-headed tracks this skew was very small (but significant) at sunset, non-significant at mid-night, and strongly negative at sunrise (Table 4). The relative skewness of the distributions, especially among lakeward-headed tracks, is evident in Figure 19. The distribution of landward-headed tracks indicated a shift from more ascending around sunset (as expected) to more descending during sunrise (as expected). Interestingly, however, the lakeward-headed tracks appear to consistently show a positively-skewed climb rates. What this suggests is that even during the mid-night period and, to some extent, during sunrise that lakeward-headed tracks are displaying a net increase in altitude over time (unexpected). This would support the earlier hypothesis that migrants are gaining altitude when crossing Lake Erie.

Contrary to what's been purported for the near-lakeshore migration (J. Buler, pers. comm.), we did not observe a consistent morning ascent within the data. Perhaps within the range we were able to detect most blips (<500m) the typical morning ascent does not occur.

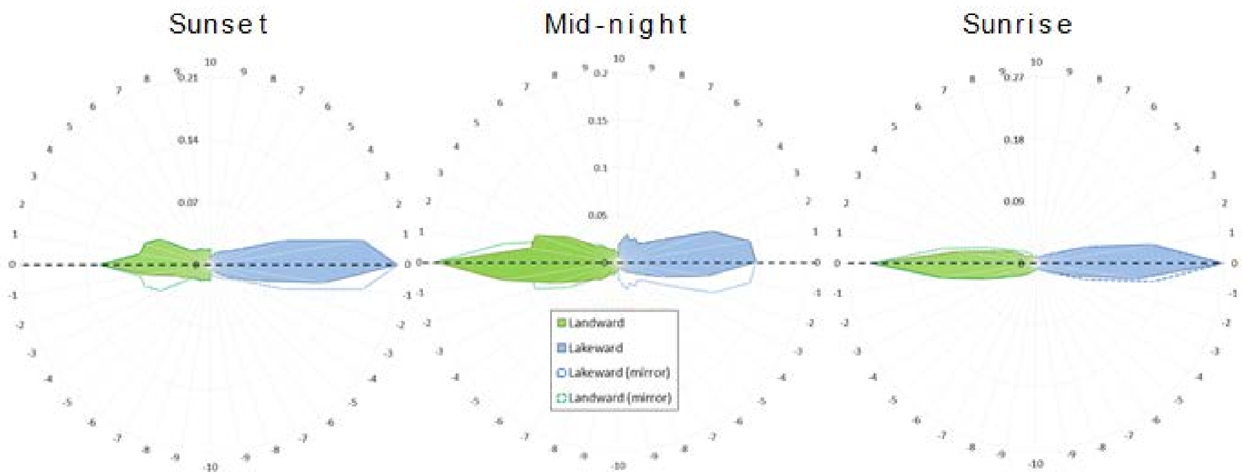

Figure 19. Relative abundance of climb rates among landward (green) and lakeward-headed (blue) tracks during sunset, mid-night, and sunrise periods of Spring 2012. The uncolored areas outlined with dotted lines illustrate a mirrored distribution to help visualize the skew within the distributions.

Environmental GIS Database Products. We also developed web-based servers to organize the data. The GIS database system uses a client/server architecture for delivering web content that can be accessed through the Internet. The ArcGIS mapping server is used for creating and managing GIS Web services, applications, and for accessing spatial data stored in the PostgreSQL database, where ArcGIS Viewer for Silverlight is used to deploy robust web applications. Some examples of this system with integrated offshore data are shown below.

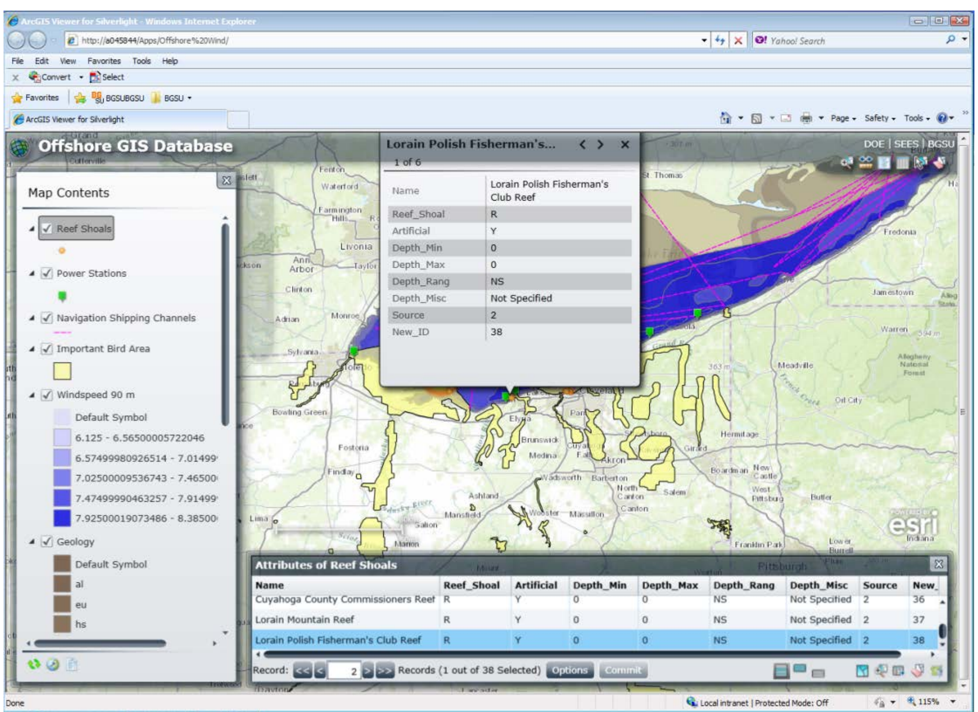

Figure 20. ArcGIS mapping interface

Other efforts were focused on developing Android applications for mobile and tablet devices. In particular we developed a mobile application for collecting locations and interactive behavior of rare birds. The collected data is stored and uploaded on a server for building, deploying, and managing database applications and expert knowledge that can be used for offshore decision making. An example of this work is shown below:

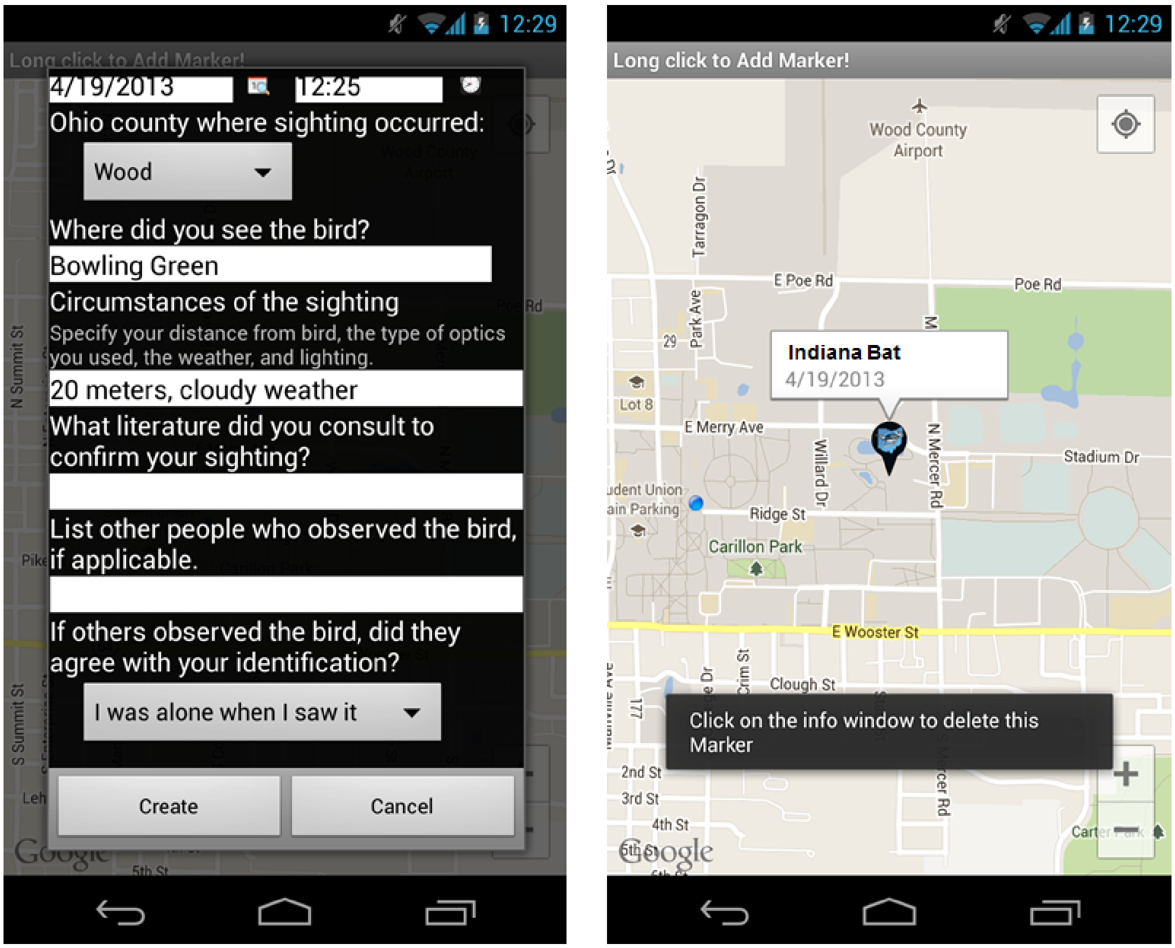

Figure 21. Android interface

One of our latest efforts was the implementation of a web-based Participatory Geographic Information System (PGIS) framework intended for offshore wind suitability analysis. The PGIS integrates GIS and decision-making tools that are intended to involve different stakeholders and members of the general public for solving complex planning problems and building consensus. Developing and executing a system that facilitates effective public involvement for resolving contentious issues can help foster longer-lasting agreements and collaborative efforts. The PGIS is implemented following a thin-client server environment with three-tier architecture. The system generates a group solution, which is used for synthesizing the different evaluation aspects such as the importance of criteria, ranking of the decision alternatives and planning issues related to environmental and socio-economic concerns from the participants. The figures below show some screenshots of the system:

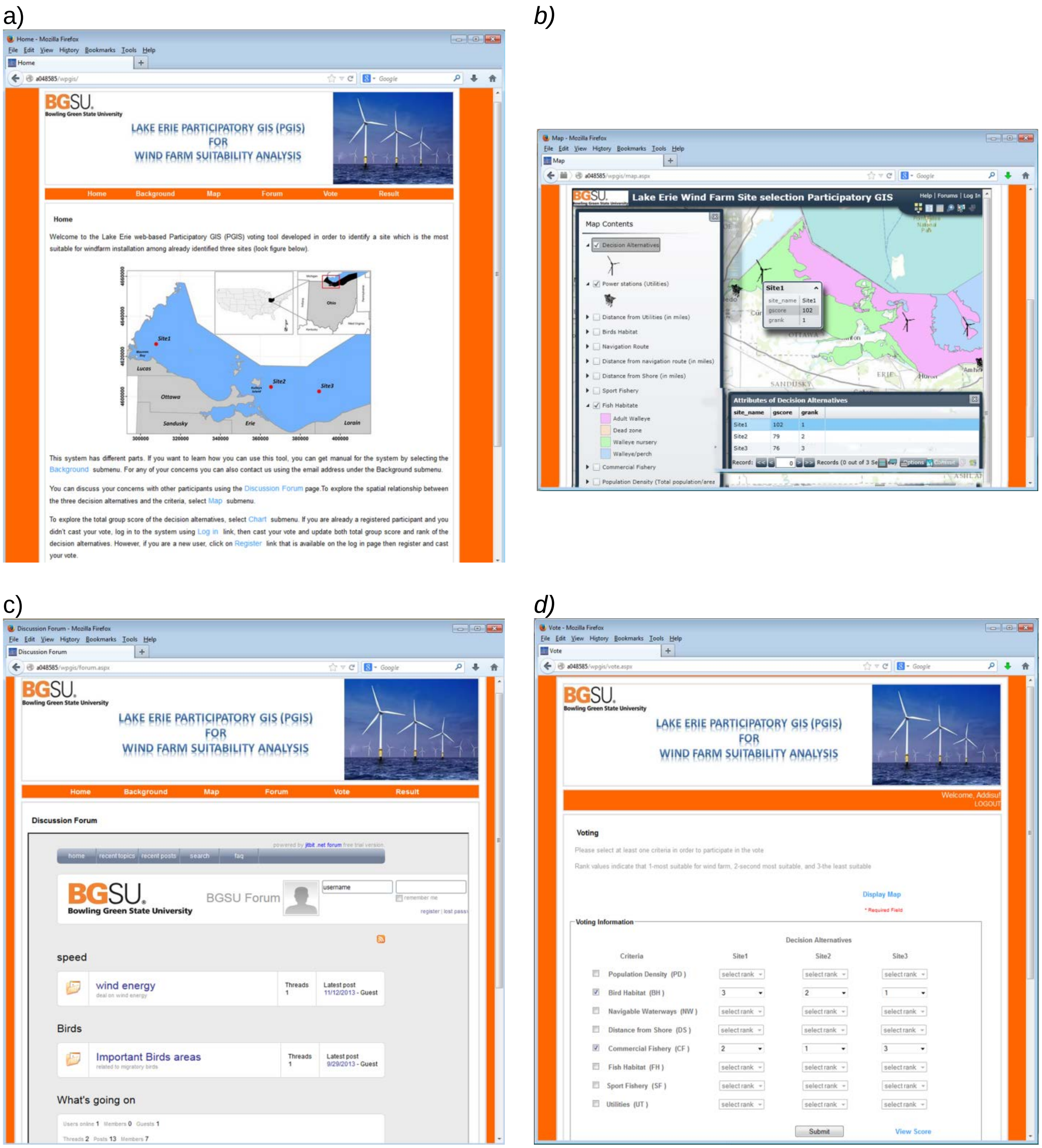

Figure 22. Web nased PGIS a) Main webpage of the project b) Mapping Tool Interface with Map Contents Dialogue Box and Attribute Table of the Decision Alternatives c) Discussion Forum; and d) Decision Tool Interface

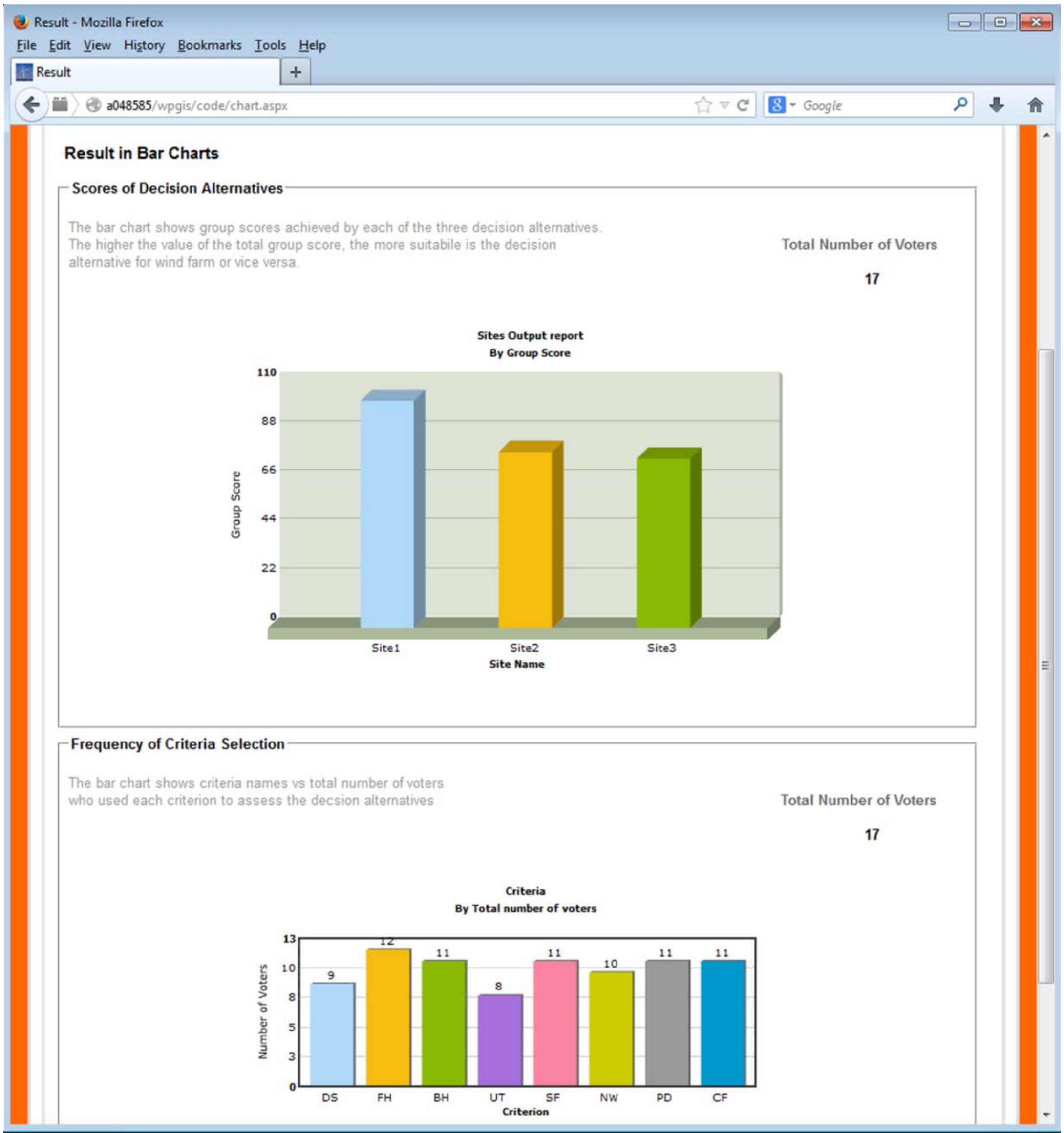

Figure23.The PGIS group solution module from individual participants involved in the ranking of decision alternatives for selection of offshore wind farm site.

Conclusions and Future Directions

In this study a cost model was developed and applied to three wind turbine models to obtain the levelized cost of energy for different wind turbine configurations. The model accounts for the cost of unscheduled (random) maintenance, as well as the predetermined maintenance. The results of the study suggest four main variables influence the levelized cost: removing one blade, installation time, replacement cost, and system availability. These factors favor a two-bladed turbine design on a floating platform. A two-bladed rotor’s advantages may not be enough to effect current offshore fixed platform wind turbine technology, but the advantages become more pronounced in a floating wind turbine application. Analysis of wind turbine loads showed that wind turbine configurations do not show a dominant trend based on the configuration under the IEC standard design load cases. The only exception was the reduced torque observed for a two-blade rotor wind turbine under all loading cases.

Wind tunnel studies of the wake flow indicated that the upwind wind turbine model created a narrower wake compared with the downstream wind turbine model. In the near wake, the turbine-tower wake for the downstream turbine was nearly similar to that of tower alone wake whereas the presence of the upwind rotor blade noticeably accelerated the rate of wake dissipation. Numerical and experimental studies of a scale model of a wind turbine platform showed that the scale model tests produce valid results for predicting floating platform motion. The results also showed that a critical factor affecting the platform movement is whether the platform is submerged or surface piercing. Whereas motion in the submerged platform is reduced, the surface piercing platform gains stiffness and enhanced stability. The result also showed that the platform motion was significantly influenced by the water depth.

Having established that scale model testing is adequate to capture the dynamic interaction of the waves and a floating platform, this work can be extended to study the stability of floating platforms both experimentally and numerically. The current research demonstrated how the stability of the platform can be affected by its design—submerged or surface piercing. This knowledge can be expanded by additional studies to create a database containing data on various operating conditions with sufficient details to support establishing design rules. Additionally, the dynamics of new offshore wind turbine concepts, such as an inclined wind turbine tower installed on a floating platform, upwind and downwind turbines configurations, and novel platform concepts can be investigated.

In the application of avian monitoring, the migratory patterns used different monitoring approaches including acoustics, infrared camera and marine radar. The sensors were deployed in the Western basin of Lake Erie in Ohio. Acoustics proved to be useful for target identification at the taxonomic level. Infrared sensing and IR video processing provided quantitative information and x-y coordinates of the targets. Marine radar generated target altitude (z-coordinates) as well as other information. Seasonal analyses from acoustics and IR cameras revealed that some of the birds (warblers) had a higher propensity to cross into the Western basin compared to the Central basin. Examining single nights, a similar pattern emerged, but further revealed that the propensity of birds to cross varied between species and prevailing wind direction. Notably, a greater abundance of calls was observed over water in the Western basin under seasonally opposing north winds. Although there are some potentially confounding ways to interpret the data, the results generally support the conclusion that, as previously reported, Western Lake Erie is more amenable to migratory lake-crossings.

Interesting patterns were also observed from the marine radar datasets. The vertical *t*-bar data from Spring 2012 suggested that Lakeward-heading tracks constituted a greater proportion of the total tracks during sunset than sunrise. Landward-headed tracks showed the opposite pattern, with higher proportions present at nearly all altitudes during sunrise rather than sunset. These patterns support our prediction that a subset of migrating birds, and possibly bats, would reverse migration direction during the sunrise period when migrants are seeking stopover habitat. Evidence indicates that this is happening during spring migration, with upticks in landward migration most pronounced at lower altitudes. Another notable pattern in the midnight climb rates was the increase in the proportion of Landward tracks that were descending. This may signal that a notable number of migrants are descending to stopover habitat long before the near-sunrise period. This tends to agree with general patterns observed in regional NEXRAD data, which show a gradual decline in the density of migration prior to the sunrise period. The horizontal data from Spring 2012 suggested that target speed differed in relationship to altitude and orientation relative to coast where targets with lower mean track speeds showed mean course directions closer to parallel with the coast. Of further note within the low-level versus high-level migration comparisons was an apparent difference in the timing when tracks were detected. Low altitude tracks near turbine height were detected before the mid-point of the night while high altitude tracks were detected after the mid-point of the night.

The project also developed a web-based Participatory Geographic Information System (PGIS) framework intended for offshore wind suitability analysis. The PGIS prototype, integrated GIS, geospatial data, and decision-making tools that are intended to involve different stakeholders and public for solving complex planning problems and building consensus. Public involvement from the early planning stage of projects with a spatial nature is very important for future legitimacy and acceptance of these projects. Therefore, developing and executing a system that facilitates effective public involvement for resolving contentious issues can help fostering long-lasting agreements.

However, the results from the monitoring tools presented here are based on a limited sampling of data and future work is required. Some possible future directions can extend for understanding scale issues and relationships between marine radar and NEXRAD; development of new algorithms; calibration of instruments used for the monitoring; integration of instruments and data fusion; better strategies for collection of spatial data; groundtruthing and validation; development of repository tools for sharing data resources; involvement of public participants; and development of expert knowledge.

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