U.S. DEPARTMENT OF ENERGY

Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

Wind Turbine – Radar Interference Mitigation

Project ID # M11

Jason Biddle

Massachusetts Institute of Technology
Lincoln Laboratory

This material is based upon work supported by the Department of Energy under Air Force Contract No. FA8702-15-D-0001. Any opinions, findings, conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the Department of Energy.

FY17-FY18 Wind Office Project Organization

"Enabling Wind Energy Options Nationwide"

Technology Development	Market Acceleration & Deployment
Atmosphere to Electrons	Stakeholder Engagement, Workforce Development, and Human Use Considerations
Offshore Wind	Environmental Research
Distributed Wind	Grid Integration
Testing Infrastructure	Regulatory and Siting
Standards Support and International Engagement	
Advanced Components, Reliability, and Manufacturing	

Analysis and Modeling (cross-cutting)

Project Overview

M11: Wind Turbine – Radar Interference Mitigation

Project Summary

This effort is aimed at solving deployment barriers for wind energy systems by developing and evaluating mitigation methods that reduce or eliminate the adverse effect of wind turbines on radar systems.
MIT Lincoln Laboratory draws on deep radar expertise to support Wind Turbine Radar Interference Mitigation (WTRIM) tasks such as interference modeling and mitigation development and demonstration. The work plan for FY17 and FY18 is aligned with the Federal Interagency Wind Turbine Radar Interference Strategy published by DOE.

Project Objective & Impact

This effort produces high-impact research and development aimed at eliminating wind turbine radar interference as an impact to critical radar missions, ensuring the long-term resilience of radar operations in the presence of wind turbines, and removing radar interference as an impediment to future wind energy development.

Project Attributes

Project Principal Investigator(s)
Jason Biddle
DOE Lead
Patrick Gilman
Project Partners/Subs
Partners: Sandia National Laboratories BEM International, LLC
Project Duration
8 years

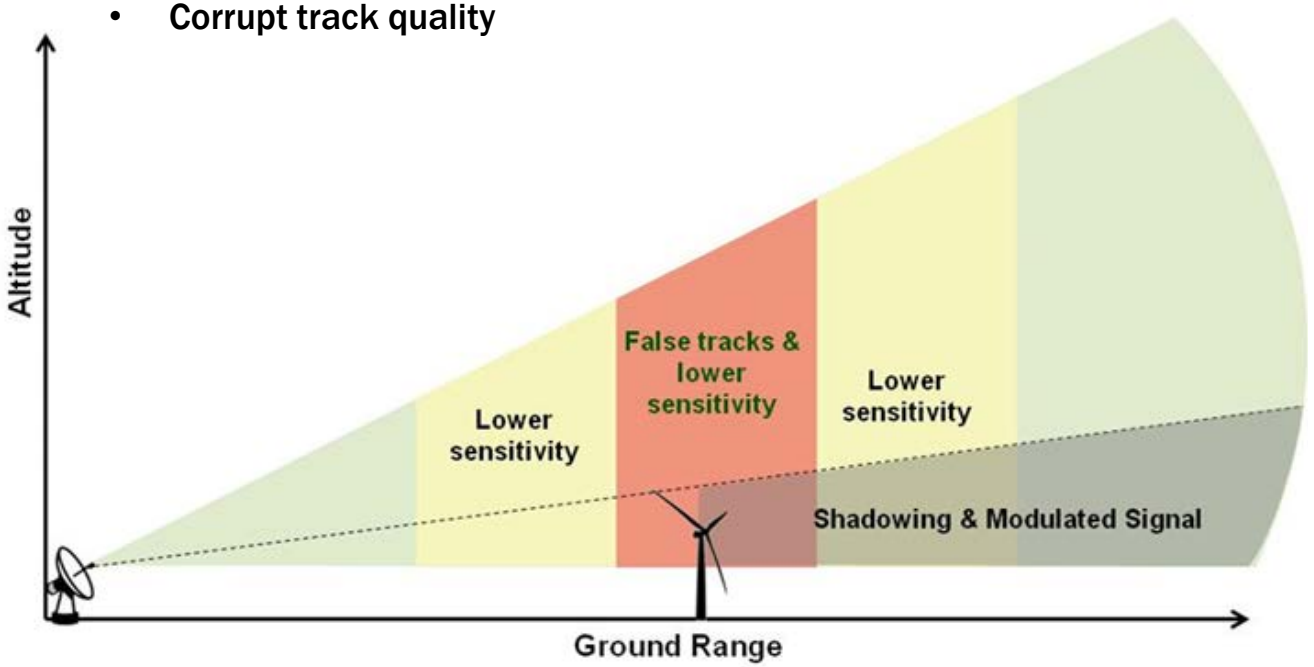
Technical Merit and Relevance

Wind turbines impact radars:

- Turbines present unique mix of moving and static clutter
- Decrease probability of detection
- Increase false alarms
- Corrupt track quality

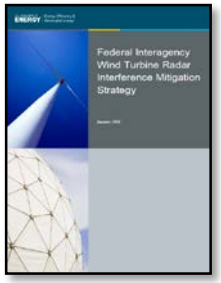
Mission impacts:

- Flight safety (FAA)
- Homeland security (DHS)
- Homeland defense (DOD)
- Weather observation (NOAA)



As wind turbines grow in size and number and move into new areas of the country, conflicts with existing radar systems are likely to increase in number and severity.

Task Alignment to Federal WTRIM Strategy



Strategic Themes

- Improve the capacity of government and industry to evaluate the impacts of existing and planned wind energy installations on sensitive radar systems
- Develop and facilitate the deployment of mitigation measures to increase the resilience of existing radar systems to wind turbines
- Encourage the development of next-generation radar systems that are resistant to wind turbine radar interference

MIT-LL FY17-18 Tasks

1. Wind Turbine Visual Classification from Overhead Images
2. Ground-Based Coastal Air Surveillance Radar WTRI Study
3. AMOSS Radar Automation System WTRI Study
4. Travis Air Force Base Pilot Mitigation Project Analysis
5. Advanced Signal Processing for Wind Turbine Clutter Mitigation

AMOSS: Air and Marine Operations Surveillance System
WTRI: Wind Turbine Radar Interference

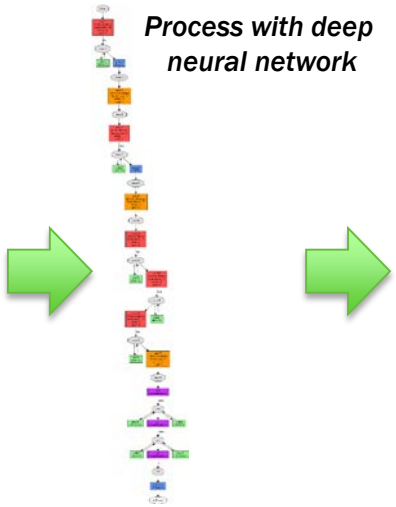
Accomplishments and Progress

Radar impact predictions require accurate wind turbine locations

Task: 1	Wind Turbine Visual Classification from Overhead Images
Objective:	Develop an automated approach to identify decommissioned wind turbines from overhead imagery
Impact:	Removing decommissioned wind turbines improves predictions and decreases likelihood of overestimating interference impacts
Status:	Complete – Decommissioned sites identified by the machine learning classifier shared with U.S. Wind Turbine Database [1]

Extract Wind Turbine Image Chips

Process with deep neural network



Representative learned examples

Decommissioned

Active

[1] Hoen, B.D., Diffendorfer, J.E., Rand, J.T., Kramer, L.A., Garrity, C.P., Hunt, H.E. (2018) United States Wind Turbine Database. U.S. Geological Survey, American Wind Energy Association, and Lawrence Berkeley National Laboratory data release: USWTDB V1.3 (January 7, 2019). https://eerscmap.usgs.gov/uswtdb.

Accomplishments and Progress

Offshore wind farms may soon be deployed near coastal radar systems

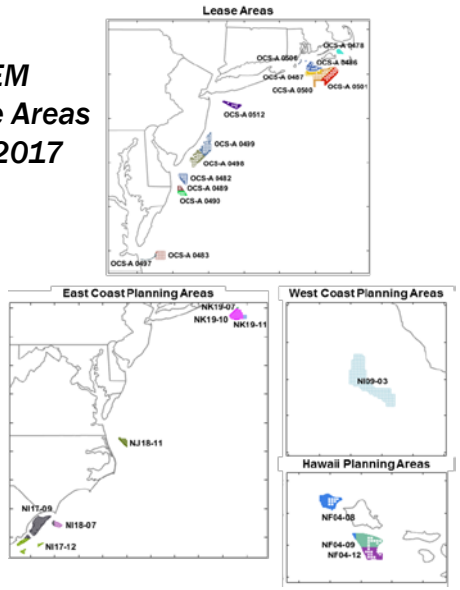
Task: 2 Ground-Based Coastal Air Surveillance Radar WTRI Study

Objective: Identify radar sites that could be impacted from a coverage perspective

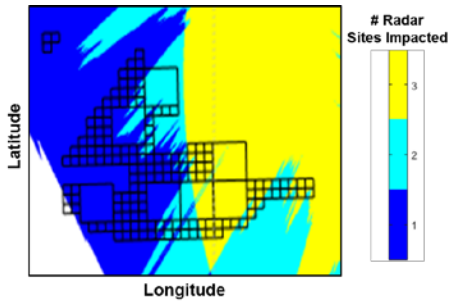
Impact: Proactively plan mitigation measures for coastal radar sites and radar types that are more likely to be affected by offshore development

Status: Complete – Analyzed coastal radar coverage for all Bureau of Ocean Energy Management (BOEM) renewable energy lease areas and wind planning areas circa 2017

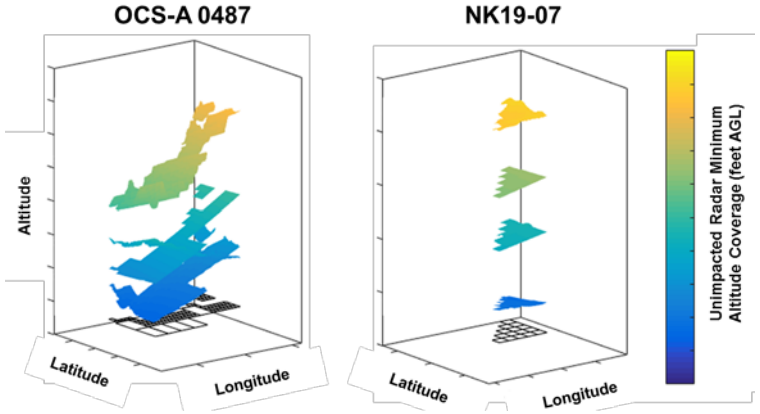
BOEM Offshore Areas Circa 2017



Example showing how many radar sites could be impacted by future offshore wind facilities deployed in different regions of offshore lease area



Example of overlapping coverage from multiple unimpacted radar systems above an offshore lease area (left) and an offshore planning area (right)



WTRI: Wind Turbine Radar Interference

Accomplishments and Progress

Improve capacity of automation and C2 systems to mitigate impacts

Task: 3 AMOSS Radar Automation System WTRI Study

Objective: Assess benefit of overlapping coverage from multiple radars above wind farms for homeland security radar fusion system

Impact: Human users monitor and base decisions upon C2 displays; thus, automation system behavior around wind farms is crucial to overall air surveillance mission performance

Status: Complete – Demonstrated that adding data feeds from existing radars not in current operational C2 network restores tracking performance over wind farms under certain geometries

Image Credits:
[1] Master Sgt. Julie Avey/AMOC
[2] https://www.wads.ang.af.mil/News/Photos/igphoto/2001698852/
[3] https://www.dote.osd.mil/pub/reports/FY2009/pdf/af/2009bcsf.pdf

AMOSS: Air and Marine Operations Surveillance System
C2: Command and Control
WTRI: Wind Turbine Radar Interference

Accomplishments and Progress

Facilitate the deployment of current off-the-shelf mitigation measures

Task: 4 Travis Air Force Base Pilot Mitigation Project Analysis

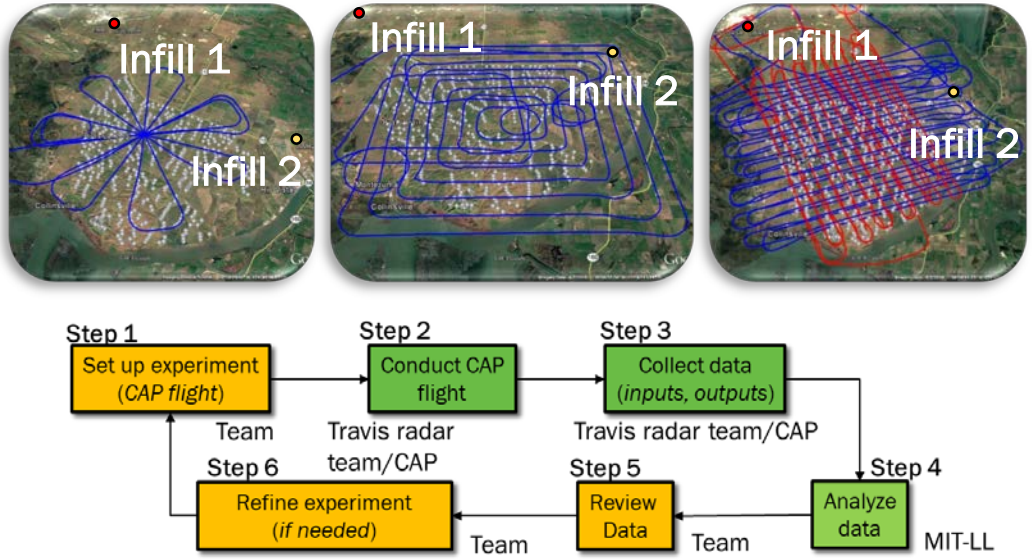
Objective: Assess infill radar performance when integrated with Air Traffic Control (ATC) automation systems in an operationally relevant environment

Impact: Establishing technical criteria for infill mitigation acceptance for ATC

Status: Ongoing – Analyzed hundreds of hours of data from multiple flight tests and experimental conditions; Completion expected end of FY19

Pilot deployment of infill radars at Travis Air Force Base

Example Civil Air Patrol (CAP) patterns from controlled flight tests to stress system performance



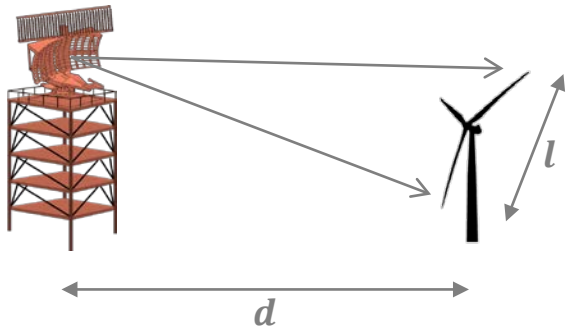
Accomplishments and Progress

Develop software upgrades to make existing radars more resilient

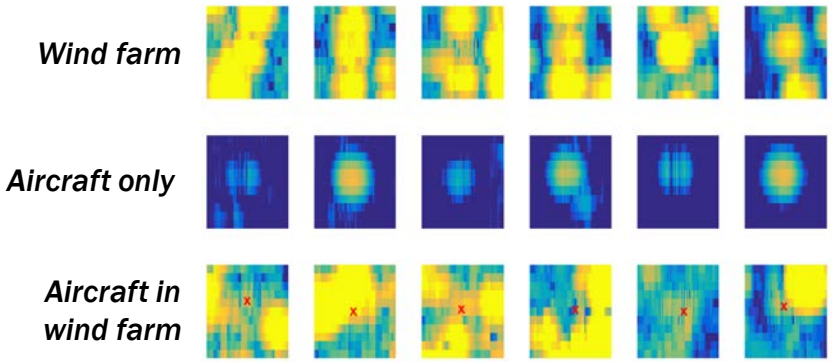
Task: 5	Advanced Signal Processing for Wind Turbine Clutter Mitigation
Objective:	Assess Space-Time Adaptive Processing (STAP) and Convolutional Neural Networks (CNNs) techniques using data from prior field tests
Impact:	Signal processing upgrades could be a lower-cost solution than wide-scale deployment of short-range infill radar systems
Status:	Complete – Demonstrated improved performance compared to baseline for existing radars but retrofit may be cost prohibitive given legacy hardware and processing capabilities; Techniques should be considered for inclusion in future radar acquisitions

STAP cancels coupled elevation / Doppler interference

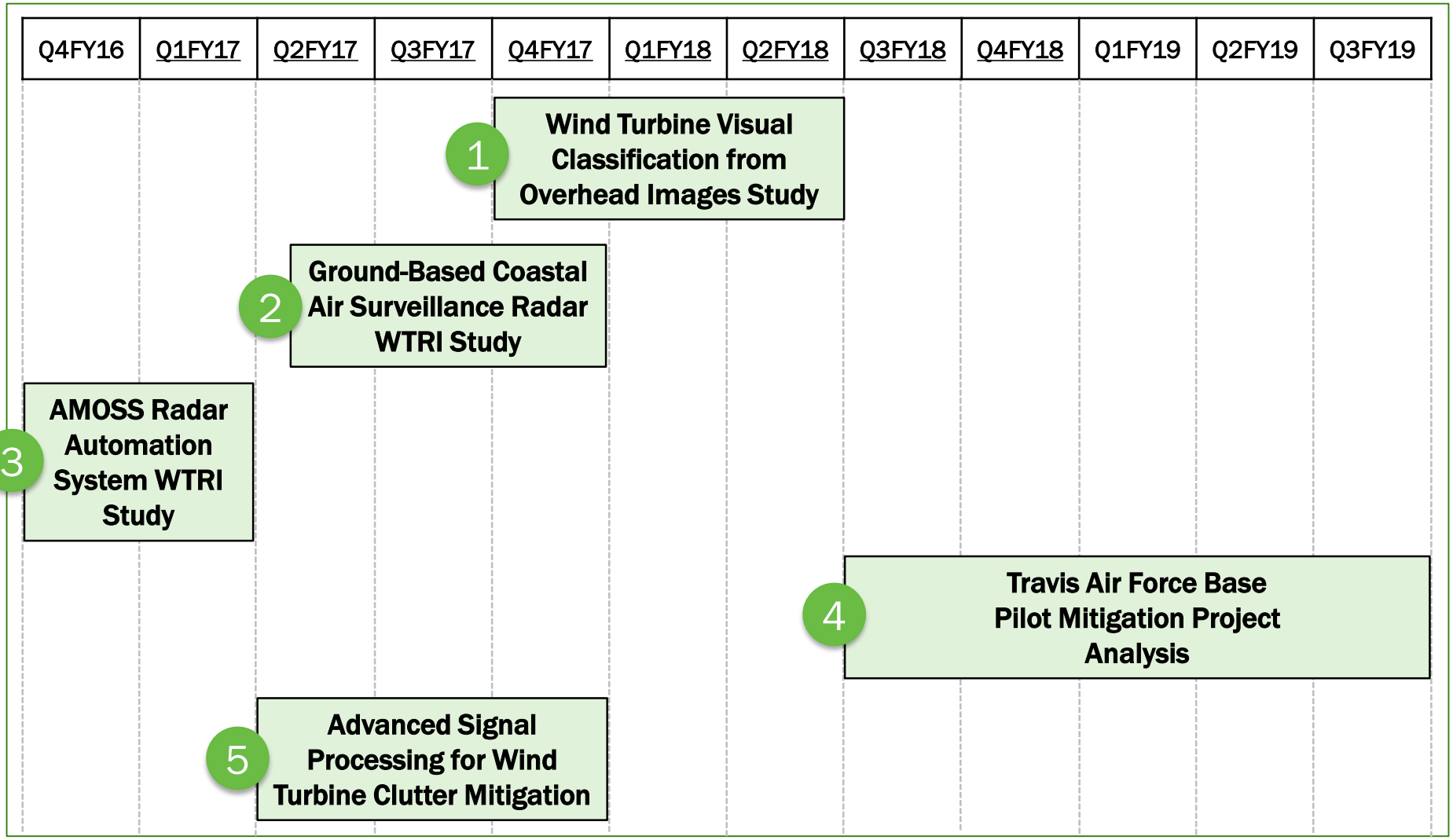
- *Upper blade moving toward radar*
- *Lower blade moving away from radar*



Examples of radar data used to train Convolutional Neural Network



Project Plan & Schedule



AMOSS: Air and Marine Operations Surveillance System
WTRI: Wind Turbine Radar Interference

Communication, Coordination, and Commercialization

- **Open Source Publications**
  - *Wind Turbine Visual Classification from Overhead Images*, 2018 IEEE International Geoscience and Remote Sensing Symposium, 22-27 July 2018. [1]
  - *Ground-Based Coastal Air Surveillance Radar WTRI Study Public Summary*, DOE Wind Energy Technologies Office Website, 8 Dec 2017. [2]
- **Limited Distribution Publications**
  - *Ground-Based Coastal Air Surveillance Wind Turbine–Radar Interference Vulnerability Study*, MIT LL Technical Report 1223, 8 Sep 2017.
  - *AMOSS Radar Automation System Wind Turbine Interference Study*, MIT LL Technical Report 1224, 8 Sep 2017.
  - *Space-Time Adaptive Processing and Convolutional Neural Networks for Wind Turbine Clutter Mitigation*, MIT LL Technical Report 1226, 14 Dec 2017.

[1] https://doi.org/10.1109/IGARSS.2018.8517960

[2] https://windexchange.energy.gov/projects/radar-interference

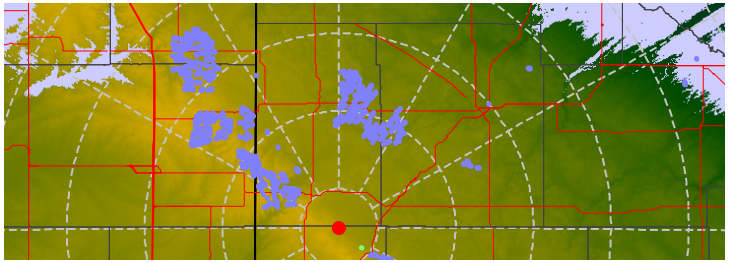
Upcoming Project Activities

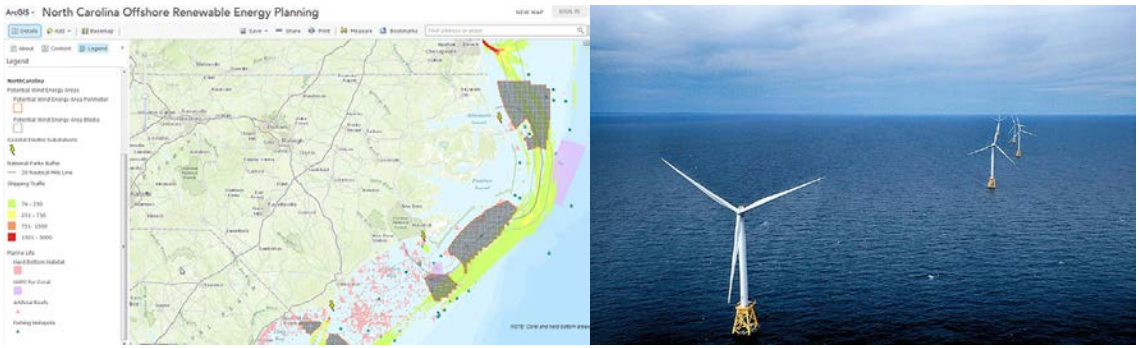
FY19/Current Research:

- Continued Travis Air Force Base Pilot Mitigation Project Analysis
- Reducing Radar Interference Through Wind Farm Layout Optimization
- Advanced Multi-Radar Fusion and Tracker Prototyping

Proposed Future Research:

- Support New Pilot Mitigation Projects
- Offshore Wind Turbine Interference Modeling, Measurements, and Mitigation





Photos Courtesy of BEM Int'l, LLC