Assessment of Offshore Wind Farm Effects on Sea Surface, Subsurface and Airborne Electronic Systems

Dr. Hao Ling (PI) and Dr. Mark Hamilton (co-PI)

The University of Texas at Austin

Webinar Presentation on September 4, 2013

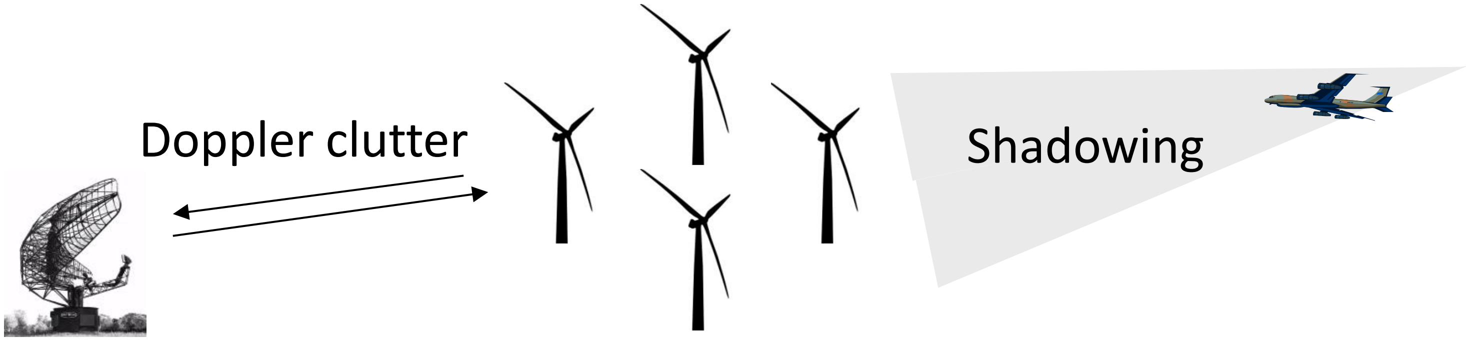
Background and Project Goals

- Award resulted from Funding Opportunity Announcement DE-FOA-0000414, entitled U.S. Offshore Wind: Removing Market Barriers, Topic Area 7: Impact on Electronic Equipment in the Marine Environment.

- The goal of this project is to provide a baseline assessment of potential impacts of offshore wind farms on electromagnetic and acoustic equipment (for surveillance, navigation and communications) operating in the marine environment.

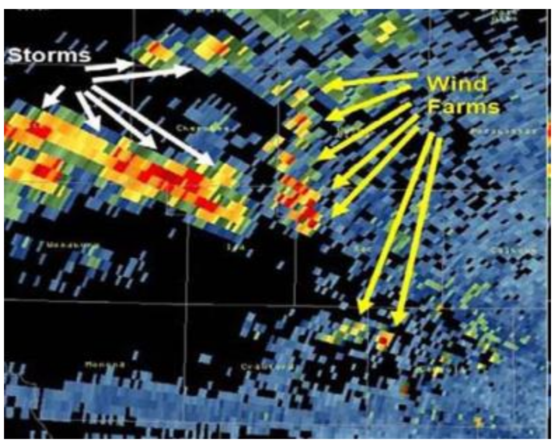
- The findings from the study will help remove the uncertainties associated with offshore wind farm deployment, and in setting future guidelines for the permitting process.

Wind Farm Interference on Radar

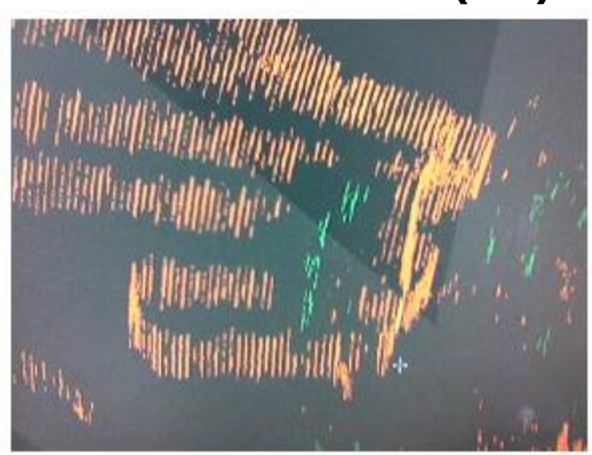


Becoming a potential hindrance to the development of wind power.

Weather Radar (US)



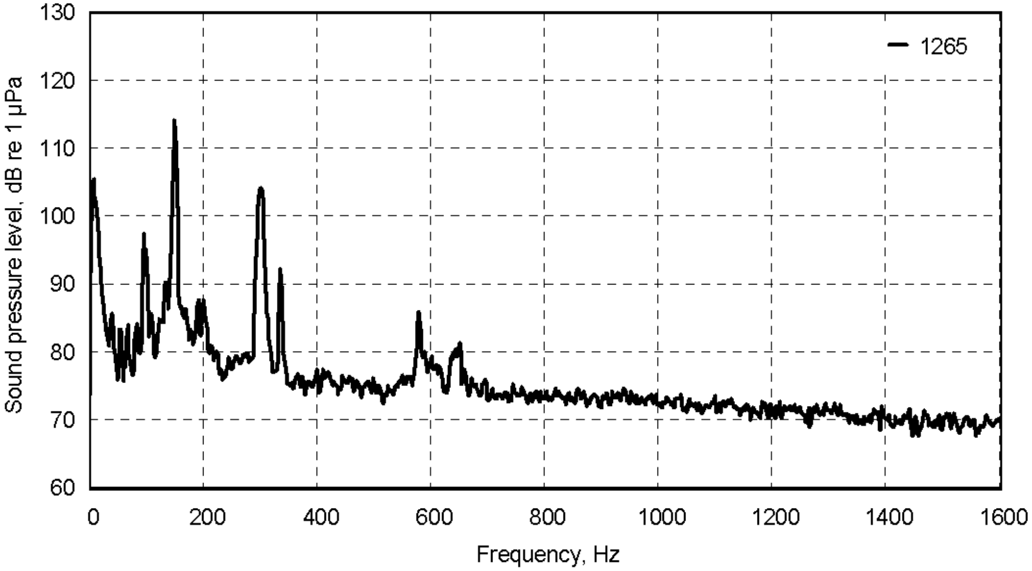
Air Traffic Control (UK)



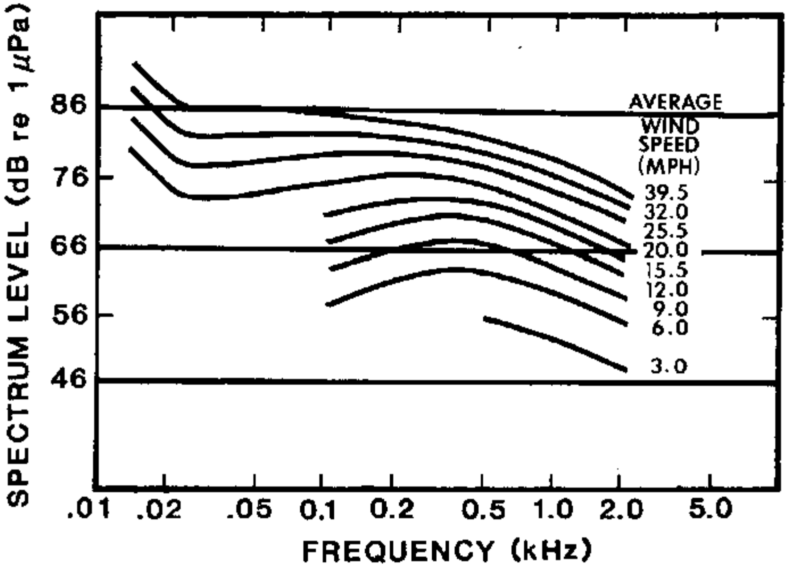
Marine Radar (UK)

Wind Farm Interference on Acoustical Systems

Typical underwater noise spectrum radiated from a single wind turbine off the coast of Denmark



Noise spectra measured along the continental shelf off the coast of Nova Scotia



Underwater noise below 1 kHz could potentially interfere with certain sonars or sensors

Team Members

- **Electromagnetics Team**

  UT-Austin: **Dr. Hao Ling (PI)**, Dr. Nick Whitelonis, Mr. Shang-Te Yang, Mr. Aale Naqvi

  SAIC: **Dr. Rajan Bhalla**

- **Acoustics Team**

  ARL:UT **Dr. Mark Hamilton (co-PI)**

  Dr. Todd Hay, Dr. Gene Brown

SAIC = Science and Applications International Corporation.
ARL:UT = The University of Texas Applied Research Laboratories.

Project Roadmap

- **Task 1 and Task 3: Survey potential challenges**

  - Developed a list of systems vs. frequency and stakeholders

  - Compiled list of references including both US and non-US activities

- **Task 2: Engage stakeholders**

  - Formulated questionnaires for both EM and acoustics

  - Conducted in-depth interviews with stakeholders

- **Task 4: Modeling study**

  - Identified priority topics based on stakeholder interviews and carried out modeling studies in EM and acoustics

- **Task 5 and Task 6: Documentation and dissemination**

Project Schedule

Months	**2012**			**2012**			**2012**			**2012-13**			**2013**			**2013**			
Tasks	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug
1) Survey potential challenges																			
2) Engage stakeholders																			
3) Survey non-US R&D activities																			
4) Conduct baseline study			SAIC start											SAIC end					
5) Document and dissemination																			
6) Meetings and reports																			

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Detailed Listing of EM Systems and Attributes

- **Marine Navigation:**

System	Description	Attributes
AIS + VTS	Automatic Identification System, vessel traffic service	161-162MHz
Marine radar	collision avoidance and navigation: Small Vessel: Raymarine digital radar Small Vessel: Garmin GMR Small Vessel: Furuno Large Vessel: Kelvin Hughes MantaDigital Radar Large Vessel: Sperry Marine (Northrop Grumman) VisionMaster	 X-band X-band X-band S- and X-band S- and X-band
GPS	Global Positioning System	L1: 1.5754GHz L2: 1.2276GHz
LORAN	in steep decline, being replaced by GPS	90-110 KHz
SOS	International calling and distress frequency (90-280km), similar to channel 16 in VHF (40-90 km). International calling and distress frequency using Morse code	2182 KHz, 500KHz
NDB	Non-Directional Beacon: used in both aviation and marine navigation In North America	190-1750KHz 190-535KHz

- **Air Traffic Control:**

System	Description	Attributes
ASR-7/8/9/11	Airport Surveillance Radar 9 and 11: aircraft position and weather conditions simultaneously	2.7-2.9GHz
ARSR-4 AN/FPS-130	250 nmiles Joint Surveillance System, for atmosphere defense jointly operated with Air Force	1.215-1.4GHz
ADS-B	Will replace radar as the primary surveillance method for ATC worldwide. Works with GPS.	1090 or 978 MHz

- **Weather and Ocean Monitoring:**

System	Description	Attributes
WSR-88D	D stands for Doppler	2.7-3GHz
TDWR	detects wind shear near main airports, funded by FAA	5.6-5.65GHz
CASA	Collaborative Adaptive Sensing of the Atmosphere, NSF-sponsored	X-band
MPAR	Multi-mission Phased-Array Radar, FAA	2.7-2.9GHz

- **Military:**

Air Defense

ARSR-4 (a.k.a. AN/FPS-130)	Joint Surveillance System	1.215-1.4GHz
AN/FPS-117	Long Range Solid-State radar, 3D, 250 nautical miles	1.215-1.4GHz
FPS-124	fill-in the gap of FPS-117, 2-70 miles	1.215-1.4GHz
AN/FPS-114	FPS-117 fill-in, cease operation except suspected air-born attack	S-band
AN/TPS-77	transportable version of FPS-117	
AN/TPS-63	Digital MTI, coded pulse, frequency agility, pulse stagger	1-2GHz
AN/FPS-20, 66, 67, 93	general air surveillance, range over 200miles	1.25-1.35GHz

Ballistic Missile Defense/Surveillance

Pave Paw	AN/FPS-115/120/123/126	420-450MHz
SBX	4700km range, sea based	X-band
Cobra Dane	AN/FPS-108	1.215-1.4GHz

Airborne Systems

E-2	search for ships in sea clutter	405-450MHz
E-8C, P-8A, P-3, Helicopters	**ISAR** for submarines	X-band
E-3	pulse-Doppler, SAR	S-band

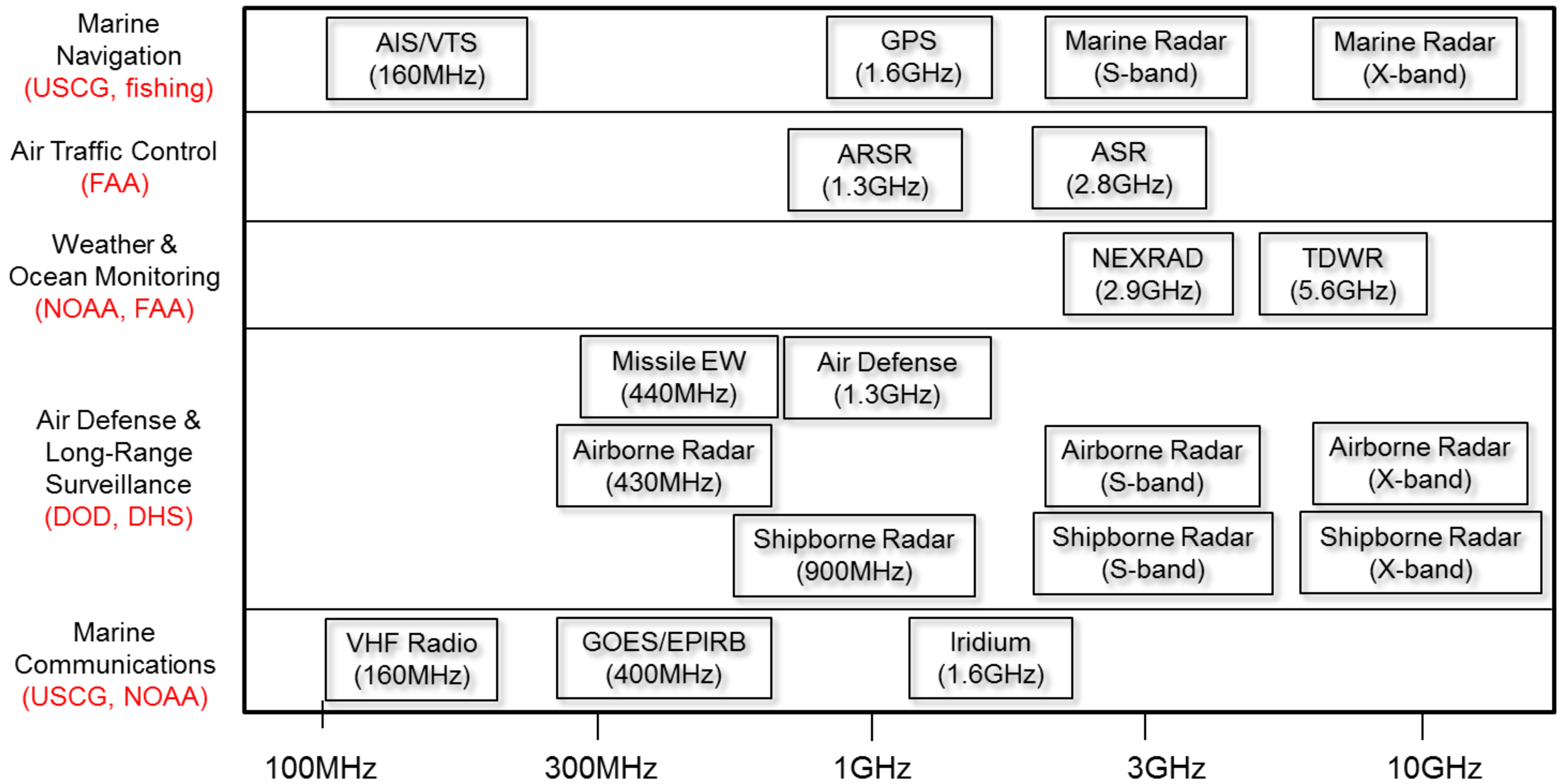
Shipborne Systems

AN/SPS-49	2D long range scan, primary air search radar	L-band, 850-942MHz
AN/SPY-1	Aegis, search and track over large area	S-band
AN/SPG-62	radar illumination for final intercept by air defense missiles	X-band
AN/SPN-43	shipboard air traffic control, 50 miles	3.5-3.7GHz

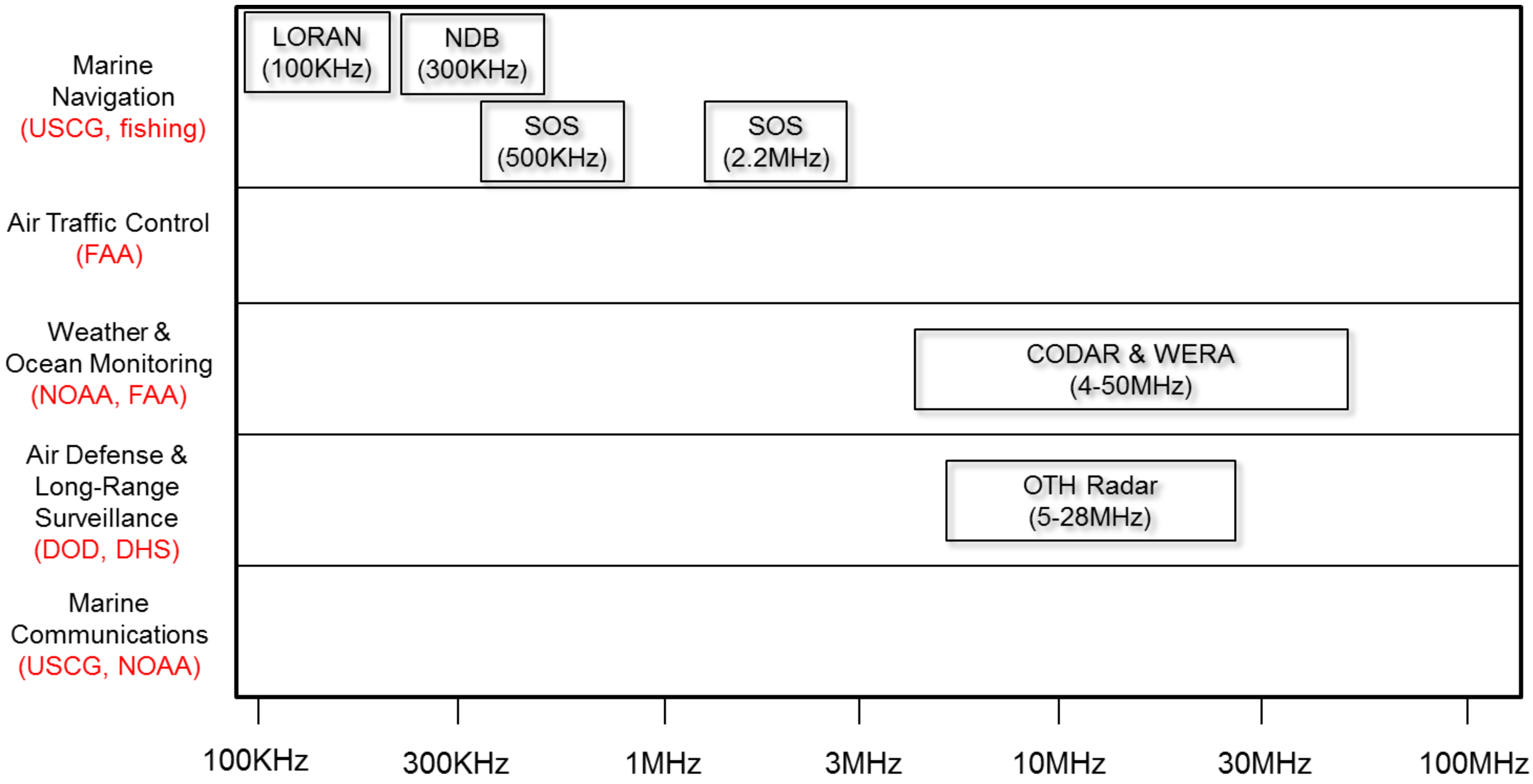
- **Marine Communication:**

System	Description	Attributes
VHF radio	channel 87/88 are reserved for AIS	156-162MHz
GOES	Geostationary Operational Environmental Satellite for data delay from weather buoys & C-MAN stations operated by NOAA	401.7-402.1MHz
Distress Radio Beacons	EPIRB (Emergency Position-Indicating Radio Beacons) 121.5MHz is obsolete	406MHz
Iridium	Satcom transceiver for DARTS buoys operated by NOAA	1.62-1.63GHz

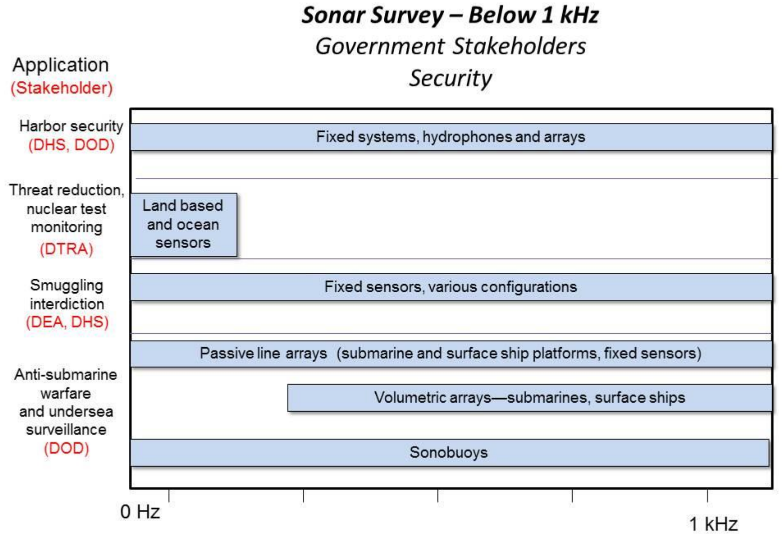
Electromagnetic Systems – Above 100MHz

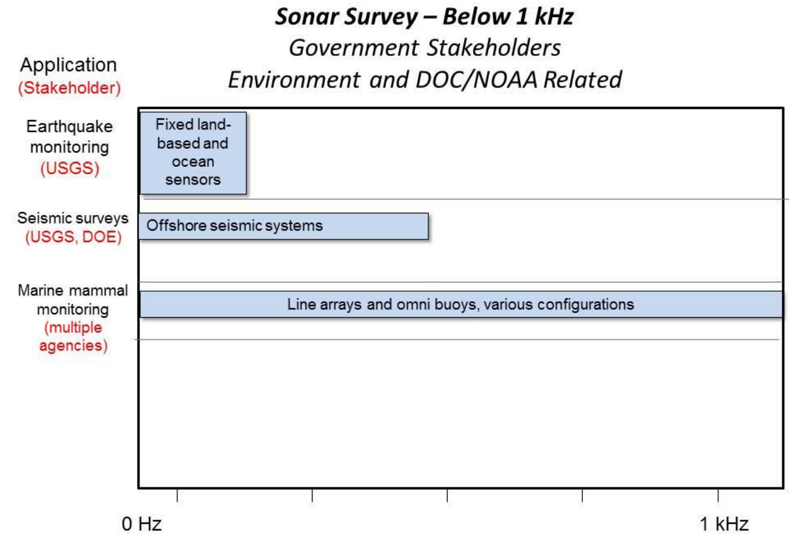


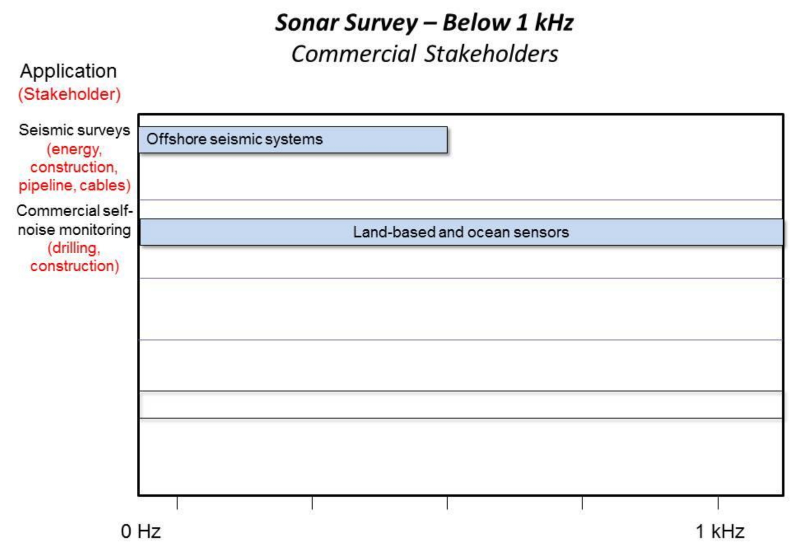
Electromagnetic Systems – Below 100MHz



Acoustical Systems – Below 1000 Hz







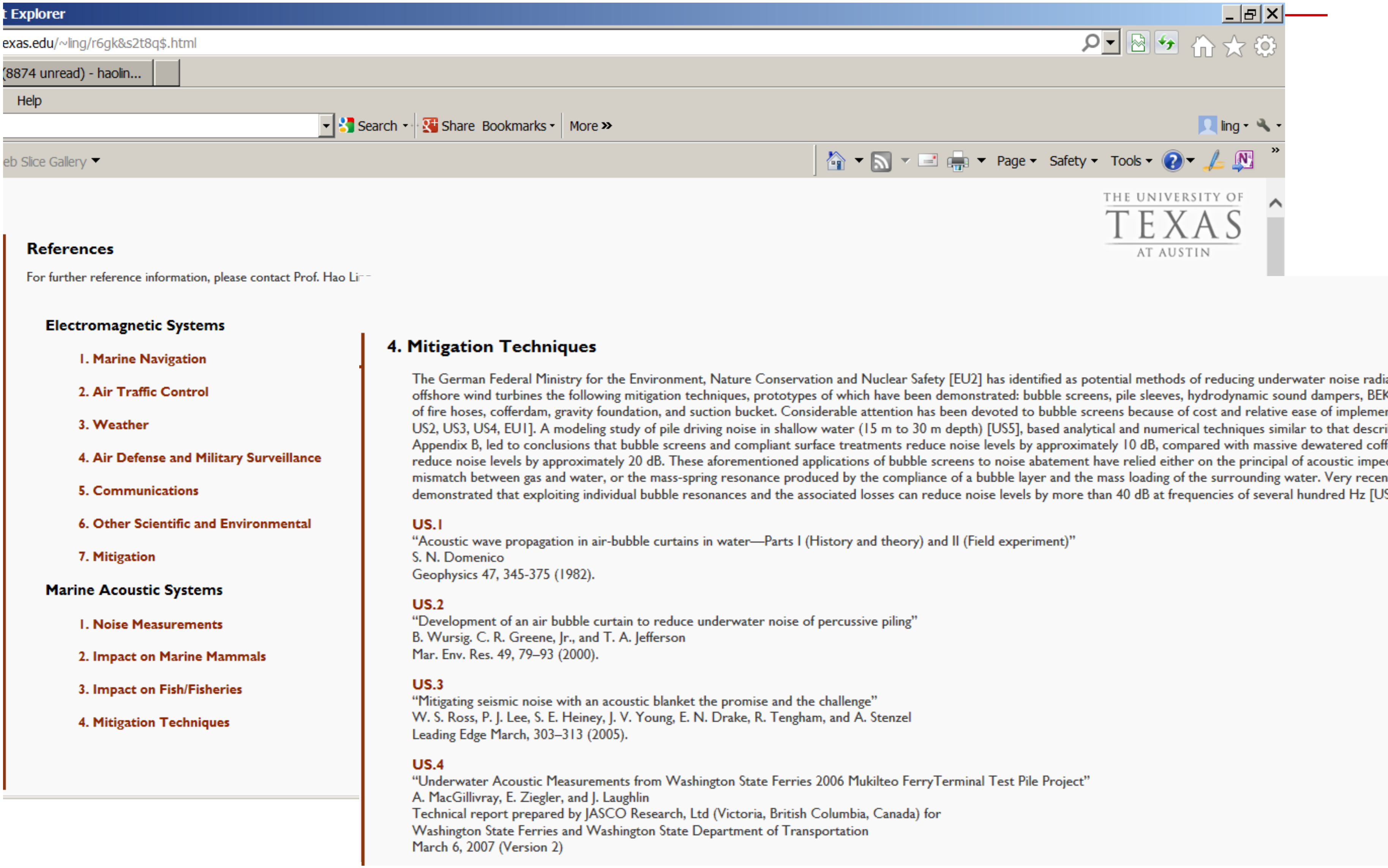
Literature Review

- **Electromagnetics** (52)
  - **Marine Navigation** (9*)
  - **Air Traffic Control** (6)
  - **Weather and Ocean Monitoring** (10)
  - **Air Defense and Long-Range Surveillance** (9)
  - **Communications Systems** (11*)
  - **Mitigation Techniques** (10)

- **Acoustics** (25)
  1. **Noise Measurements** (6)
  2. **Impact on Marine Mammals** (8)
  3. **Impact on Fish/Fisheries** (3)
  4. **Mitigation Techniques** (8)

* 3 of the references addressed multiple topic areas.

Snapshots of the web page



References

For further reference information, please contact Prof. Hao Li

Electromagnetic Systems

1. Marine Navigation
2. Air Traffic Control
3. Weather
4. Air Defense and Military Surveillance
5. Communications
6. Other Scientific and Environmental
7. Mitigation

Marine Acoustic Systems

1. Noise Measurements
2. Impact on Marine Mammals
3. Impact on Fish/Fisheries
4. Mitigation Techniques

4. Mitigation Techniques

The German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety [EU2] has identified as potential methods of reducing underwater noise radiate offshore wind turbines the following mitigation techniques, prototypes of which have been demonstrated: bubble screens, pile sleeves, hydrodynamic sound dampers, BEKA of fire hoses, cofferdam, gravity foundation, and suction bucket. Considerable attention has been devoted to bubble screens because of cost and relative ease of implementa US2, US3, US4, EU1]. A modeling study of pile driving noise in shallow water (15 m to 30 m depth) [US5], based analytical and numerical techniques similar to that describe Appendix B, led to conclusions that bubble screens and compliant surface treatments reduce noise levels by approximately 10 dB, compared with massive dewatered coffer reduce noise levels by approximately 20 dB. These aforementioned applications of bubble screens to noise abatement have relied either on the principal of acoustic impeda mismatch between gas and water, or the mass-spring resonance produced by the compliance of a bubble layer and the mass loading of the surrounding water. Very recently demonstrated that exploiting individual bubble resonances and the associated losses can reduce noise levels by more than 40 dB at frequencies of several hundred Hz [US6]

US.1
"Acoustic wave propagation in air-bubble curtains in water—Parts I (History and theory) and II (Field experiment)"
S. N. Domenico
Geophysics 47, 345-375 (1982).

US.2
"Development of an air bubble curtain to reduce underwater noise of percussive piling"
B. Wursig. C. R. Greene, Jr., and T. A. Jefferson
Mar. Env. Res. 49, 79–93 (2000).

US.3
"Mitigating seismic noise with an acoustic blanket the promise and the challenge"
W. S. Ross, P. J. Lee, S. E. Heiney, J. V. Young, E. N. Drake, R. Tengham, and A. Stenzel
Leading Edge March, 303–313 (2005).

US.4
"Underwater Acoustic Measurements from Washington State Ferries 2006 Mukilteo FerryTerminal Test Pile Project"
A. MacGillivray, E. Ziegler, and J. Laughlin
Technical report prepared by JASCO Research, Ltd (Victoria, British Columbia, Canada) for
Washington State Ferries and Washington State Department of Transportation
March 6, 2007 (Version 2)

Summary of Literature Review - EM

- In Europe, electromagnetic interferences from both land-based and offshore wind farms have been studied. For offshore wind farms, a number of systems have been characterized through in-situ measurements.

- In the US
  - Significant efforts have already taken place to address electromagnetic interference from land-based wind farms.
  - For offshore wind farms, only limited modeling studies have been done. No comprehensive baseline assessment is available.
  - Measurement data collection has not been possible due to the lack of any operating offshore wind farms.

Summary of Literature Review - Acoustics

- The vast majority of studies of underwater sound radiation by operational offshore wind farms have been performed in Europe and primarily to assess impact of the radiated noise on marine mammals.

- No studies of how underwater sound affects acoustical equipment and systems were identified.

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Task 2 – Stakeholder Engagement

- **Goal:**

To engage key stakeholders in government and industry to identify concerns on interference from offshore wind farms.

- **Methodology:**

- In-depth personal interview was chosen as the research approach.
- Initially, a pool of candidates was gathered with the help of DOE. The candidates were first contacted via e-mail to request their participation in our study. The participant pool then expanded via snowball sampling.
- Those who agreed to participate were contacted to arrange a phone interview. All interviews were semi-structured, with broad and open-ended questions to allow for a more stakeholder-centric view from the interviewees.
- The interviews were conducted during the summer and fall of 2012.

Interviews

- **Stakeholders:**

- A total of 22 participants in EM and 18 participants in acoustics were interviewed. The list included DOD, FAA, USCG, NOAA, DHS, NTIA, commercial fisherman's association, and oil & gas industry.
- The interviews lasted 40 minutes on average. Immediately after each interview, key notes taken were summarized into written form.

- **Questionnaire:**

- During the first part of the interview, stakeholders were asked to comment on the effect of existing land based wind farms on their systems (EM only).
- During the second part of the interview, stakeholders were asked to comment on the potential effect of future offshore wind farms on their systems.

Key Findings - Electromagnetics

- The interference from land-based wind farms on land-based radar systems (weather, air traffic control, and long-range surveillance) has been widely observed and is considered well understood.
- Mitigation processes are either already in place or being put in place:
  - mechanisms to evaluate new wind farm proposals (FAA's obstruction evaluation process, NTIA's and DOD's energy siting clearinghouses).
  - R&D programs to examine various mitigation approaches (Interagency Field Test and Evaluation program).
  - new software tools under development to better predict impact.
- A number of stakeholders believed that interference from future US offshore wind farms on land-based radar systems can be dealt with using the existing approval mechanisms and technical solutions.
- However, offshore wind farms do raise some new concerns for other stakeholders. These new concerns include marine navigation and communications, airborne radar, and coastal HF radars.

Key Findings - Acoustics

- Due to the virtual absence of noise exceeding background levels radiated underwater by wind turbines at frequencies above 1 kHz, interference with underwater acoustical systems is deemed to be unlikely at such frequencies.
- At frequencies below 1 kHz, the tones radiated by wind turbines may cause interference with certain acoustical systems when placed in close proximity to a wind farm, or at longer ranges in certain acoustic environments.
- While interference with seismic sensors in coastal waters is possible, stakeholders anticipate being able to mitigate using standard signal processing methods.
- The Navy currently possesses no empirical data to suggest that their systems have been affected in the past, but there may be interference from future wind farms in U.S. coastal waters.
- Commercial fish-finding sonar operates at frequencies much too high to experience interference.

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Task 4 – Modeling Studies

- **Goal:**

To carry out first-principle modeling studies and to provide quantitative assessment of the effects.

- **Electromagnetics:**

1. Marine radar.
2. Airborne radar.
3. Coastal HF radar.
4. Communications systems.

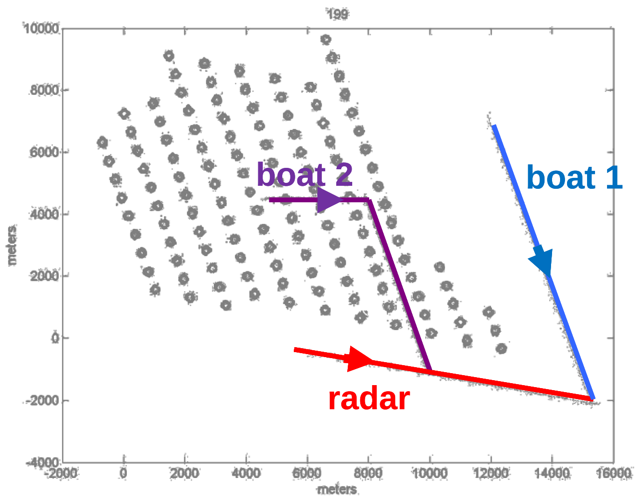
- **Acoustics:**

1. Noise propagation over different seabed compositions investigated.
2. Bathymetries of several proposed wind farm sites incorporated.
3. Propagation off continental shelf into open ocean simulated.

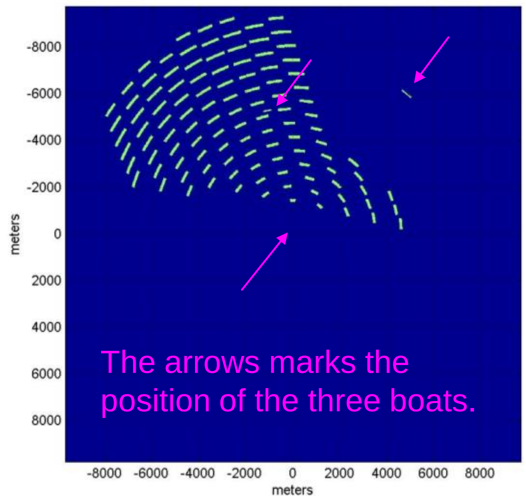
EM Case 1. Marine Radar Study

- SAIC performed a study to simulate the effect of wind farms on marine radars installed on boats and shipping vessels.
- XPATCH was used to generated the radar signatures of wind turbines and boats, and the resulting signature was projected into PPI displays.

Cape Wind Configuration



Our Results



TSC Simulation (2009)

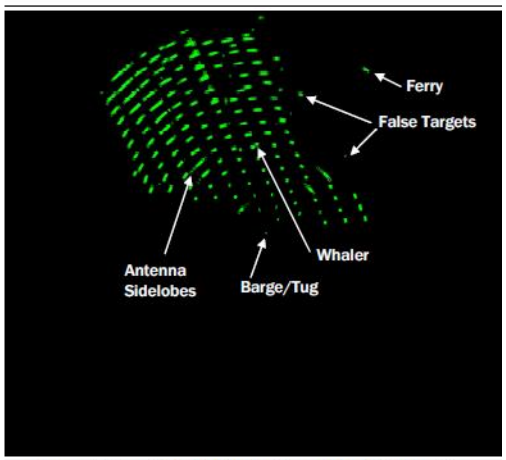
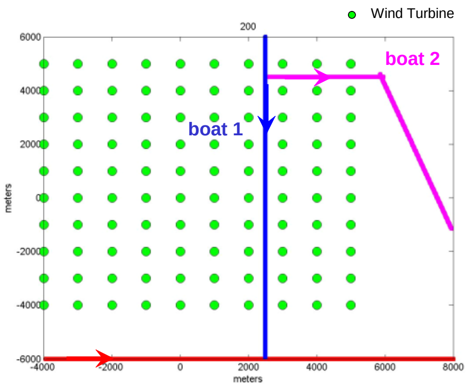


Figure 7: Sample 6 NMI Radar Sweep from Oil Barge/Tug

Wind farm configuration : GE 3.6MW turbine with 55.5 m blade length.
130 wind turbines distributed over 24 sq miles (~ 1000m x 630m apart). Radar frequency: 3GHz.

Results for a 10x10 Wind Farm

Wind farm configuration:
wind turbines with blade length of 63 m and height of 90 m.
100 wind turbines distributed over 100 sq km (1km x 1km apart).



Radar parameters:
Frequency = 3GHz
Range resolution = 15 m
AZ Beamwidth = 2 deg
Antenna Gain = 31dB
Sidelobe level = 20dB

Simulation of PPI Display

Assessment

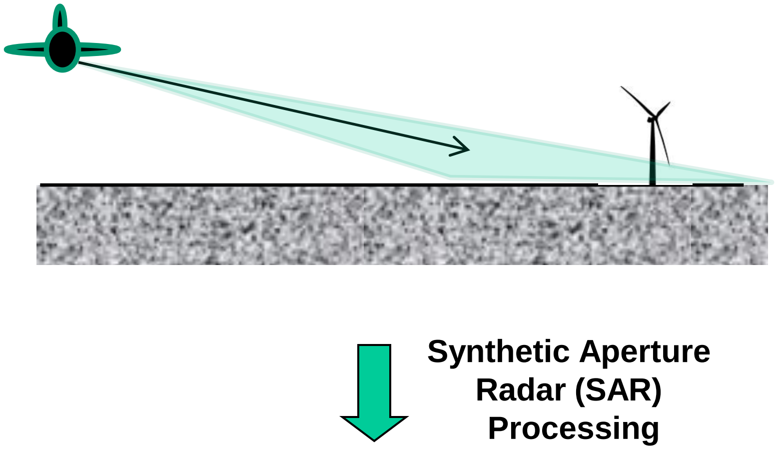
- The wind farm scattering would produce a confusing navigational picture when the boat being tracked is inside the wind farm.

- There would be minimal interference to navigation and tracking once the boat exits the wind farm.

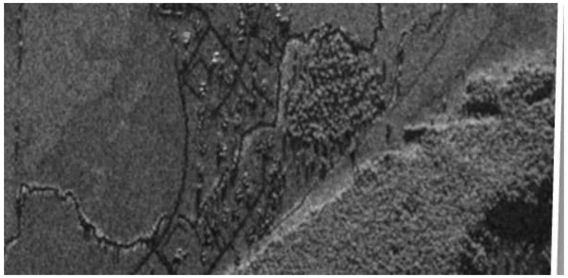
- This study agrees with the earlier Coast Guard determination on the Cape Wind project that "The Coast Guard assessment of impact on navigation safety falls within the moderate impact level."
  - *Page 12, Coast Guard Memorandum, "Report of the Effects on Radar Performance of the Proposed Wind Farm Project and Advance copy of the USCG Findings and Mitigations", 2009*

EM Case 2: Airborne Radar Study

- DOD operates a number of airborne sensors that may have coverage over coastal waters.
- Use sophisticated processing algorithms (GMTI, SAR, ISAR), which may be affected by wind turbine induced Doppler clutter.

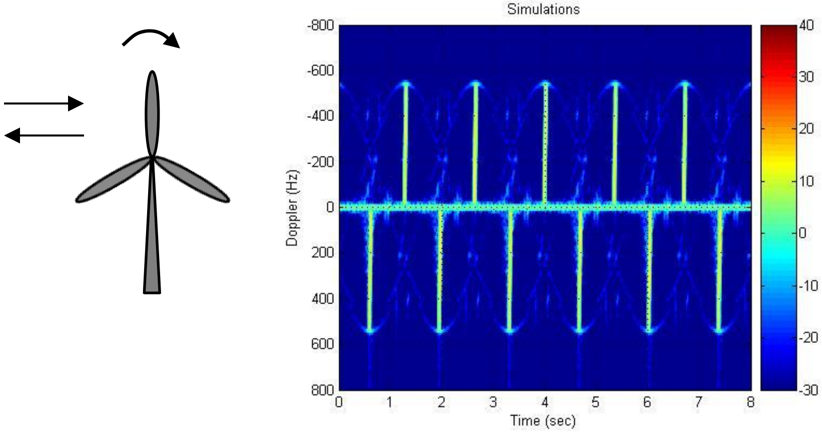


Synthetic Aperture Radar (SAR) Processing

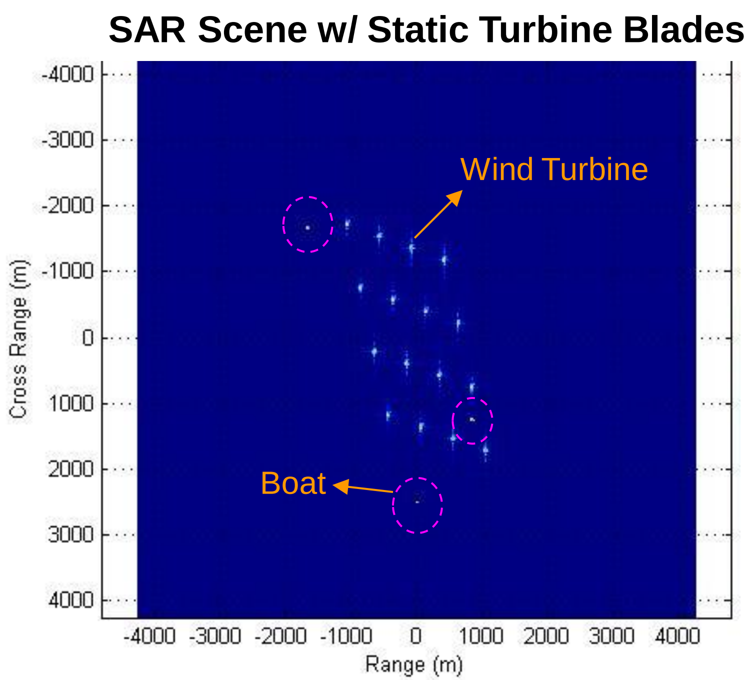


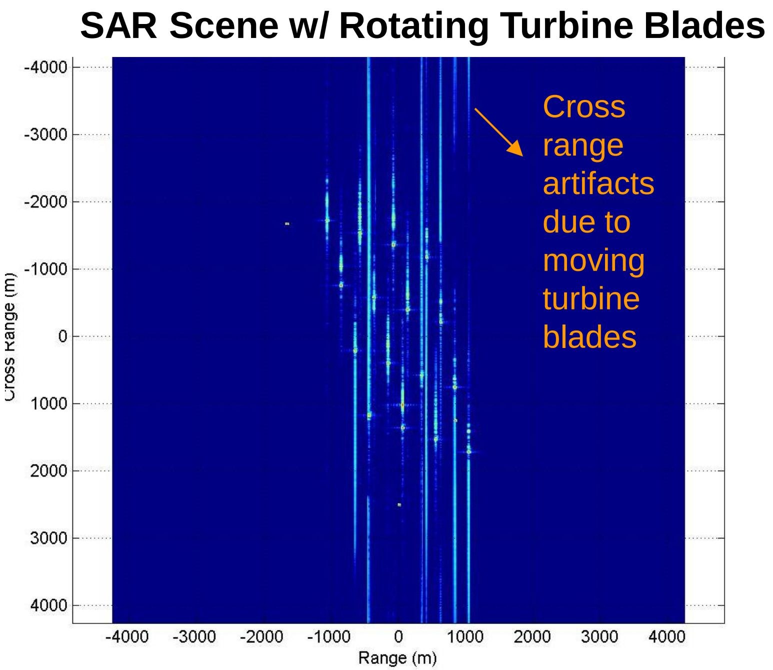
SAR Image

Wind Turbine Doppler Spectrogram



SAR Image Simulation



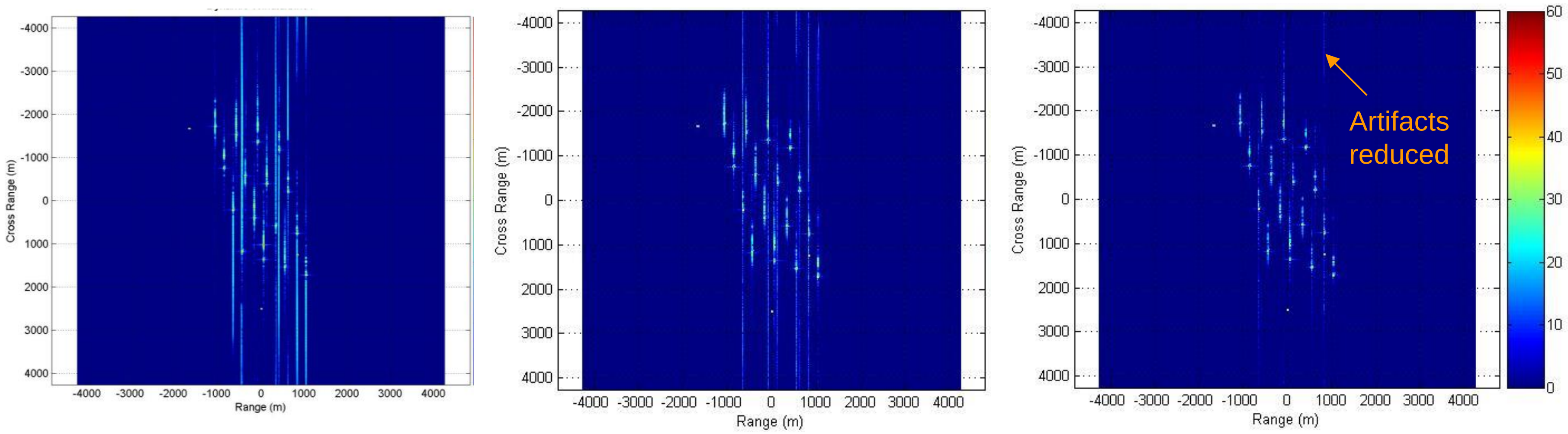


- SAIC performed a study using Xpatch to simulate the SAR and GMTI images from an X-band airborne radar of boats around a wind farm.
- Doppler due to rotating turbine blades introduces artifacts in SAR and GMTI images. These artifacts can potentially interfere with target detection and recognition.

Mitigation Based on Signal Processing

- Exploit the transient nature of the wind turbine clutter to perform a median filter on a series of SAR images.
- For fast transients such as wind turbine clutter, a percentile filter works well because the transients are only in a few frames whereas the stationary SAR features are persistent in all the SAR frames.

Original SAR Image | **SAR Image with median filter (40th Percentile)** | **SAR Image with median filter (10th Percentile)**



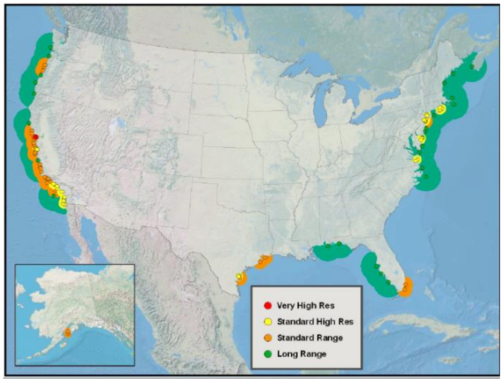
Assessment

- Wind farm scattering will produce serious artifacts in SAR and GMTI signatures generated by airborne sensors. This could potentially impact the performance of radar recognition and tracking algorithms.

- Signal processing of the signatures may be a viable approach to mitigate the effect of dynamic wind turbine clutter. If these algorithms are properly designed and implemented, the impact of wind farms on airborne radar recognition and tracking could be reduced to within a moderate level.

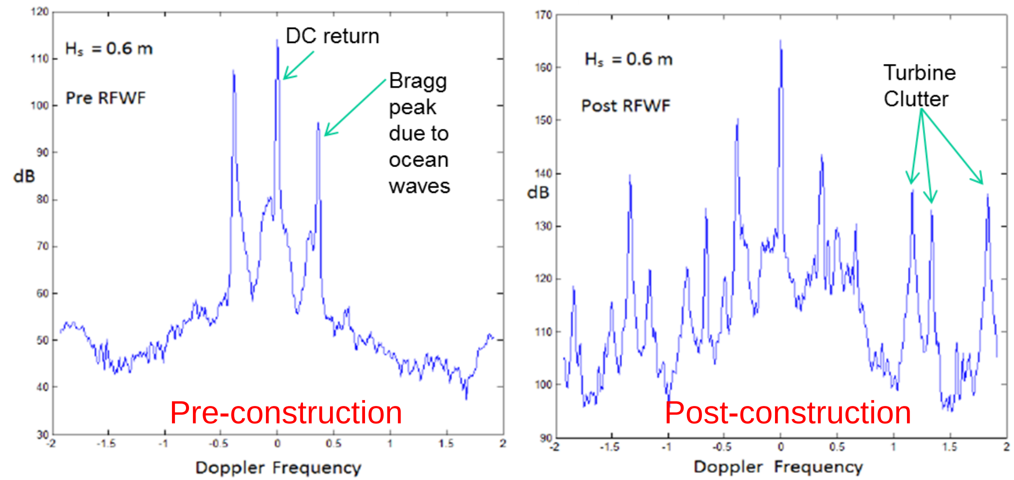
EM Case 3: Coastal HF Radar

US HF Radar Network



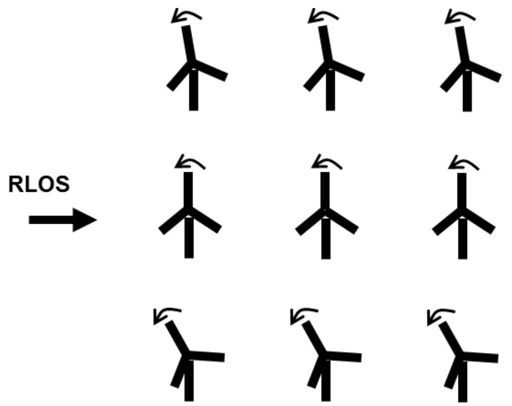
(from Jack Harlan, US Integrated Ocean Observing System Program Office, NOAA)

UK Wave Radar Results (Wyatt, 2011)



- A network HF radar sensors (CODAR, WERA) is operated by NOAA for large-area ocean surface current monitoring (out to 250km).
- Measurements using a WERA system by Wyle at UK’s Rhyl-Flats wind farm showed elevated clutter level.
- A preliminary simulation study of the clutter produced by a single turbine on the CODAR system was reported by Teague & Barrick in 2012.

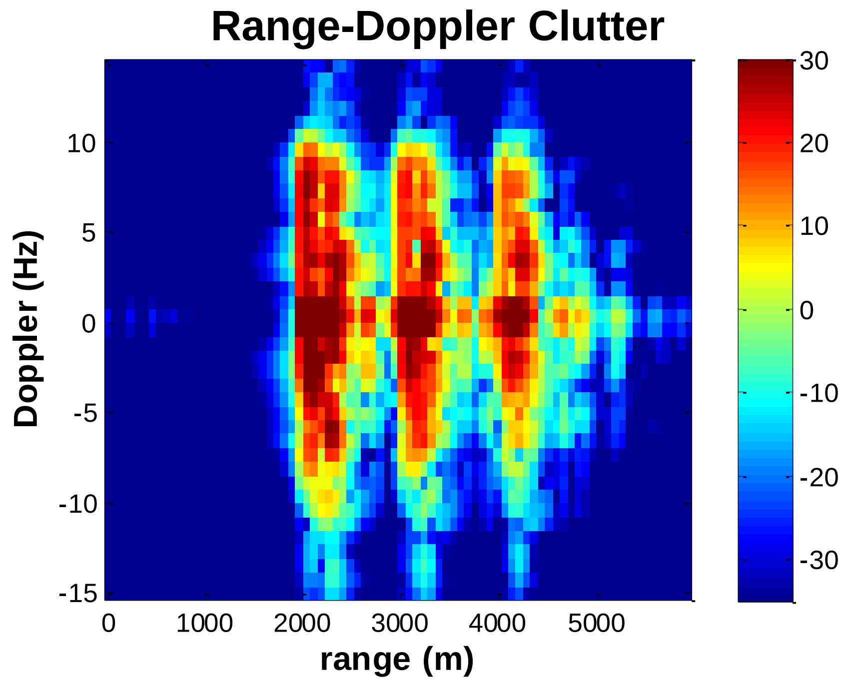
Simulated Clutter Level



Full-wave simulation (FEKO)
Tower length 90 m, blade length 63m, rotation speed 15 rpm, turbine spacing 1000m.

Monopole excitation at 3000 m edge-on incidence in the presence of an infinite ground plane.

Frequency: 12-14 MHz, range resolution: 75m, processed over 120 deg blade rotation window, results displayed in dBsm.



- **Localized in range.**
- **Doppler spread due to blades (limited to ±9Hz at 13MHz).**
- **No significant shadowing/blockage.**

Assessment

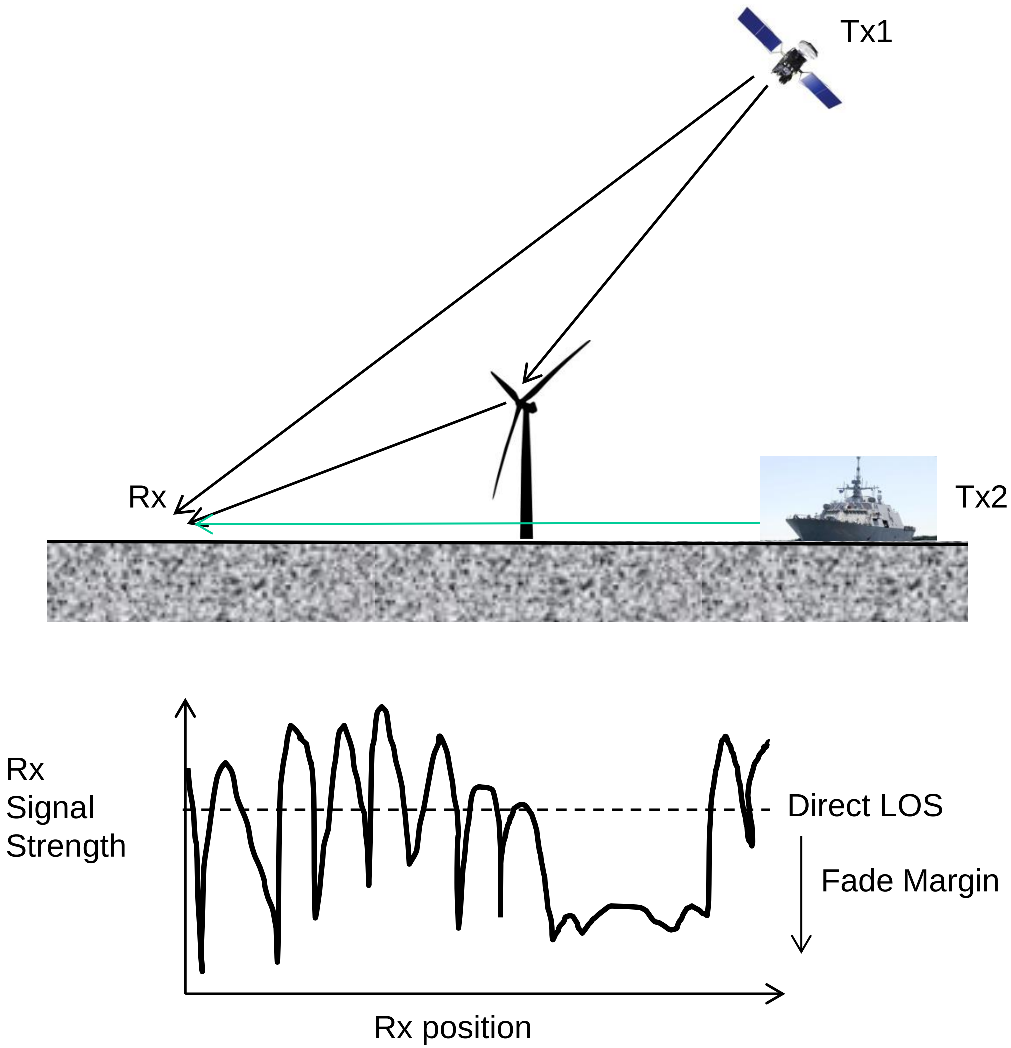
- The strength of the wind farm clutter is estimated to be 18dB below the scattered signal from the ocean surface being mapped by HF coastal radars.

- However, turbine clutter may be comparable to the weaker, second order returns from the ocean surface that are also of interest. Moreover, turbine clutter will be aliased in Doppler due to the slow PRF (2 or 4Hz) of these radars.

- Mitigation approaches using range, azimuth and Doppler filtering may be possible and should be further researched. Mitigation solution needs to be assessed from both the technical as well as cost point of view.

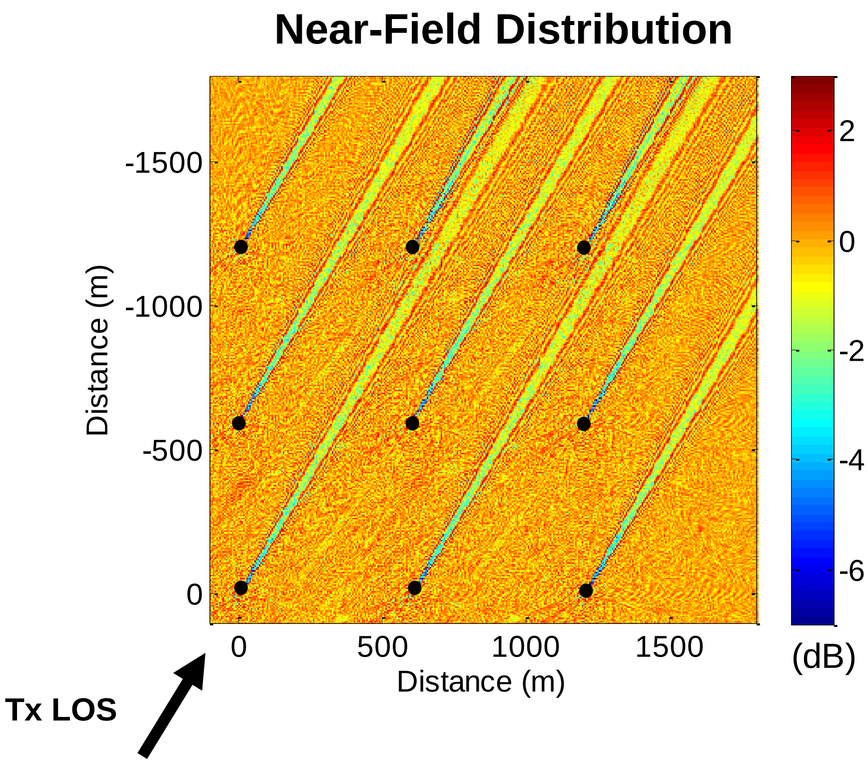
EM Case 4: Communications Systems

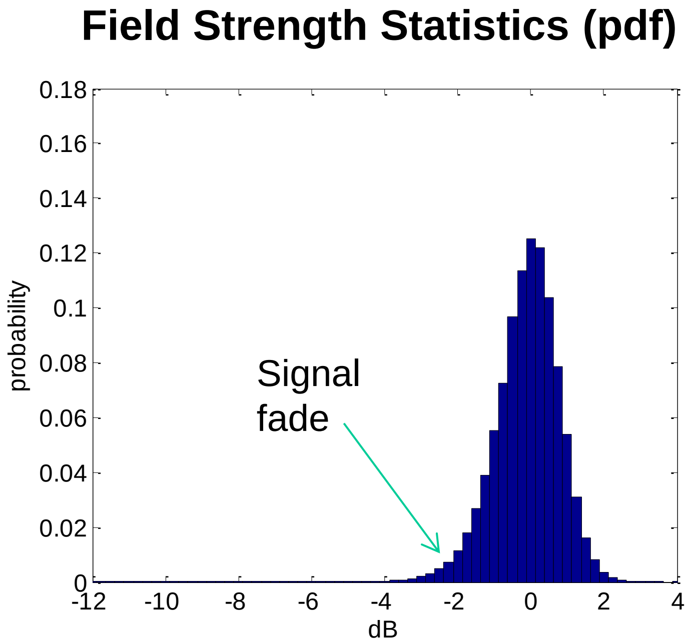
- Wind farm structures may affect communication systems including AIS/VHF radio (160MHz), GOES (400MHz uplink), GPS (1.6GHz downlink), Iridium (1.6GHz, uplink).
- Past studies have found no significant effects for GPS (UK North Hoyle, 2004)
- One-way vs. two-way signal path of communication signals vs. radar signals.



Near-Field Distribution Around a Wind Farm

- Tower diameter = 3.3 m
- 3x3 farm
- turbines spaced 600m apart
- Frequency = 500MHz
- Simulated using FEKO with Born approximation





Assessment

- Only a small degree of the signal fade (<6dB) is found in the limited shadow region close to the turbine tower. Since communications systems have built-in link margins to combat signal fading, the effect of wind farms on communications systems is expected to be low.

- For radar, the shadowing factor should be doubled (from 6dB to 12dB) to account for the two-way propagation loss. This may lead to a some loss in detection range when either the target or the radar is in the deep shadow of the turbine. However, this is still limited to be a small region behind the tower.

- Future measurement data collection is recommended to corroborate the results of this simulation study.

Summary - Electromagnetic Systems

- Communications Systems	Not likely to experience interference	
- Marine Radars - Coastal HF Radars	May experience interference under certain proximity and operating conditions	Pre-deployment investigation is warranted. Mitigation measures may be required.
- Airborne Radars	May experience significant interference if wind farms are located within the radar operational area	Pre-deployment investigation is warranted. Mitigation measures may be required and will need to be further investigated.

Task 4 – Modeling Studies

- **Goal:**

To carry out first-principle modeling studies and to provide quantitative assessment of the effects.

- **Electromagnetics:**

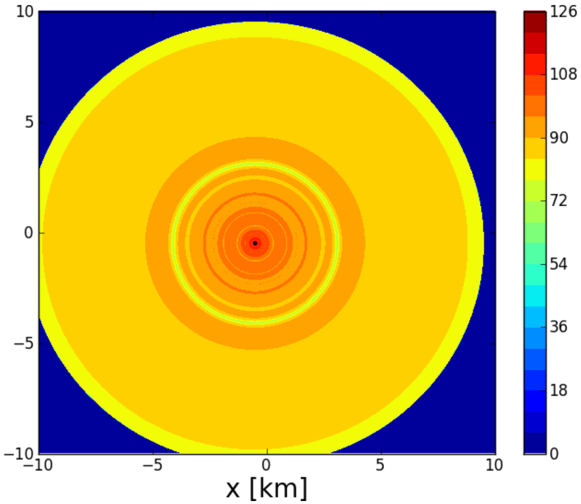
1. Marine radar.
2. Airborne radar.
3. Coastal HF radar.
4. Communications systems.

- **Acoustics:**

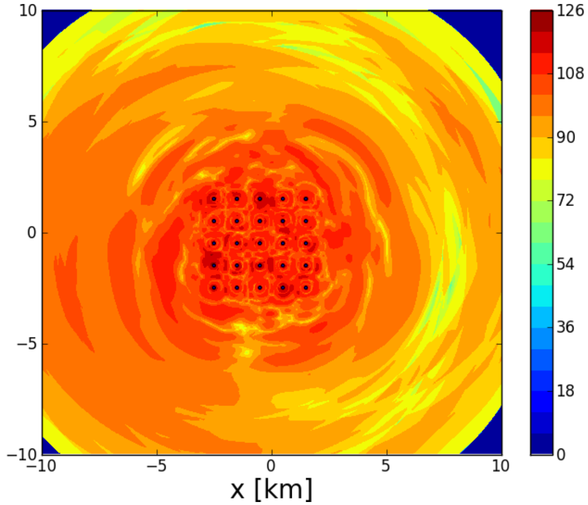
1. Noise propagation over different seabed compositions investigated.
2. Bathymetries of several proposed wind farm sites incorporated.
3. Propagation off continental shelf into open ocean simulated.

Underwater Sound Fields at 277 Hz

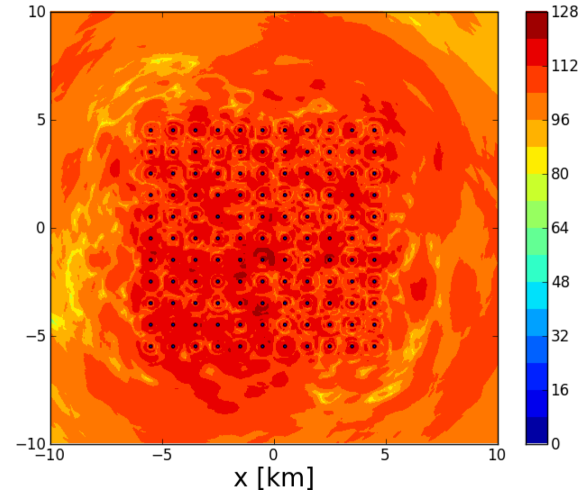
1 x 1 array (1 tower)



5 x 5 array (25 towers)

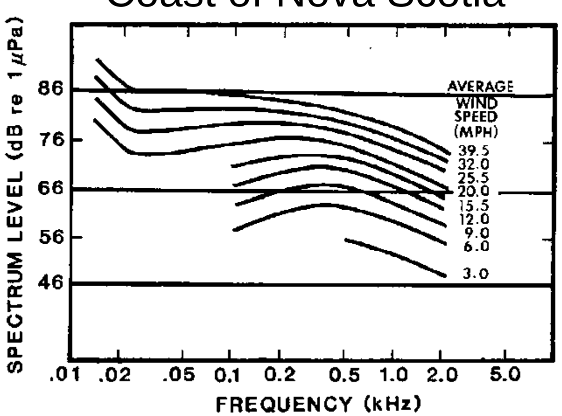


11 x 11 array (121 towers)



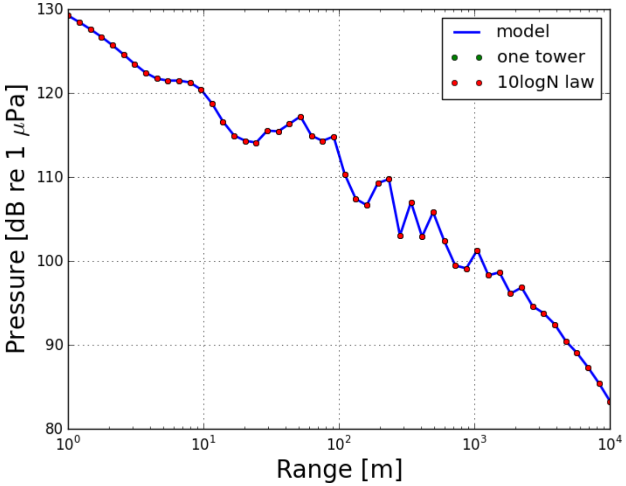
- Sandy bottom
- Water depth = 25 m
- Tower spacing = 1 km
- Color bars are SPL (dB re 1 µPa)

Noise Levels Along
Coast of Nova Scotia

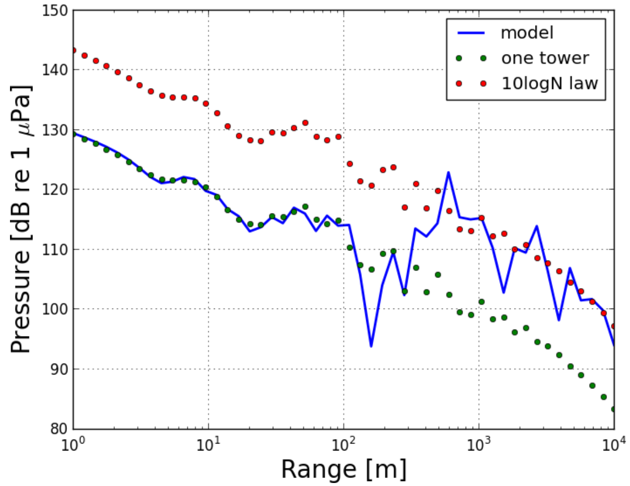


Underwater Sound Fields at 277 Hz

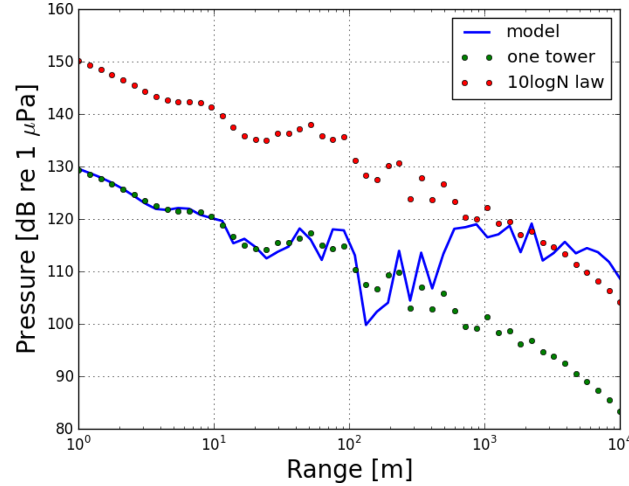
1 x 1 array (1 tower)



5 x 5 array (25 towers)

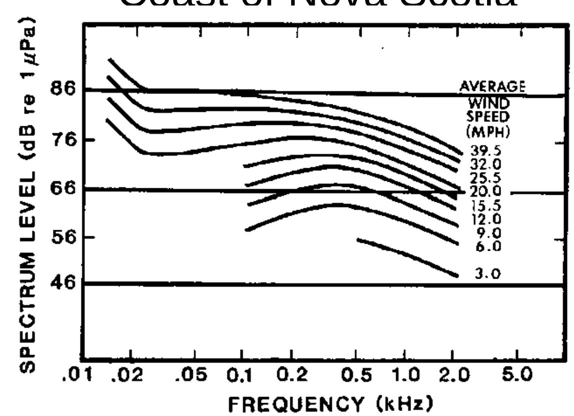


11 x 11 array (121 towers)

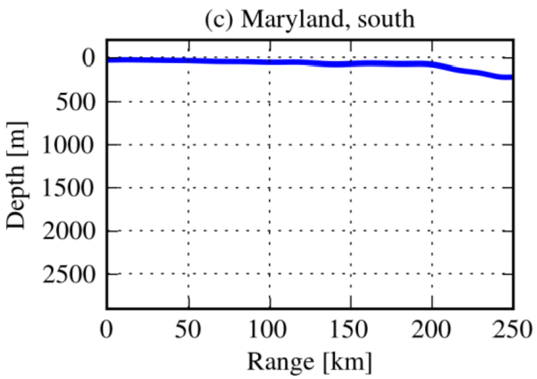


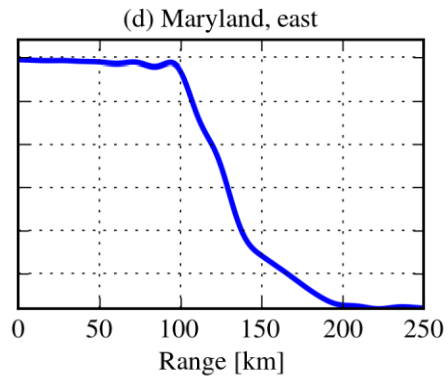
- Sandy bottom
- Water depth = 25 m
- Tower spacing = 1 km

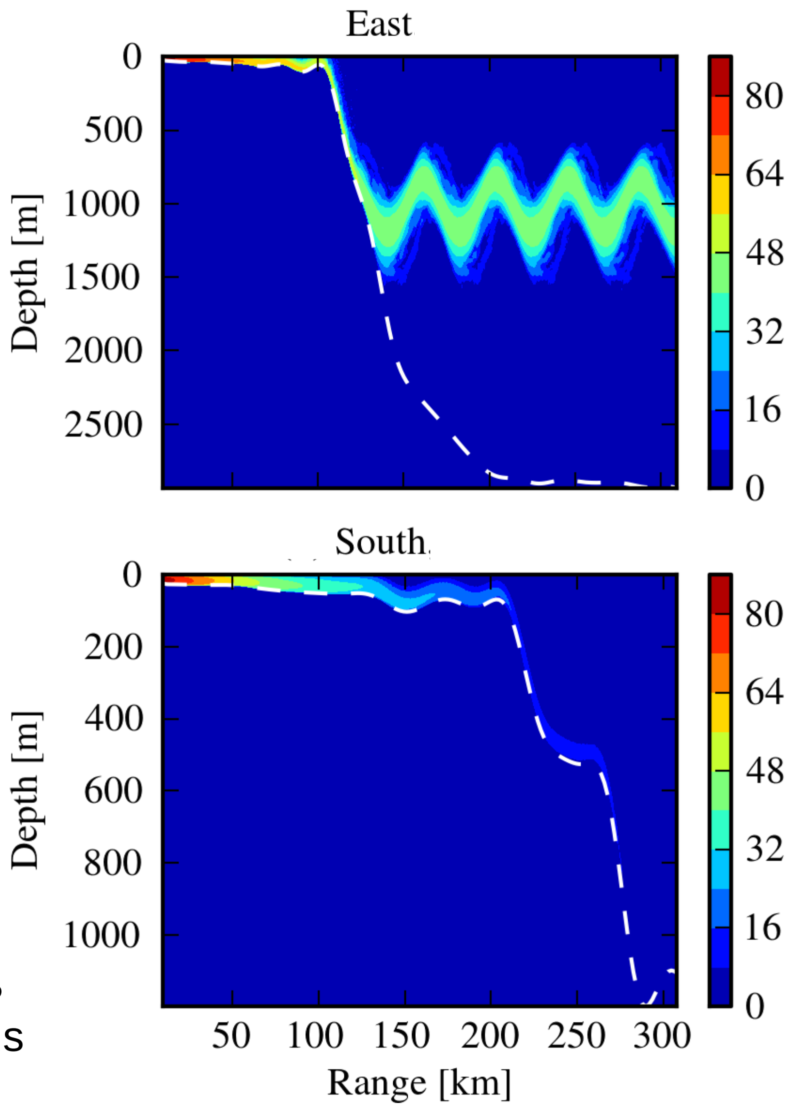
Noise Levels Along Coast of Nova Scotia

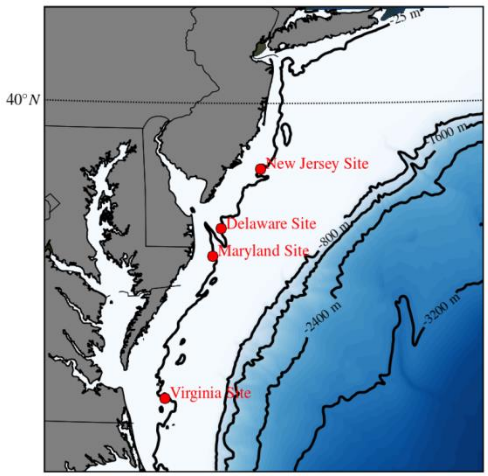


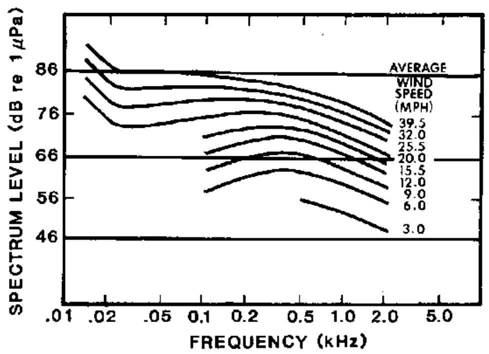
Propagation at 277 Hz from 1 Tower at MD Site











- Noise level from single tower down to about 50 dB at 100 km, so about 70 dB for 100 towers, and thus still comparable to background noise levels

Summary - Acoustical Systems

1. Ambient sound pressure levels in shallow coastal waters used for wind farms are nominally in the range of 60 to 80 dB (re 1 μPa) depending on wind speed.

2. Noise levels at long range are very sensitive to bottom composition.

3. A simulation performed with real bathymetric conditions at a proposed wind farm location off the coast of Maryland indicates that the noise from a farm with 100 wind turbines will be below the ambient level as it propagates off the continental shelf and into deep water.

Project Roadmap

- **Task 1 and Task 3: Survey potential challenges**

  - Developed a list of systems vs. frequency and stakeholders

  - Compiled list of references including both US and non-US activities

- **Task 2: Engage stakeholders**

  - Formulated questionnaires for both EM and acoustics

  - Conducted in-depth interviews with stakeholders

- **Task 4: Modeling study**

  - Identified priority topics based on stakeholder interviews and carried out modeling studies in EM and acoustics

- **Task 5 and Task 6: Documentation and dissemination**

  - Final report completed. Reviewed by DOE, stakeholders, and IFT&E experts.

Recommendations

1. Collect measurement data to corroborate findings.

Measurement data should be collected on electronic systems both before installation and after installation of the new Advanced Technology Demonstration projects funded by the DOE Wind Program. These new facilities, which should become operational between 2015 and 2017, will provide an excellent testing ground to collect in-situ electromagnetic and acoustic data in order to confirm the modeling predictions.

2. Perform system-specific risk assessment.

A more complete risk assessment on individual systems should be made by combining the results from our study with detailed system-specific information. These are best performed by stakeholders who not only hold such information but have the expertise to make a holistic risk assessment. For underwater acoustics, it is recommended that a future study be conducted that focuses on specific acoustical systems that operate at frequencies below 1 kHz, which was not addressed in the present report. Such a study should include further engagement with stakeholders, including a classified forum in which the Department of Defense may voice its concerns.

Recommendations

3. Conduct R&D on mitigation.

Research and development into approaches to mitigate the impact of offshore wind farms on electronic systems should be initiated through new research funding. The systems to be addressed, in order of their sensitivity to wind farm interference, are: 1) airborne radars operating in high-resolution sensing modes, 2) coastal HF radars, 3) marine radars, and 4) acoustical sensors operating below 1 kHz. For radar systems, particular focus should be placed on low-cost solutions such as those based on signal filtering algorithms or modified navigation practices. In the case of underwater noise, one might investigate possibilities for expanding techniques currently focused on pile driving operations (such as bubble screens, pile sleeves and hydrodynamic sound dampers) to entire wind farm installations.

4. Form government working group for information sharing.

A government working group focusing on the new offshore scenario should be established to encourage sharing of information from various agencies and help set protocols for addressing the offshore wind farm interference problem. This working group may be set up as an extension of the existing interagency field test and evaluation (IFT&E) group for land-based radar systems.

Recommendations

5. Develop simulation capability for site-specific assessment.

The development of electromagnetic and acoustic simulation capabilities should be continued. Currently, no end-to-end simulation tool exists that can address the various offshore wind farm interference scenarios. An accurate, user-friendly prediction tool will benefit future site-specific assessment tasks. Higher order electromagnetic effects such as those due to multiple scattering, interactions with the ocean surface and non-conducting turbine materials should be further examined.

6. Collect ambient acoustic noise data.

Ambient underwater noise measurements should be made at potential offshore wind farm sites or, if possible, collected from available databases, and then catalogued for use in future modeling studies aiming to determine acoustical impact.

7. Investigate other tower types.

The acoustic source model for underwater noise radiated by submerged wind turbine towers, which was developed under this project, should be extended from cylindrically symmetric monopile towers to more complicated but geometrically similar constructions such as tripods, and a new approach should be developed to model noise radiated from floating platforms. Similarly, the implications of new tower constructions should be examined for their above-surface electromagnetic scattering effects.

THANK YOU !

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- DOE project monitoring team: Michael Hahn, Gretchen Andrus, Brian Connor, Patrick Gilman, Gary Norton, Bryan Miller

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