11B.6 CONTINUED PROGRESS IN ASSESSING AND MITIGATING WIND FARM IMPACTS ON WSR-88Ds

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1. BACKGROUND

Wind power is one of the primary renewable energy sources being aggressively pursued by government and industry as one solution to fossil fuel dependence. In July 2008, the Department of Energy (DOE) released a feasibility study on wind energy *20% Wind Power by 2030, Increasing Wind Energy's Contribution to U.S. Electricity Supply*. The report provides a roadmap for reaching the report title's goal. Also, 26 states have now established Renewable Portfolio Standards (RPS) mandating that utilities provide a certain percentage of electric power from renewable energy sources. Soon after the release of the DOE report, T. Boone Pickens, an oil man, announced his Pickens Plan, which aims to replace natural gas-fueled electric power plants with wind generated power and use the freed-up natural gas to fuel transportation vehicles. The above efforts, along with the maturing of wind power technology, are fueling the rapid growth of the wind energy industry. This past summer the U.S. wind energy industry became the world's leader, surpassing Germany, in wind energy generation capacity with 20GW installed. However, this is still only 2% of the Nation's total electric supply. The DOE report estimates that to reach the goal of 20% of the electric supply will require 300GW of wind power capacity. Today's typical wind turbine generates a max power of 1.5MW, so reaching the goal would currently require the installation of about 200,000 wind turbines across the country. In Fig. 1 you can see that installed wind power capacity is indeed accelerating.

New wind farms sometimes have over 100 wind turbines with the maximum height of blade tips at over 150 m (492 ft) above ground level (AGL). Greater blade-tip heights are expected in the near future, especially offshore. As the number and height of wind turbines increase, there is growing potential for turbines to be constructed close to weather radars and interfere with radar performance. Optimum locations for weather (and other) radars and for wind turbines are often the same – relatively high, unobstructed terrain.

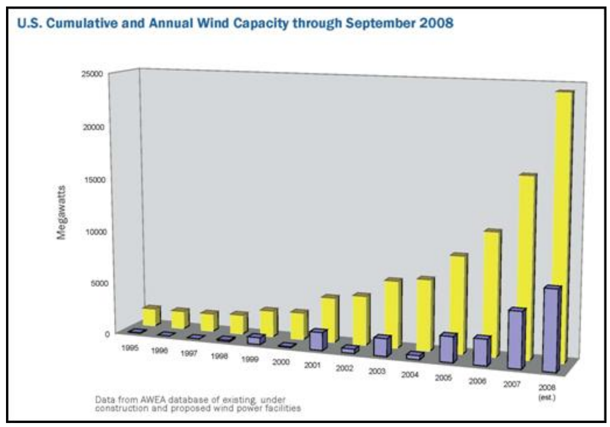

Fig 1. Annual U. S. wind power capacity (MW), net annual increase (purple bars) and cumulative capacity (yellow bars) from 1995 through 2008 (estimated). (American Wind Energy Association 2008)

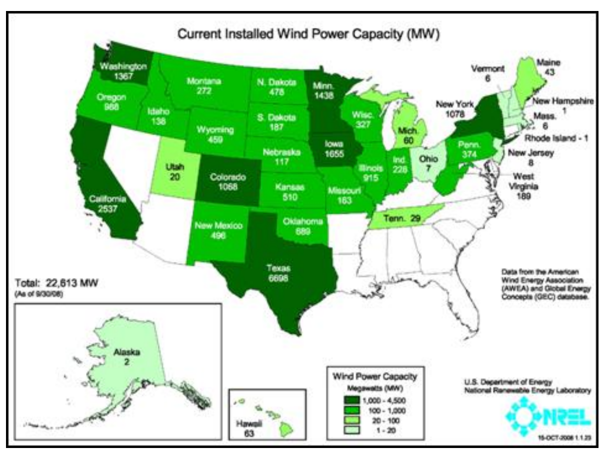

Fig 2. Current installed wind power capacity (Megawatts) by state, as of 9/30/08. (US Dept of Energy 2008)

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The geographic distribution of wind turbines favors certain areas of the country (Figs. 2 and 3) – further increasing the potential for wind turbines to be built in close proximity to radars.

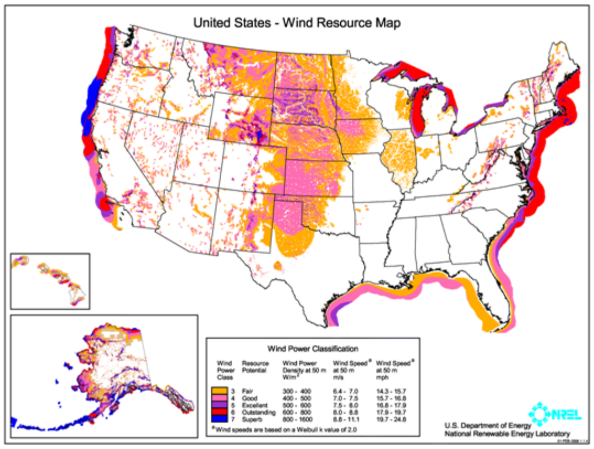

Fig 3. US Dept of Energy wind resource map showing areas (colored) favorable for wind energy development.

Nearly all wind farms installed before 2006 did not include consideration of their potential impact on weather radars. Permitting for wind farm construction is generally done at a local level. The federal government has no regulatory authority over wind turbine construction on private property. The Federal Aviation Administration is notified of structures over 200 feet tall and determines if the structures are a hazard to aviation via Obstruction Evaluation/Airport Airspace Analysis (OE/AAA) (Title 14 of the Code of Federal Regulations CFR Part 77), but does not consider possible weather radar interference.

In September 2006 the Department of Defense (DOD) reported to Congress (DOD 2006) on the impact of wind turbine installations on military readiness and air surveillance radars. The primary finding in the report was that to preclude adverse impacts on defense radars, developers should avoid locating wind turbines in the radar line of sight (RLOS). This approach requires a case-by-case analysis. The report deferred to the National Oceanic and Atmospheric Administration's (NOAA's) National Weather Service (NWS) to address impacts on weather radars.

Data from the national network of 159 Weather Surveillance Radar-1988, Doppler (WSR-88D) systems are a key component in the decision-making processes for issuing weather forecasts and severe weather warnings, and supporting the National Airspace System. Experience has shown that when wind turbines are within a WSR-88D's RLOS (defined as the cone of the half-power points, approximately 1 degree in width), spurious signals returned by the turbine towers and the rotating blades can negatively impact radar data quality and degrade the performance of radar algorithms.

This paper updates the paper presented at the 2008 IIPS Conference (Vogt et al 2008). This paper provides: updated examples of wind farm impacts on WSR-88D base products and algorithms; the WSR-88D Radar Operations Center (ROC) outreach efforts to the wind energy industry; ROC efforts to mitigate wind farm impacts on WSR-88D radar data quality; and plans to continue to work with the wind energy industry to mitigate the impacts of wind farms on WSR-88D systems.

2. IMPACTS OF WIND FARMS ON WSR-88D SYSTEMS

Wind farms can impact coherent (Doppler) radars in three ways if the turbine blades are moving and they are within the radar's line of sight. If close enough (within a few kilometers) they can partially block a significant percentage of the beam and attenuate data down range of the wind farm. They can also reflect energy back to radar and appear as clutter on the radar image and contaminate the base reflectivity data. The base reflectivity data is used by radar algorithms to estimate rainfall and to detect certain storm characteristics. Finally, they can impact the velocity and spectrum width data, which are also used by radar operators and by a variety of algorithms in the radar's data processors to detect certain storm characteristics, such as mesocyclones, relative storm motion, turbulence, etc. The WSR-88D has a sophisticated clutter removal scheme. Since weather is always in motion, the scheme was designed to filter returns that have essentially no or very low motion. This is effective for removing the returned signals from terrain, buildings, and other non-moving structures. Unfortunately, the radar sees rotating wind turbine blades as targets having reflectivity and motion, hence processes these returns as weather.

Wind farms at "extremely close" ranges to radars have all the impacts listed above and additional ones. Inter-turbine scatter and multi-trip/multi-path returns create false signals down-radial from the real wind farm echo regions. These down-radial returns have been observed for turbines located within 10 miles (16 km) of the radar, and can extend down radial for 25 miles (40 km) or further. In some cases the disturbed areas are large enough to cause additional forecaster confusion and distraction, and to affect forecasts and radar data (particularly Velocity Azimuth Display Wind Profile) assimilations into numerical models.

If wind turbines are in the main radar beam and within 600ft (183m) of radars (in the near field), damage to both the radar's and turbines' electrical components might occur, and construction or maintenance personnel may be exposed to microwave energy that exceeds Occupational Safety and Health Administration (OSHA) thresholds for occupational exposure. Turbines within 1 mile of a NEXRAD can prevent the radar's beam from properly forming, thus causing significant radar estimation errors down range from the turbines. Finally, within 10 miles of a NEXRAD, the microwave radio frequency field strength can cause bulk cable interference (inductive coupling) with the turbines electronic controls if they are not properly shielded.

Examples of how wind farms appear on operational WSR-88Ds are shown in Figs. 4 - 9. These and other examples are available at: http://www.roc.noaa.gov/windfarm/windfarm_impacts.asp

Wind turbine clutter has not yet become a major negative impact on forecast operations. However, with more and larger wind turbine installations coming on line in the near future, experience gained to date strongly suggests that negative impacts should be anticipated -- some sufficient to compromise the ability of radar data users to perform their missions.

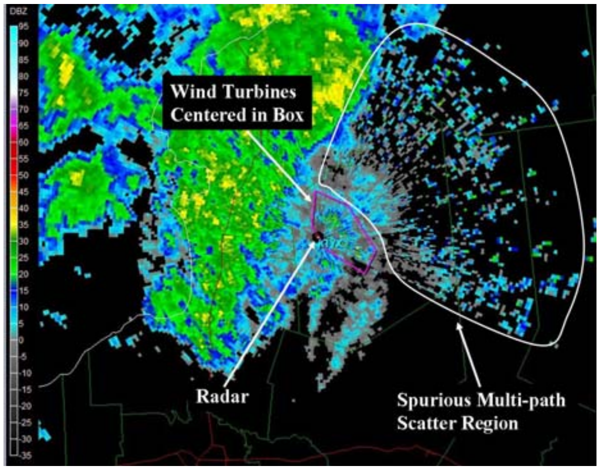

Fig 4. A 0.5 degree scan Reflectivity product from the Fort Drum, NY WSR-88D (KTYX) on December 15, 2008 at 1307 GMT. A wind farm is approximately 6 - 14 km north - southeast of the radar (see annotations). The blue and green pixels that extend down-radial of the wind farm are due to multi-path and inter-turbine scattering of the radar beam. The echoes west of the radar are from an approaching area of rain. The echoes north through southeast near the radar are not weather.

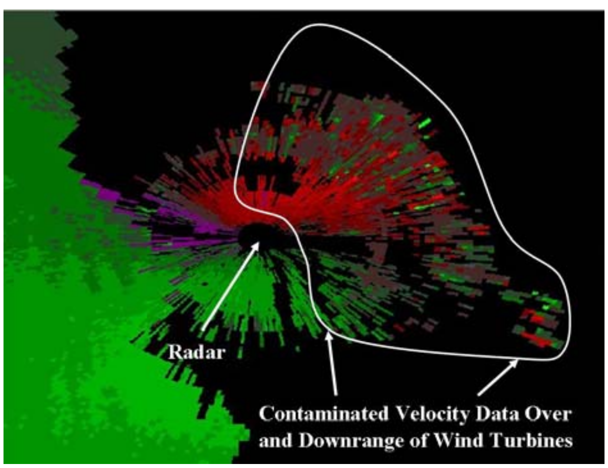

Fig 5. A zoomed 1.5 degree scan Mean Radial Velocity product from the Fort Drum, NY WSR-88D (KYTX) on March 10, 2007 at 1234 GMT. Red colors indicate outbound velocities and green colors indicate inbound velocities. The imagery shows contaminated velocity data due to the rotating turbine blades in the vicinity of and down range of the wind farm. Note the anomalous and more "chaotic" wind velocities depicted down range of the wind farm in comparison with the velocities in the "real weather" data west of the radar. These echoes could confuse data users, and, contaminate radar meteorological algorithms particularly since they are occurring in multiple elevation tilts.

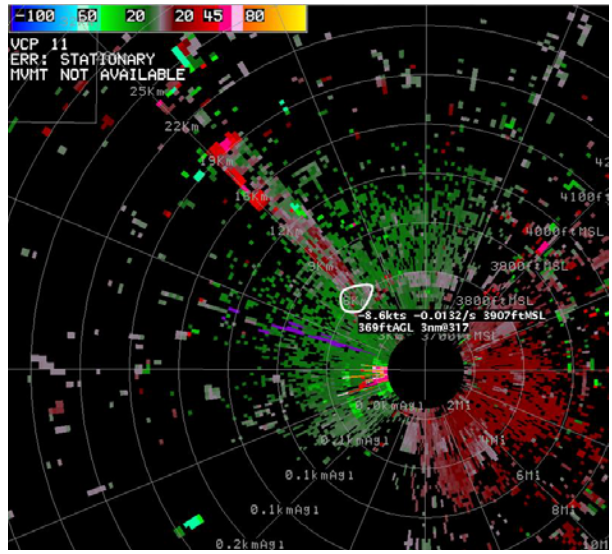

Fig 6. This Velocity image (0.5 degree scan) from the Great Falls, MT WSR-88D (KTFX) on February 9, 2006 at 1859 GMT shows how only a few turbines located close to the radar can cause a relatively large impact. The 6 turbines are approximately 5 km from the WSR-88D and the RLOS is approximately 200 feet below the top of the rotating turbine blades. The velocity data is contaminated in azimuth for 9 degrees and out beyond 20 km due to multi-path and inter-turbine scattering.

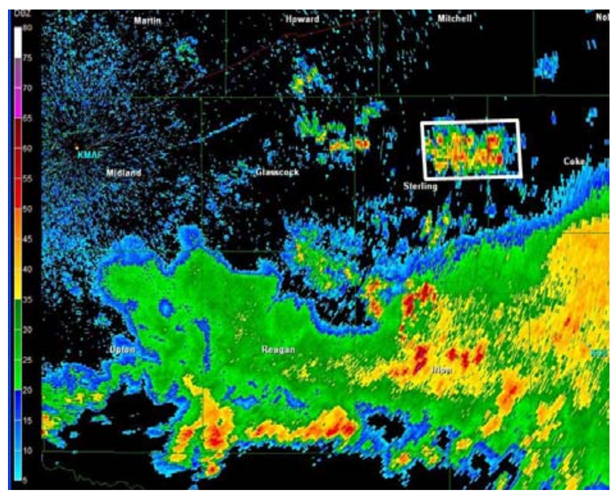

Fig 7. This Reflectivity image (0.5 degree scan) from the Midland/Odessa, TX WSR-88D (KMAF) on August 11, 2008 at 1144 GMT shows how a large area of wind turbines relatively far from the radar can appear during AP (ducting) conditions. The turbines are typically not visible at this distance because they are not in the RLOS under standard propagation conditions. The area in the square contains 200+ turbines from several wind farms extending from approximately 60 to 100 km east of the radar. Cool outflow from these storms likely contributed to the AP conditions and complicates the forecaster's analysis of storms in the vicinity of the wind farms.

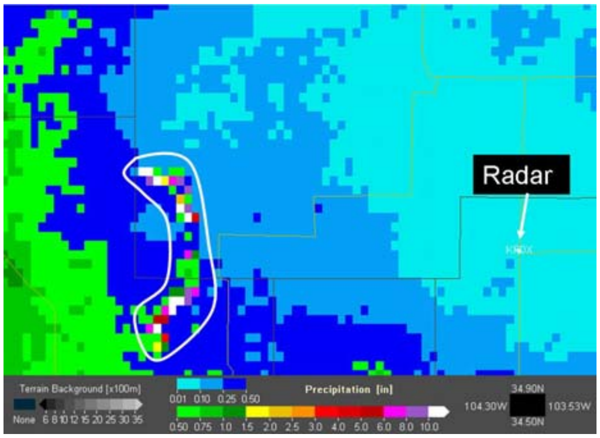

Fig 8. This Hybrid Scan Reflectivity Mosaic incorporates the 24-hour precipitation accumulation from the Cannon, NM WSR-88D on May 02, 2007 at 1300 GMT. Erroneous 10+ inch radar-estimated Storm Total Precipitation accumulations resulted due to the large wind farm 36 km west of the WSR-88D. The anomalous accumulations make estimates of the amount of rainfall over an area/river basin more difficult to determine.

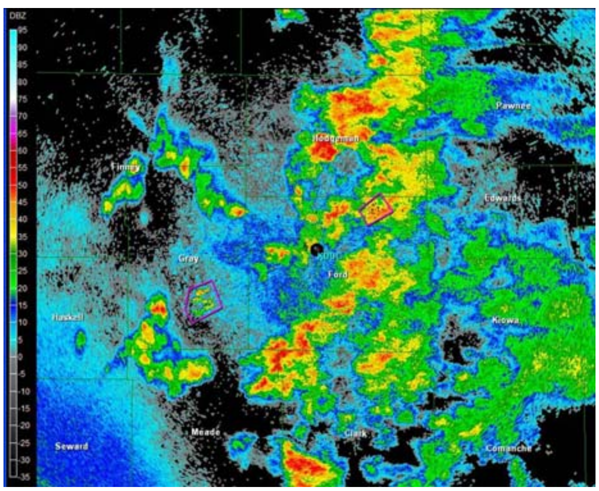

Fig 9. This Reflectivity image (0.5 degree scan) from the Dodge City, KS WSR-88D (KDDC) on August 25, 2008 at 1220 GMT shows how a large area of wind turbines (NE of radar) can look similar to weather returns appear. In addition, weather returns down range of the two wind farms (NE and SW of the radar) do not appear to be greatly affected by attenuation due to the wind farm. Potential partial blockage/signal attenuation of radar signals by wind farms need to be analyzed on a case-by-case basis.

3. HOW THE ROC ASSESSES THE IMPACTS OF WIND FARM PROPOSALS

The ROC learns of wind farm developments through both formal and informal methods. Formally, the Department of Commerce's National Telecommunications and Information Administration (NTIA) acts as clearinghouse for developers to voluntarily submit wind farm proposals for review by several federal agencies, including NOAA. This formal process is recognized by the wind industry in the American Wind Energy Association's (AWEA) Wind Siting Handbook (AWEA 2008). Informally, the ROC learns of wind farm projects from local forecast offices who sometimes email news articles or web links to stories about planned wind farms. The ROC tries to proactively contact the developers if the project appears to have potential impacts to the nearby WSR-88D.

Based on the wind farm proposal the ROC receives, the ROC provides a case-by-case analysis of potential wind farm impacts on WSR-88D data and forecast/warning operations. In the last 2 years, the ROC has provided over 375 individual analyses. The ROC uses a geographic information system GIS database that utilizes data from the Space Shuttle Radar Topography Mission to create a RLOS map with delineated areas corresponding to turbine heights of 130 m, 160 m, and 200 m AGL. Multiple radar elevation angles are considered for projects close to the radar.

The ROC then performs a meteorological and engineering analysis using: distance from radar to turbines; maximum height of turbine blade tips; the number of wind turbines; elevation of the nearby WSR-88D antenna; an average 1.0 degree beam width spread; and terrain (GIS database). From this data the ROC determines if the main radar beam will intersect any tower or turbine blade based on the Standard Atmosphere's refractive index profile.

Finally, the ROC estimates operational impacts based on amount of turbine blade intrusion into RLOS, number of radar elevation tilts impacted by turbines, location and size of the wind farm, number of turbines, orientation of the wind farm with respect to the radar (radial vs azimuthal alignment), severe weather climatology, and operational experience. The ROC also compares the wind farm to other operational wind farms to estimate impacts.

The ROC has adopted the RLOS as a benchmark for seeking further discussions with developers to determine if alternative siting strategies (e.g., relocation, terrain masking, and/or a more optimum deployment pattern) could reduce the potential impact of wind turbines on radar performance. About 21% of analyzed wind farm proposals have been projected to be in the RLOS of a WSR-88D. As a result of these analyses the ROC has met or had conference calls with over 20 developers to discuss possible mitigation strategies for wind farms. Some developers have stated they will re-site planned turbines to more favorable locations with respect to the WSR-88D.

Figure 10 depicts an example of the primary categories of wind farm analysis requests and replies.

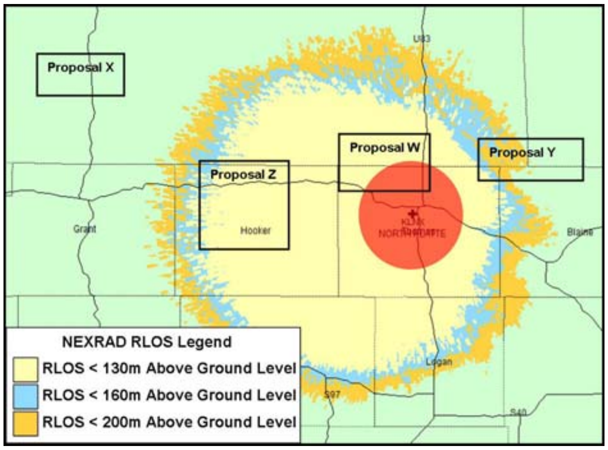

Fig 10. An example radar line of sight (RLOS) map generated by the WSR-88D ROC for a wind farm analysis. Four hypothetical proposals: W, X, Y, and Z as described below are shown.

Proposal X: clearly out of the RLOS, would have minimal to no impact on the radar.
Proposal Y: minimal to moderate impacts on the radar if turbines were built in the western portion of the proposal area. The NEXRAD Program would seek to consult with the developer to determine if most/all wind turbines could be located in the eastern portion of the proposed area.
Proposal Z: potentially minor to moderate impacts on the radar. The NEXRAD Program would seek to consult with the developer to determine if there is flexibility to consider impact mitigation techniques and to ensure the developers are aware of potential impact on forecast/warning operations.
Proposal W: potentially large impacts on the turbines and the NEXRADs for the portion of the proposal in the red area. The NEXRAD Program would seek to consult with the developer to ensure they are aware of the likely impact on forecast/warning operations, the NEXRAD system, and the wind turbines/personnel.

4. PAST ROC ACTIONS

Weather radar operators began reporting radar – wind farm interactions early in this decade. In 2006, the NOAA/NWS and the ROC, on behalf of the Next Generation Weather Radar (NEXRAD) Program, began systematic efforts to investigate radar – wind farm interactions. These efforts included creating awareness of the issue within the wind energy industry and the meteorological community, collaborating with other impacted federal agencies, and exploring potential radar-based solutions.

a. Creating Awareness of the Issue

Many developers in the wind industry are unaware of the impacts wind farms can have on Doppler radars in general and the WSR-88D in particular. Because of some high-profile cases, developers are more aware of impacts to the long-range air surveillance radars, which are jointly operated by the DOD and Department of Homeland Security (DHS).

During 2008 the ROC took many actions, including the following, to create awareness of the potential impacts of wind farms on WSR-88Ds and promote a collaborative, low-impact co-existence between WSR-88Ds and wind farms:

(1) Participated, via presentation, poster and paper, in various American Meteorological Society (AMS), American Wind Energy Association (AWEA), and other wind energy-related meetings and conferences. Met with developers to provide WSR-88D information and invited them to consult with us
(2) Continued to maintain and upgrade a portion of the ROC web site (http://www.roc.noaa.gov/windfarm/windfarm_index.asp) dedicated to wind farm issues. The page has information on the WSR-88D, maps of the RLOS for each WSR-88D in the CONUS, and examples of wind turbine impacts on the WSR-88D and imagery of wind farms as seen by operational WSR-88Ds. Wind farm developers, WSR-88D operators, and WSR-88D data users have visited the web site.
(3) Activated a NEXRAD "toolkit" on the FAA OE/AAA web site. This toolkit enables developers to anonymously ascertain, early in their planning process, potential wind farm impacts on WSR-88D systems. https://www.oeaaa.faa.gov/oeaaa/external/portal.jsp.

b. Collaborating with Other Impacted Federal Agencies

The NEXRAD radar is not the only radar affected by wind turbine clutter. The long-range Air Route Surveillance Radars (e.g. ARSR-4), used jointly by the DOD and the Department of Homeland Security (DHS) for tracking aircraft, have also been impacted by large wind farms. The ROC is working with the DOD/DHS Long-Range Radar Joint Program Office to build off of their experience with this issue. During 2008 the ROC took the following actions to collaborate with other federal agencies:

(1) Briefed on NEXRAD efforts to mitigate wind turbine interactions at the JASON Technical Meeting on Wind Farms and Radar (January 2008). This high-level DOD scientific advisory board was investigating impacts of wind farms on DOD radars. Other federal agencies; AWEA; and private sector participated.
(2) Participated in the DOD/DHS Long-Range Radar Joint Planning Office Annual Meeting (October 2008).
(3) Exchanged information with other federal agencies operating radars.

c. Investigating Radar-based Solutions

The ROC is funding studies of potential signal-processing techniques by the Atmospheric Radar Research Center (ARRC http://arrc.ou.edu) at the University of Oklahoma (e.g., Isom et al 2009). One goal of these sophisticated signal processing methods is to automatically identify the turbine-corrupted data through spectral features, temporal continuity, etc., flag it, and potentially recover the underlying weather information. When this detection algorithm is finalized, the NEXRAD has a flexible, open architecture signal processor that would enable relatively low cost and timely implementation of the new signal processing technique.

In addition to detection, signal processing methods based on real-time, telemetry-based algorithms are being explored by the ARRC. These knowledge-based techniques would exploit wind turbine data of blade rotation rate, orientation, etc., and are a good example of the benefits of collaboration with wind farm operations. An initial phase is currently being conducted in a controlled laboratory environment using scaled models and scattering experiments (Fig 11). Further, electromagnetic simulations are being conducted to determine expected radar cross-section from turbines, which will be used to validate laboratory measurements and to enhance adaptive signal processing algorithms.

Fig 11. Model wind turbine in the ARRC Lab at the University of Oklahoma

Finally, more advanced radar designs are being studied as a long-term solution to wind turbine interference. In particular, OU's ARRC is investigating the possibility of using adaptive null steering with phased array radars as a means of mitigating clutter from moving targets (Palmer et al 2009). Promising results have already been obtained using sophisticated numerical simulation techniques previously developed by the ARRC (Cheong et al 2008). The potential exists for a possible solution to this difficult problem, but further research and additional funding sources are needed.

Success of these ARRC studies could depend on partnering with other federal agencies and/or the wind energy industry. However, these techniques, if achievable, will take several years to operationally implement. For further details, see the related paper entitled *Spatial Filtering of Wind Turbine Clutter Using Adaptive Phased Array Radars* (8B.6).

5. PLANNED ACTIONS FOR 2009

The ROC, on behalf of the NEXRAD Program, plans to continue to expand contacts with the wind energy industry in 2009 and beyond to promote earlier and more frequent sharing of information and collaboration. The ROC is also developing a template for developers to use for submitting project plans to the NTIA. The ROC will also continue its interaction with other federal agencies to leverage off their progress. The ROC has accepted an invitation to participate in the February 2009 AWEA Wind Siting Workshop and has submitted an abstract for the June 2009 AWEA annual meeting, WINDPOWER 2009. The ROC will continue to work with AWEA to explore a possible agreement on braking turbine blades in critical weather situations.

Locally, the ROC plans to continue to support studies by the University of Oklahoma of potential radar-based mitigation strategies. Finally, the ROC will post a significant update to its NEXRAD – Wind Farm Interaction web page in January 2009.

6. MITIGATION ACTIONS FOR RADAR OPERATORS

Wind farm interference on radars is a relative term, but the bottom-line metric is the impact the interference has on the operational mission. Weather forecasters can learn to recognize wind farm weather radar signatures; reduce impacts somewhat through proper radar configuration; and attempt to accommodate or "work around" the wind farm impacts in their decision process (Burgess et al 2008). For example, forecasters can:

(1) Establish exclusion zones to limit precipitation overestimation or false accumulations. However, exclusion zones only apply to real-time precipitation algorithms and do not remove the contamination from the base data.
(2) Ensure clutter suppression is active. This only excludes stationary targets and is not effective on clutter arising from turbine blades in motion.
(3) Look at higher elevations to "see over" wind farms. This can result in the loss of low-altitude information crucial in some forecast situations, e.g., onset of a tornado.
(4) Look at adjacent radars that have coverage over the wind farm area.

Operational forecasters can often distinguish wind turbine clutter (WTC) from weather signals using their experience. However, a major concern is the effect of these echoes on automated detection algorithms and users not as experienced or used to the appearance of WTC.

7. MITIGATION ACTIONS FOR DEVELOPERS

Early in the wind farm planning process, developers can do a quick, anonymous analysis of their project's potential impact on the NEXRAD radar network by using the new NEXRAD Tool on the FAA's Obstruction

Evaluation (OE/AAA) web site (https://oeaaa.faa.gov/oeaaa/external/portal.jsp). An example of the tool's analysis screen is seen in Fig. 12. The tool uses input coordinates to determine if the project is in a NEXRAD's RLOS (200m AGL) and displays a color-coded map to indicate the level of impact (Green = no impact, Yellow = minor to moderate impact, Red = significant impact). If the tool indicates potential impacts, there are several actions the developer can take to mitigate them. First, the developer should contact the ROC for a more thorough analysis and learn about possible mitigation options.

The best mitigation technique is to avoid locating wind turbines in the RLOS of a NEXRAD. This strategy may be achieved by distance or terrain masking. Mitigation of impacts, if turbines are in the RLOS, can be achieved by reducing the number of turbines in the RLOS, the amount of blade penetration into the RLOS, greater separation from the radar, or through selective turbine siting; e.g., to reduce the azimuthal extent of the turbines with respect to the radar. Each situation requires case-by-case analysis.

The NEXRAD Program is looking into another promising option for developers to consider. This involves the developer entering into discussions with the local Weather Forecast Office (WFO) or military Base Weather Station to define severe weather scenarios or criteria under which the wind farm operators will stop the wind turbines to allow the WFO to receive uncluttered radar data from the wind farm area. Stopping the turbines typically eliminates WTC in most circumstances, except when wind turbines are very close to the radar and in the RLOS. The Wind Farm Operator and WFO could develop an informal document detailing the weather scenarios or criteria, points of contact on each side, and the agreed-to operating procedures.

In summary, here is a prioritized list of mitigation options for developers to consider:

1. Site wind turbines out of the RLOS.
2. If within the RLOS, stop the turbines during severe weather.
3. Within the RLOS, site wind turbines as far as possible from the radar (assuming level terrain).
4. In hilly areas, use terrain masking by placing wind turbines on the far side of the hill below the peak.
5. Try to minimize azimuthal spread relative to radar, especially when siting very close to the radar.
6. If azimuthal spread is large, provide open radials from the radar by bunching turbines into groups with space between these groups. When the wind turbines are very close (within 10 miles) to the radar, this provides clear radials of data when multipath effects (ghosting, beam attenuation) are occurring down radial from the wind farm.
7. When choosing the height of wind turbines, shorter turbines are preferred if they would not penetrate into the RLOS. However if shorter turbines would still be in the RLOS, then fewer, taller turbines over a smaller area may be preferable.

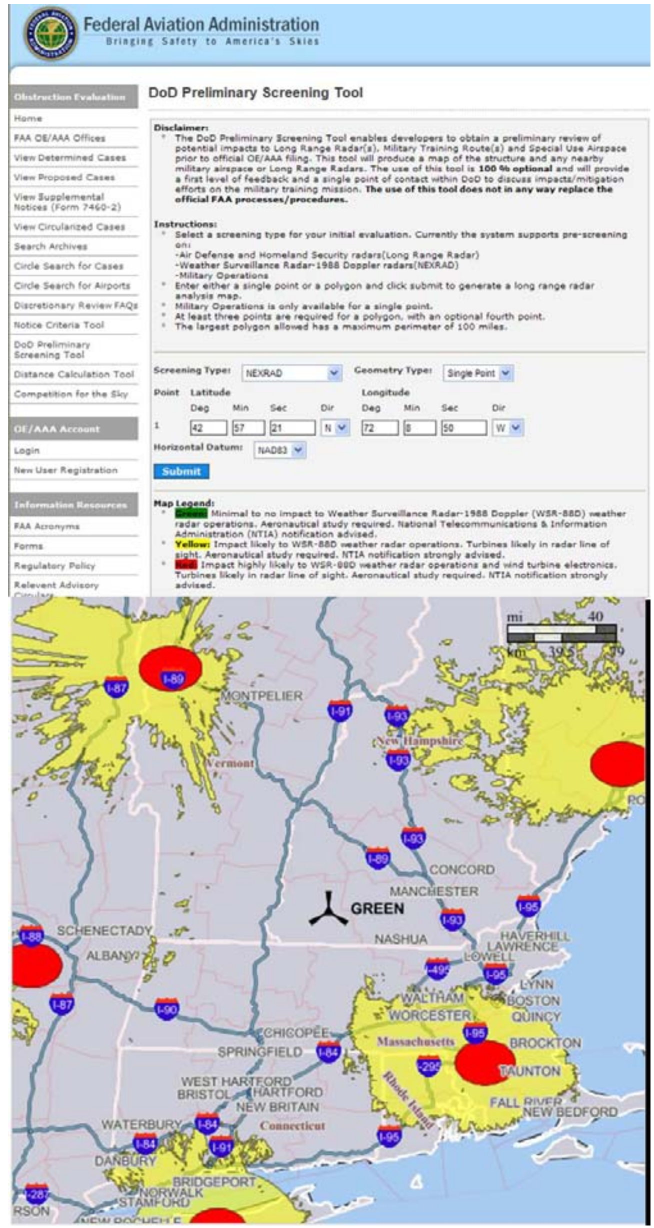

Fig 12. Example of NEXRAD Tool on FAA's OE/AAA web site.

8. LONG-TERM STRATEGIES:

Our current strategy is two-fold. First, to educate the wind energy industry and radar users on the potential impacts of wind farms on NEXRAD Doppler weather radars. Second, to reach out to individual developers as we learn about planned wind farm developments, evaluate potential impacts, and work with the developers to mitigate any significant impacts. This is a labor-intensive process that will only increase as more developers seek to place wind farms on land with the best wind resource, which is often near weather radars. A more effective approach will be needed to ensure this critical, national radar asset is not significantly degraded. In cooperation with the wind industry and other federal agencies, the ROC is exploring two possible areas: new national guidelines for the wind industry and new funding, federal and/or industry, to find technical solutions to the interference problem.

a. New National Guidelines**:**

New national guidelines might include one or more of the following:

(1) A Memorandum of Understanding (MOU) between the wind energy industry and federal agencies, similar to an existing British MOU, with agreement on:

a. No-build zones very near radars
b. Notification of federal agencies with Doppler radar assets
c. Consultation to mitigate impacts
d. Halting wind turbine blades during significant weather events

(2) A National "clearing house" for developers to submit wind farm proposals to all federal agencies with radar assets – DHS, DOD, FAA, and NOAA. This clearinghouse would work similar to the FAA's Obstruction Evaluation Office for determining obstructions in navigable airspace; refer to FAA Regulation Part 77

(3) Federal Statutory Authority

a. Mandatory developer notification of projects and government evaluation of potential wind farm impacts, similar to FAA Regulation Part 77,
b. Define no-build zones very near radars

b. New Funding:

New funding might be used to help develop radar-based and/or wind-turbine based solutions:

(1) Radar-based mitigation funding to:

a. Develop modeling software that produces estimated radar impacts
b. Develop signal processing technology that eliminates wind turbine clutter – a difficult technical challenge for which there may not be a solution
c. Build additional radars for an alternate view of impacted areas
d. Build taller radar towers to see over wind turbines
e. Move existing radars, where more favorable sites are available and wind turbine development is unlikely

(2) Wind turbine-based mitigation funding to develop radar-friendly "stealthy" wind turbine blades and towers.

9. SUMMARY

The rapidly increasing number of wind farms used to generate electricity is beginning to negatively impact weather surveillance radar data. At present, the operational impacts appear to be minor. However, experiences to date indicate the on-going near-exponential growth in the number of such installations is cause for concern, particularly where numerous large developments significantly encroach upon WSR-88Ds. NOAA's NWS is involved in studying the impacts of wind farms and mitigation opportunities to ensure the network of WSR-88Ds can continue to provide mission-critical support to essential forecast and warning operations for the nation.

10. RELATED URLs

American Wind Energy Association:
http://www.awea.org/

Department of Energy *20 % Wind Power by 2030, Increasing Wind Energy's Contribution to U.S. Electricity Supply*.
http://www1.eere.energy.gov/windandhydro/pdfs/41869.pdf

Federal Aviation Administration Obstruction Evaluation / Airport Airspace Analysis (OE/AAA):
https://www.oeaaa.faa.gov/oeaaa/external/portal.jsp

National Telecommunications and Information Administration (NTIA) Interdepartmental Radio Advisory Committee (IRAC):
http://www.ntia.doc.gov/osmhome/irac.html

Pew Center on Global Climate Change Renewable Portfolio Standards:
http://www.pewclimate.org/what_s_being_done/in_the_states/rps.cfm

Pickens Plan: http://www.pickensplan.com/act/

University of Oklahoma Atmospheric Radar Research Center: http://arrc.ou.edu/

WSR-88D Radar Operations Center Wind Farm Page:
http://www.roc.noaa.gov/windfarm/windfarm_index.asp

11. REFERENCES

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