HOW NEXRAD WEATHER RADAR DATA CAN BENEFIT THE WIND ENERGY INDUSTRY

Richard. J. Vogt* and Timothy D. Crum
NEXRAD Radar Operations Center, Norman, Oklahoma

Edward J. Ciardi and Ronald G. Guenther
SERCO, NEXRAD Radar Operations Center, Norman, Oklahoma

William H. Greenwood
Cooperative Institute for Mesoscale Meteorological Studies, University of Oklahoma
Norman, Oklahoma

1. INTRODUCTION

The Nation's federal weather radar operators (Departments of Commerce, Defense, and Transportation) and the wind energy industry share common goals of enhancing the Nation's economy and quality of life for its citizens. Data from the Nation's network of remote sensors (e.g., weather radars, wind profilers); in situ sensors (e.g., surface and upper air observations); and numerical weather prediction models are readily available to wind energy industry and their private sector weather service suppliers to support their weather-sensitive operations.

Federal weather radars include the Next Generation Weather Radar (NEXRAD (also known as Weather Surveillance Radar-1988, Doppler (WSR-88D)) and the Federal Aviation Administration's (FAA's) Terminal Doppler Weather Radar (TDWR). Federal weather radar data -- both real time and archived – are a rich source of information that can be used by the wind energy industry to improve efficiency of power generation and siting decisions. Real-time weather radar data can improve short-term (0 to ~2 hour) forecasts of wind energy production and resource protection decisions. Radar data are used to initialize numerical weather prediction models operated by the National Oceanic and Atmospheric Administration's National Weather Service (NOAA's NWS) and wind energy industry private sector wind forecasting services. Archived weather radar data can be useful for several wind energy industry needs (e.g., wind climatology studies, forensic cases, and bird/bat migration patterns).

This poster and paper discuss ways NEXRAD and TDWR can support the wind energy industry operators and private sector wind forecasting services. This paper also explains how to obtain radar data and products, in real time and via extensive archives, existing NEXRAD capabilities, and planned improvements.

2. FEDERAL RADAR NETWORK OVERVIEW

NEXRAD. To meet the Nation's need for detailed weather radar data, NEXRAD systems were installed at 159 operational locations across the contiguous United States (Fig. 1), Alaska, Hawaii, Puerto Rico, and select overseas sites. (Developers can obtain the location and elevation of one or more NEXRAD radars by sending a request to "wind.energy.matters@noaa.gov"). The radar is a high-power Doppler system designed to detect weather targets and storm-scale winds at long ranges. In addition, its receiver is sensitive enough to detect clear-air (without the presence of clouds or rain) boundaries such as temperature and humidity discontinuities. The NEXRAD radar transmits a pulsed ~10 cm wavelength signal, with a 1° beam spread at a peak power of 750 kW. (Vogt et al. 2009) Operationally, the radar automatically scans the atmosphere in pre-defined coverage patterns from 0.5° to 19.5° elevation above the horizon, then processes and distributes reflectivity, mean radial velocity, and spectrum width (a measure of the variability of radial velocities in the resolution volume) data. (FMH-11) From this data, computer algorithms generate a suite of meteorological and hydrological products and aids that forecasters utilize in preparing short-term forecasts, advisories, and warnings for significant weather events such as tornadoes, hail, wind shear, downbursts, flash floods, and other weather phenomena.

---

* Corresponding author address:
Richard J. Vogt, WSR-88D Radar Operations Center, 1200 Westheimer Drive, Norman, Oklahoma 73069; e-mail: Richard.J.Vogt@noaa.gov.
The views expressed are those of the authors and do not necessarily represent those of NOAA's National Weather Service.

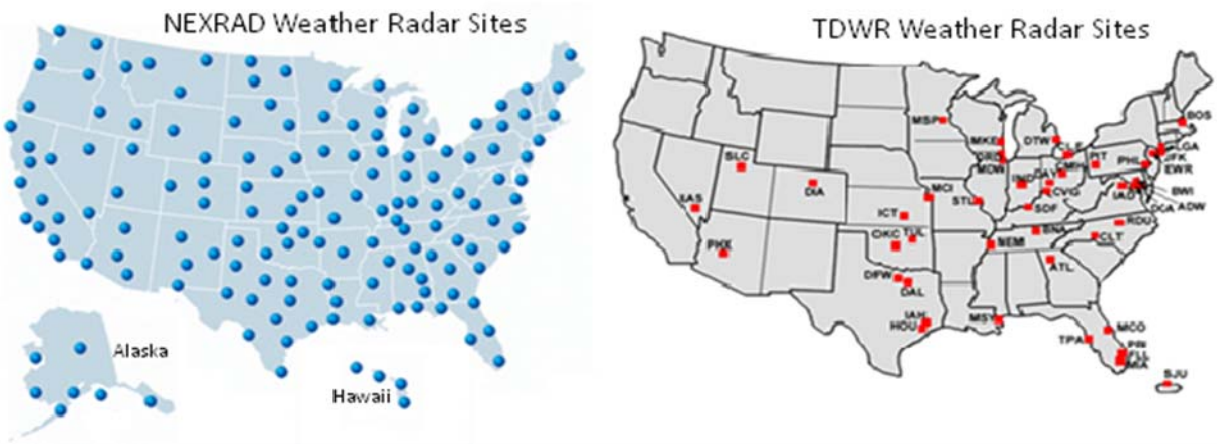


Fig. 1. Left image: Location of the 154 operational Next Generation Weather Radars (NEXRAD) systems in the U.S. Right image: Location of the 45 operational FAA Terminal Doppler Weather Radar systems (TDWR).

TDWR. The FAA's TDWR was designed at MIT's Lincoln Laboratory in the late 1980s and early 1990s, built by Raytheon, and deployed near 45 large U.S. airports with significant exposure to Low Altitude Wind Shear (Fig. 1). The radar's mission is to provide wind shear detection and precipitation reflectivity data to air traffic controllers, and its data are used in larger FAA systems that integrate weather data from other sources. The NWS now centrally collects, distributes, and archives TDWR products in real time.

NEXRAD Planned Improvements. The NEXRAD Program is preparing to install a dual polarization capability in all NEXRAD systems from late 2010 to late 2012. Dual polarization will provide more accurate radar-estimated precipitation accumulations; improved detection and delineation of liquid/frozen/melting precipitation (e.g., areas of snow, frozen rain, freezing rain, hail); higher quality data; and a hydrometeor classification algorithm that may better identify movements of large flocks of birds.

3. "SHORT – TERM" FORECASTS (0 TO ~ 2 HOURS)/RAMP EVENTS

The NEXRAD systems "see" changes in the atmosphere that may not be visible to the naked eye. As a remote sensor, the radar provides thousands of atmospheric measurements in real time and on a continuous basis. Weather radar data can support improved short-term forecasts, also termed "now casting," primarily though visual interpretation of radar product data. We provide examples of weather situations where we believe radar data can best support the wind energy industry.

a. Wind Shift Boundaries

The NEXRAD's highly sensitive receiver enables the system to detect the boundaries generated by differences in air mass types due to several different meteorological phenomena. Two examples are shown below (Figs. 2 and 3). The NEXRAD can produce "base products" of reflectivity and radial velocity from each scanning angle.

(1) Thunderstorm Outflows.

Thunderstorm outflows can cause a wind ramp event (a sudden increase or decrease in wind, which in turn increases or decreases power generation) and the wind energy industry needs to be able to predict their onset in order to balance power output going to the grid. The collapse of a mature thunderstorm pushes cool, dry air to the surface of the earth. When the air reaches the surface it spreads in all directions. Since the air is cooler and drier than the surrounding air, there is a discontinuity between the air masses that the NEXRAD can detect.

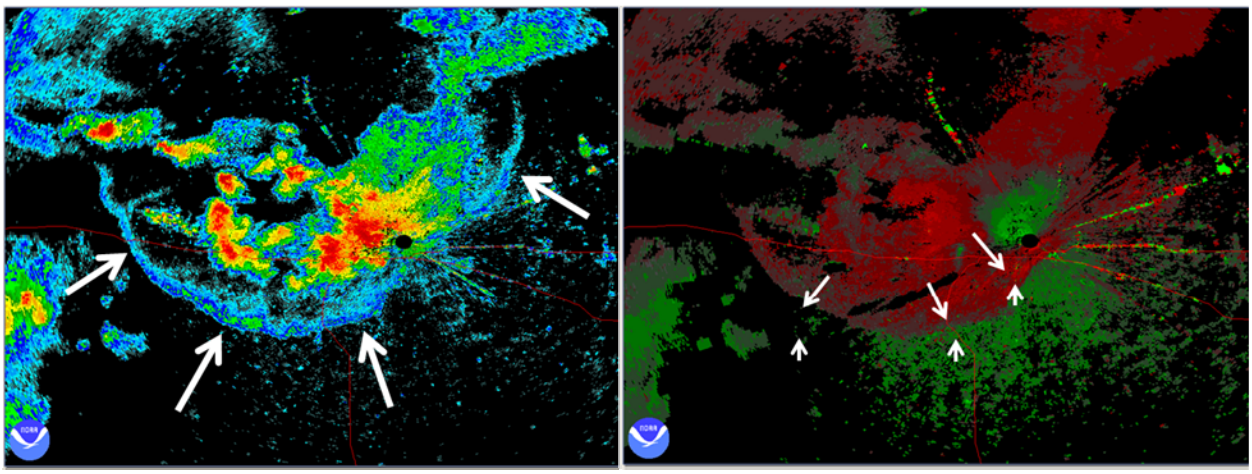


Fig. 2. Base products, 0.5° elevation, from the Amarillo, TX NEXRAD (10 Aug 2009, 2250 UTC). Left image: Base Reflectivity Product. Arrows point to the outflow boundary of cooler and drier air spreading from the thunderstorm. Right image: Mean Radial Velocity Product. Arrows annotate the direction of the surface wind (arrow length proportional to speed). Note the near 180° shift of wind direction along the outflow boundary and increased wind speed behind the advancing boundary (green colors represent wind flow toward the radar and red colors represent wind flow away from the radar).

(2) Dry Lines, Sea/Lake Breeze, or Frontal Boundaries.

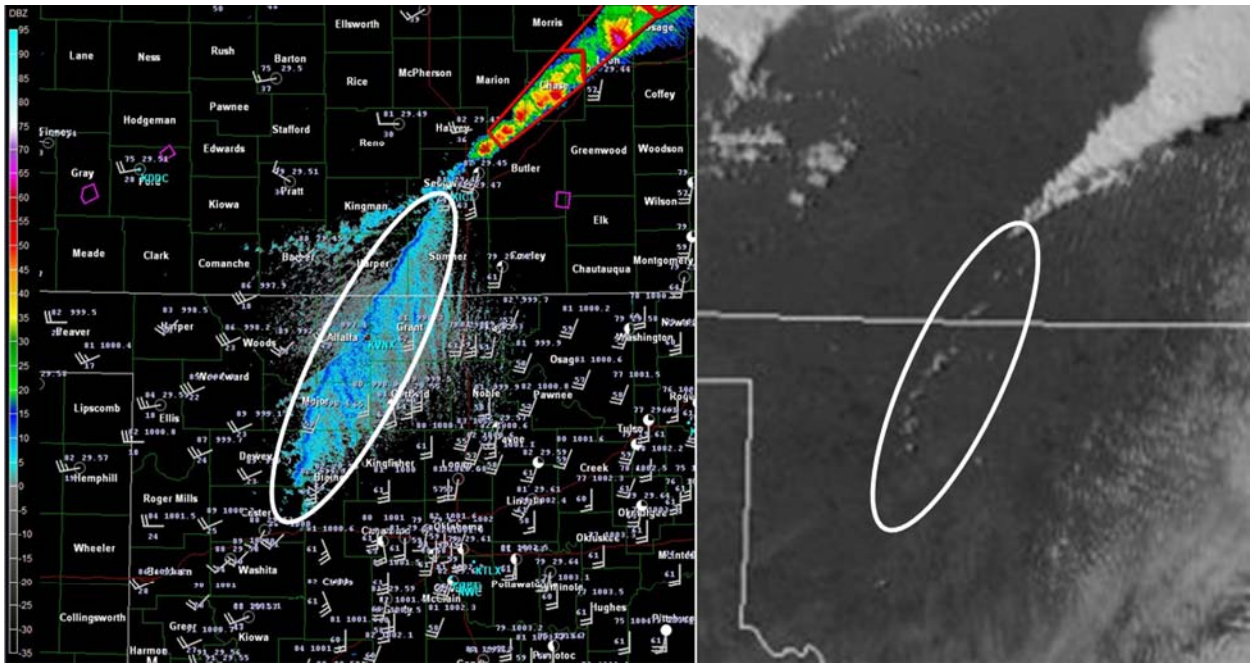


Fig. 3. Left image: Base Reflectivity Product, 0.5° elevation, from Vance AFB, OK NEXRAD (6 Apr 2010, 2040 UTC). The color codes for the reflectivity values are on the left side. The reports from automated surface observations are also plotted and depict a slight wind shift when crossing the boundary. Right image: GOES satellite photo of the Kansas – Oklahoma area at 6 April 2010, 2045 UTC. The circle annotations are in the same location and highlight the ability of the radar to depict boundaries in the atmosphere (dry line in this case) even though the satellite imagery does not.

Knowing where boundaries are occurring and the speed/direction of winds approaching a wind farm can provide advance information on the need to change operation of the turbines and forecast changes in power production. We encourage users to incorporate various sensors in their operations planning and forecasts.

b. Severe Weather

Severe thunderstorms can generate tornadoes and damaging hail. Their location and movement is important to the wind industry.

(1) Severe Thunderstorms or Tornadoes.

The NEXRAD generates several products to aid in the identification of tornadic activity and the motion of storms. Complex algorithms identify storm locations and generate "forecast" positions for up to one hour. The storm track product is generated with each volume scan and provides forecasted storm positions at 15 minute intervals (Fig. 4). Along with the graphical display, a table containing storm characteristics is created.

Knowing where tornadoes/severe storms may/did occur can provide advance information on the need to change operation of the turbines and forecast changes in power production. The path of a suspected/actual severe/tornadic thunderstorm can also help focus efforts to determine any damage to equipment.

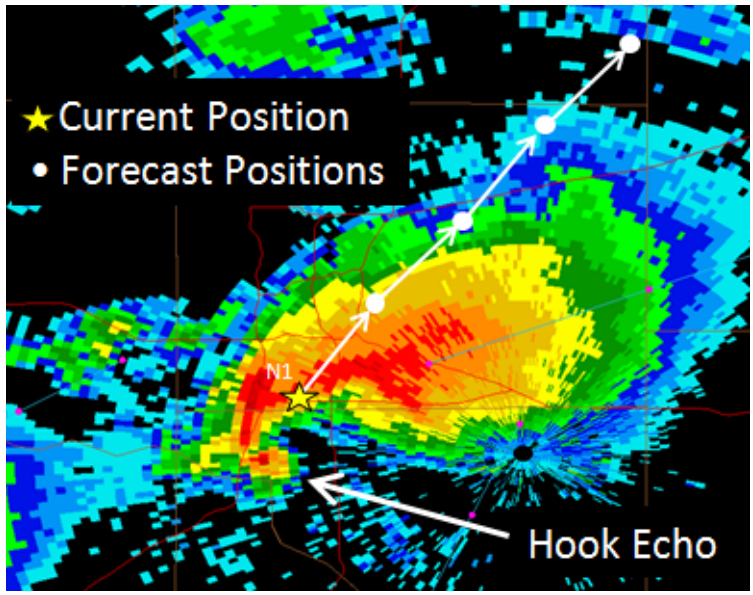


Fig. 4. Base Reflectivity Product, 0.5° elevation, from Norman, OK NEXRAD (3 May 1999, 0017 UTC) with the Storm Tack Information product overlaid. Forecast positions are in 15- minute intervals. This was a tornadic storm.

(2) Hail.

The NEXRAD has a complex algorithm used to predict hail probability and maximum size. Along with this algorithm, classic hail signatures, such as a hail spike, can aid in the determination of hail. A hail spike, usually accompanied by a high reflectivity hail core, occurs down radial from the storm when hail is large enough to create multipath scattering within the storm (Fig. 5).

Knowing where hail may occur can provide advance information on the need to change operation of the turbines and forecast changes in power production. The path of a suspected hail-producing thunderstorm can also help focus efforts to determine any damage to equipment.

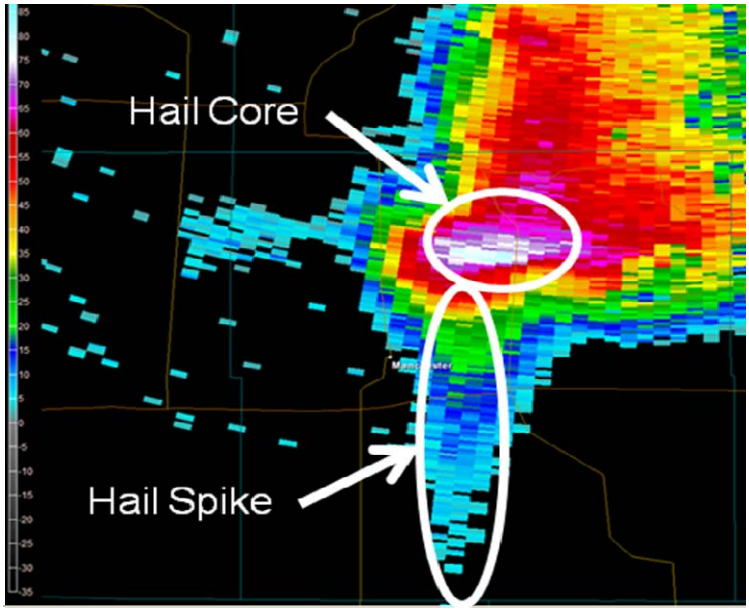


Fig. 5. Base reflectivity product, 0.5° elevation, from La Crosse, WI NEXRAD (24 Jul 2009, 1929 UTC). The color codes for the reflectivity values are on the left. Radar algorithms estimated hail stones as large as 3.75 inches in the hail core. Spotters observed 2.5 inch hail near this area.

c. Non-Severe Weather

(1) Liquid/Freezing/Frozen Precipitation.

Combined with other sensors, radars can help identify areas of snow or freezing precipitation. The NEXRAD upgrade to Dual Polarization will provide more information about the type of precipitation through a series of new products and algorithms. An example of a Dual Polarization NEXRAD product is in Fig. 6.

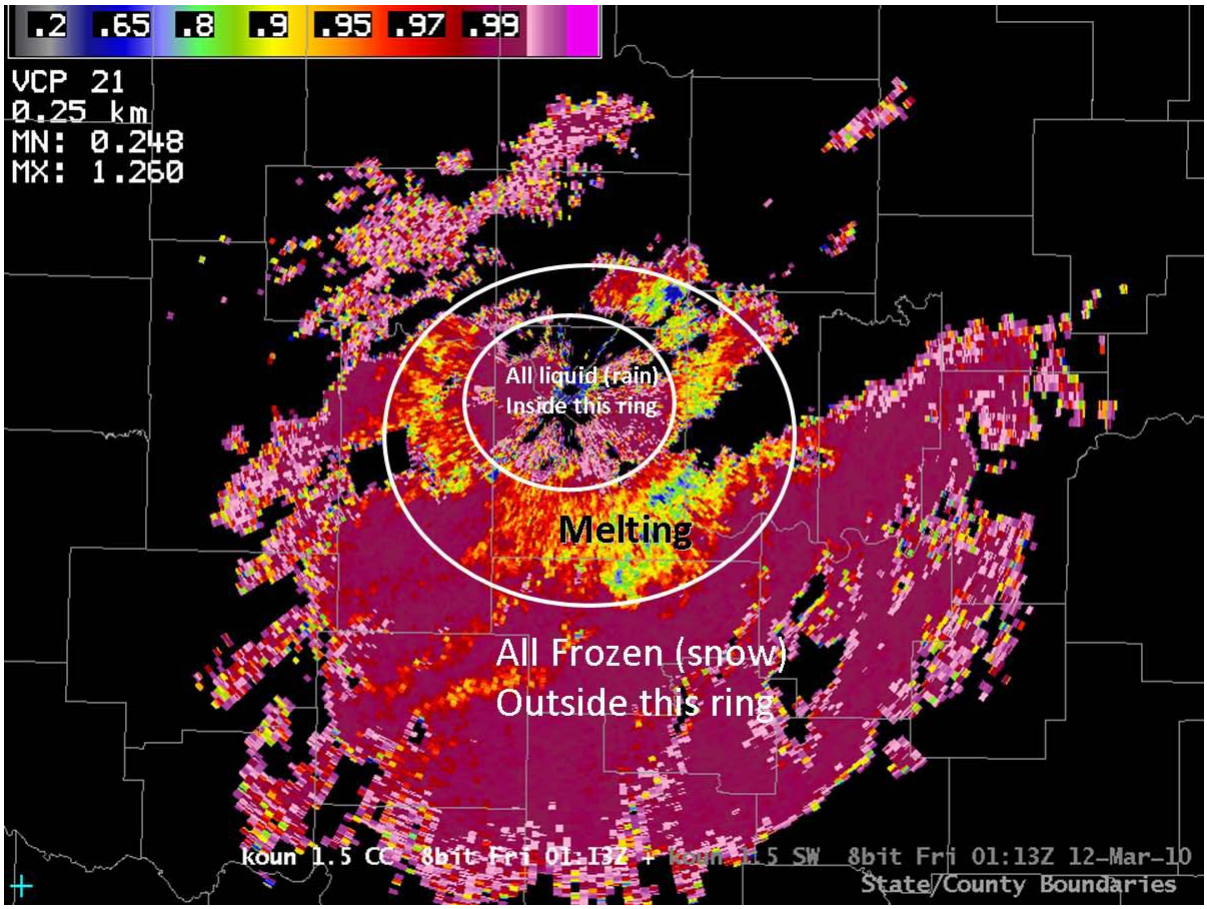


Fig. 6. Dual Polarization Hydrometeor Classification Algorithm product from the NEXRAD test radar in Norman, OK on 12 March 2010. The color codes for the Dual Polarization Cross Correlation values are in the upper left. The annotated areas can be used by forecasters to improve their forecasts, with respect to today's capability, of areas with liquid/freezing/frozen precipitation.

Knowing where freezing precipitation is occurring may assist wind farm operators decide whether operations can continue safely.

(2) Winds Aloft and Radial Velocities.

Using the system's Doppler capability, NEXRAD can provide products of the component of wind velocity coming toward/away from the radar at any scanning angle, as shown in Fig 2. The NEXRAD can also provide vertical profiles of wind speed and direction similar to those provided by wind profilers. An example of a NEXRAD Velocity Azimuth Display Wind Profile product is in Fig. 7.

Wind profiles are useful to forecasters monitoring weather events that may soon impact wind energy production. Also, these radar-derived wind profiles could augment other sources of winds aloft to initialize numerical weather prediction models.

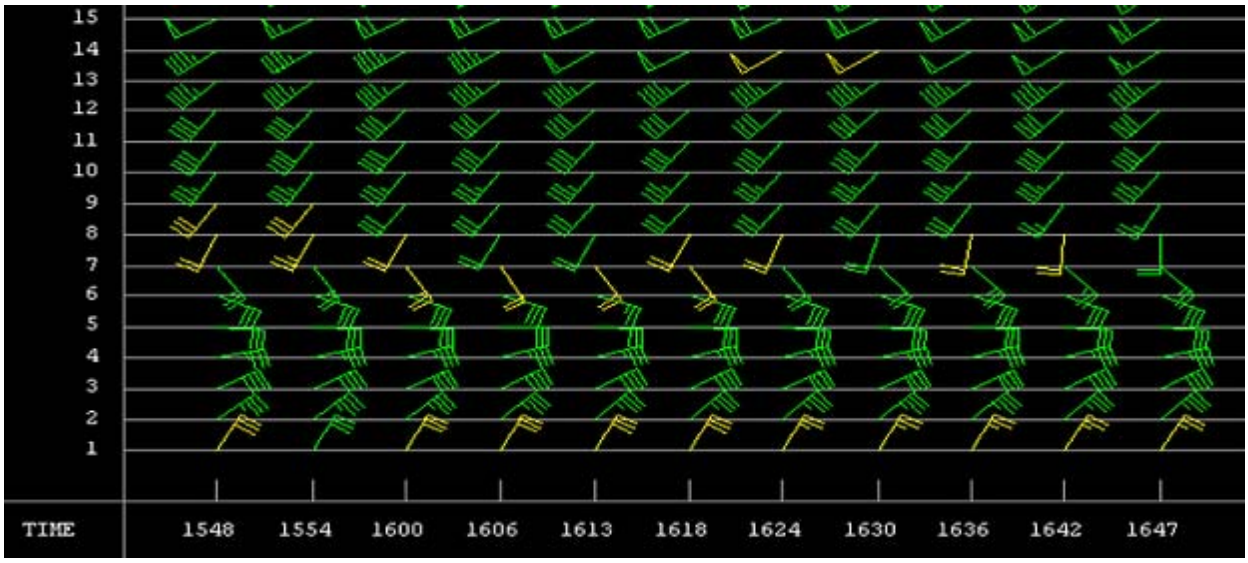


Fig. 7. This example of a Velocity Azimuth Display Wind Profile Product shows the radar-wind estimates displayed in the vertical for the last 11 radar volume scans. The altitudes on the vertical axis are in thousands of feet above Mean Sea Level.

d. Non-Weather Phenomena

(1) Birds/Bat Daily/Seasonal Migration.

The NEXRAD reflectivity products, especially when used in time-lapse mode, can be used to detect and track migratory or daily roosting movements of birds (Fig. 8).

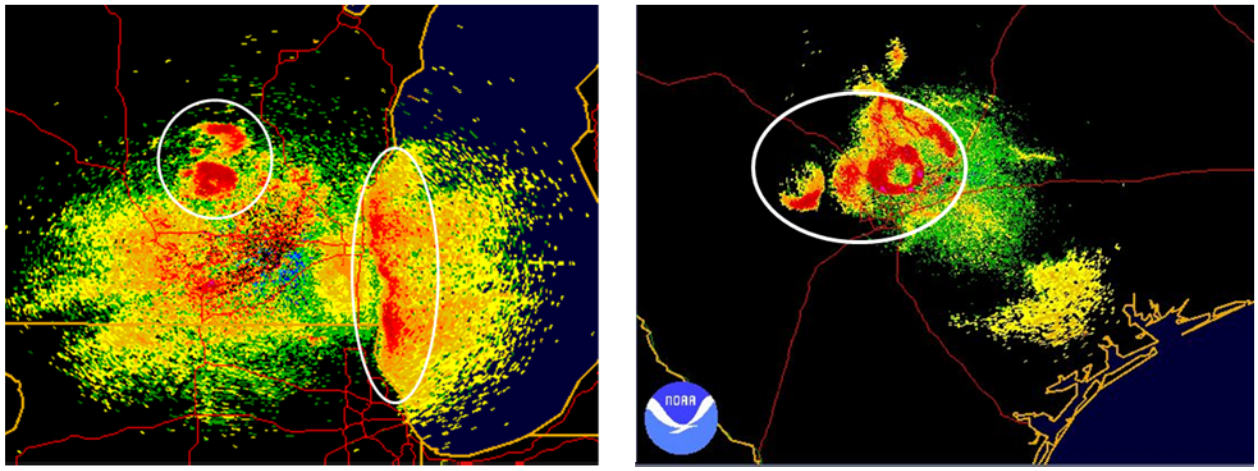


Fig. 8. Avian detection by the NEXRAD. Left image: Milwaukee, WI NEXRAD base reflectivity product indicating birds flying along the Lake Michigan shore and northeast of Madison, WI (both circled in white). Right image: Austin/San Antonio NEXRAD base reflectivity product indicating bats (circled in white) leaving roosts near Austin, TX.

One of the earliest contacts the NEXRAD Program had with the wind energy industry was from wind farm project siting consultants wanting information on the nearest NEXRAD to aid their bird migration studies. At least one private sector company uses real-time NEXRAD base/Level II data to provide bird migration/movement information to customers.

(2) Grass/Wild Fires

The NEXRAD's high sensitivity can enable the detection of smoke plumes (Fig. 9). This capability could help wind farm operators determine the location and movement of wild fires that could impact their wind turbines.

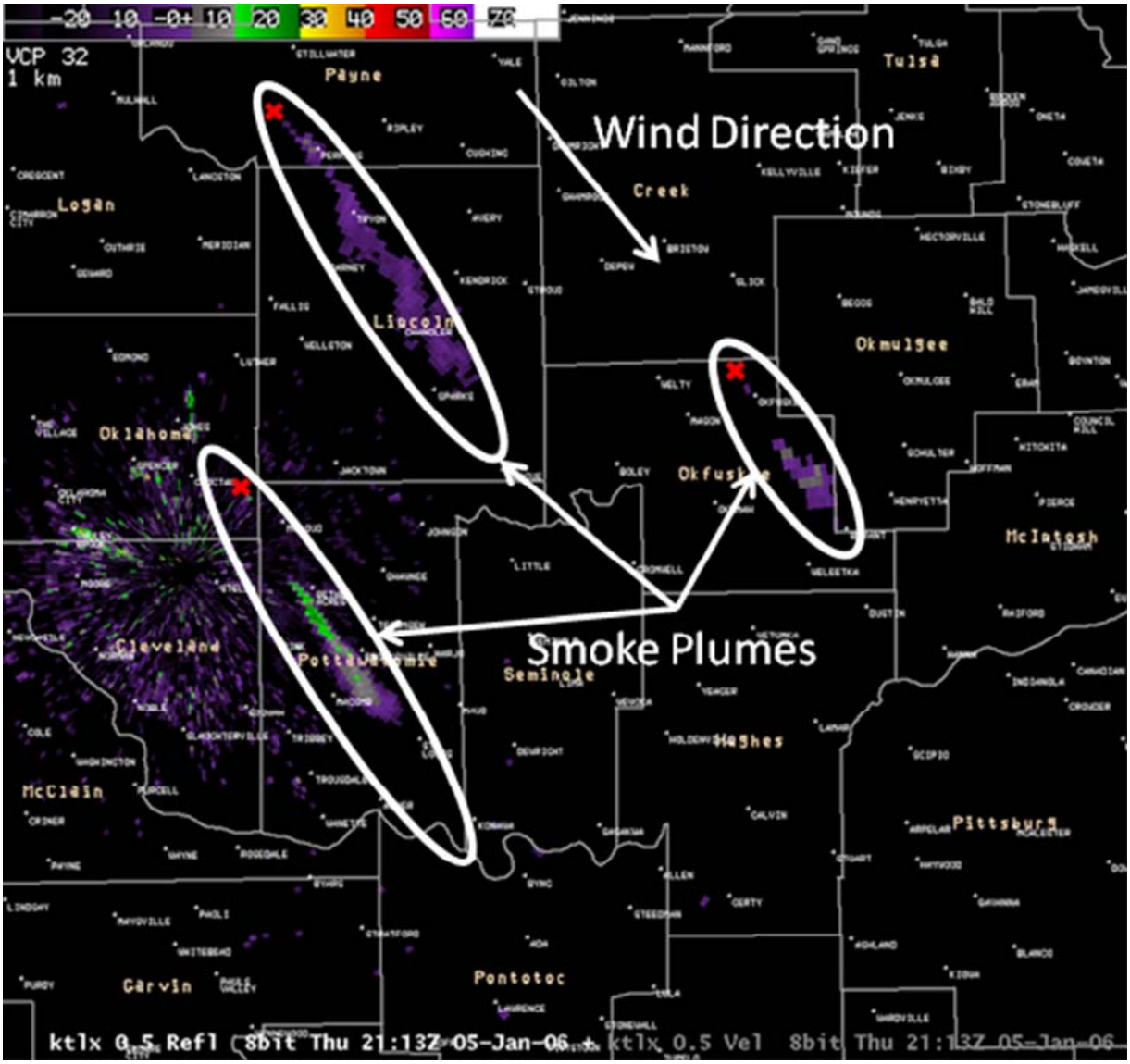


Fig. 9. Base Reflectivity Product, 0.5° elevation, from Oklahoma City, OK NEXRAD (5 Jan 2006, 2113 UTC). The color codes for the reflectivity values are in the upper left. The circled area shows where the NEXRAD is able to display smoke plumes from grass/wild/forest fires and their source (grass fires in this case indicated by the red X).

4. "LONGER-TERM"/DAY-AHEAD FORECATS

Radar data is often used in the generation of numerical weather prediction (forecast) models. Initializing numerical forecast models with radar reflectivity data can increase the accuracy of precipitation forecasts. NOAA's National Center for Environmental Prediction (NCEP) assimilates NEXRAD radar data into the Rapid Update Cycle (RUC) model to improve short-term forecasts. Researchers at NOAA are planning improved models that will make more use of weather radar data (Fig. 10). Other modelers may consider adding the radar data to their data assimilation process.

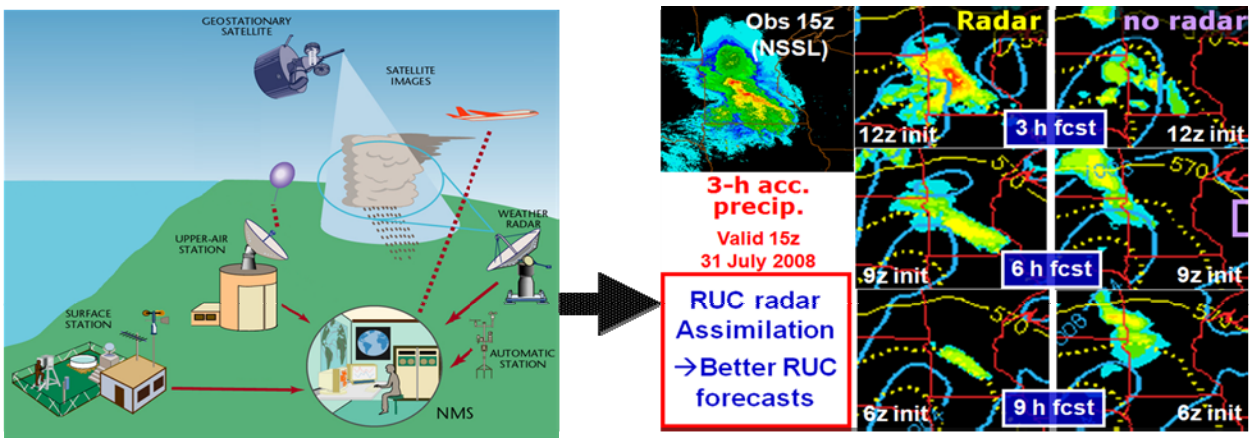


Fig. 10. Left image is a conceptual drawing of environmental data being collected and brought together in numerical weather prediction model data assimilation. Right image shows a comparison of RUC output with and without use of radar data. In this example, the locations of precipitation areas are more accurate when radar data is used. (Courtesy of Stan Benjamin, NOAA/ESRL/GSD/AMB)

Improved numerical weather prediction forecasts of wind, aided by increased use of weather radar data, will provide more accurate and reliable wind forecasts for the wind energy industry.

5. HOW TO OBTAIN WEATHER RADAR BASE DATA AND PRODUCTS

Two types of radar data are available; radar base data (Level II) and radar products (Level III). Level II data is the unprocessed stream of radial base data consisting of reflectivity, velocity, and spectrum width. You need radar product generation software to process this data and produce viewable products. Level III data consists of radar products. The NOAA/NWS has established an extensive real-time collection and distribution of WSR-88D Level II and Level III data, and TDWR Level III data. TDWR Level II data are not collected and archived at this time. The Level III products are collected from 155 of the 159 WSR-88D sites (not including 4 remote overseas DoD WSR-88Ds) and all 45 operational TDWRs. The WSR-88D Level II data are collected at ~140 sites, but this number continues to increase as resources become available. These data are also archived at NOAA's National Climatic Data Center (NCDC). Further information on the radar archives is available at Kelleher et al. 2007.

a. Real Time

Real-time radar data and products can be obtained from many sources.

(1) Products (Level III). The weather enterprise has many vendors that provide commercial customers with value-added products or products as produced by the NEXRADs in real time. The NWS provides several sources of real-time NEXRAD products: Family of Service subscriptions, a satellite broadcast network (NOAAPORT), and anonymous FTP (http://www.nws.noaa.gov/tg/rpccds.html).

(2) Base Data (Level II). These data contain the highest spatial and data resolution data the NEXRAD produces. The data rates are much higher than for products. As with products, there are many sources to obtain these data. The NWS transmits the data to three nodes (University of Oklahoma, Purdue University, and the Education and Research Consortium of the Western Carolinas). The points of contact at these nodes are at: http://www.roc.noaa.gov/WSR88D/Level_II/Level2Info.aspx. Many private sector vendors also redistribute the Base/Level II data.

b. Archived

The NCDC radar archives contain over 1.5 Petabytes of data. The inventory and data are accessible electronically. Most requests for archived data are at no cost to the requestor and can be downloaded from an FTP site within 24 hours. (http://www.ncdc.noaa.gov/oa/radar/radarresources.html#welcome)

The NCDC also provides software (the NOAA Weather and Climate Tool Kit) to view the Level II and Level III data. Many private vendors have developed software for displaying and creating value-added products.

The NWS provides software to read Level II data and emulate the generation of products at NEXRAD sites. The software, called the WSR-88D Common Operations and Development Environment (CODE), is open source and runs on LINUX platforms. (http://www.weather.gov/code88d/)

6. SUMMARY

Federal weather radars produce data and products that are readily available in real time to the wind energy industry. These real time data can assist industry efforts to improve their energy generation efficiency and resource protection. Archived weather radar data can also be a valuable tool to the wind siting process, and for forensic studies. With the planned installation of a NEXRAD dual polarization capability in 2011 and 2012, the radar data could be of even greater value to the wind energy industry.

7. RELATED URLs

Federal Meteorological Handbook No.11 (FMH-11): http://www.ofcm.gov/homepage/text/pubs.htm

NCDC Archive Data: http://www.ncdc.noaa.gov/oa/radar/radarresources.html#welcome

NWS Radar Product Central Server: http://www.nws.noaa.gov/tg/rpccds.html

WSR-88D Common Operations and Development Environment: http://www.weather.gov/code88d/

WSR-88D Radar Operations Center

- Home Page: http://www.roc.noaa.gov/WSR88D/
- Interface Control Documents: http://www.roc.noaa.gov/WSR88D/Program/ICDs.aspx
- Level II/Base Data Information: http://www.roc.noaa.gov/WSR88D/Level_II/Level2Info.aspx
- Level III/Product Information: http://www.roc.noaa.gov/WSR88D/Level_III/Level3Info.aspx
- TDWR Product Information: http://www.roc.noaa.gov/spg/

NOAA Earth System Research Laboratory: http://www.esrl.noaa.gov/research/themes/regional/

TDWR/Lincoln Laboratory: http://www.ll.mit.edu/mission/aviation/faawxsystems/tdwr.html

8. REFERENCES

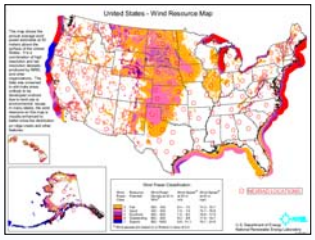
Kelleher, K.E. et al., 2007: Project CRAFT, A real-time delivery system for NEXRAD Level II data via the Internet. *Bull. Amer. Meteor. Soc.*, **88**, 1045-1057.

Vogt, R. J., T. D. Crum, J. B. Sandifer, E. J. Ciardi, and R. Guenther, 2009: A way forward wind farm - weather radar coexistence. Preprints, *WINDPOWER 2009, American Wind Energy Association Conference and Exhibition, Chicago, IL.*

HOW NEXRAD RADAR DATA CAN BENEFIT WIND INDUSTRY

NEXRAD (Next Generation Weather Radar)

- 159 radars operated by NWS, USAF, FAA throughout the US
- Doppler radar designed to detect weather targets and storm-scale winds
- 750 KW, S-band (~10 cm), ~1° conical ("pencil") beam
- Highly sensitive receiver capable of detecting "clear air" atmospheric boundaries such as dry lines.
- New digital signal processor and receiver

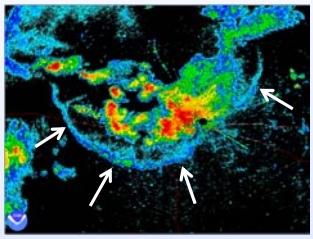


NEXRAD Can Help Increase Wind Farm Production

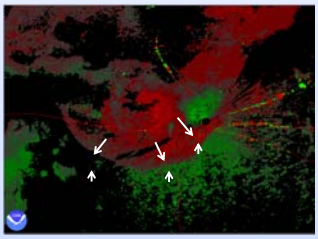
- Anticipate "Ramp" Events
  - Real-time radar data (0-2 hour forecasts)
- Day-Ahead Energy Production Forecasts
  - Radar data input for initialization of Numerical Weather Forecast Models
- Climatological and Bird Migration/Bat Studies
  - "Forensic" studies of past weather events that affect wind power operations/ efficiency; Bird/Bat studies

Ramp Events and 0-2 Hour Forecasts

Wind Shift Boundaries from Thunderstorm Outflow

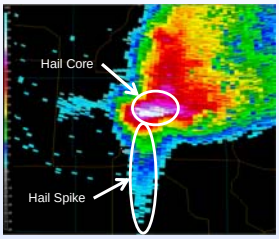


Amarillo, TX NEXRAD
0.5° Base Reflectivity
10 Aug 2009 at 2250 UTC



Amarillo, TX NEXRAD
0.5° Radial Velocity
10 Aug 2009 at 2250 UTC

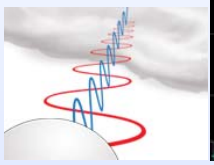
Severe Weather

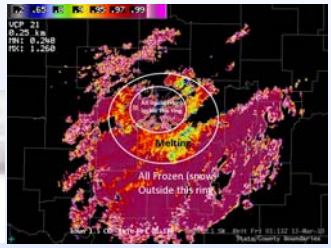


La Crosse, WI NEXRAD 0.5° Base Reflectivity on 24 Jul 2009 at 1929 UTC
- Radar estimated 3.75" hail with 2.50" reported

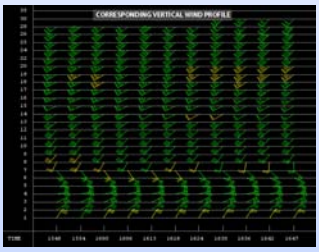
Detection of Freezing/Frozen Precipitation

- Dual Polarization
  - Enhanced detection of freezing precipitation
  - Data available in 2011





Winds Aloft

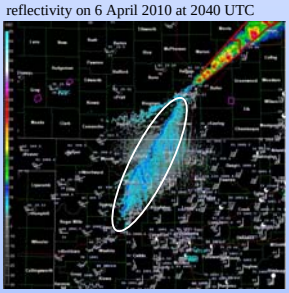


Example of a Vertical Wind Profile product produced by the NEXRAD Doppler radar

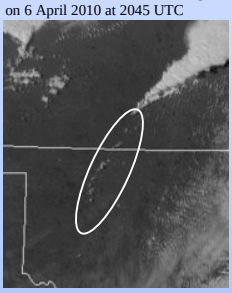
NEXRAD 30-meter Tower and Radome

Wind Shift from Dry Line Boundary

Vance AFB, OK NEXRAD 0.5° base reflectivity on 6 April 2010 at 2040 UTC

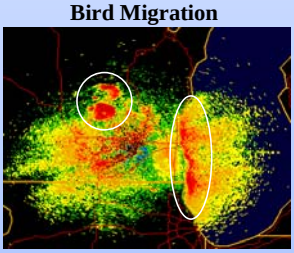


GOES-East visible satellite image on 6 April 2010 at 2045 UTC



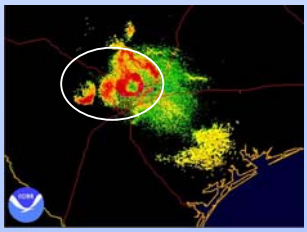
Dry line wind shift boundary (blue line) in Southern Kansas and Northwest Oklahoma clearly identifiable on radar, but barely visible on satellite

Bird Migration



Milwaukee, WI NEXRAD reflectivity image indicating birds flying along the Lake Michigan shore and northeast of Madison, WI

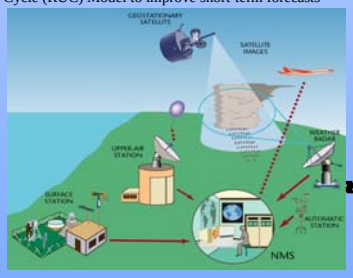
Bats

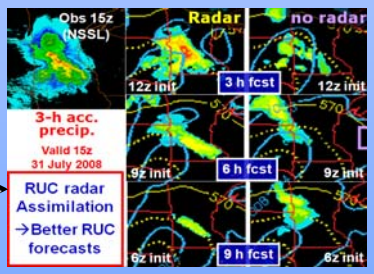


Austin/San Antonio NEXRAD reflectivity image indicating bats leaving the roosts near Austin, TX

3- to 12-Hour and Day-Ahead Forecasts

- Numerical weather model output can be used to make day-ahead energy production forecasts
- NOAA's National Center for Environmental Prediction (NCEP) assimilates NEXRAD radar data into the Rapid Update Cycle (RUC) Model to improve short-term forecasts





How to Obtain NEXRAD Radar Data

Real-Time Data

- The National Weather Service sends NEXRAD "base" (Level II) data (Reflectivity, Radial Velocity and Spectrum Width) to 4 distribution nodes. Private sector users can obtain Level II data from any of 3 nodes: Purdue University, Education and Research Consortium of the Western Carolinas, or the University of Oklahoma.
- For more information visit: **http://www.roc.noaa.gov/WSR88D/Level_II/Level2Info.aspx**
- Real-time radar products from 155 NEXRAD and 45 FAA Terminal Doppler Weather Radars are available at: **http://www.nws.noaa.gov/tg/rpccds.html**

Archive Data

- Radar (Level II) data and derived products are available at no cost through the National Climatic Data Center.
- For more information visit: **http://www.ncdc.noaa.gov/oa/radar/radarresources.html#welcome**

Summary – What Doppler Weather Radar Can Do For Wind Industry

- Real-time analysis of ramp and other events:
  - Severe weather (e.g. hail)
  - Wind shift boundaries
  - Freezing precipitation
  - Migratory birds and bats
- Next year, Dual Polarization capability will improve:
  - Detection of freezing/frozen precipitation and hail
  - Data quality

- Aids short-term forecasts for wind farm operators and commercial weather forecasters
- Helps the Wind Energy industry make better production decisions
- Important input to initializing weather forecast models
- Provides thousands of virtual data points of weather information

- Archived radar data is available to support forensic and climatology studies of:
  - significant weather events
  - wind assessments
  - bird and bat migration

Author address: Richard J. Vogt, NEXRAD Radar Operations Center, Norman, OK 73069; Phone:405-573-8803; e-mail: Richard.J.Vogt@noaa.gov; NEXRAD Web site: http://www.roc.noaa.gov/WSR88D/ ; Wind Project Evaluations: wind.energy.matters@noaa.gov