December 2010
Issue 20

Dual Polarization is Coming to NEXRAD!

Beginning in 2011, all WSR-88Ds will undergo a modification to implement dual polarization capability. This new technology allows the WSR-88D to simultaneously transmit and receive in the horizontal and vertical planes, providing an additional dimension of weather features and giving the weather forecaster additional and improved tools to serve the public.

Dual Polarization technology has been the subject ofresearch since the 1970's. However, it was not until the Joint Polarization Experiment (JPOLE) was conducted by the National Severe Storms Laboratory (NSSL) in 2002-2003 the technology was demonstrated to provide significant benefits to the forecaster. The operational benefits include improved rainfall estimation, discrimination of precipitation types, discrimination between hydrometeors and non-hydrometeors, and improvement in data quality.

Based on the results of JPOLE, the National Weather Service Office of Science and Technology entered into a contract with L3 Communications/Baron Services in September 2007 to develop and deploy this new functionality. The contractor had the requirement to implement dual polarization on the existing WSR-88D antenna and integrate new functionality into the Radar Data Acquisition subsystem. The Government retained responsibility to ingest new dual polarization data at the Radar Product Generator and make available base and derived dual polarization products to the forecaster/users.

Throughout the program there have been two main technical areas of focus:

Sensitivity – Because dual polarization requires splitting of the transmitted signal into horizontal and vertical components we expected slight reduction in radar sensitivity. Prior to contract award, NSSL studied the subject in a WFO setting and concluded the effect should not be operationally significant. In March of this year, we utilized data from the Dual Polarization prototype in a Subject Matter Expert review and reached the same conclusion. The Operational Assessment conducted in August with 20 field forecasters was consistent with these earlier findings.

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What's Inside?

Dual Polarization

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Calibration – It is critical that any bias between the horizontal and vertical channels be accurately determined. The contractor has implemented an automated calibration process to periodically check this differential reflectivity (Zdr) bias. The contractor and consulting government subject matter experts have also spent a great deal of time refining the calibration process which must be conducted by the on-site technician (e.g., when certain parts are replaced).

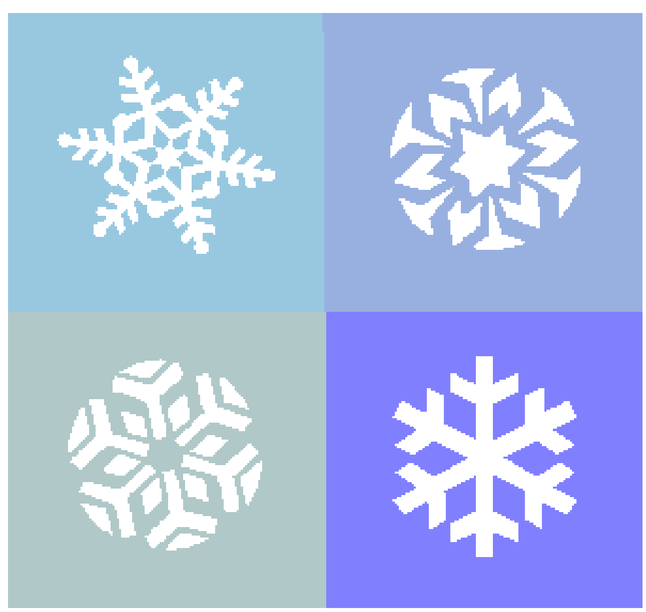
Maintenance and operations training are a big part of the Dual Polarization program. The contractor conducted a 'Train-the-Trainer' session with the NWS Training Center in support of dual polarization maintenance training curriculum development. The intent is to follow the Open RDA training model, with the NEXRAD Product Improvement program paying travel costs for two technicians at each site, and at least one technician trained prior to their site being modified. The deployment schedule will drive the training schedule, timing the training of the technicians in a time period not so early the training cannot be retained, and not so late there is inadequate time to assimilate the training.

Operations training takes on new criticality, given the addition of even more data available to the forecaster and the complexity of the dual polarized data itself. During the last two years, Warning Decision Training Branch staff have been developing distance-learning courses for forecasters, as well as outreach material for public and private users of radar data (e.g., emergency managers). These materials are available at http://www.wdtb.noaa.gov/.

Current plans call for beta test to start in Wichita, KS in January 2011, with production deployment to follow beta test completion. The installation requires the site be off-line for up to12 days, requiring careful planning to ensure contiguous sites are available to provide coverage and to avoid typical periods of adverse weather in the region. Production installation will begin slowly with initially only two teams in the field. We intend to ramp to five teams as deployment progresses. Deployment is scheduled to be completed in January 2013.

We look forward to bringing this important new technology to the WSR-88D for the benefits it will bring to the public. Please do not hesitate to contact our office with questions. Additional information on the project is available at the "Dual Polarization" section of the ROC web site: http://www.roc.noaa.gov/WSR88D/.

Greg Cate
NEXRAD Product Improvement



Improving the VWP

One of the most widely used products in the Weather Surveillance Radar – 1988, Doppler (WSR-88D) product suite is the Velocity Azimuth Display Wind Profile (VWP) product. The VWP product provides a time verses height wind profile for the volume above the radar location.

The VWP product uses the wind estimate derived by the Velocity Azimuth Display (VAD) algorithm for each desired VWP height. At the beginning of each volume scan, the VAD algorithm calculates the elevation/slant range pair for the active Volume Coverage Pattern (VCP) required to achieve the heights specified for the VWP product. The VAD algorithm uses a slant range parameter (default = 30 km) to guide the selection of the elevation angle for each required height. For any particular height, the elevation angle with slant range closest to the slant range parameter is used to compute the wind.

The VAD wind estimate for each height is based on the data from a single elevation/slant range pair. (For Clear Air Mode an average of three range bins is used.) This assumes that adequate return is available, using the single elevation/slant range pair to calculate a representative wind estimate for the particular height. However, in many meteorological situations, this is not a valid assumption.

The Enhanced Velocity Azimuth Display Wind Profile (EVWP) function is designed to improve the availability and accuracy of VWP wind estimates. The concept behind the EVWP function is the fact that each VWP height is achieved at different slant ranges, depending on theelevation. At the beginning of each volume scan, the EVWP function calculates every possible elevation/slant range pair for the active VCP that achieves a height specified for the VWP product (see Figure 1). As each elevation is scanned, the EVWP function passes these additional slant ranges to the VAD algorithm to process. The VAD algorithm computes a wind

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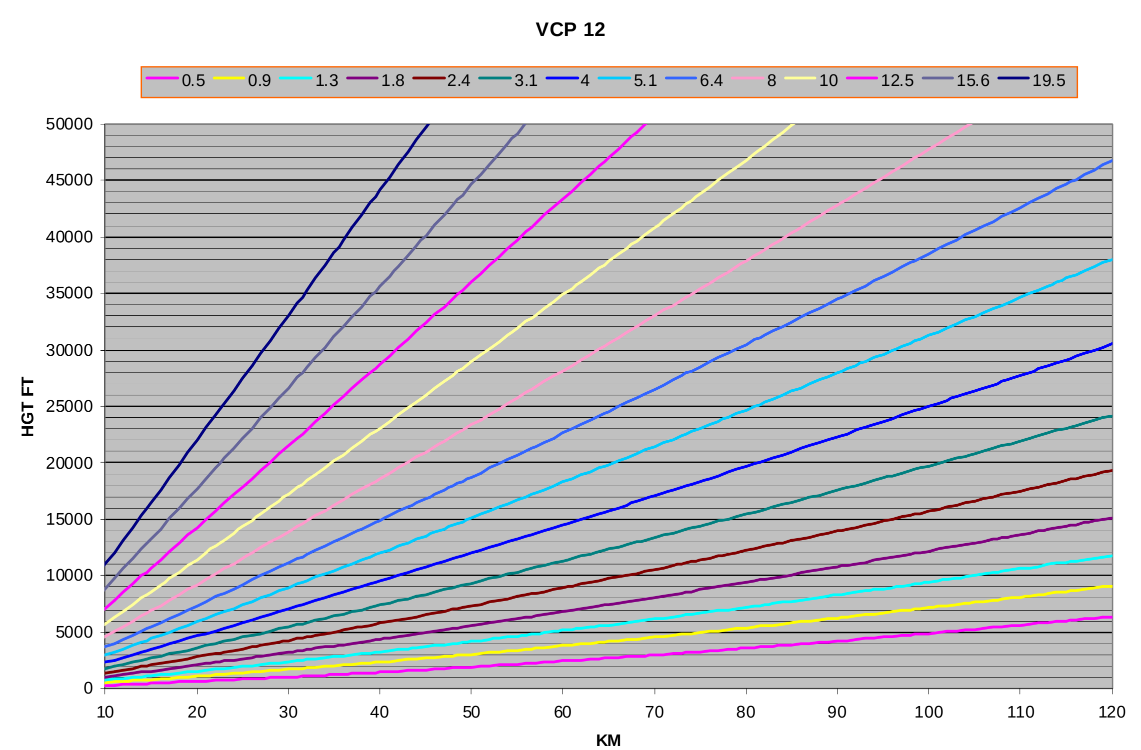

Figure 1: VCP 12 Elevations Plotted on Range/Height Grid

VWP

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estimate for each height (identified slant range) intersected by the elevation scan. Each wind estimate is passed to the EVWP function for validation. Using multiple elevation/slant range pairs for a given height increases the likelihood of sampling valid returns from which to derive a representative wind estimate for that height. At the end of the volume scan, the EVWP function selects the "best" VAD estimate for each height. These "best" wind estimates are used to build the final VWP product.

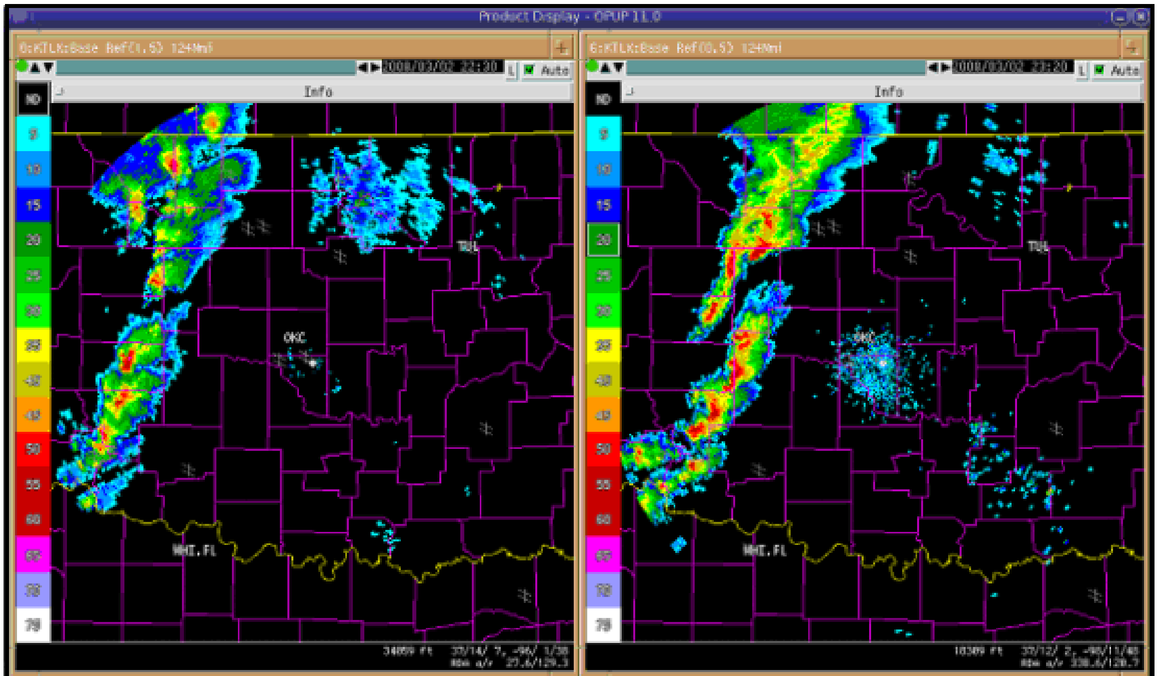

Figure 2: KTLX Reflectivity Products from 22:30Z and 23:20Z

To support meteorological testing, the EVWP function was installed on a Radar Operations Center (ROC) test bed Radar Product Generator (RPG) and the associated display code was installed on an Open System Principal User Processor (OPUP). These test bed assets are used to process Level II data collected from multiple operational

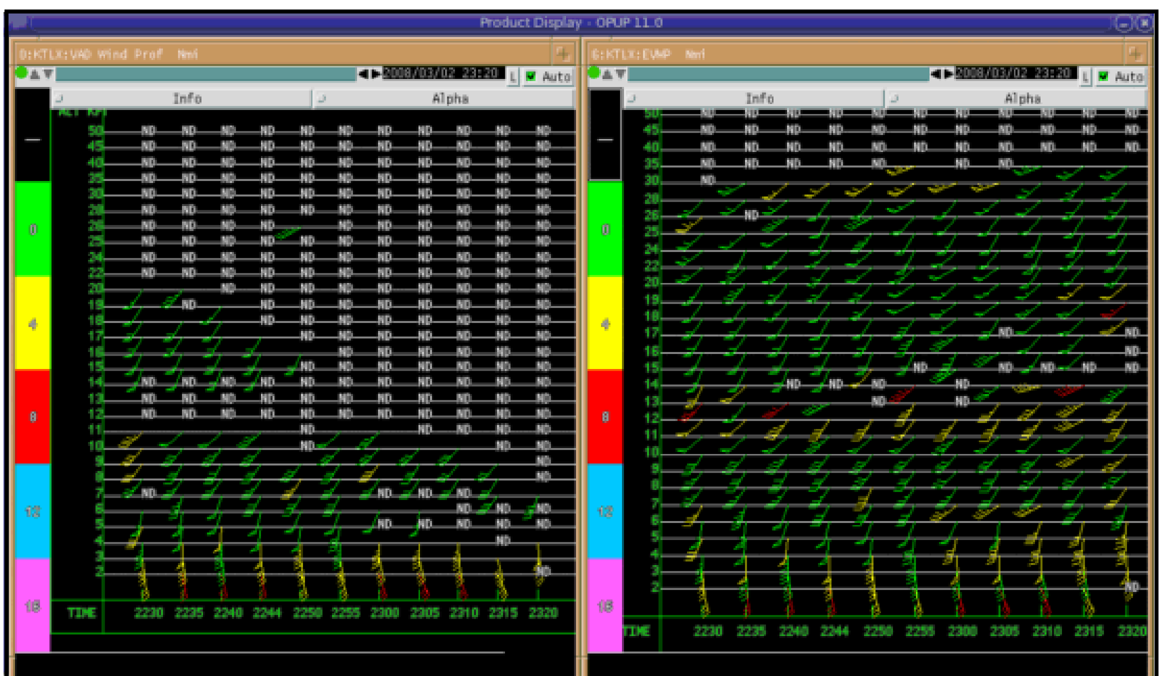

Figure 3: KTLX VWP and EVWP comparison

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VWP

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WSR-88Ds. To facilitate evaluation of any improvement provided by the EVWP function, the test code produces an "Original" VWP product and an "Enhanced" VWP (EVWP) product that incorporates the wind estimates selected by the EVWP function. The example (Figures 2, 3 and 4) is representative of the test results, to date.

line. The design of the EVWP function is to provide additional wind estimates to augment the wind data available for inclusion on the VWP product. This implementation will not change the basic format of the VWP product and, therefore, will not impact downstream processing and display systems.

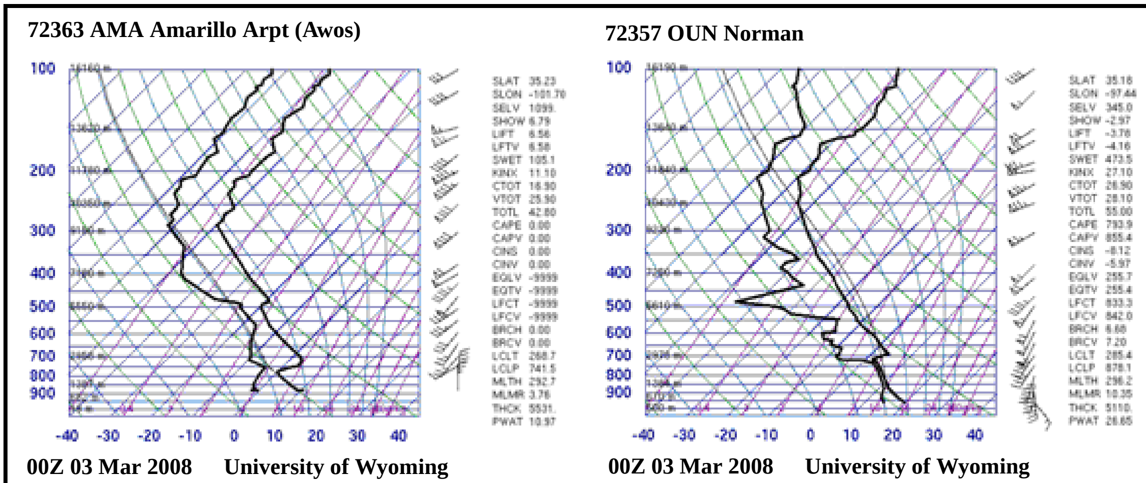

Figure 4: KAMA and KOUN Skew-Ts 00Z March 3, 2008

The EVWP function is still undergoing developmental testing. Results of testing, to date, indicate that the EVWP function consistently provides additional wind estimates not initially available from the legacy VAD/VWP algorithms. Additionally, the inclusion of these supplemental wind estimates in the VWP product can improve the overall operational usability of the VWP product. For more information, please refer to the Chrisman and Smith paper titled, Enhanced Velocity Azimuth Display Wind Profile (EVWP) Function for the WSR-88D, available at http://www.roc.noaa.gov/WSR88D/PublicationsROC.aspx.

The EVWP function is expected to be ready for inclusion into the WSR-88D RPG Build 13.0 base-

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ROC Engineering Branch

The New Architectured WSR-88D Level II Data Collection, Distribution, and Archive Network

The National Weather Service (NWS) collects Weather Surveillance Radars – 1988, Doppler (WSR-88D) Level II data at select sites via OPSnet. As the interest and use of Level II data has grown, the methods for data transport, immediacy and storage have evolved accordingly. The number of WSR-88D sites on the Level II network has grown to all of the 121 NWS WSR-88Ds, plus 13 DOD and 5 FAA sites (139 sites in all). An additional eight CONUS DOD sites are scheduled to be added to the Level II distribution network in 2011.

The NWS has a requirement to archive WSR-88D Level II data for post event analysis, algorithm development, etc. When data collection and archiving started network-wide in 1994, the data was recorded on 8mm tapes in the Radar Data Acquisition (RDA) shelter and physically shipped to the National Climatic Data Center (NCDC). The equipment in the RDA efficiently stored 10 tapes but was plagued with a relatively high failure rate. The recording approach also required a technician to go to the RDA shelter to retrieve the recorded tapes and send them to NCDC. Data latency (time between data collection and data archive at NCDC) was up to a month.

Over time, an operational requirement developed for the availability of real-time Level II radar data for assimilation into numerical forecast models at the National Center for Environmental Prediction (NCEP). Meeting this operational requirement required a new approach to Level II data collection. The concept of a real-time network transmission of Level II data was proved in a collaborative effort (Collaborative Radar Acquisition Field Test project - CRAFT) involving 59 WSR-88D sites. CRAFT included several NOAA Offices, the University of Oklahoma, the University of Washington, National Science Foundation, Unidata, and private industry. In April 2002 the NWS Corporate Board's Operations Committee approved using funds for the deployment of a network-based solution to collect WSR-88D Level II data in real-time.

The NWS Office of Science and Technology System Engineering Center, NWS Office of the Chief Information Officer, and Radar Operations Centers (ROC) collaborated to design the NWSNet / Internet 2 WSR-88D Level II Archive Data Network. The initial solution was to aggregate the data from each WSR-88D site to one of four associated regional headquarters. The regions would then transmit the data over Internet 2, making it available to users in a matter of seconds. The NWS Telecommunications Operations Center (TOC) was tasked to monitor, support and maintain the system when it became operational in 2004. Level II data flow was monitored via the MAX, a server located at the University of Maryland. Local Data Manager (LDM) developed by Unidata, was selected as the software application used to disseminate across the Level II network. LDM was chosen for its rich suite of software tools, reliability of data transmission, flexibility with how the data is handled, and ease of configuration.

Using 8mm tapes, data availability at NCDC ranged between 40-60%. The NWSnet regional-server Level II design boosted availability to over 95% with a latency of a few seconds. However,

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Level II

Continued from Page 6

the regional architecture exposed two significant issues. The first was staffing. The majority of the network IT equipment was only staffed during normal working hours. Secondly, the servers at the NWS regional headquarters were designed for high availability; however, the network connectivity from each region to their independent Internet 2 gateways was not. The combination of these two issues left the system prone to extended regional outages. These outages led to demands by the user community for higher data delivery reliability.

In 2009, the ROC was tasked with improving the Level II Archive Data network-based design. The regional server implementation was eliminated in favor of a nationalconcept. In addition to increasing data reliability, the refresh addressed the need of replacing IT equipment that had exceeded end-of-life support.

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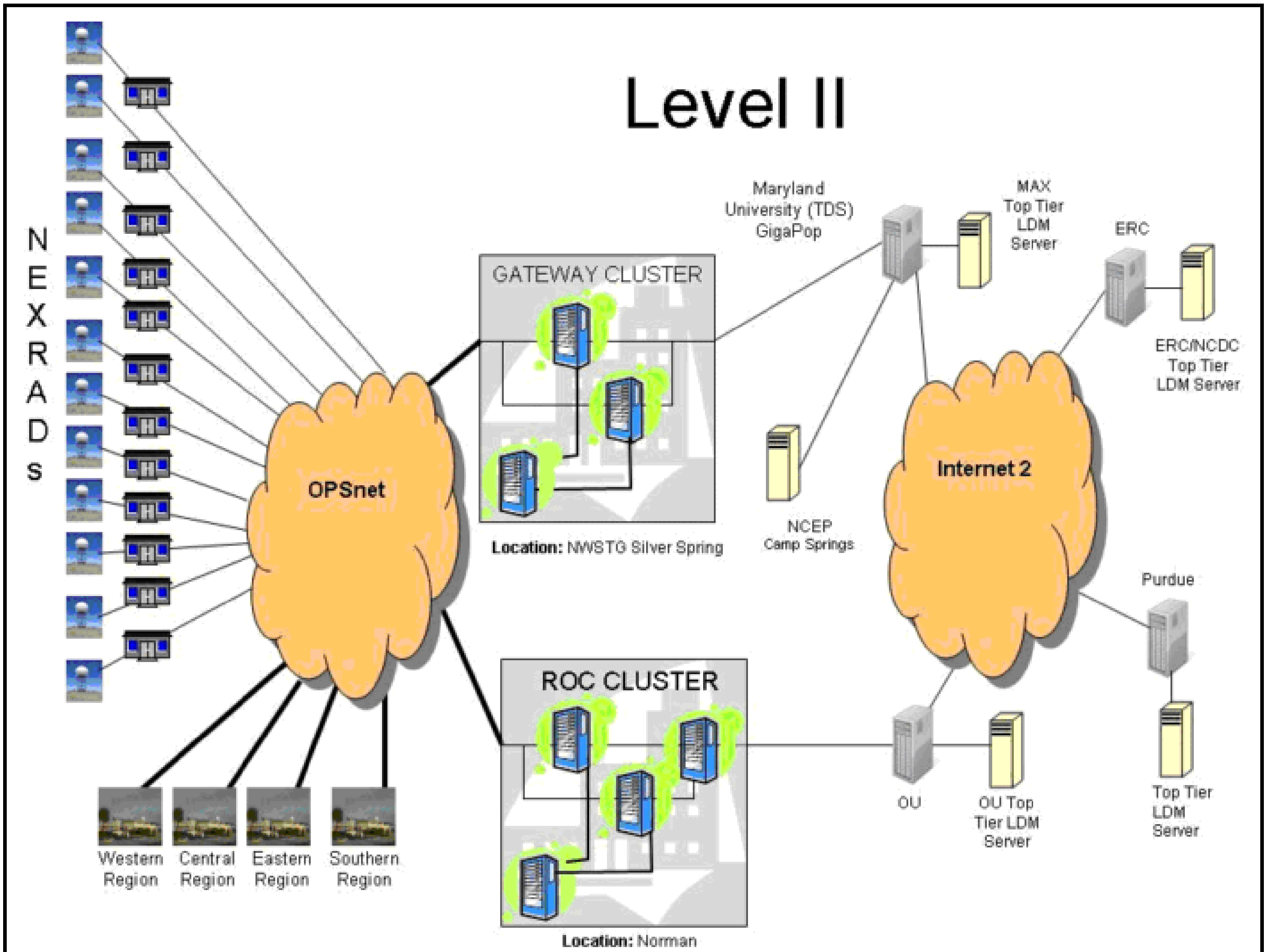

Figure 1: Level II Refresh Overview

Level II

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The new national system (Figure 1) continues to be monitored 24/7 by the TOC. The NWSnet (region frame relay) connection to Internet 2 has been migrated to NOAAnet, now OPSnet. To reduce the single point of failure concerns, an online backup facility has been established at the ROC in Norman, OK. The ROC houses a 24/7 support center for WSR-88D systems that provides backup monitoring of the Level II network. A second Internet 2 access gateway has been implemented at the University of Oklahoma. The new design ensures duplicate Level II data feeds onto Internet 2 from two geographically diverse locations.

Redundancy and Backup

Each facility (TOC and ROC) houses a cluster of servers that allow for seamless aggregation of data. The biggest constraint on the new design was the limited bandwidth from each WSR-88D site. This complicated the design by requiring only one stream of Level II data be transmitted per site. As it was not feasible to increase bandwidth at each site due to the cost, the new design relied upon each national server monitoring system status and automatically changing roles as needed.

The automatic changing of roles ensures only one national Level II server is allowed to communicate directly with WSR-88D sites at any given time. Any one of the four processors in the Level II system can support the aggregation role. A set of deterministic rules is used to determine the role of each server. The primary cluster is at the NWS TOC and the alternate cluster is at the ROC.

In "Normal" or default operation, the TOC receives (aggregates) the Level II data directly from the WSR-88D sites. If the primary server fails (or goes off-line for maintenance), the secondary server within the cluster is automatically promoted to primary server and takes over the aggregation role. If both servers in the TOC fail, or go off-line, the aggregator role will be automatically transferred to the primary server in the alternate cluster at the ROC in Norman. When a TOC server comes back on line, the system will automatically return aggregation to the TOC. Server roles can be manually assigned to a primary server at any time. An example of a server monitoring screen (at the TOC and ROC) is shown in Figure 2.

The new monitor page shows additional information. It shows the connectivity to the WSR-88D sites, between the Level II clusters, and to the Level II Top Tiers. The monitor gathers the Level II data and can provide historical information, as well (Level II and WSR-88D).

The Level II network hardware at the MAX was deployed in 2004 and is the last vestige of the original infrastructure, and is beyond the end of serviceable life. The ROC is planning to deploy a TOC Distribution Server (TDS) to disseminate the WSR-88D Level II data to the Top Tiers, in spring 2011. This would meet the Internet 2 gateway functional requirements the MAX serves today. The ROC is working with the additional clients of the MAX to determine what can be done to ensure they continue to have access to Level II data.

The new national Level II system is part of the WSR-88D baseline and is supported as part of the WSR-88D system. The ROC is responsible for hardware, software, security, testing, and configuration management for the system. As part of this

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Level II

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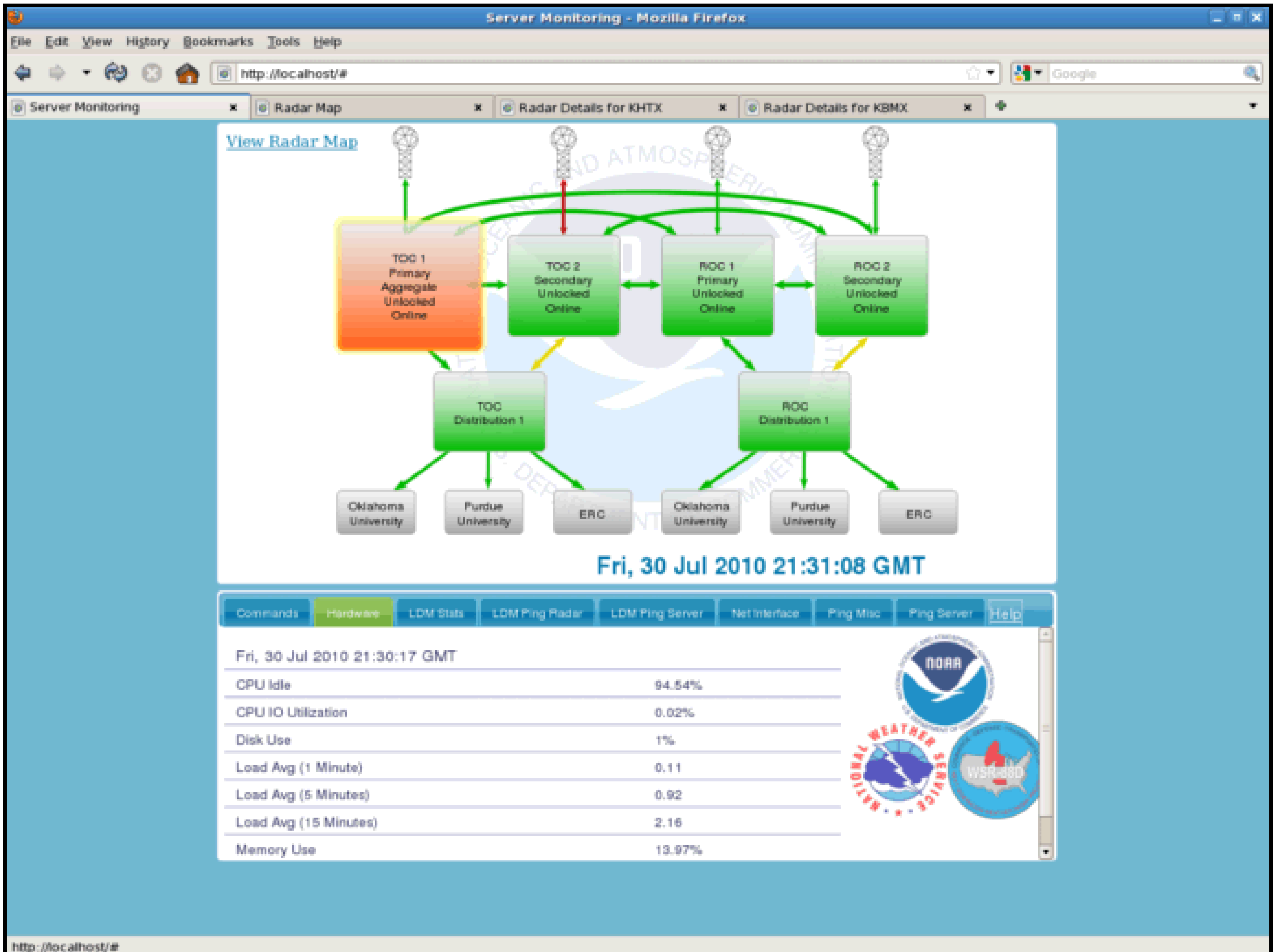

Figure 2: Level II Monitor (Server View)

effort, a new and comprehensive test facility was built at the ROC. The test facility allows developers and engineers to test the complete path of Level II data from collection at the WSR-88D to the final dissemination over Internet 2.

The Future

The ROC support for Level II is an ongoing effort. There are several approved projects which will further increase the capacity and stability of Level II data flow. The next major effort for the Level II system is to connect the Radar Product Generator (RPG), which transmits Level II from a WSR-88D directly to OPSnet. This will remove all regional and site specific connections to ensure no other active component is dynamically involved in the transmission of data to the Level II system.

Beginning in 2011, the WSR-88Ds will be upgraded to dual polarization technology. The dual polarization data will be added to the Level II

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ROC Stars

The WSR-88D program is staffed by dedicated professionals around the world. Here at the Radar Operations Center (ROC) we are proud of our employees, many of whom have been recognized for their outstanding work and commitment to excellence. These ROC employees have received recognition in the past several months:

- The Isaac M. Cline Award for Leadership was presented to Dan Berkowitz, Olen Boydstun, Joe Chrisman, and Dave Zittel.
- The Isaac M. Cline Award for Outreach was awarded to Lynn Allmon, Joe Chrisman, Tim Crum, Tony Ray, and Randy Steadham.
- The 2009 NOAA Bronze Medal Award was presented to Edward Berkowitz, Jeffrey Turner, and Keith Peabody.
- 2009 Oklahoma Federal Executive Board Employee of the Year nominees:
  - Capt. Chuck Parish - Tech, Professional, Admin. DOD GS-9 and above
  - David Zittel - Technical, Professional, Admin. Civilian GS-9 or above
  - Cheryl Stephenson - Supervisory-Civilian
- ROC Employee of the Quarter
  1st Quarter FY 2010 – Stan Grell, Operations Branch
  2nd Quarter FY 2010 – Darcy Saxion, Engineering Branch
  4th Quarter FY 2010 - Jim Schofield, Operations Branch
- ROC Team Member of the Quarter
  1st Quarter FY 2010 – Tanylle Casper, Operations Branch
  2nd Quarter FY 2010 – Ruth Jackson, Program Branch
  3rd Quarter FY 2010 – Michael Karbowski, Program Branch
  4th Quarter FY 2010 - Joe Manora, Program Branch

Nancy Beck
ROC Director's Office

Level II

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data stream and is expected to double the amount of data transmitted over the Level II network.

Operational support and monitoring of Level II data is performed by the NWSTG TOC, while the ROC performs hardware, software, lifecycle support, and back-up monitoring. Level II Distribution is supported from the University of Oklahoma, Purdue, and the Education and Research Consortium of the Western Carolinas, Inc. (ERC). It's interesting to note that what began as a collaborative effort continues to thrive as a collaborative effort.

Don Horvat
ROC Engineering Branch

Christina Horvat
ROC Engineering Branch

Chris Calvert
ROC Engineering Branch

Tim Crum
ROC Director's Office

Information "Tid Bits" for Improved WSR-88D Operations

Terminal Doppler Weather Radar (TDWR)/ Supplemental Product Generator (SPG) Data

Two major TDWR/SPG project milestones have been reached since the last issue of *NEXRAD Now.*

(1) TDWR/SPG Modification Note 1, "Retrofit of SPG to TDWR LAN Connection," was distributed and installed at sites with a TDWR/ SPG connection(s). The purpose of the modification was to reduce occurrences of SPG/TDWR LAN connection disruptions due to the FAA Hub to NWS TinyBridge LAN connection 'locking up.' This problem occurred due to the characteristics of the one-way transmit cable (hub to tiny-bridge) and possibly power fluctuations forcing device re-initialization, both of which interrupt broadcasting User Datagram Protocol (UDP) to the SPG located in the WFO. The LAN switch installed between the FAA hub and the NWS TinyBridge will minimize communication problems, and connecting SPG devices into an UPS or 'critical power' source will reduce effects of power fluctuations.

(2) TDWR/SPG program management responsibility was transferred from OS&T to the ROC. While this change is transparent to most field sites and operations, it is a landmark in the progress of providing TDWR data to forecasters and the Central Server/RPCCDS/ NOAAPORT.

There have been many instances of WFO and other users integrating the TDWR/SPG data to improve forecast and warning operations. The most recent success story related to TDWR data integration occurred during the late September tornado outbreak in the New York City area. Note the following input from the NWS Eastern Region Radar Focal Point:

> The Tornado Warnings issued by the Upton, NY WFO were completely based on the TDWRs. The WSR-88D did not indicate a tornadic threat (beam too high). The forecasters mainly used data from the TJFK TDWR. In addition, TDWRs were also likely very important for Tornado Warnings in Ohio.

The ROC recommends informally interacting with the local FAA TDWR maintenance staff to strengthen relationships and help FAA TDWR maintainers better understand how the WFO uses the TDWR/SPG products during life/property saving forecast and warning operations.

Information on the FMH-11, Part A, Update

The ROC is working with the NEXRAD tri-agencies and the Office of the Federal Coordinator for Meteorology to update the Federal Meteorological Handbook (FMH) Part A to the November 2010 Build 12.1 and Dual Polarization baseline. This update will provide a listing of new Dual Polarization products. A copy of the current Part A is available at: http://www.ofcm.gov/homepage/text/pubs.htm. The ROC is beginning work to update FMH-11 Parts C and D to the Dual Polarization baseline, but is not expected to be completed until at least late 2011. Unfortunately, the Part B update will be even later due to staff workloads.

How Long Can the WSR-88D Operate?

At times people see the "88" in the WSR-88D name and assume the system is frozen as of 1988

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Tid Bits

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technology. Oh, not true! The WSR-88D has undergone continuous modification/retrofit to avoid obsolescence, increase system reliability, control operations and maintenance costs, and meet new system requirements. In addition, original algorithms have been continuously upgraded or deleted, with new algorithms added to the system to ensure the WSR-88D is state of the art and the best radar in the world. We plan to continue this evolutionary process and expect the WSR-88D can be operationally and economically viable until at least 2020. The need for a decision around 2015 is anticipated to determine if the WSR-88D must remain in operation through 2030 or beyond. If so, the ROC expects to implement a Service Life Extension Program (SLEP) that will possibly include: Pedestal Refurbishment; Transmitter Refresh; and UPS Refresh. Please consider viewing a poster regarding this topic, presented by the ROC at the April 2010 NWS MIC/HIC meeting, located at (http://www.roc.noaa.gov/WSR88D/PublicDocs/MIC_HIC_2010_Poster.pdf).

Exclusion Zones…Part of the Enhanced Precipitation Preprocessing Algorithm (EPRE)

Some WSR-88D sites have areas where clutter filtering cannot completely remove non-meteorological returns. This residual undesired return is usually the result of:

- very high power from ground targets, such as mountain ranges; or
- moving ground-based targets, such as traffic on roads or returns from wind turbines (wind turbine clutter).

To address this problem, EPRE allows radar operators to define exclusion zones; however, some radar users misunderstand what exclusion zones do for precipitation estimation. The EPRE works on the fundamental premise that the lowest unblocked, uncontaminated sample bin will be used at any location for conversion of returned power (dBZ) to rainfall accumulation. Exclusion zones simply tell the EPRE not to use the area within the defined zone(s) for precipitation accumulation estimation, but instead use the next higher elevation angle. Exclusion zones are defined from azimuth to azimuth in the clockwise direction, range to range, and up to a maximum elevation angle. Figure 3 demonstrates one way of defining exclusion zones to address wind turbine clutter at a close range. Exclusion zones only prevent contamination of the rainfall products, and *do not affect* the base data. Up to 20 Exclusion Zones can be defined.

The example below (Figures 4 and 5) illustrates the application of an Exclusion Zone on the KCXX (State College, PA) WSR-88D to reduce anomalously large accumulations of Storm Total Precipitation due to wind turbine clutter (before and after site operators implemented the appropriate exclusion zone).

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zone	Begin Azimuth	End Azimuth	Begin Range	End Range	Max Angle
1	35.0	117.0	3	10	1.1
2	75.0	105.0	4	5	2.1
3	0.1	35.0	2	5	3.1

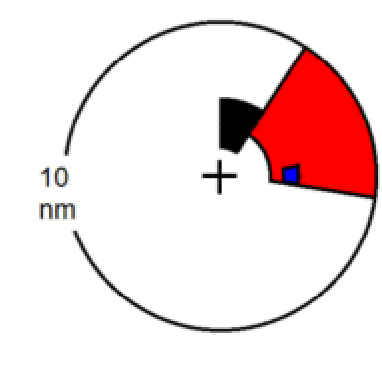

Figure 3: Exclusion Zones defined to address wind turbine clutter.

Tid Bits

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Operators having questions about adding an exclusion zone to the WSR-88D can, (1) review Section 7.6.5 of the *RPG Adaptable Parameter Handbook*, or (2) call the WSR-88D Hotline for assistance.

WSR-88D Data Collection, Distribution, and Archive Update

Many exciting events have taken place and are planned for the collection, distribution, and archiving of WSR-88D dual polarization data and products.

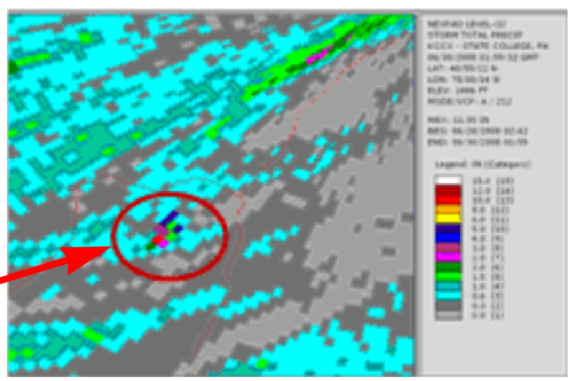
(1) The NWS has implemented a new architecture for the Level II network, as of mid 2010. Read the article "The New Architectured WSR-88D Level II Data Collection, Distribution, and Archive Network," which begins on Page 6 of this issue of *NEXRAD Now.*

(2) The NWS will add the remaining eight CONUS DoD WSR-88D sites to the real-time network beginning in early 2011.

(3) The NWS will add the three dual polarization moments to the Level II data stream from all CONUS sites as the dual polarization modification is installed, beginning in spring 2011. These data will be critical for optimizing WSR-88D Dual Polarization algorithms and forecast interpretation of the Dual Polarization data for improving forecasts.

(4) The NWS will add 40 products based on the three dual polarization technology to the Level III data stream as the dual polarization modification is installed, beginning in spring 2011. The list of dual polarization products the NWS plans to make available via NOAAPORT and the Central Product Server is located at http://www.roc.noaa.gov/WSR88D/DualPol/DPLevelIII.aspx.

Storm Total Precipitation - 6/30/2008

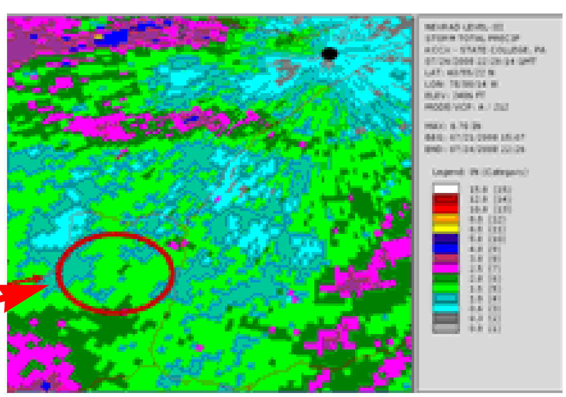


Wind farm contamination

• Without an Exclusion Zone over wind farm.

Figure 4: No Exclusion Zone defined.

Storm Total Precipitation - 7/24/2008



Wind farm contamination removed

• With an Exclusion Zone over wind farm.

Figure 5: Exclusion Zone applied.

Addition of a Doppler Weather Radar to Western Washington

The plan to add a Doppler weather radar along the western Washington coast is on track for an operational date of 30 September 2011. Since the last issue of *NEXRAD Now*, it has been confirmed that the key WSR-88D assets needed to build a WSR-88D

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Tid Bits

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(pedestal, transmitter, and RDA) have been transferred from the Keesler AFB, MS maintenance training facility to the NWS for this project. (Air Force technicians will now receive their WSR-88D maintenance training at the NWS Training Center.) This enables the installation date to be a year earlier than that of plans to buy a commercial S-Band Doppler and Dual Polarization radar to meet WSR-88D specifications/requirements. In addition to the earlier operation, the deployment of a baseline WSR-88D will enable the installation of future WSR-88D modifications and dual polarization technology to keep the radar at the state-of-the science, and part of the WSR-88D network/logistics/training baseline.

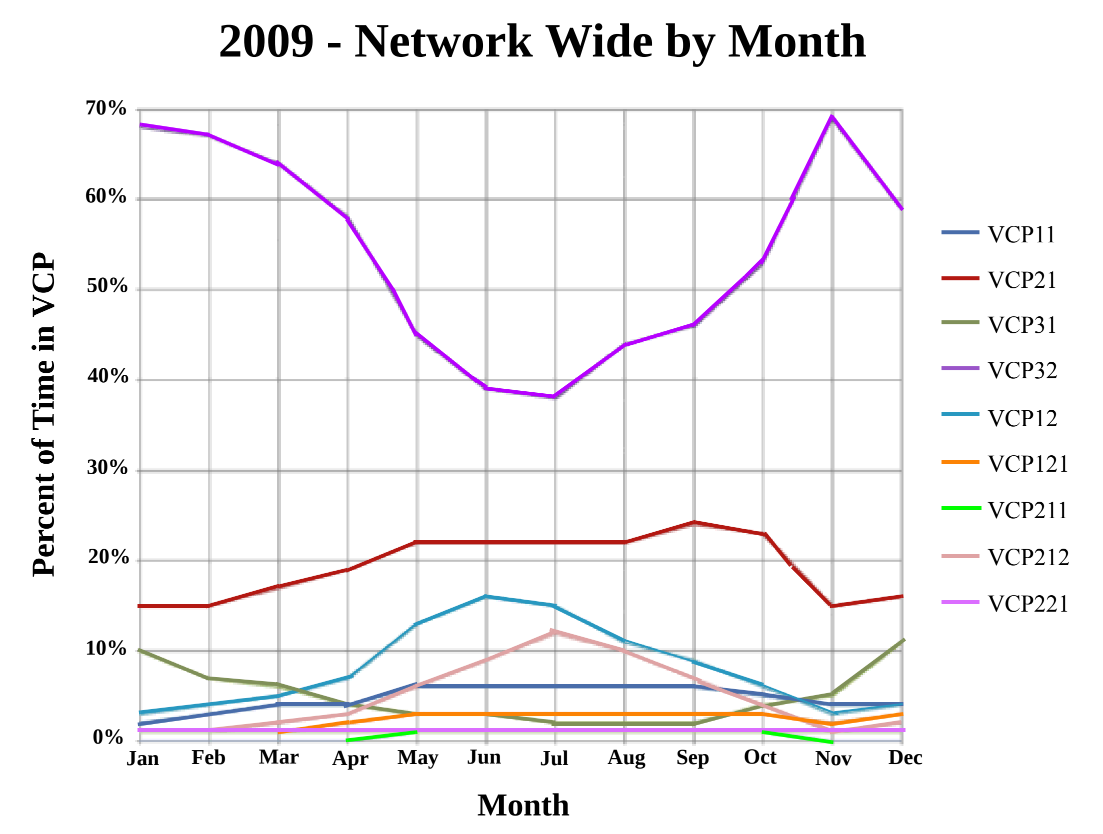

Figure 1: Monthly VCP usage

WSR-88D Volume Coverage Pattern (VCP) Usage

Ever wonder how often the various WSR-88D VCPs are used? We have provided graphs of monthly usage in 2009 (Figure 1) and the annual average usage for 2004-2009 (Figure 2). The ROC recommends adopting a faster VCP than VCP 21 as the default Precipitation Mode VCP, especially during the "warm" season. The faster updates and more scans at the lower elevation angles improve radar estimates of precipitation rates and accumulation.

Conducting Semi-Annual URC Meetings?

Please remember that Chapter 4 of the *Memorandum of Agreement among the Department of Commerce, Department of Defense, and Department of Transportation for Interagency Operation of the Weather Surveillance Radar-1988, Doppler* (http://www.roc.noaa.gov/WSR88D/) requires all WSR-88D sites with two or more NEXRAD agencies connected to have semi-annual Unit Radar Committee (URC) meetings. All but four WSR-88Ds should have an active URC, especially as we transition to the Dual Polarization

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Tid Bits

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technology. Sites should feel free to contact the WSR-88D Hotline with questions regarding starting/restarting their local WSR-88D URC. The Hotline will also be glad to participate in future URC telecons to answer questions or address system-wide topics on the agenda.

WSR-88D Related NWS Notices

With the many changes in products, the addition of Dual Polarization technology, addition of sites collecting Level II data, etc., the ROC has been teaming with NWS HQ to release several Technical Implementation Notices, Public Information Statements, and Service Change Notices. The archive of these notices can be found at http://www.weather.gov/os/notif.htm. Also, many of these notices are listed on the "News & Information" section of the ROC web site: http://www.roc.noaa.gov/WSR88D/.

Tim Crum
ROC Director's Office

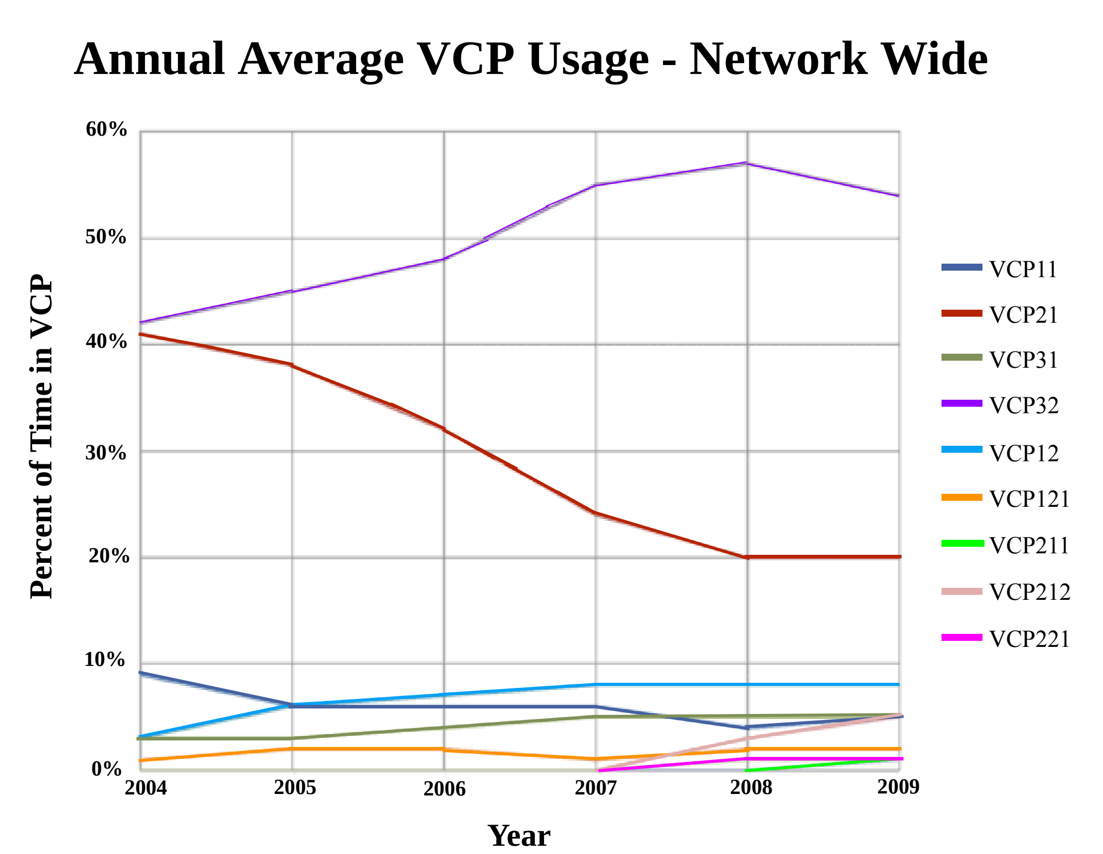

Figure 2: Annual VCP usage

What's Your Question?

There is quite a bit of interest in the upcoming Dual Polarization (Dual Pol) enhancement to the WSR-88D. Regarding this upgrade, the Engineering Branch of the Radar Operations Center received the following question, "A rumor floating around suggests the Dual Polarization upgrade, while providing additional polarmetric information, will cause a loss in radar sensitivity. I have two questions regarding this rumor. First, how much sensitivity loss can be expected with the upgrade? And second, will this loss in sensitivity impact the calibration of the strength of the reflectivity values we are used to seeing (e.g., storm cores, etc.,)?"

First, the quick answers, followed with a more detailed explanation. Yes, the Dual Pol hardware upgrade will result in about a 3.5 to 4.0 dB loss in sensitivity. No, the loss of sensitivity *will not* impact the radar's displayed reflectivity values (calibration) or magnitude of the reflectivity return. An easy way to think of it is reds stay red, but some gray may be gone.

Background: The WSR-88D radar was designed to detect precipitation. More explicitly, it was designed to detect falling liquid precipitation. As liquid precipitation falls it assumes the shape of an oblate spheroid. In other words, due to the surface area being distorted by wind resistance, falling liquid drops have a larger horizontal cross section than vertical cross section. To increase detection capabilities, single polarized weather radars, such as the current WSR-88D, employ horizontally polarized waves to exploit this difference in cross section extent. The three base moments (Z, V and SW) are calculated from the return from this horizontal wave form. With improved weather radar signal processing capabilities, the benefits of comparing returns from horizontal and vertical waveforms to infer drop shape has become feasible. The Dual Pol upgrade will enable the WSR-88D to transmit and receive in both the horizontal and vertical planes. Dual Pol variables are then calculated using both horizontal and vertical returns.

Sensitivity: Sensitivity is the minimum signal that a radar can detect at a given range. The two most important variables impacting sensitivity are transmitted power and system noise. The Dual Pol upgrade changes the WSR-88D from the single horizontally polarized transmit path to dual simultaneously transmitted horizontal and vertical polarization transmit paths. To accomplish this, the transmitted power is split between the horizontal and vertical transmit channels. Remember that a reduction (or increase) in power by ½ equals 3dB. Simply splitting the transmit power to accommodate the vertical channel results in 3dB less power available for the horizontal transmit channel. The Dual Pol hardware will cause an additional loss of about 0.5 – 1.0dB. Therefore, the expected loss of sensitivity in the horizontal channel due to the Dual Pol upgrade is 3.5 – 4.0dB.

As in the past, the Base Moments are calculated using only the horizontal return.

The reduced sensitivity will result in fewer of the lowest quantization reflectivity (gray) bins being displayed. The significance of the sensitivity loss is dependent on the type of return sampled by the radar, because the weaker returns are the most affected. The weather event that has the weakest precipitation return, and therefore may experience the greatest potential impact, is freezing drizzle.

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GIS Methods for Evaluating Wind Turbine Impacts on NEXRAD

The Radar Operations Center (ROC) has had an outreach program to constructively engage the wind energy development community since 2006. One component of the program is the evaluation of the potential impact of proposed wind farms and wind turbines on neighboring WSR-88D installations. With only minimal information available at the time the evaluations are performed, ROC engineering and operations personnel found that a technique using radar line of sight (RLOS) penetration, the extent of that penetration, and the areal relationship of the wind turbines/farms to the radars provided the foundation for an impact assessment.

Building upon prior software and GIS (geographical information system) developments, the ROC created several GIS-enabled databases to model the interactions of wind farms and wind turbines with the WSR-88D network. A natural outcome of the evaluations was the creation of historical databases of wind farm and wind turbine GIS data that could be used by the ROC Hotline for field support. For a more complete description of the data and processing visit http://www.roc.noaa.gov/WSR88D/WindFarm/GIS.aspx?wid=dev.

Ron Guenther
ROC Engineering Branch

Question?

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Calibration: Calibration is the ability of the radar system to scale the returned power to a magnitude consistent with the standard derived from a known trusted source. The calibration procedure measures the path losses and system gains caused by the various radar hardware components. These gains and losses are included in the weather radar equation used to calculate the reflectivity magnitude related to the returned power. Given the same weather within the sample volume, every calibrated radar should produce the same magnitude (value) for reflectivity. Although the Dual Pol upgrade will change the calibration procedures, the resultant calibration should produce consistent reflectivity values. Thus, red on the radar display is still red!

Summary: While it is true that the Dual Pol upgrade will result in a reduction in sensitivity of about 3.5 – 4.0dB, it will not impact the accuracy of the radar's reflectivity. In other words, red is still red, but some gray may be gone.

Joe N Chrisman
ROC Engineering Branch

Wind Farms and the WSR-88D -- An Update

Wind Energy Industry Update

It's time for an update on the wind energy industry, on some changes in the ROC evaluation of radar impacts, and on the ROC efforts to raise the visibility of the potential impacts of wind farms on Doppler weather radars. Although 2010 was a down year for the wind industry overall (Figure 1), the ROC continues to receive and evaluate a steady stream of proposed wind farm notifications. As soon as the economy revives, wind farm installations will likely resume at a rapid pace, spurred by federal tax incentives and states' renewable energy mandates. Only ~3% of the Nation's current total electric supply is from wind power, and the federal goal is to reach 20% from wind power by 2030 (See July 2008 DOE Report: 20 % Wind Power by 2030, Increasing Wind Energy's Contribution to U.S. Electricity Supply). Thus, most of the wind farm construction is yet to occur.

The distribution of wind farms is not uniform across the country (Figure 2). The Great Plains states from Texas to North Dakota, and to a lesser extent the Great Lakes area, have vast wind resources and plenty of available land on which to build wind farms. The number of wind farms developed near WSR-88Ds is likely to increase, especially in those two geographic areas. Therefore, it is no surprise that states like Texas, Iowa, Illinois, Colorado and Minnesota are among the top ten states with installed wind energy capacity.

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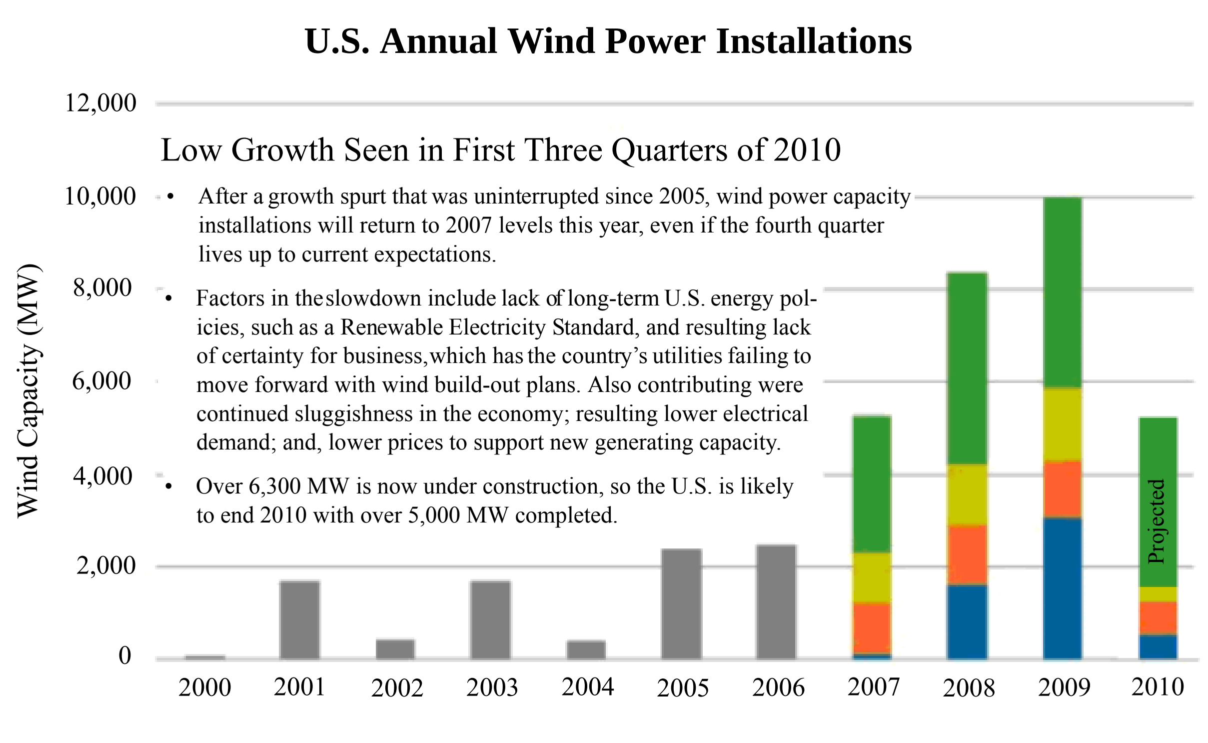

Figure 1: A slow year so far for wind turbine installations (Source: American Wind Energy Association (SWEA) 3rd Quarter 2010 Market Report).

Wind Farms

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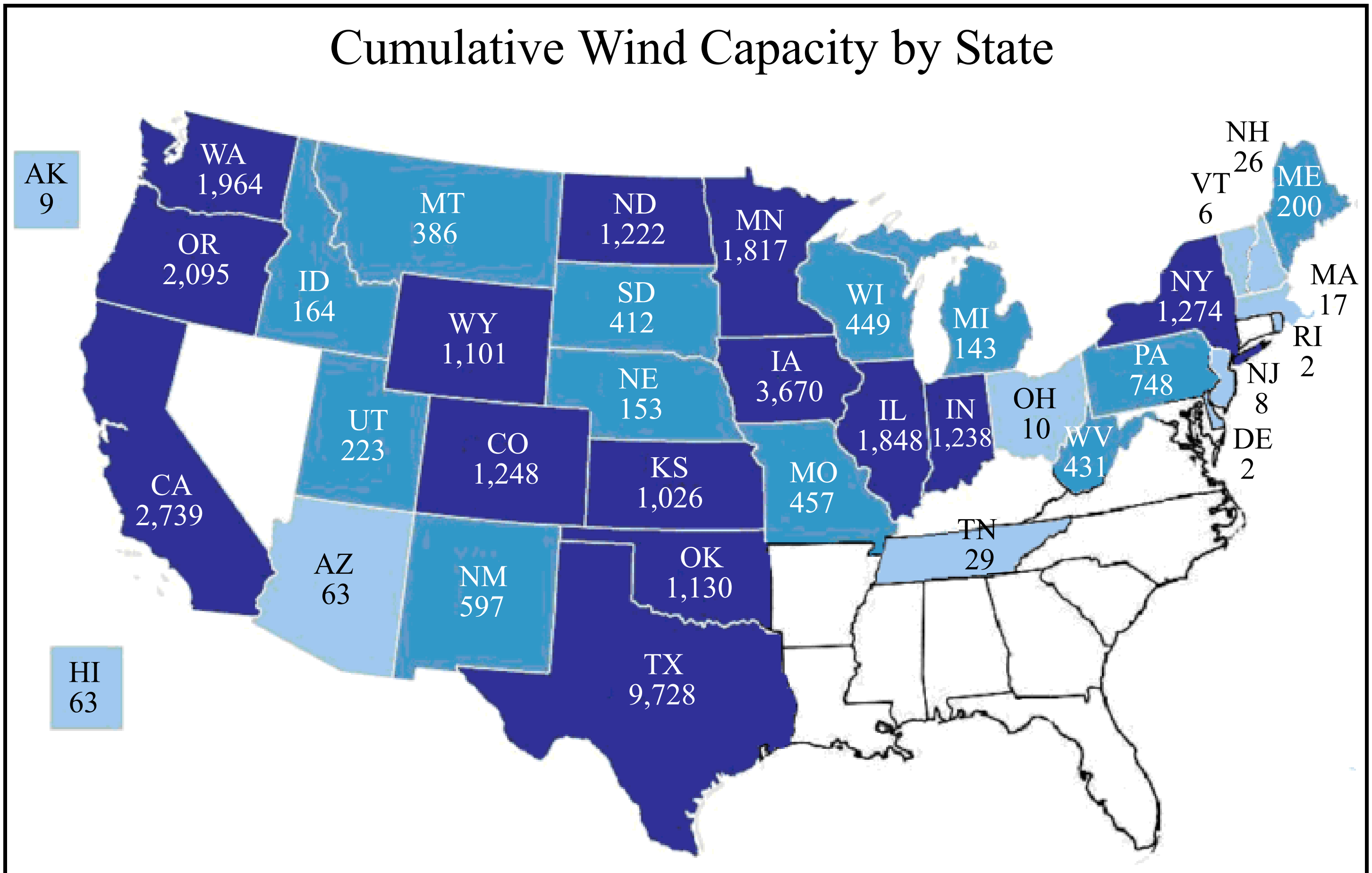

Figure 2: Installed wind power capacity (MW) through 3rd quarter 2010. (Source: American Wind Energy Association (AWEA) 3rd Quarter 2010 Market Report)

ROC Changing How it Evaluates Wind Turbine Impacts

Operating wind farms can be "seen" by the WSR-88D at varying distances, depending on atmospheric conditions, the intervening terrain, and the height of turbines relative to the height of the WSR-88D antenna. When atmospheric conditions cause super-refraction of the radar beam, wind farms can sometimes be seen over 150 km from the radar. The reflectivity patterns from these wind farms can occasionally look just like showers or thunderstorms. Typically, they disappear in the second or third elevation scan. In most of these situations, forecasters can "work around" the influences without impacting severe weather forecast/warning operations, just as they do for other clutter issues, such as those caused by anomalous propagation, terrain blockage, migratory birds, etc.

Wind farms that are much closer to the radar, approximately 18 to 30km, are frequently in the radar's line of sight (assuming standard atmospheric conditions) and "visible" in the radar data.

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Wind Farms

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Wind farms sited within 18km may begin to cause additional impacts, including contamination of data in multiple elevation scans, and contamination of data beyond the wind farm area due to multi-path scattering of the radar beam. Within 3km more serious impacts can occur that afect the radar data through its entire range. For example, the ROC and other published work have estimated that the large hubs of turbines, which can be as large as 12 meters across, can significantly block (25%) the radar beam if sited within 3km of the radar antenna, and completely block it within 1km of the radar. Figure 3 is a generalized graph depicting these impacts versus distance. One can think of the yellow, orange, and red areas as signifying low, moderate, and high impact. The distances of impacts in this graph assume level terrain and a utility-scale turbine (blade tips that commonly reach at least 130 meters high). The actual distance in which impacts occur varies with terrain.

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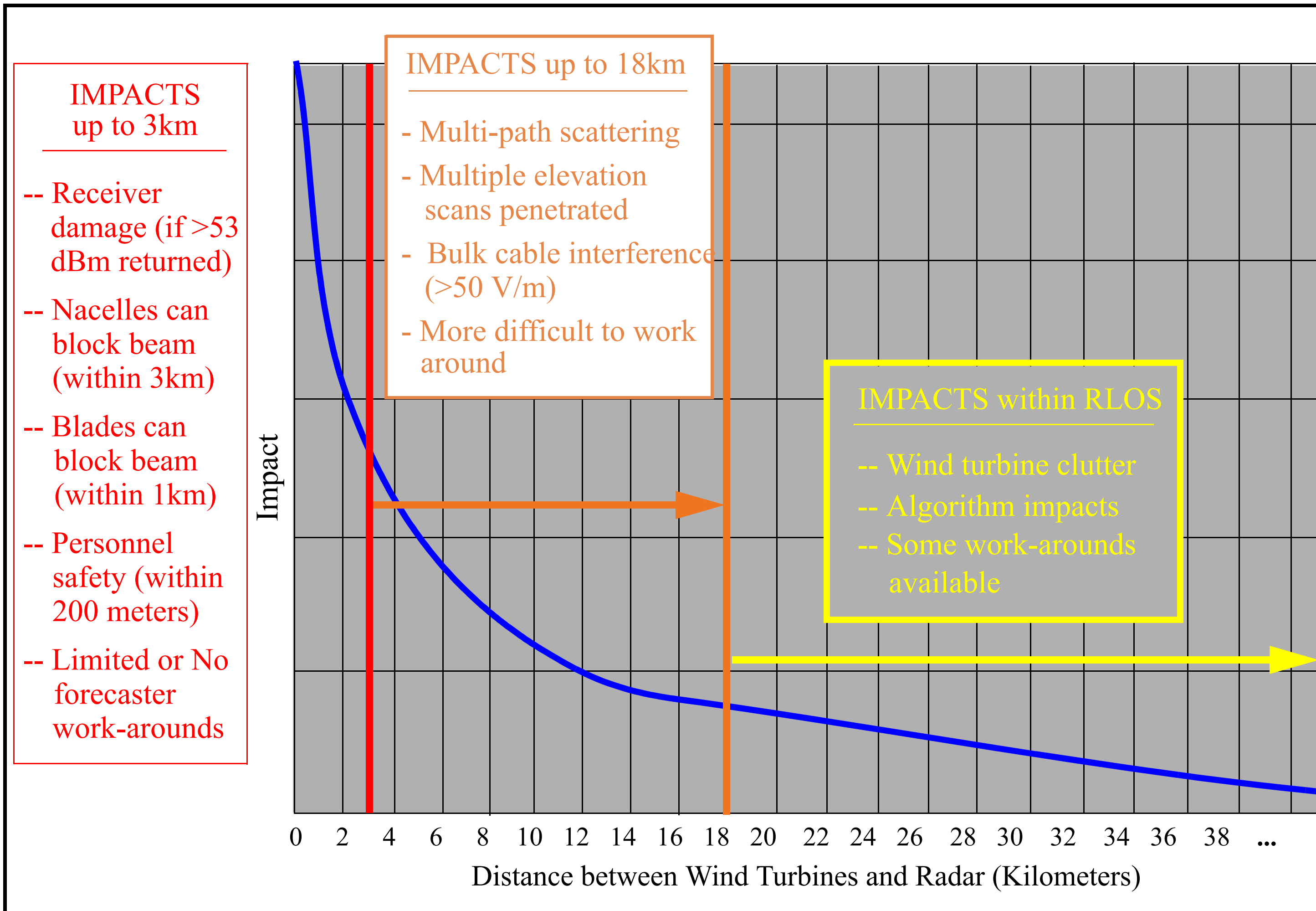

Figure 3: A schematic showing the estimated potential impacts on severe weather operations by wind turbine clutter as a function of range. The distances and impacts will continue to be refined based on additional experience.

Wind Farms

Continued from Page 20

Lately, the ROC has been placing greater emphasis on working with developers proposing wind farms with the potential for high and moderate impacts (i.e., within 3km and within 18km of a WSR-88D). Those developers proposing wind farms within 3km - and there have been a handful of them - get serious attention. The ROC has stopped proactively working with developers whose wind farms would "only" cause clutter in the first elevation scan and are beyond approximately 18km, since the impacts are not as significant and work-arounds are available.

Currently, the closest wind farm to a WSR-88D is 4km from the Ft Drum, NY WSR-88D. That wind farm causes significant clutter from multipath scattering out to 50km from the radar over approximately 120 degrees of azimuth and impacts the 3 lowest elevation scans (through 1.5 degrees). The ROC has received and evaluated several proposals for wind farms closer than 3km from a WSR-88D, but none have been built yet. When the ROC receives a proposal that would be very close to a WSR-88D, we make an effort to engage the developer to ensure they understand the potential impacts on the radar and operations. Since the federal government has no land-use authority over private land, changes to the siting plan is voluntary. Thus, ensuring early contact with developers when their investment in project planning is relatively low is very desirable.

In the past year there has been increasing attention paid by congress to the wind farm-radar issue, as some large wind farm projects have run into objections from federal agencies. In the long run, this is good news because additional resources will be needed to study and develop solutions to wind turbine interference on radars. Visibility of the problem at the congressional level may help obtain the necessary resources and early wind farm planning notification from developers.

ROC Initiatives

The ROC has several on-going and planned initiatives to help WFOs work-around wind turbine clutter impacts.

First, new AWIPS GIS (geographical information system) files will soon be available on the NOAA1 server for WFOs/RFCs to download and use as overlays of wind farm locations. Two types of files will be available - polygons of wind farm locations based on long-accumulation radar-QPE (quantitative precipitation estimation) data (developed by NSSL) and individual "as built" turbine locations from the FAA. The FAA maintains a database of all structures taller than 200 ft as part of their mission to evaluate the potential for such structures to pose a hazard to aviation safety. These GIS wind-farm overlays will be particularly useful for distant wind farms that intermittently appear in the radar data.

Second, the Warning Decision Training Branch (WDTB) has released a Commerce Learning Center course providing initial training on identifying wind farms on radar products, some mitigation strategies, and ROC outreach efforts. NWS Forecasters can access this course in the LMS (and bypass the search requirement) by clicking the following link: Login for National Weather Service LearnCenter. NWS partners and others can access the course at the following link: National Weather Service - Warning Decision Training Branch.

The ROC also continues to leverage the efforts of other federal agencies, such as DOD/ DHS/ and FAA, who also have wind turbine generated radar interference issues. For example, the DHS has a large 3-D wind-turbine impact modeling effort

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Wind Farms

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underway for air surveillance and weather radars. This contract is expected to be awarded soon.

The ROC is working with a couple WFOs and wind farm developers to explore the possibility of "operational curtailment" of wind turbines under certain severe weather potential situations. A draft Letter of Intent is being reviewed by these wind farm developers.

The ROC Needs Your Help

The ROC needs the support of field offices in order to better define the impacts of wind turbines on the WSR-88D and operations, and to convincingly make the case for those impacts. The ROC needs to be informed if sites are already dealing with wind turbine clutter and encountering cases that impact their forecasts and/or warning operations. WFOs may want to document wind turbine clutter impacts for their particular radar with the goal of developing a "climatology" of the clutter (how often it occurs, under what conditions, products affected, etc.) The ROC is interested in collecting significant impact cases (missed or delayed weather warnings) from around the country to better understand the interaction between wind turbines and the WSR-88D, and if warranted, make a case for action by policy makers. A clearer picture of the impacts may also help the development of a formal policy for working with the wind energy industry and avoid over-reacting or under-reacting to this issue. While NOAA supports renewable energy production, we must preserve our ability to issue accurate and timely severe weather warnings and forecasts using radar data.

Also, if it is learned that a proposed wind farm would be located close to a WSR-88D, please notify the wind farm team at the ROC by sending an email to wind.energy.matters@noaa.gov. We will follow-up.

For more information, please visit previous *NEXRAD Now* articles and/or the Wind Farm Interaction section on the ROC web site to learn more about the wind turbine clutter issue (Radar Operations Center - WindFarm Index). Several posters, papers and briefings have been posted on this web page.

Tim Crum
ROC Director's Office

Ed Ciardi
ROC Director's Office, Centuria

NEXRAD Now is an informational publication of the WSR-88D Radar Operations Center (ROC).

We encourage our readers to submit articles for publication. Please email all articles and comments to:

ruth.e.jackson@noaa.gov

All previous issues of NEXRAD Now can be viewed on the ROC Home Page at:

http://www.roc.noaa.gov/WSR88D/NNOW/NNOW.aspx

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Deputy Director...............Terry Clark
Editor...........................Ruth Jackson

Integrated Real-Time Performance Monitoring of Observing Networks in China

Introduction

For the past 30 years, NOAA and the China Meteorological Administration (CMA) have successfully collaborated in the field of Atmospheric Science and Technology under the auspices of a Joint Working Group (JWG). CMA and NOAA/NWS both operate, maintain, and upgrade similar ground-based meteorological sensor networks including Radar, ASOS/AWS, Upper Air, and Climate Reference Networks and their associated integrated display systems. As NWS Chairperson of the Meteorological Modernization Working Group of JWG-17 I, Ed Berkowitz, Program Branch Chief of the Radar Operations Center (ROC), have become familiar with how CMA monitors the performance and data quality of their sensor network. The following article provides a detailed overview including architecture of the CMA Atmospheric Observing System Operations Monitoring and Maintenance (ASOM) system. I believe readers will find this information interesting and useful.

An Integrated Meteorological Observing System forms the vital basis of China's weather forecasting service. Understanding climate, weather and equipment status requires the development, maintenance and evaluation of a robust integrated meteorological observing system. A major function of the Meteorological Observation Center (MOC) of the CMA is

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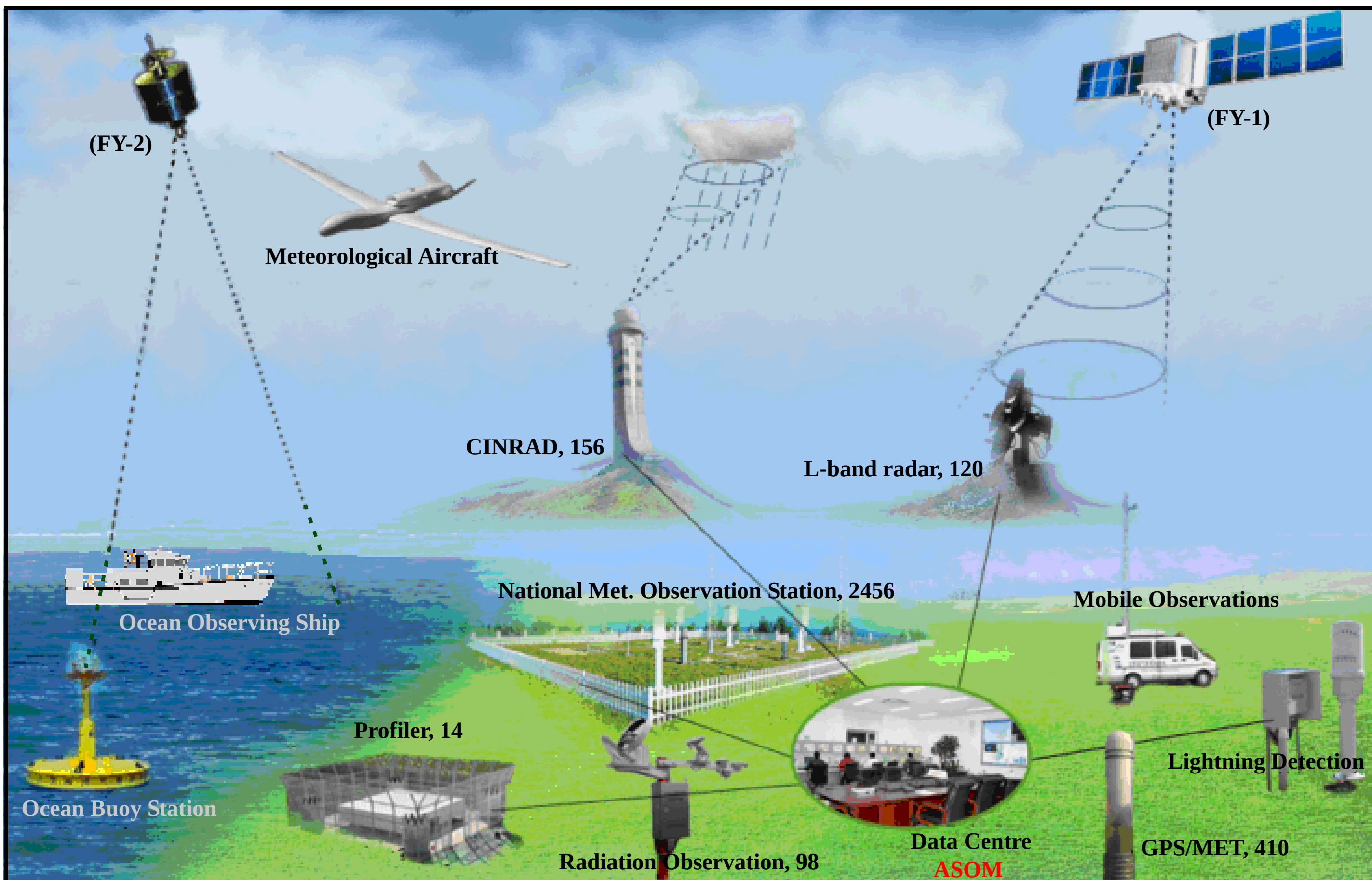

Figure 1: The Integrated Observation Systems in China.

China

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to provide such a system. The Atmospheric Observing System Operations Monitoring and Maintenance (ASOM) system assists all users in China with monitoring the performance and data quality of the integrated meteorological observing system, identifying problems, providing technical support for maintenance, managing logistics, and evaluating the adequacy of the observations to support forecasting, research and management.

CMA Integrated Observing System Overview

The China Meteorological Administration (CMA) has established anintegrated meteorological observation network including Satellites Observing System; Surface Meteorological Observing System; Upper Air Sounding System; Doppler Weather Radar Network; Wind Power Resource Observing Network; Agricultural Ecology Observing System; etc. Today, more than 120 upper air sounding stations; 156 Doppler Weather radars (CINRADs) and 58 conventional, non-Doppler digital meteorological radars; 21,000 mesoscale Automated Weather Stations (AWSs); and 400 wind power resource observing stations (used for sighting of China wind source distribution) work in consonance to support the CMA's weather forecasting and public services (Figure 1).

One of the missions of the MOC of CMA is to provide sustained support to all CMA operational networks, using the ASOM system, that assists all users in China with monitoring the performance and data quality of the integrated meteorological observing system, identifying problems in near real-time, providing technical support in maintenance, managing sites database and integrated logistics, evaluating the adequacy of the observations to support weather and climate forecasts, research and management.

Beginning in 2003, MOC started design and development of a monitoring system, for CINRADs only, by ingesting and processing performance data. Afterwards, additional functionality was developed and additional sensor observation networks, such as AWSs, were being considered to be supported by this experimental system with a GIS-based (geographical information system) user interface. The challenge to experts in the MOC was not how many additional observation networks to monitor and maintain, but rather the optimal method to support these additional sensors: should we develop a separate system for a specific observation network and use portal technology to integrate all these systems, or develop an extendable platform to support most of our various sensor observation networks? After two years of research, in mid 2008, the MOC began the process of building a totally new system concept, the Atmospheric Observing System Operation Monitoring and maintenance System (ASOM), aiming to allow many separate networks to be visualized and managed as one integrated system. Four different observing system networks, including the CINRAD new generation weather radars, automated weather stations, upper air sounding systems, and wind power resource observing stations were integrated into ASOM during the initial phase of this project. ASOM is now fully operational with planned upgrades to integrate additional weather sensor networks.

ASOM Introduction

ASOM was initially designed to provide three important characteristics:

1) One central database and four levels of applications, including national-level users, provincial-level users, urban area users and site users. See Figure 2.

2) One system with an extensible architecture, allowing the following different networks to "plug in" and to be visualized and managed.

3) Integration, i.e., data integration, workflow

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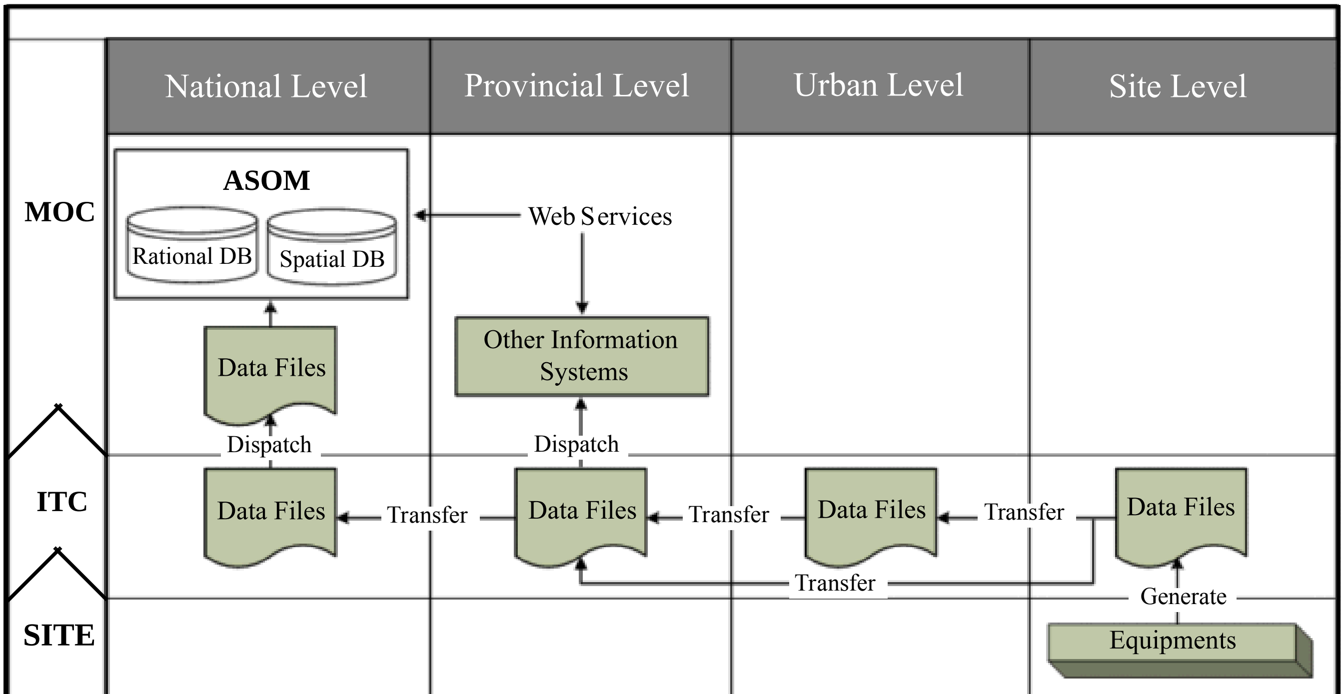

Figure 2: ASOM Data Flow

integration, user interface integration and information release integration, etc. Figure 3 represents the data integration among the subsystems.

ASOM has five main subsystems:

Operational Monitoring Subsystem. The operational monitoring subsystem performs the data processing work in the background, including collecting and extracting data, data quality control, near–real time products generation and data archiving. It then displays current and historical status of nationally distributed meteorological data based on GIS, and automatically identifies the coverage of any given collection of platforms and parameters. With the use of this subsystem, the CMA sensor networks are able to be "monitored" for their operational status and data quality in near real-time.

Maintenance Subsystem. The maintenance subsystem provides 4-levels of a users' collaborative platform for preventative and corrective maintenance: it collects all sensors maintenance data with the use of the embedded preventative and corrective maintenance forms and work orders to manage maintenance routinely and effectively, while also generating equipment systems and operational MTBF, MTTR and availability. Meteorologists and engineers can provide assistance or recommendations through the ASOM system to the site technicians who are restoring the systems or replacing sensors on site. A maintenance knowledge repository was then created to provide basic and standard steps to repair a malfunction. It is also a tool to share maintenance knowledge and "lessons-learned" experiences. Online technical support is provided as an additional benefit to the traditional Hotline service.

Logistics Subsystem. The logistics subsystem supports online spares management with spares location, and four levels of ordering and shipping. It provides tools for the management of asset inventory, online repaired parts management and spares

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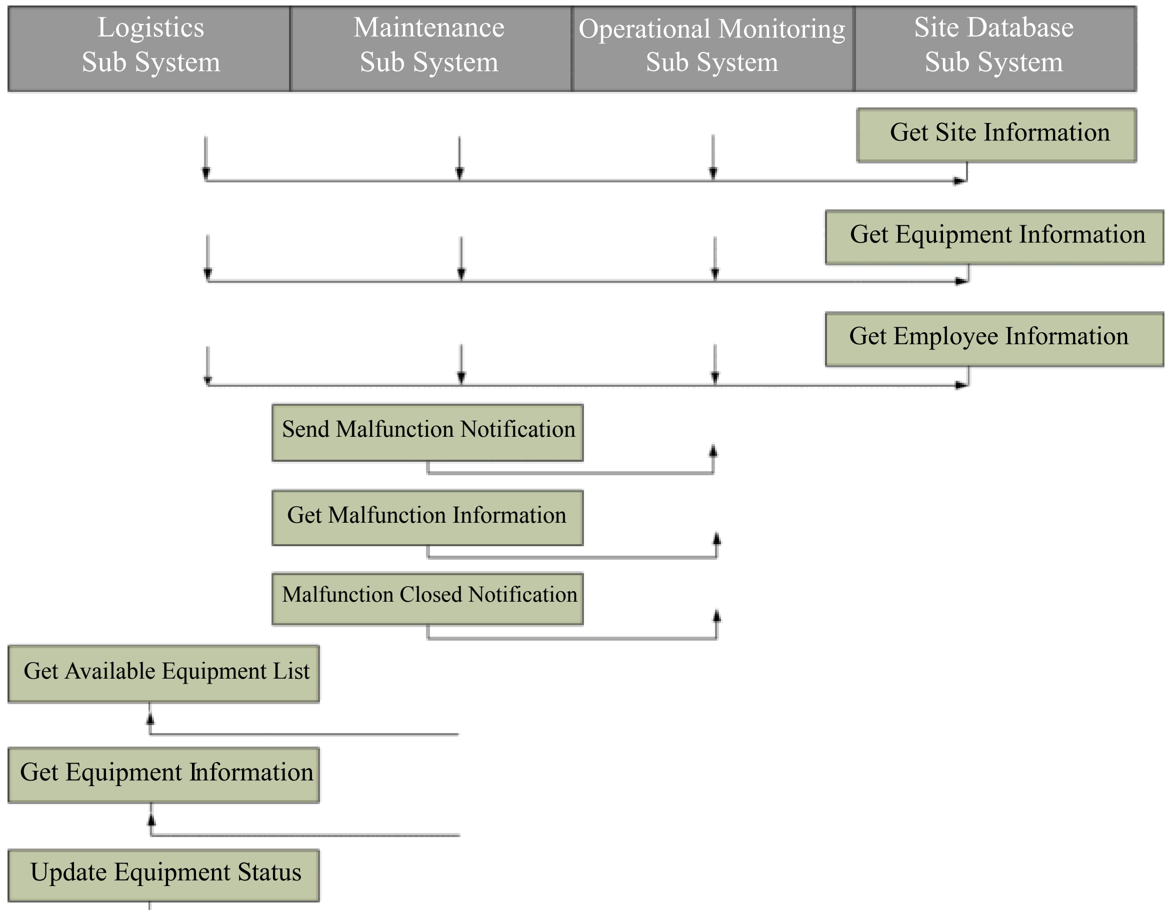

Figure 3: ASOM Subsystems Interaction Sample.

quality control management. The asset life-cycle management is also designed and implemented in the current system, which makes sense to managers following sensor reliability assessment. It designs logistics support plans, dynamically manages assets, warns of stock quantity thresholds and quality traceability online, etc.

Site Database Subsystem. The site database subsystem is the basis of the other five subsystems. As the core the ASOM, the site database is a database of all CMA sensors' metadata which contains definitions of all systems and instruments from separate networks and sites identification information. This database is then used to drive the different subsystems to assist in monitoring and maintaining the nation-wide meteorological observing systems. It provides a serial integrated evaluation for selection.

Evaluation & Reporting Subsystem. The evaluation and reporting subsystem is used to assist managers CMA-wide with decision making, based on meteorological observation networks' availability, maintainability, data quality, parts usage and associated cost, funding needs etc. All information is released either via webpage, text messages or emails. Other subsystems are also integrated in ASOM, such as video monitoring subsystem, etc.

ASOM Architecture & Features

Thus, ASOM is an n-tier architecture as shown in Figure 4:

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The IT Infrastructure layer and *Operating System layer* provide the basic IT environment for ASOM.

The ASOM Database layer is a central data store for meteorological systems and equipment's metadata, operational monitoring of raw data, product data, evaluation data, maintenance knowledge repository data, etc. In order to provide an extensible database schema, ASOM creates a metadata data standard for all meteorological assets. All meteorological assets' attributes must be compatible for the metadata data standard. All subsystem interactions use metadata data standard compatible interfaces so that ASOM platform can manage and visualize different meteorological networks, without knowing what type of networks ASOM is involving. In the same manner, ASOM uses a Shared Equipment Metadata table to store the most basic attributes of all equipment. Each type of equipment uses a separate table to store equipment-specific attributes. Metadata of all equipment resides in the

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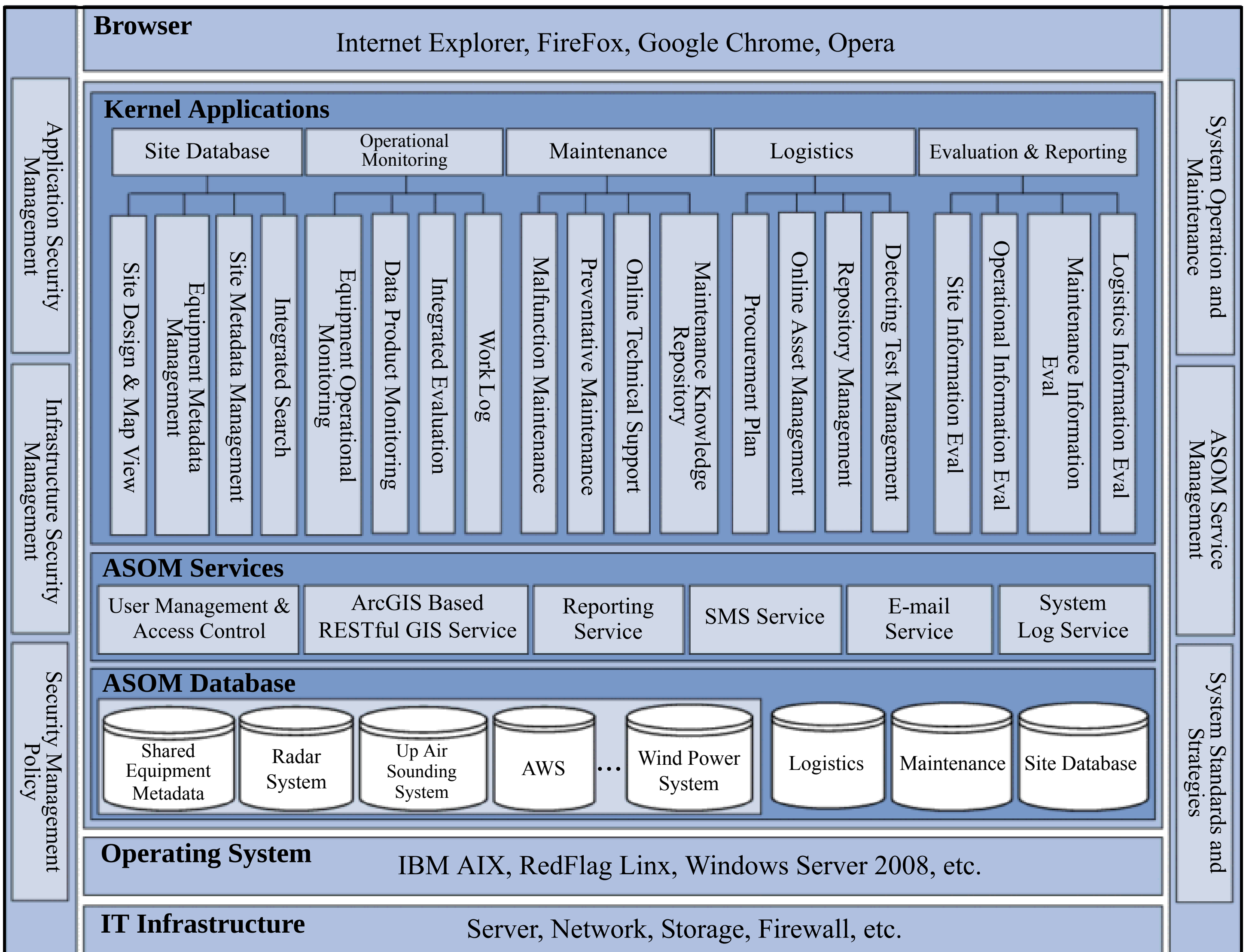

Figure 4: ASOM Architecture

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site database. This equipment design in ASOM permits the use of such a hierarchy throughout the platform as shown in Figure 5.

The ASOM Services layer is an encapsulation of systematic reusable functionalities using SOA. For example, both the site navigation in the site database subsystem and coverage displays of the specific radar in the operational monitoring subsystem uses the same GIS service, ArcGIS based RESTful service. A significant effort was put into the low level services encapsulating the universal functionalities of ASOM. Thus network specific tools can be developed readily, effectively, efficiently and inexpensively.

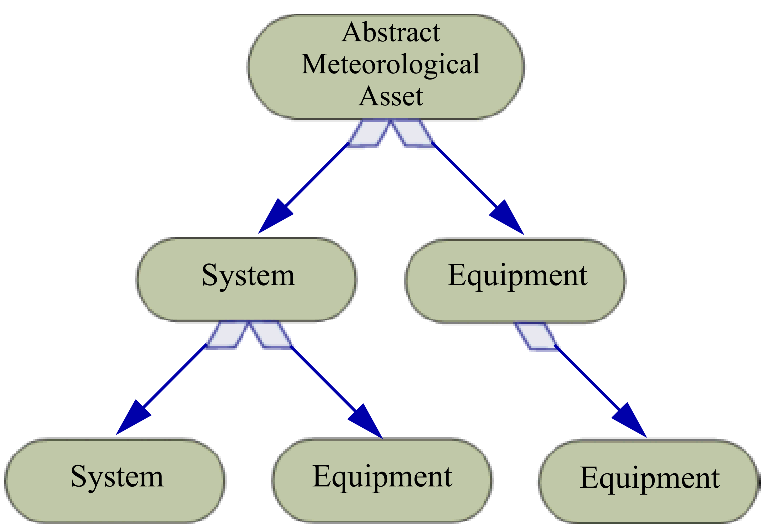

Figure 5: Meteorological Systems and Equipment Hierarchy in ASOM.

The Kernel Applications layer is the main part of ASOM, providing tools for different functionalities, such as data processing, data quality control, status monitoring and data monitoring, maintenance management, work order management, logistics management and evaluation and information release, etc. Every tool works for all compatible meteorological networks.

The Browser layer is the presentation layer. ASOM is available via the CMA intranet using Internet Explorer, Firefox, and other mainstream browsers and can be used to deliver information from the MOC to other centers of the CMA, national partners, and international partners.

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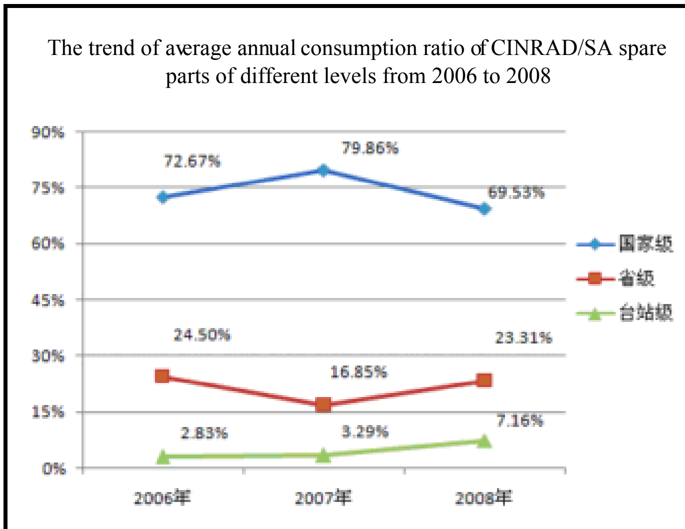

Figure 6-1: The usage of radar parts.

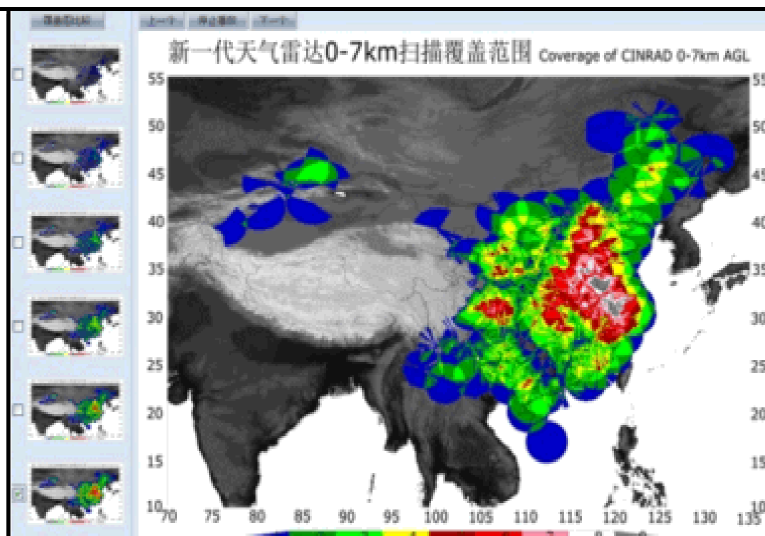

Figure 6-2: Site database applications.

Figure 6: Evaluations and applications in ASOM.

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ASOM Benefits

The ASOM system features an integrated and cost-effective monitoring and maintenance system for all of the CMA's observing networks. It manages all sensors' associated status data, performance data, maintenance data, logistics data and site database data. It provides the integrated evaluation results and service information for various CMA users with differing operational and research requirements.

Since implementation of the ASOM system among all the various CMA offices, it has resulted in major improvements to the operational service availabilities of the multiple sensor networks and the MTBFs of the associated equipment. For example, the CINRAD Ao has been improved significantly from 89% in 2006 to above 96% in 2009. See Figure 7-1.

The ASOM system also provides many products to serve the weather warning decision makers. It dynamically collects data from sites' sensors and then generates many kinds of instant weather products to the public, to reduce fatalities and property damage. These applications help the CMA prevent and mitigate weather-related disasters (Figure 8).

Since the ASOM system is an integrated system, it gathers radar, AWS, L-band radar upper air and wind resource observing data. We then compare the observing data elements simultaneously to find the difference among them and attempt to calibrate the errors though scientific algorithms. It helps our engineers and forecasters to support operations and to make more dynamic and accurate weather "watching."

In ASOM, the key point is "integrated." It accesses observing data, performance data, status data, maintenance data, logistics data and site base data interactively through a data bus, processing them with scientific algorithms, and then generates the useful products to support operations, maintenance, forecasts and public services. It greatly decreases the work-load and reduces staff resource requirements and saves funding. Additionally, it enhances the performance for the CMA observing networks, shortens the duration of outages, extends the usage of parts, quickly helps forecasters know what's happening at sites to correct the Now Castings. The ASOM provides network management tools for our managers to optimize the entire

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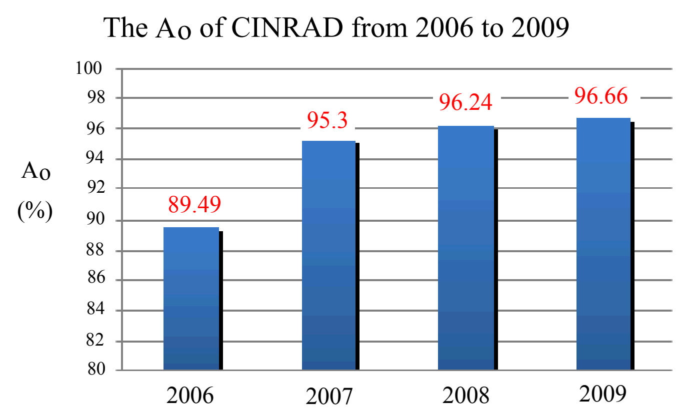

Figure 7-1: Radar availabilities

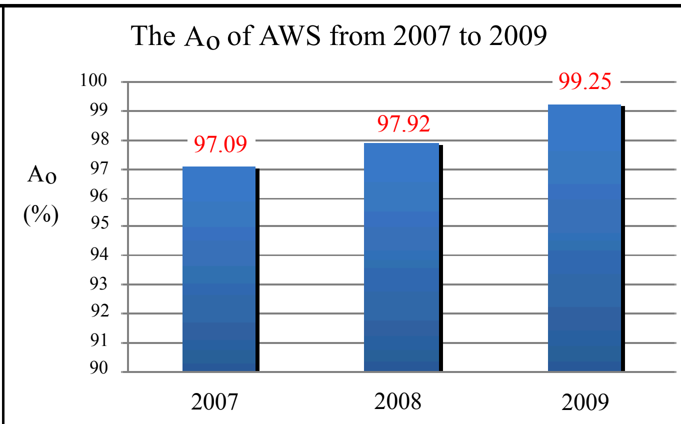

Figure 7-2: AWSs data quality improvements

Figure 7: Improvements to Radar and AWS availabilities.

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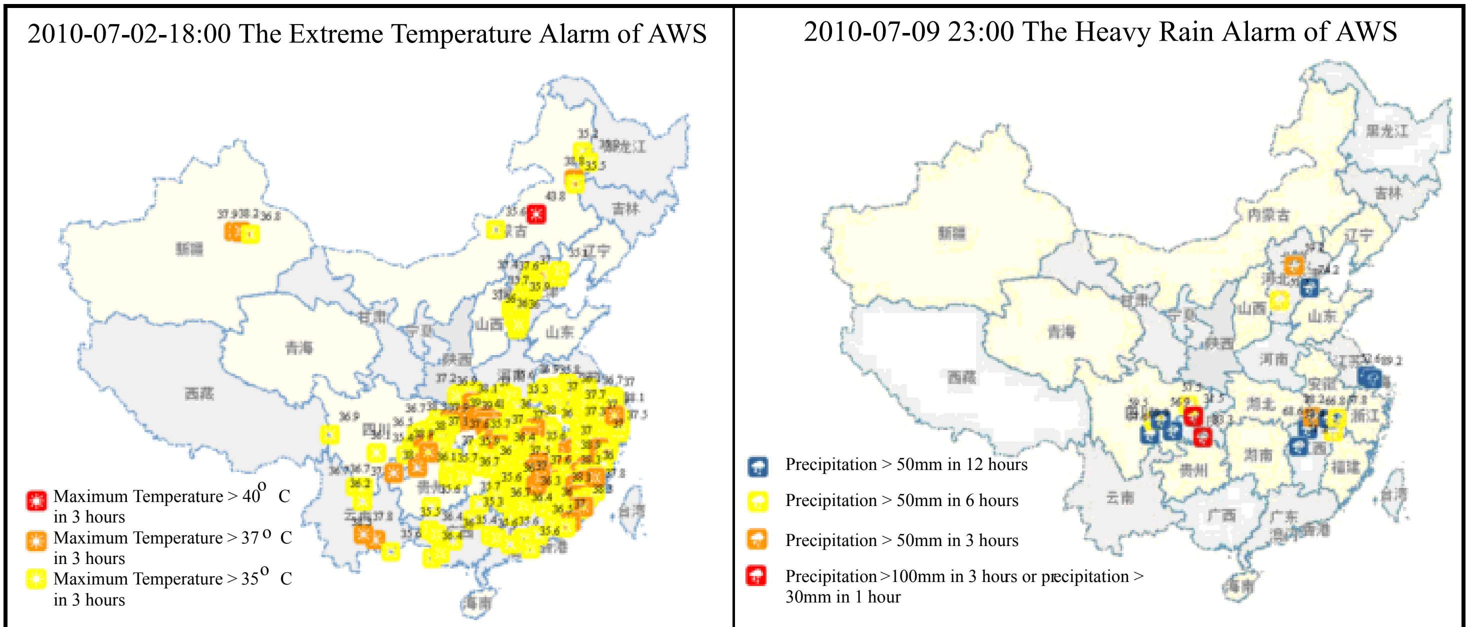

Figure 8: Monitoring extreme value using ASOM.

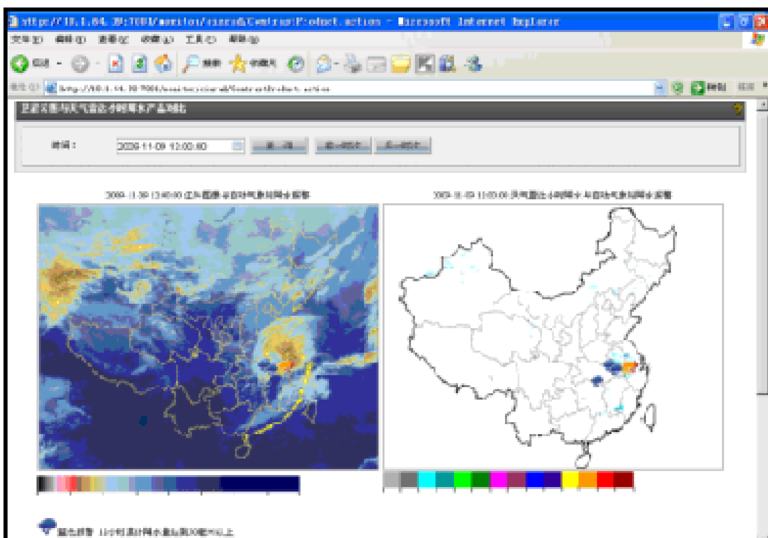

Figure 9-1: Satellite and AWSs monitoring.

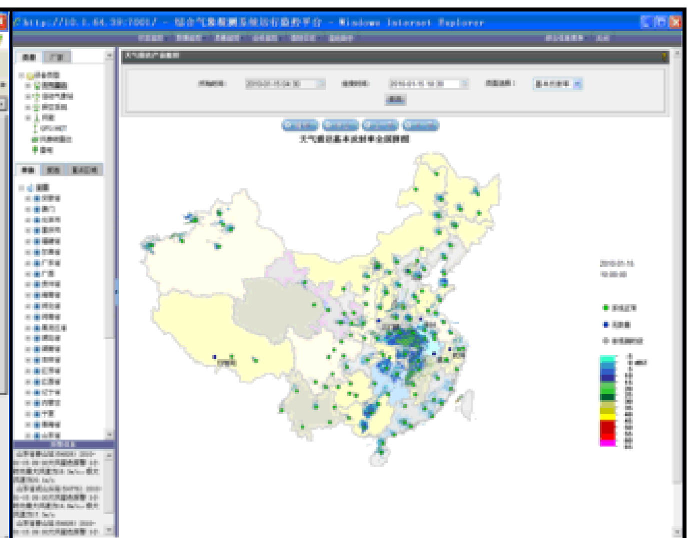

Figure 9-2: Radar precipitation mosaic monitoring.

Figure 9: Comparison of the Severe Precipitation Weather Region through ASOM.

CMA observing network. Moreover, it results in economic and social benefit gains.

Chong Pei
Senior Engineer,
Director of Operations and Science & Technology Department of Meteorological Observation Centre, CMA

An Historical Look at NEXRAD

Radar, also known as radio detection and ranging, is one of the earlier technological developments that had a huge impact on the field of meteorology. Weather Surveillance Radar-1988, Doppler (WSR-88D) Next Generation Weather Radar (NEXRAD) has become a staple technology for the National Weather Service (NWS) to meet the needs of its mission in detecting severe atmospheric features such as tornadoes, hail, and snow squalls. This technology, first used by the military to detect the movement of objects such as planes and ships in WWII, is now used in real-time operations to detect the sorts of atmospheric phenomena that could impact public safety and property. Here we will discuss the historical family line of radars that eventually led to the development of NEXRAD used by the NWS today.

The British were actually the first to "develop radio-location, direction-finding devices that could locate thunderstorms" through the efforts of Sir Robert A. Watson-Watt around 1935. Then, in the U.S. from 1942-1944, the Massachusetts Institute of Technology's (MIT) Radiation Laboratory (Rad Lab) showed that weather could be detected on certain types of radars out to ranges of 150 miles and at different wavelengths. Because of this, the Army Air Forces Weather Service established a program for the use of weather radar. Most U.S radar research and development was conducted at MIT's Rad Lab during WWII. In addition, because there were air traffic control and harbor defense radars set up on the Atlantic and Pacific sides of Panama, scientists from the MIT Rad Lab were able to visit and determine the effects of the atmosphere and usefulness of radar in observing atmospheric phenomena. The early use of this first radar network for weather detection and surveillance led to the recognition of many basic features of storm structure and organization and helped to realize the value of this information for operational purposes. All of these factors really helped to spur the growth of radar meteorology as a science.

After WWII, the NWS, formally known as the Weather Bureau, obtained various aircraft radars from the Navy. Most of them were AN/APS-2F radars which stood for Airborne Radar and they were modified and put into operation around the U.S. at about 5 per year. These were then renamed Weather Surveillance Radar (WSR) -1s, -1As, -3s, and -4s. All of these radars were pretty much the same and differed by some controls and indicators. The first WSR was installed at Washington, D.C. National Airport on March 12, 1947 and on June 1, 1947 a second WSR was installed at a NWS office in Wichita, Kansas. The radar in Wichita proved its worth when it was used to help guide and aircraft threatened by severe weather into clear skies so it could land safely.

WSR radars were all beginning to show their value in similar circumstances as what became known as the U.S. Basic Weather Radar Network began to form and expand after 1947. This network consisted of the early WSR-series systems, air force, civil government and cooperative radars. Eventually radars were being developed specifically for meteorological use and one of the first was known as the AN/CPS-9 Storm Detection Radars, produced by Raytheon Manufacturing Company. The CPS-9's were actually acquired by the Army

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Air Forces Weather Service and installed at military bases all over the world. Studies and research models of the CPS-9 were also conducted by MIT Rad Lab, as well as by the Signal Laboratory.

As the NWS considered expanding their radar network in the 1950s, a few major severe weather events occurred and lead to the formation of the Texas Tornado Warning Network and the establishment of communications between the NWS offices and local public officials. The NWS agreed to operate and maintain WSR-1, -1A, -3, or -4s at their offices and to provide warnings to the public when confirmed sightings were made - establishing volunteer spotter networks. Today, a more formal spotter program called SKYWARN® is run by the NWS where volunteers are trained to identify and describe severe local storms. Since the program formally started in the 1970s, the information provided by SKYWARN® spotters, coupled with Doppler radar technology, improved satellite and other data, has enabled NWS to issue more timely and accurate warnings for tornadoes, severe thunderstorms and flash floods.

In 1953, a tornadic feature known as a hook-shaped echo was first detected by a radar near Champaign-Urbana, Illinois and a couple of months later, two additional recordings of these echoes were made in Waco, Texas and Worcester, Massachusetts.

The installation of the WSR radars was a joint effort between local, state and the federal government, as well as universities. A great example of the partnership between the weather service and the local community occurred on April 5, 1956 when a tornado watch was issued by a weather service office in Kansas City for a specific area around Bryan, Texas at about noon. By 2pm on April 5, 1956, the Texas A&M University radar began seeing hook-echoes and University meteorologists were able to call the Bryan Police Department and the College Station School District to let them know about the impending touchdown of tornadoes. The school district decided to keep their students in school a bit longer instead of releasing them at their normal dismissal and this probably saved numerous lives. As one of the first known tornado warnings based solely on radar detection, the value of this technology was becoming more visible to society as a whole.

Hurricanes became another driver for the installation of radars. Their design used a frequency known as S-band, which allowed for longer range and more power in detection. After some extensive hurricane-force wind damage and flooding from 5 hurricanes in 2 years from 1954-1955, the NWS developed a major budget proposal for Congress to improve its warning services for hurricanes and severe weather, which was quickly approved. The budget included funding for the design, procurement, installation, and staffing for what became the WSR-57 radar. Raytheon Manufacturing Company was selected as the prime contractor; 31 radars were ordered by the NWS and installed at already existing weather service offices beginning in 1959 in Miami, Florida and ending in the early 1960s. While the main purpose was to install these near coastal areas, eleven of them were installed in the Midwest to detect severe storms. Fourteen additional radars were purchased in the late 60s to expand the network east ofthe Rocky Mountains. It is also important to note that these newer installations were placed in locations where weather service offices did not already exist. The main focus was to space the radars out optimally for coverage and continuity with the already existing radars.

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Some of the major design specifications included an "improved ability to detect storms behind intervening rainfall as to observe hurricanes at great distances." In 1963 the NWS began to standardize the performance of the WSR-57s through calibration techniques. The WSR-57 also had a near real-time telephone transmission line for data and eventually a dial-in capability was added to allow access by military, airline offices and television stations, providing radar data remotely. Remote access is still an important part of the radar network today.

As discussed above, the NWS had installed many conventional, non-Doppler weather radars around the country but eventually they had to consider the technology with which they should replace them due to the aging WSR -1s, -1As, -3s, and -4s. Spare parts were disappearing and the 1940s technology upon which they were designed was just no longer feasible. The Office of the Federal Coordinator for Meteorological Services and Supporting Research began releasing a Federal Plan for Weather Radars and Remote Displays which was used by Congress as a "single source for reviewing the overall Federal program in meteorological services and supporting research." The 1969 edition indicated that the NWS intended to buy more modern local-warning radars to replace the WSR -1s, -1As, -3s, and -4s. By fiscal year 1976, the NWS received funding for 3 years to replace those older radars, and the replacements were manufactured by Enterprise Electronics, which became known as WSR-74C. Additionally, Enterprise Electronics also manufactured some WSR-74S radars, which were used to fill some remaining gaps for special hurricane and heavy precipitation detection on the S-band frequency.

When computer technology began to emerge in the 1960s, researchers were able to more efficiently process radar data and application software for their radars. Eventually more sophisticated algorithms and techniques were developed that were also expanded to operational radars and it led to an improved knowledge base for the weather forecasters who had come to rely on radar data to do their daily jobs. Color monitor technology was also introduced, which made it even easier for meteorologists to be able to recognize storm echoes and other features.

During this same time, the MIT Rad Lab had been looking at the use of the Doppler Effect to measure target velocities by radar as a potential measurement for wind speeds, but the development of pulse-Doppler technology for operational use took a while. In 1971, the first Doppler radar was installed at the National Severe Storms Laboratory (NSSL) in Norman, Oklahoma and in 1973 a second Doppler radar was installed at Cimarron Airport in Oklahoma – both were meant to study the morphology of storms and used S-band frequency. By 1976, the Department of Commerce (DOC), Department of Defense (DOD) and the Department of Transportation (DOT) formed the tri-agency Joint Doppler Operational Project (JDOP) to explore the benefits of Doppler radar observations. Doppler radar was considered the next upgrade over conventional radar (i.e. WSR-57, -74) because of its ability to "measure the phase difference between transmitted and received radar signals. The rate of change of the phase difference is directly proportional to the radial component of target motion relative to radar, which is known as the Doppler velocity. As Doppler radar scans horizontally, it measures both reflectivity and the component of target motion along the radar beam axis." This method

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shows a more accurate detection of circulations associated with tornadoes and other significant weather. The JDOP conducted field tests for three years with the NSSL Doppler radars and an Air Force Geophysical Lab Doppler radar in real-time to test various processing and display capabilities. In 1979, they delivered a final report with recommended specifications for the tri-agencies.

The JDOP reported out seven basic findings for the use of Doppler radar. A few of them were: Doppler radar is superior to conventional radar and spotters/public reports; Doppler radar can distinguish between severe and non-severe thunderstorms at a longer range; the size of a warning area can be smaller and much more specific due to increased precision by Doppler radar; and average lead time for detecting storms before occurrence would be increased.

Finally, the NWS recognized the increased need for standardized training of radar operators since Doppler radar data was much different from conventional radar data. They specifically noted that operators would need an introduction to basic Doppler principles and meteorologists would also need to be able to interpret velocity data. As a result of this, the National Weather Service Training Center (NWSTC) located in Kansas City, MO developed various foundation courses and intensive short courses that eventually became a job requirement for forecasters who were hired by the NWS.

In mid-1979, the JDOP reported to the House Committee on Appropriations proposing that a "new weather radar called NEXRAD, which had Doppler capability, be integrated into a national system to meet the requirements concerning the location, intensity, and movement of hazardous

weather activity to meet their agencies' missions." In this report, it was also noted that NEXRAD would be useful for more than just detecting the hazards of severe weather. The JDOP proposed that NEXRAD be useful for water resource management; it would also foster economic value when used by various industries such as private meteorologists, TV stations, and the airlines to name a few. There was also interest internationally for this type of data.

By late 1979, the Federal Committee for Meteorological Services and Supporting Research (FCMSSR) established a Joint Systems Project Office (JSPO) to run the planning, programming and management of development, procurement and installation of NEXRAD. With the establishment of the JSPO, key documents such as the joint operational requirements (JOR), NEXRAD technical requirements (NTR) and a research and development plan resulted. All of these fed into the JSPO Interim Operational Test Facility (IOTF) operations set up in Norman, OK to develop many of the concepts for what eventually was to become the WSR-88D. Beginning in 1982, contracts for concept development, validation and risk reduction were awarded and finally, after other various operational testing and evaluations, Unisys Corporation was selected as the NEXRAD contractor for full scale production in 1990.

The WSR-88D network that exists today is the result of a billion-dollar weather service modernization that began in the late 1980s into the early 1990s. NEXRAD was just one part of the modernization of observation technologies being incorporated to improve NWS services. In 1995, the National Research Council (NRC) stated that "based on an intensive 6-month study, their NEXRAD Panel of the National Weather Service

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Modernization Committee (NWSMC) arrived at a strong overall conclusion that weather services on a national basis will be improved substantially under the currently planned NEXRAD network." It took almost eight years from when the first WSR-88D system installation near Norman, Oklahoma in 1990 to last operational WSR-88D installment in northern Indiana in 1997. It is important to note that all agencies (mainly NWS, DOD, and FAA) that have weather radar programs are using the same radar systems and this has allowed for substantial cost savings in sharing new algorithms or other improvements as they are developed. Today, there are now 159 operational NEXRAD radar systems deployed throughout the United States and at selected overseas locations. Radar technology and its application to the atmospheric sciences have revolutionized our ability to 'see' the weather. By the 1990s, the NWS was finally able to provide a substantial amount of warning time for severe storms to the public in a more consistent manner throughout the entire United States through the use of Doppler radar technology. Finally, the current upgrade of the WSR-88D weather radars with dual polarization is the next stage of improvements for storm detection and the provision of warnings that will continue to assist our forecasters in the protection of life and property for the citizens of the United States.

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