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NCAR Fellows News

JANUARY EVENTS

January 15: Research Reviews

11:00 am, FL2-1001, Minghui Diao, Yumin Moon, and Jorge Salazar.

JANUARY NEWS

NCAR will be closed January 20 in observance of Martin Luther King Day.

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Are Phased Array Antennas the Future of Atmospheric Radar Technology by Jorge Salazar

Are phased array antennas the future of atmospheric radar technology? This is a question many scientists and radar engineers ask today. The purpose of this article is to discuss some technical aspects and review progress in the development of phased array technology that can help us understand the current state of weather radar, the needs of the radar community, and the benefits and limitations of phased array antennas as a key component of advanced weather radar systems.

The use of radar systems to understand atmospheric phenomena has had a large impact on how scientists, researchers, and weather forecasters observe, analyze, and predict meteorological events. Today, radar is considered one of the most important instruments for atmospheric research. Radar can achieve a high temporal resolution and provide three-dimensional information for a large portion of the atmosphere in a few minutes. Further, it can make measurements in both clear air and precipitation at spatial and temporal scales that feed numerical forecast models for better predictions of an atmospheric event.

There are many operational and research weather radars. The weather radar system that most significantly contributes to researchers and weather forecasters is the S-band operational radar network system WSR-88D (NEXRAD) (Crum 1993). This radar network system consists of about 150 nearly identical radars deployed over the United States and some overseas locations and is operated by U.S. agencies. It provides atmospheric observations to a range of 460 km for reflectivity and 230 km for velocity. The resolution and sensitivity allow operators to see features, such as cold fronts, thunderstorm gust fronts, and mesoscale features of thunderstorms. NEXRAD radars also provide volumetric scans of the atmosphere, allowing operators to investigate the

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vertical structure of storms and provide detailed wind profiles above the radar site. A recent radar upgrade with dual-polarization capabilities offers NEXRAD users the possibility of improving hail detection for severe thunderstorm warnings, improved rainfall estimation for flood and flash flood warnings, and rain/snow discrimination for winter weather warnings (Zrnic et al. 1998)

One of the biggest limitations of long-range radar systems such as NEXRAD is that beyond the 250 km range, radar detects only at higher altitudes because of the

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curvature of the earth. In the case of WSR-88D/ NEXRAD, the radar beam is about 3 km high at the 250 km range. This is a serious limitation for current radar systems because radar cannot observe weather phenomena that occur near the ground. One potential solution to this problem is the proposed short-range CASA radar network. The Engineering Research Center (ERC) for Collaborative Adaptive Sensing of the Atmosphere (CASA) addresses lower atmosphere coverage (below 3 km) using the concept of a low-cost, low-power, dense radar network. The approach assumes that a much more dense network of low-cost low-power radars can fill in the low altitude measurement voids in the NEXRAD system. CASA developed and deployed a four-radar network in Oklahoma (McLaughlin et al. 2005). Each radar unit operates at 9.41 GHz (X-band) using a 1.2 m parabolic dish antenna for dual polarization capability. To perform at high temporal resolution, each unit is implemented with a high-performance pedestal that provides scan rates of 24 deg/sec. Since 2007, a number of CASA-developed algorithms have been evaluated in various weather conditions, including: sensing node radar parameter computation to networked processing; resource allocation to task optimization; nowcasting to meteorological assimilation; and end user integration to adaptive scan strategy. Analysis of the CASA radar system and algorithms has demonstrated improved scan performance, providing scanning update rates five times faster than the nearest WSR-88D. Faster scanning permits rapid update of observations of developing weather and improves the timeliness of public hazardous weather alerts

Conventional radar systems use a heavy and relatively slow mechanical pedestal for continuous scan in azimuth and stepped-in elevation. NEXRAD scanning updates occur about every 5 minutes, while CASA IP1 radar improves this time to 1 minute. Further enhancements to mechanize the scanning rate is not an option because it increases the stress and cost of the mechanical parts, thus reducing their operational lifetime. The use of a single transmit source, such as a magnetron and klystron, makes the system less reliable and more expensive to operate.

Phased array antenna technology can solve many of these issues by replacing or eliminating the mechanical moving parts in the antenna and distributing a single power source (magnetron or klystron) to thousands of discrete power sources in the aperture array. This reduces the failure rate significantly, prolongs the radar lifetime, and considerably reduces the operational cost of the radar system. The most attractive feature of phased array technology is the implementation of rapid scanning. An electronically scanning array allows sampling the same atmospheric volume in a fraction of the time of a mechanically scanned conventional radar system. (Heinselman et al. 2008)

The significant improvement in the performance of the RF compo-

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Jorge Salazar at the NCAR APAR Lab

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nent and the rapid proliferation of digital wireless market technologies (GSM, CDMA, PCs, Wifi, WiMAX, etc.) and reduction of cost of RF microwave components (high-power amplifiers, phase shifters, low-noise amplifiers, etc.), seem to have been the triggers for the use of phased array technology for civil applications. In 1993 the European Union (EU) Cooperation in Science and Technology (COST) group implemented a five-year European research program concentrating on advanced weather systems to develop guideline specifications for a future generation of European radar systems using phased array technology (P. Meischner et al. 1997). In 2001 the National Research Council (NRC) identified phased array technology as the best candidate for upgrading the current U.S. radar system (P. Smith et al. 2008). Replacing 500 radars (for weather or air traffic surveillance) with a multi-function phased array radar (MPAR) network of 300 has the potential to be a cost-effective solution, reducing the life cycle cost by $3 billion. In 2006 a committee of radar experts sponsored by the U.S. National Oceanic and Atmospheric Administration (NOAA), Federal Aviation Administration (FAA), Department of Defense (DoD), and the Department of Homeland

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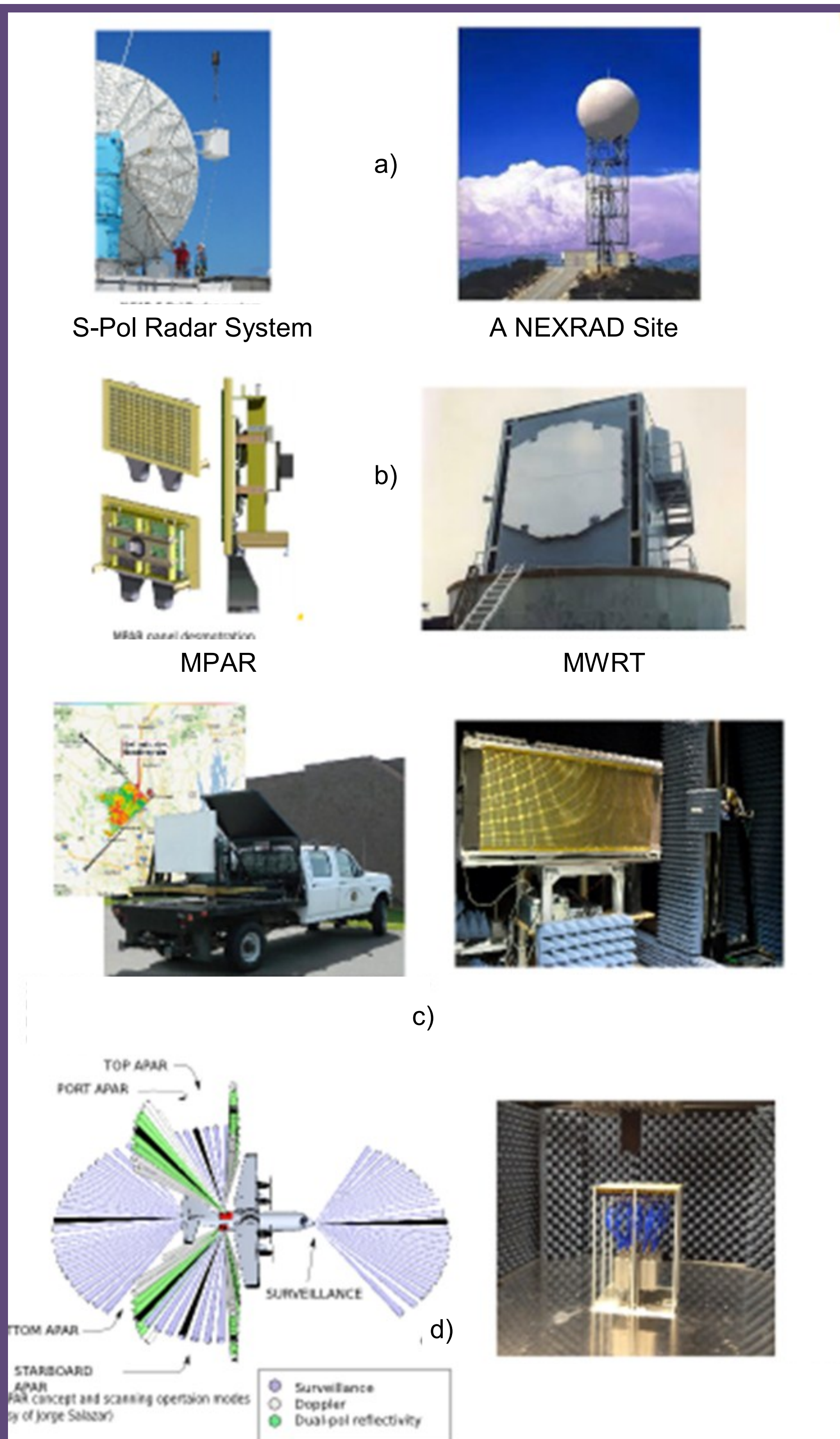

Figure 1. a) S-Pol and WSR-88D conventional radars. b) Multifunction Phased Array Radar (MPAR) project concept and National Weather Radar Tested (MWRT). c) Mobile and Low Cost 1D Phased-array weather research radars. d) Concept of Airborne Phased Array Radar (APAR) and array antenna prototype (8x8 elements)

Phased Array Antennas (continued)

Security (DHS) undertook planning for the possible replacement of existing radar networks with an MPAR system designed to meet the surveillance needs and mission requirements of the several agencies simultaneously.

At the same time, two X-band mobile radars implemented with electronic scanning array antennas were deployed in the southern plains of the United States in order to evaluate convective storms. Shapiro and Wurman (2003) presented measured results of the evolution of a tornado in Kansas, demonstrating the great advantages offered by fast-scanning radars for significantly improving the capability to evaluate fast-evolving convective storms. Later in 2008, another converted military hybrid, mechanically phased array antenna called MWR-05XP (Mobile Weather Radar-2005, X-band, Phased Array) was used in the field as a weather radar. Due to its rapid update time (10-30 seconds), this radar permits better observation of convective storms, such as tornado events.

Since 2004, scientists at the NOAA/National Severe Storms Laboratory (NSSL) have been exploring the high-temporal resolution scanning capabilities of the S-band phased array antenna as part of the National Weather Radar Testbed (NWRT) program in Norman, Oklahoma. Like prior electronically scanning radars, the NWRT is a military radar that operates at S-band (AN/SPY1-A of the Navy's Aegis system) modified to be operated as a weather radar. The phased array is a single polarized passive array antenna composed of 4,352 open-ended waveguides that provide an electronic beam (with HPBW of 1.5 deg.), scanning in both azimuth and elevation on a pulse-to-pulse basis. In 2008, NSSL examined data from three different convective storms (collected in 2006 using the NWRT over a sector scan of 90 deg in azimuth). It demonstrated the capability to adaptively scan storms at a high temporal resolution that is not possible with the weather surveillance radar WSR-88D (Heinselman et al. 2007).

One of the biggest challenges of using phased array technology for weather applications is achieving similar polarization performance of conventional dish radars. Electronically scanned patterns do not have well-match beam patterns and the same cross-polarization when the beam is steering. In order to overcome this constraint, several approaches have been proposed. NSSL and the University of Oklahoma are evaluating the possibility of prototyping a Cylindrical Polarimetric Phased-Array Radar (CPPAR) for practical scan-invariant weather measurements (Zang et al. 2008). Another approach, proposed by CASA, consists of a low-power, low-cost, dual-polarized, phased array radar. To overcome polarization distortion, the CASA radar performs the electronic scan only in the principal planes where cross-polarization isolation is relatively easy to obtain (Salazar et al. 2011).

In 2007, CASA ERC initiated the development of X-band, dual-polarized, low-cost active phased array radar for weather research. In February 2011, a large planar array composed of 2048 elements was successfully implemented and tested (Salazar 2011). The prototype antenna also serves as a testbed and proof of concept for exploring a potential future network comprised of many antennas arranged in a dense network. The design of the CASA phased array antenna was successfully transferred to CASA industrial and academic partnerships: CASA has licensed the design to ITT, EWR, Vaisala and Raytheon. The Microwave Remote Sensing Laboratory is currently adapting the design for a spaced antenna wind retrieval weather radar system. The company, First RF, in collaboration with Raytheon, used the CASA phased array antenna concept to implement a low-cost phased array radar (Orzel et al. 2011).

It seems that phased array technology is generally accepted in the weather community. During the last decade, important political decisions in the U.S. and Europe have been made to include phased array antennas part of the technology for weather applications. This has allowed innovative research programs at academic institutions to be more involved in the development of phased array antennas for ground-based radar applications.

The 2012 NSF Community Workshop on Radar Technologies identified four future major research themes: (1) extreme events, (2) hydrology and water resources, (3) global climate and climate change, and (4) the integration of radar data with models. Multiple radars (networks) in dual-Doppler configuration with polarization capability that estimate dynamical and microphysical characteristics of clouds and precipitation are critical in order to address these research themes. A large portion of these aforementioned phenomena occurs either in remote mountainous regions (e.g., orographic precipitation) or over the oceans (e.g., tropical cyclones, tropical convection, oceanic fronts, atmospheric rivers) that can only be effectively sampled by airborne Doppler radars (Bluestein and Wakimoto 2003).

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In addition, the *2012 Lower Atmospheric Observing Facilities Workshop: Meeting the Challenge of Climate System Sciences* lists an airborne phased array radar with polarimetric capabilities as a high priority project that would impact future climate research. This capability was noted during independent breakout sessions addressing a number of future research areas (Smith et al. 2012). The National Center for Atmospheric Research (NCAR) has investigated potential configurations for a next-generation airborne radar that is capable of retrieving dynamic and microphysical characteristics of clouds and precipitation (Loew et al. 2007). NCAR has proposed a challenging development of a novel airborne phased array radar (APAR) with dual-Doppler and polarimetric capabilities to be operational on the NSF/NCAR C-130 aircraft. The proposed APAR would replace the now-retired ELectra DOppler RAdar ELDORA (Lee et al. 2014). Spatial resolution would be greatly improved, and polarimetric measurement capability will be added to the airborne radar. One of the key features of APAR, combined with current C-130 in-situ and remote sensing measurements, would be their ability to collect observations in both clear air and precipitation at spatial and temporal scales that will match time and spatial scales of numerical models, a critical factor in data assimilation and model verification.

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What a severe yet master artist old Winter is.... No longer the canvas and the pigments, but the marble and the chisel. ~John Burroughs, "The Snow-Walkers," 1866

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