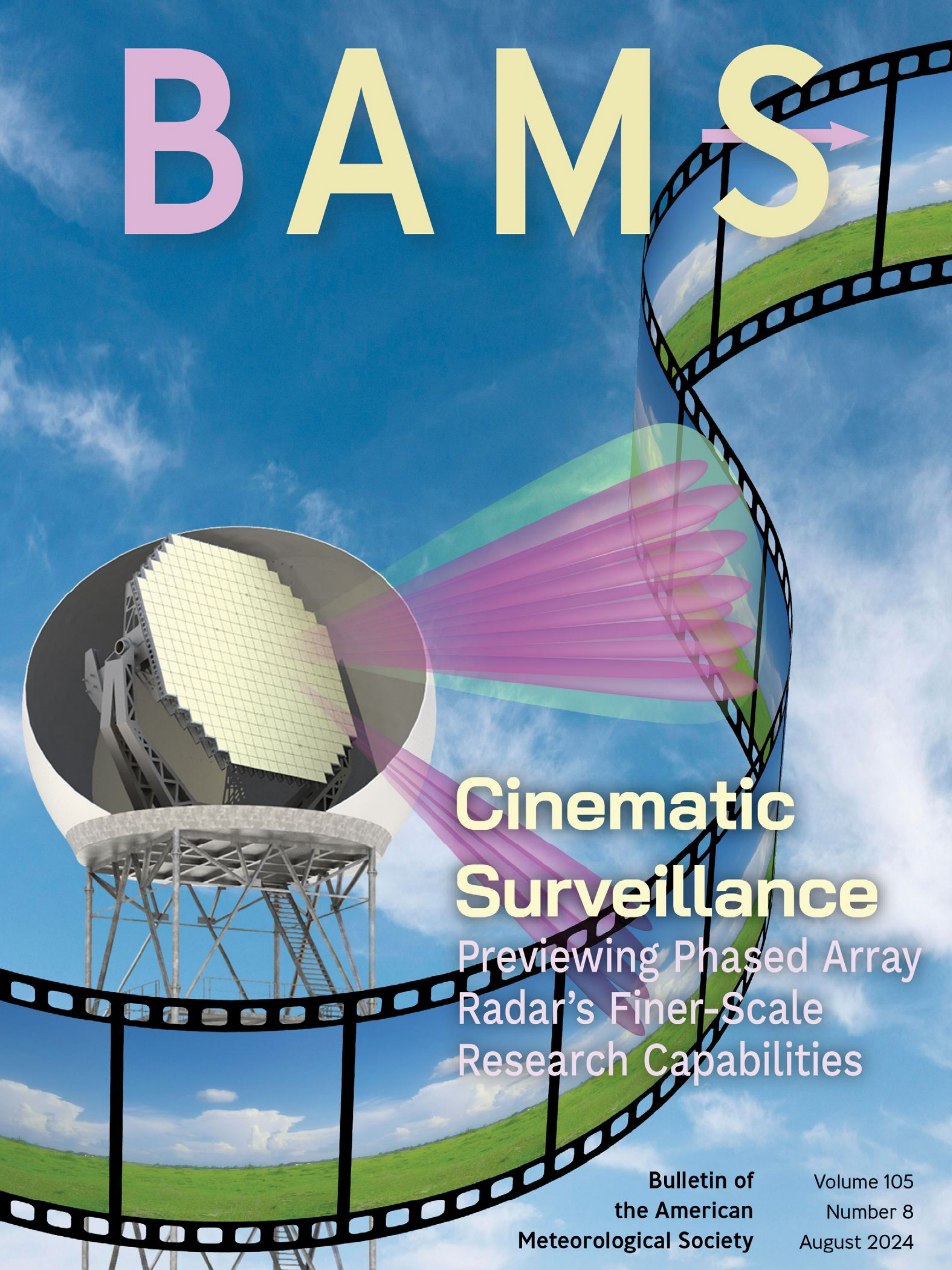

BAMS

Cinematic Surveillance

Previewing Phased Array Radar's Finer-Scale Research Capabilities

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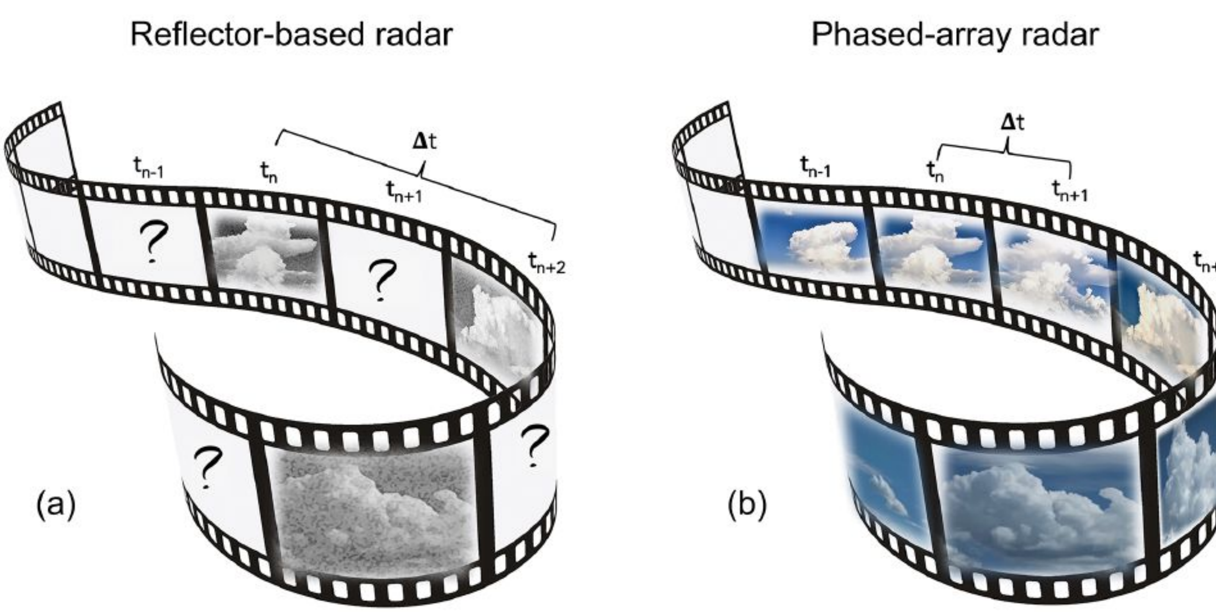
Key messages from "Science Applications of Phased Array Radars," by **Pavlos Kollias** (State University of New York, Stony Brook, and Brookhaven National Laboratory), **Robert Palmer, David Bodine, Toru Adachi, Howie Bluestein, John Y. N. Cho, Casey Griffin, Jana Houser, Pierre. E. Kirstetter, Matthew R. Kumjian, James M. Kurdzo, Wen Chau Lee, Edward P. Luke, Steve Nesbitt, Mariko Oue, Alan Shapiro, Angela Rowe, Jorge Salazar, Robin Tanamachi, Kristofer S. Tuftedal, Xuguang Wang, Dusan Zrnić**, and **Bernat Puigdomènech Treserras**. Published online in BAMS, October 2022. For the full, citable article, see https://doi.org/10.1175/BAMS-D-21-0173.1.

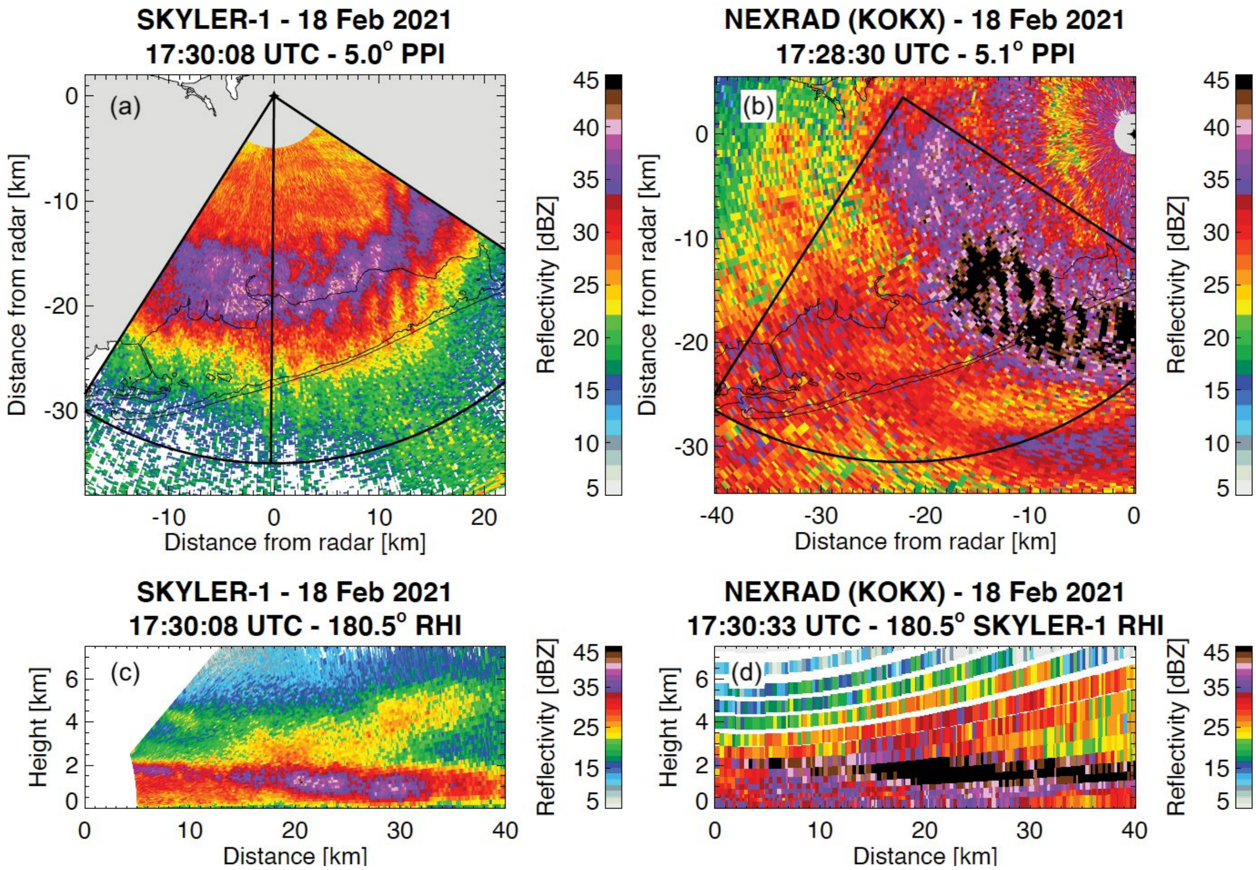
Agile Adaptive Radar Sampling

PARs Can Revolutionize the Way We Observe Cloud and Precipitation Processes



By way of an analogy to movie film, (a) reflector-based radars can only capture coarse spatiotemporal resolution information on the cloud life cycle, while (b) phased array radars can offer the sequence of the convective clouds' life cycle at a higher rate (frames per second) and higher spatial (pixel) resolution.

Phased array radars (PARs) offer near instantaneous sampling of the atmosphere when and where it is needed without mechanical inertia limitations. In addition, PARs offer the ability to change the shape of the radar beam using imaging from pulse to pulse. Thus, for the first time, researchers take full control of the antenna, the component that connects the radar transceiver with the atmosphere. This offers transformative capabilities for sampling rapidly evolving atmospheric phenomena. Scientists need to rethink how they use radars in field experiments if they want to harness the full potential of PARs. For example: How should such agile adaptive radar

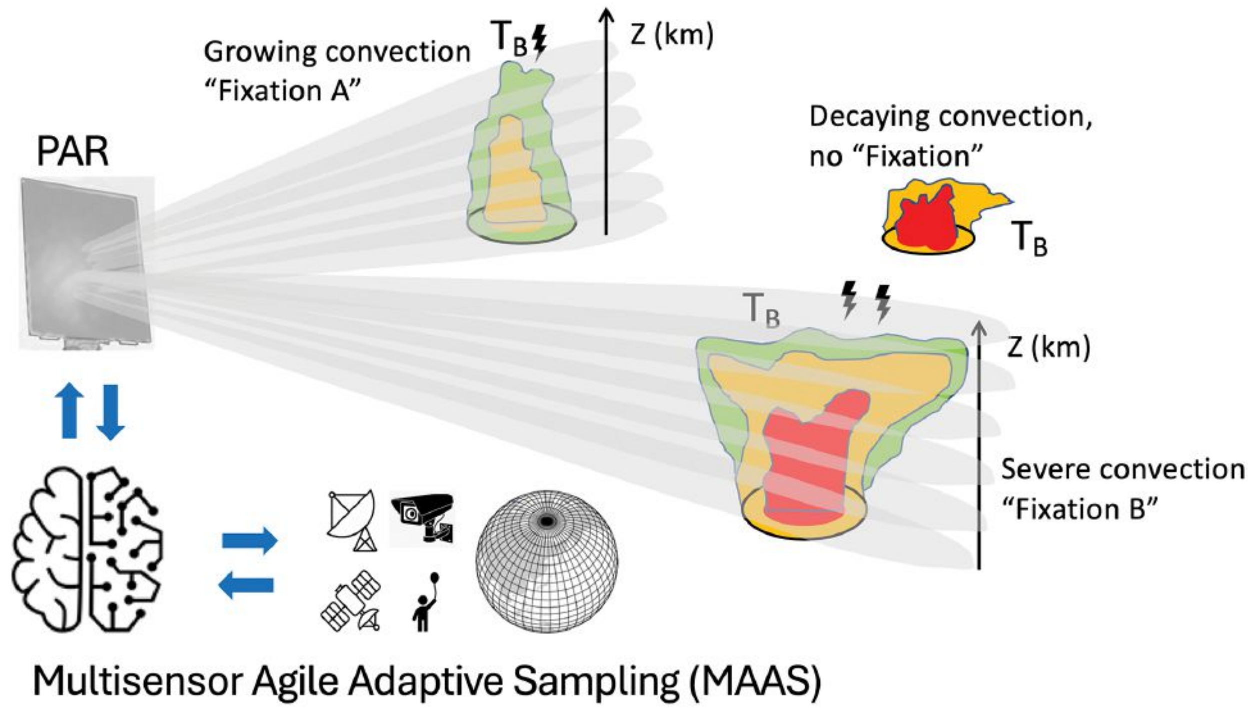


(a) Example plan position indicator (PPI) at 5° from a winter storm on 18 Feb 2021 at 1730:08 UTC in Long Island, NY, from the Raytheon SKYLER-1 system at Stony Brook University; (b) the corresponding PPI from the KOKX WSR-88D at Upton, NY; (c) a SKYLER-1 range–height indicator (RHI) at azimuth 180.5° collected instantaneously with the PPI; and (d) the corresponding reconstructed vertical structure as captured by all the KOKX PPIs along the SKYLER-1 RHI two-dimensional plane.

systems be operated for science applications? What are the new science questions that the PARs' transformative capabilities allow us to tackle?

Surprisingly, until now, PAR research and development efforts have not focused on addressing these questions. Instead, efforts have focused on two main areas: the ongoing debate encompassing the next generation of operational weather radar systems in the United States, and the ongoing engineering efforts for the maturation of the technology needed to develop PAR systems that can reproduce the well-established high standards on the quality of the amplitude, phase, and polarization measurements we have enjoyed with reflector-based radars.

We introduce a different narrative that focuses on the PAR research applications. In particular, our article is the starting point for a broader discussion on how the PAR agile adaptive features can revolutionize the way we observe the atmosphere. We examine several research areas where PARs can provide a leap forward in observational capabilities.



High spatiotemporal resolution observations of fast-evolving atmospheric phenomena such as convective storms and severe weather are discussed. Emphasis is given to current limitations in documenting convective updrafts and how PARs can substantially improve our ability to capture the 3D structure of convective updrafts. Another research area of great interest is the quantification of process rates in convective and stratiform precipitation. This can be achieved if the PAR performs Lagrangian tracking of a volume of cloud to estimate the rate of change in the radar observables due to microphysical processes. Finally, the ability to multifunction between clear air and weather surveillance objectives for the benefit of improved midlevel horizontal wind estimates is discussed.

We look at several strategies on how to integrate PARs in atmospheric research. Their augmentation with reflector-based radars and their integration with other observing systems can offer substantial improvements in our observing capabilities. One common characteristic of the PAR research applications is the need to steer the beam toward the area of interest (i.e., location of a convective core or microphysical process) using agile adaptive sampling. To truly capitalize on the benefits of an inertia-free beam requires a break from the sit-and-spin

A multisensor agile adaptive sampling (MAAS) framework provides situational awareness and manages the PAR resource according to rules based on scientific input and model verification and validation needs. The PAR agile flexible architecture translates the sampling guidance to a mixture of surveillance and tracking strategies.

style notions of preplanned (static) sampling strategies. In 2020, the first iteration of an intelligent agent for weather radars that uses multisensor input for agile adaptive sensing was developed, and its evolution from a static observing system into an intelligent observing protocol system was demonstrated by the author and his research team. The intelligent agent, called Multisensor Agile Adaptive Sampling (MAAS), integrates in real time the data (sensor fusion) from a network of sensors [e.g., cameras, satellites (GOES), radars (WSR-88D), lidars] into an artificial intelligence system that can identify phenomena of interest, allocate resources for their tracking and sampling, and create the proper warning/response output. A new National Science Foundation (NSF) award aims to integrate PARs into the MAAS communication and computation cyberinfrastructure. Projecting this approach further, as the PAR becomes integrated with machine learning capabilities, it becomes the input sensor (or eyes, so to speak) of an intelligent atmospheric computer vision system.

The potential scientific gains enumerated above can only be realized with widespread community access to PAR technology. Recently, NSF awarded the University Corporation for Atmospheric Research (UCAR) a grant to develop the Airborne Phased Array Radar (APAR) that can be mounted on the fuselage of an aircraft, which expands the potential pool of airborne weather radar platforms onto C-130 and other large-fuselage airplanes. In addition to the APAR system, a couple of research-grade PAR systems are at the hands of researchers at universities. Future field campaigns using PAR should be designed by integrating multiple PARs and instruments (e.g., lidars, aircraft measurements), and their deployments should be optimized prior to field campaigns using numerical models and radar simulators. The organization of a future workshop that focuses specifically on PARs to broaden the potential applications and user base of this technology is recommended. One way to increase PAR accessibility to the community is to develop a consistently documented, centrally located database of PAR cases. Our hope is that a concise discussion on the breadth of scientific deadlocks that PARs can overcome in atmospheric measurements will increase the number of early PAR adopters and provide federal agencies with the justification to support PAR-based facilities.

METADATA

BAMS: What would you like readers to learn from this article?

Pavlos Kollias (State University of New York, Stony Brook, and Brookhaven National Laboratory): *PARs are not turnkey systems that will automatically translate science objectives into agile adaptive sampling strategies; it is on scientists to work to harness their full potential. The research community needs to develop the rules, priorities, and intelligence needed to operate PARs in atmospheric experiments in a way that will facilitate scientific discoveries.*

BAMS: How did you become interested in the topic of this article?

PK: *During my Ph.D. studies at the University of Miami, I was fortunate to receive great mentorship from two legends in their respective fields: Bruce Albrecht, an expert in cloud physics and thermodynamics, triggered and developed my curiosity in cloud-scale processes, while Roger Lhermitte, one of the true pioneers of radar meteorology, taught me all about radars.*

BAMS: What surprises you the most about the work you document in this article?

PK: *For nearly 20 years, scientists and engineers have been entertaining the idea that PARs will eventually replace the operational weather radar systems in the United States and the NCAR airborne radar systems, yet it surprises me how few people have considered the research applications of PAR systems.*

BAMS: What is the biggest challenge you encountered while doing this work?

PK: *The biggest challenge is to establish widespread community access to PAR technology. It is imperative that atmospheric scientists of all career stages, from students to mature researchers, have ample opportunities to interact with, operate, and experiment with PARs. Community access to PAR technology will accelerate the adoption of the technology, ensure educational equity, and prepare students to become our future work force.*