INTEGRATING CLASSROOM LEARNING AND RESEARCH

The Pennsylvania Area Mobile Radar Experiment (PAMREX)

BY YVETTE RICHARDSON, PAUL MARKOWSKI, JOHANNES VERLINDE, AND JOSHUA WURMAN

FIG. 1. (top left) Course instructor Yvette Richardson and student James Marquis inside the DOW; (top right) students (Nat Johnson, Timothy Kovich, Kira Altmann, Anthony Chipriano, and Julie Malingowski) participating in a lake-effect snow mission; (bottom left) DOW3 scanning at sunrise on 4 Nov 2003. Mount Nittany is in the background; (bottom right) DOW2 scanning during a stratiform rain event on 24 Nov 2004. (PHOTOS: Top left, Annemarie Mountz; all others, P. Markowski.)

The Pennsylvania Area Mobile Radar Experiment (PAMREX), a collaborative effort between the Department of Meteorology at The Pennsylvania State University and the Center for Severe Weather Research (CSWR), was a student-centered field project with an accompanying, highly interactive sequence of radar meteorology courses having objectives seamlessly integrated with PAMREX's research objectives. The ability to examine meteorological problems specific to the Pennsylvania region with mobile Doppler radars and the desire to integrate field research and coursework were the motivation for PAMREX and the accompanying courses. A two-course sequence was offered in the 2003–04 and 2004–05 academic years, with students collecting PAMREX data during eight-week periods within the fall semesters and analyzing these data in the spring semesters. Students in an additional radar course offered in the spring semester of 2006 also analyzed the data.

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In Pennsylvania, interactions between the complex topography and the lowest few kilometers of the atmosphere can exert substantial controls on the weather. For example, the motion of fronts and air masses is affected by even shallow barriers like the ubiquitous mountain ridges in Pennsylvania. These same topographical features also commonly alter precipitating weather systems, leading to tremendous variability of rainfall and snowfall. The complex terrain of Pennsylvania can produce atmospheric circulations capable of initiating thunderstorms,

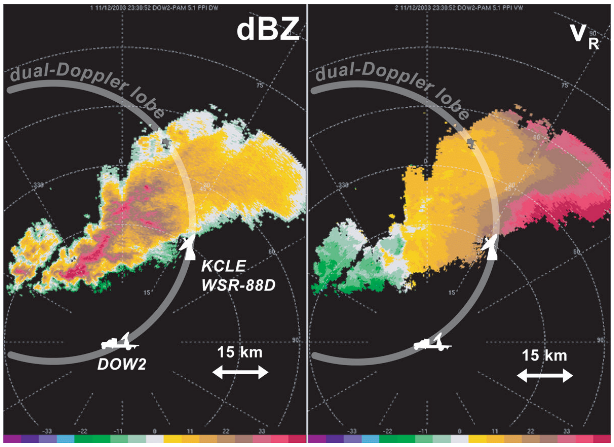

Fig. 2. (left) Reflectivity (dBZ) and (right) radial velocity (m s^{-1}) observations by DOW2 of a severely sheared, low-topped thunderstorm near Cleveland, Ohio, at 2331 UTC 12 Nov 2003. The environment was characterized by exceptionally strong vertical wind shear (0–6 km shear of ~50 m s^{-1}). The DOW2 reflectivity is uncalibrated. The locations of the KCLE WSR-88D and dual-Doppler lobe are overlaid.

in addition to influencing already mature thunderstorms and their attendant severe weather. Surface temperature and roughness differences between Lake Erie and the land surface of Pennsylvania routinely affect small-scale weather as well, with "lake-effect" snowbands being perhaps the most widely known of these lake-induced phenomena. It is even possible that ongoing urban development in central Pennsylvania will increasingly affect circulations near the ground. High-resolution dual-Doppler observations very rarely have been available for the study of these phenomena in the northeastern U.S.

During PAMREX, students used a pair of the CSWR's Doppler On Wheels radars (DOW2 and DOW3; Fig. 1) to study the aforementioned meteorological problems. The DOWs are 3-cm (~9.4 GHz) radars (X-band), which provide an optimal balance between resolution and rain penetration for studying a wide range of phenomena, including snowbands, thunderstorms, and boundary layer motions in clear air. The half-power beamwidth of the DOWs is 0.93°, which yields an azimuthal resolution of 25–200 m for sampling at our typical ranges. Typical gate lengths during PAMREX were 25–50 m. The scanning rate (up to 40° s^{-1}) allows three-dimensional volumes to be scanned in 1–2 min in most scenarios, thereby increasing the temporal resolution by a factor of 2 to 6 over typical operational radars. Simultaneous data collection by a pair of Doppler radars, as was the case for most of the PAMREX missions, allows determination of the full three-dimensional vector wind field, the knowledge of which is critical to further our understanding of the atmospheric phenomena that motivated PAMREX.

Approximately 10 graduate and 22 undergraduate students enrolled in the radar course sequence and/or participated in the field project. Of the undergraduates, 11 went on to pursue graduate degrees, 4 participated in the Rotation in Thunderstorms and Tornadoes Experiment (ROTATE) as crew members of the mobile Doppler radars, 4 use knowledge of remote sensing in private industry, and 3 used mobile radar data analysis directly in their graduate theses. Part I of the course sequence ("Radar Observations and Analysis I") was three credits and offered in the fall semesters. The first six weeks of this course presented a highly accelerated treatment of radar hardware, the radar equation, and Doppler radar, followed by a midterm exam. Following this intensive classroom instruction was an 8-week period of data collection in the field in conjunction with PAMREX, with the driving philosophy being "if you point the microscope at almost anything, you are bound to find something interesting." The students played vital roles in all aspects of PAMREX, including premission planning, forecasting, experimental design, radar operations, and data archival. In fact, PAMREX and its associated radar class very closely emulated what

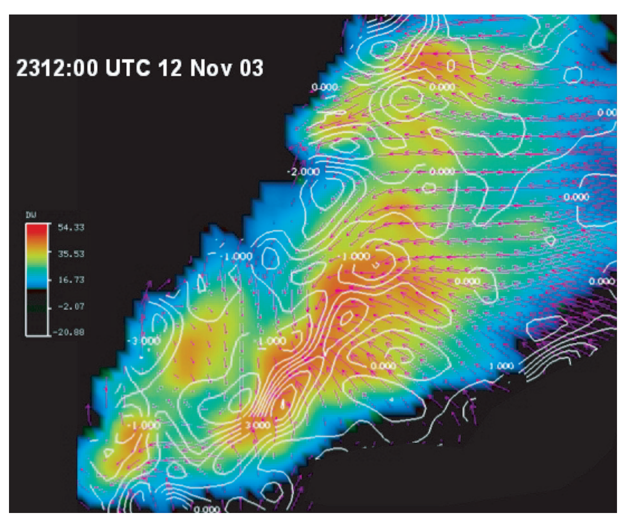

Fig. 3. Dual-Doppler analysis depicting storm-relative winds (magenta vectors), vertical vorticity (white contours every 1 x 10^{-3} s^{-1}), and reflectivity (dBZ) factor at 300-m AGL at 2312 UTC 12 Nov 2003. See also Fig. 2.

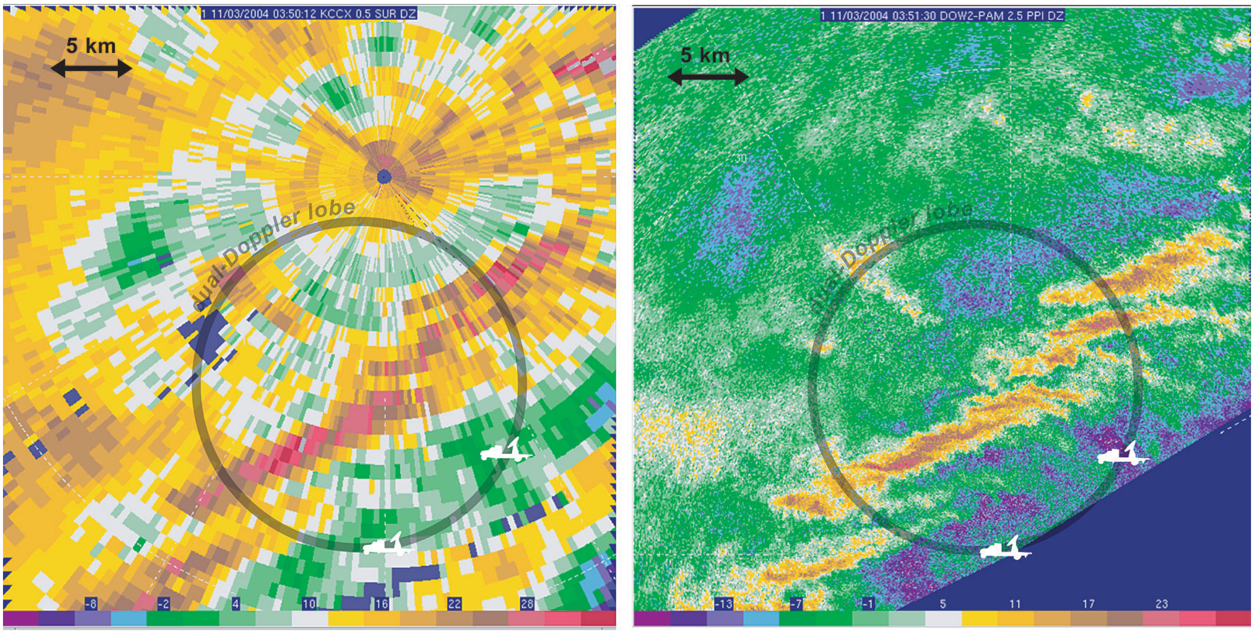

Fig. 4. Radar reflectivity (dBZ) observations of a narrow cold-frontal rainband at 0351 UTC 3 Nov 2004 as seen by the (left) KCCX WSR-88D and (right) DOW2. The DOW2 reflectivity is uncalibrated. The locations of the two DOW radars and the dual-Doppler lobe are overlaid.

occurs in much larger "real" field experiments—long and irregular hours, intergroup conflicts (e.g., a dispute arose between two groups in the class who both wanted to study the same phenomenon), intragroup conflicts (e.g., one member not agreeing with another member's logistical decision in the field), the adrenaline rush of catching the "big event" (e.g., severe thunderstorms in Ohio and a lake-effect snowband in central Pennsylvania), and even the frustration of a missed opportunity, either because of technical difficulties or human error.

Part II of the course sequence ("Radar Observations and Analysis II") involved analysis of the data obtained during the field phase in Part I. Specifically, students learned about radar data editing (e.g., removing noise, ground clutter, and sidelobe contamination, and dealiasing folded velocities), objective analysis (i.e., the gridding of reflectivity and radial velocity data), and dual-Doppler analysis techniques. The students also gained considerable expertise with popular radar community software such as SOLO (used for radar data perusal and editing), REORDER (objective analysis software), and CEDRIC (dual-Doppler wind synthesis software), which were created and are maintained by the National Center for Atmospheric Research. In most cases, the same students who enrolled in Part I also enrolled in Part II.

MISSION HIGHLIGHTS. Many interesting phenomena were sampled during PAMREX. Perhaps the highlight for students was a dual-Doppler storm intercept in Ohio (Figs. 2 and 3) in an environment with small Convective Available Potential Energy (CAPE) and unusually large vertical shear. Another quality dataset involved dual-Doppler observations of a narrow cold-frontal rainband with meso-γ-scale structure (Fig. 4), which was presented by the students at the 2006 AMS student conference ("Dual-Doppler Analysis of a Cold Frontal Rainband on 3 November 2004" by Anthony Chipriano, Timothy Kovich, Victoria Sankovich, Jessica Scollins, and Eric Wanenchak). Other datasets include observations of east–west-oriented banding in a broad cold-frontal rainband, postfrontal longitudinal rolls in a cold-air outbreak accompanied by damaging winds, banded structures within stratiform rain (Fig. 5), possible modulation of boundary layer convection by mountain-valley circulations, and lake-effect snow (Fig. 6).

LOGISTICAL CONSIDERATIONS. The PAMREX project was funded by a three-year George H. Deike Jr. Research Grant awarded by the College of Earth and Mineral Sciences at Penn State to "promote innovative research of high scholarly merit."

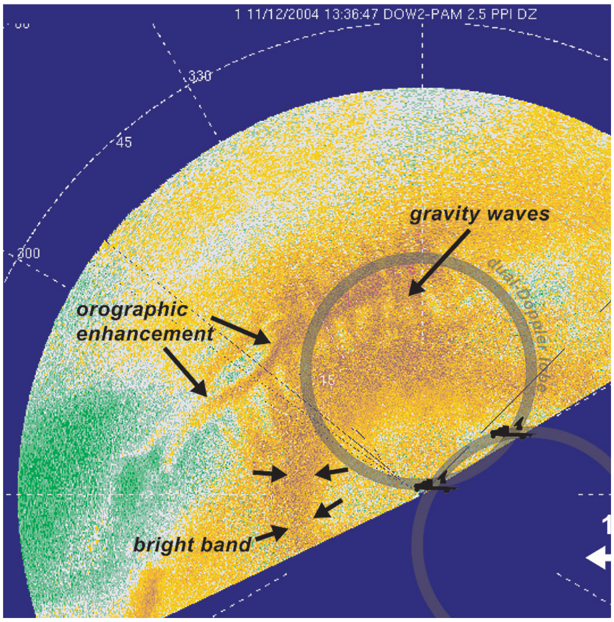

Fig. 5. DOW2 reflectivity (dBZ) at 1337 UTC 12 Nov 2004 during a stratiform rain event. The reflectivity is uncalibrated. The image reveals gravity wave, bright band, and orographic enhancement signatures. The locations of the two DOW radars and the dual-Doppler lobe also are overlaid.

The total award was $45,000 and was used for the travel expenses incurred by driving the DOWs from Colorado to Pennsylvania in both field years, the housing of the DOWs while at Penn State, the gas and minor repairs for the DOWs during the PAMREX project, a computer for data analysis, limited overnight stays by the crew away from Penn State, and the rental of a support vehicle during the field phase. Due to the limited funding available, the instructors served as technicians for the radars, and CSWR provided the DOW radars "at cost" in support of this pilot project. The DOWs are now NSF National Facilities available by request.

The field phases of the project occurred during the regular academic semester, making crew scheduling a particular challenge. Fortunately, between the instructors and graduate students, sufficient flexibility existed to assemble a sufficient crew for all daytime missions, with undergraduate students joining these missions whenever possible and playing a large role in the nighttime missions.

CLOSING REMARKS. The new course sequence offered at The Pennsylvania State University in conjunction with PAMREX intertwined cutting-edge atmospheric science research and a student experience that was highly unusual in its degree of hands-on learning through participation in a complete research project beginning with data collection and experimental design and continuing through to completed analysis of those data. Students had a firsthand taste of what research is all about, particularly field research. The datasets obtained by the students are of research quality, and,

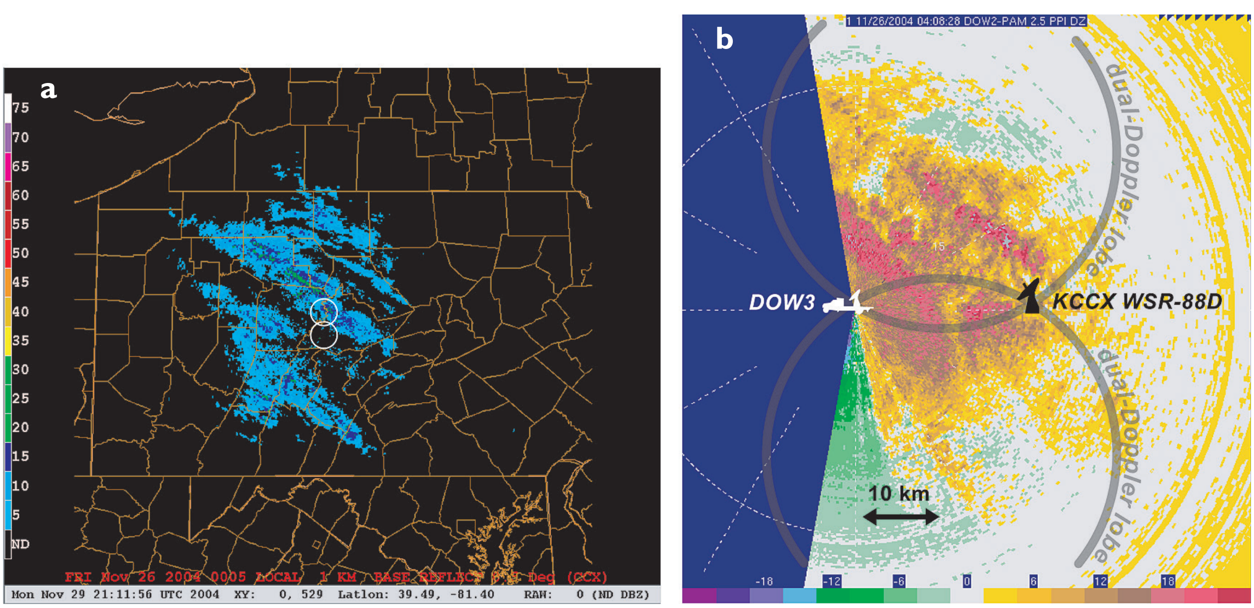

Fig. 6. Lake-effect snowbands on 26 Nov 2004 as seen by the (a) KCCX WSR-88D at 0330 UTC and (b) DOW3 at 0408 UTC. The locations of the KCCX WSR-88D and dual-Doppler lobes are overlaid. Reflectivity is in dBZ.

pending additional analysis, may yet lead to significant contributions to the mesoscale meteorological community. Overall, we found the experience to be challenging and highly rewarding.

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FOR FURTHER READING

Wurman, J. M., 2001: The DOW multiple-Doppler network. Preprints, *30th International Conf. on Radar Meteorology,* Munich, Germany, Amer. Meteor. Soc., 95–97.

——, J. Straka, E. Rasmussen, M. Randall, and A. Zahrai, 1997: Design and deployment of a portable, pencil-beam, pulsed, 3-cm Doppler radar. *J. Atmos. Oceanic Technol.,* **14,** 1502–1512.