

## Resources for Operational Application of Polarimetric Radar Observations

Updated January 2018

### WEBSITES:

- [Dual-pol training from the Warning Decision Training Division](#)
- [Radar & Applications Course \(RAC\) from the Warning Decision Training Division](#)
- [Information from the National Severe Storms Laboratory](#)

### BOOKS:

- Bringi, V. N., and V. Chandrasekar, 2001: *Polarimetric Doppler Weather Radar: Principles and Applications*. Cambridge University Press, 636 pp.
- Doviak, R. J., and D. S. Zrnić, 1993: *Doppler Radar and Weather Observations*. Academic Press, 562 pp.
- Fabry, F., 2015: *Radar Meteorology: Principles and Practice*. Cambridge University Press, 272 pp.
- Hong, Y., and J. J. Gourley, 2014: *Radar Hydrology: Principles, Models, and Applications*. CRC Press, 176 pp.

### JOURNAL ARTICLES:

- *Convection, Severe Local Storms, and Supercells*
  - Bluestein, H. B., M. M. French, R. L. Tanamachi, S. Frasier, K. Hardwick, F. Junyent, and A. L. Pazmany, 2007: Close-range observations of tornadoes in supercells made with a dual-polarization, X-band, mobile Doppler radar. *Mon. Wea. Rev.*, **135**, 1522-1543.
  - Bluestein, H. B., M. M. French, J. C. Snyder, and J. B. Houser, 2016: Doppler radar observations of anticyclonic tornadoes in cyclonically rotating, right-moving supercells. *Mon. Wea. Rev.*, **144**, 1591-1616.
  - Crowe, C. C., W. A. Peterson, L. D. Carey, and D. J. Cecil, 2010: A dual-polarization investigation of tornado-warned cells associated with Hurricane Rita. *Electron. J. Oper. Meteor.*, **11(4)**.
  - Crowe, C. C., C. J. Schultz, M. Kumjian, L. D. Carey, and W. A. Peterson, 2012: Use of dual-polarization signatures in diagnosing tornadic potential. *Elect. J. Oper. Meteor.*, **13(5)**, 57-78.
  - Dawson, D. T., E. R. Mansell, Y. Jung, L. J. Wicker, M. R. Kumjian, and M. Xue, 2014: Low-level  $Z_{DR}$  signatures in supercell forward flanks: The role of size sorting and melting of hail. *J. Atmos. Sci.*, **71**, 276-299.
  - Dawson, D. T., E. R. Mansell, and M. R. Kumjian, 2015: Does wind shear cause hydrometeor size sorting? *J. Atmos. Sci.*, **72**, 340-348.
  - Frame, J., P. Markowski, Y. Richardson, J. Straka, and J. Wurman, 2009: Polarimetric and dual-Doppler radar observations of the Lipscomb County, Texas supercell thunderstorm on 23 May 2002. *Mon. Wea. Rev.*, **137**, 544-561.
  - French, M. M., D. W. Burgess, E. R. Mansell, and L. J. Wicker, 2015: Bulk hook echo raindrop sizes retrieved using mobile, polarimetric Doppler radar observations. *J. Appl. Meteor. Climatol.*, **54**, 423-450.

- French, M. M., P. S. Skinner, L. J. Wicker, and H. B. Bluestein, 2015: Documenting a rare tornado merger observed in the 24 May 2011 El Reno-Piedmont, Oklahoma, supercell. *Mon. Wea. Rev.*, **143**, 3025-3043.
- Griffin, C. B., C. C. Weiss, A. E. Reinhart, J. C. Snyder, H. B. Bluestein, J. Wurman, and K. A. Kosiba, 2017: In situ and radar observations of the low reflectivity ribbon in supercells during VORTEX2. *Mon. Wea. Rev.*, in press.
- Homeyer, C. R., and M. R. Kumjian, 2014: Microphysical characteristics of overshooting convection from polarimetric radar observations. *J. Atmos. Sci.*, **72**, 870-891.
- Houser, J. L., H. B. Bluestein, and J. C. Snyder, 2015: Rapid-scan, polarimetric, Doppler radar observations of tornadogenesis and tornado dissipation in a tornadic supercell: The “El Reno, Oklahoma” storm of 24 May 2011. *Mon. Wea. Rev.*, **143**, 2685-2710.
- Houser, J. L., H. B. Bluestein, and J. C. Snyder, 2016: A finescale radar examination of the tornadic debris signature and weak-echo reflectivity band associated with a large, violent tornado. *Mon. Wea. Rev.*, **144**, 4101-4130.
- Johnson, M., Y. Jung, D. T. Dawson II, and M. Xue, 2016: Comparison of simulated polarimetric signatures in idealized supercell storms using two-moment bulk microphysics schemes in WRF. *Mon. Wea. Rev.*, **144**, 971-996.
- Klees, A. M., Y. P. Richardson, P. M. Markowski, C. Weiss, J. M. Wurman, and K. K. Kosiba, 2016: Comparison of the tornadic and nontornadic supercells intercepted by VORTEX2 on 10 June 2010. *Mon. Wea. Rev.*, **144**, 3201-3231.
- Knight, C. A., 2006: Very early formation of big, liquid drops revealed by  $Z_{DR}$  in continental cumulus. *J. Atmos. Sci.*, **63**, 1939-1953.
- Kumjian, M., and A. Ryzhkov, 2007: Polarimetric characteristics of tornadic and nontornadic supercell thunderstorms. Preprints, *33rd Conf. on Radar Meteorology*, Norman, OK, Amer. Meteor. Soc., 206-208.
- Kumjian, M. R., and A. V. Ryzhkov, 2008: Polarimetric signatures in supercell thunderstorms. *J. Appl. Meteor. Climatol.*, **47**, 1940-1960.
- Kumjian, M. R., and A. V. Ryzhkov, 2009: Storm-relative helicity revealed from polarimetric radar measurements. *J. Atmos. Sci.*, **66**, 667-685.
- Kumjian, M. R., A. V. Ryzhkov, V. M. Melnikov, and T. J. Schuur, 2010: Rapid-scan super-resolution observations of a cyclic supercell with a dual-polarization WSR-88D. *Mon. Wea. Rev.*, **138**, 3762-3786.
- Kumjian, M. R., 2011: Precipitation properties of supercell hook echoes. *Electronic J. Severe Storms Meteor.*, **6(5)**, 1-21.
- Kumjian, M. R., and A. V. Ryzhkov, 2012: The impact of size sorting on the polarimetric radar variables. *J. Atmos. Sci.*, **69**, 2042-2060.
- Kurdzo, J. M., D. J. Bodine, B. L. Cheong, and R. D. Palmer, 2015: High-temporal resolution polarimetric X-band Doppler radar observations of the 20 May 2013 Moore, Oklahoma tornado. *Mon. Wea. Rev.*, **143**, 2711-2735.
- Loney, M. L., D. S. Zrnić, J. M. Straka, and A. V. Ryzhkov, 2002: Enhanced polarimetric radar signatures above the melting level in a supercell storm. *J. Appl. Meteor.*, **41**, 1179-1194.
- Mahale, V. N., J. A. Brotzge, and H. B. Bluestein, 2012: An analysis of vortices embedded within a quasi-linear convective system using X-band polarimetric radar. *Wea. Forecasting*, **27**, 1520-1537.
- Martinaitis, S. M., 2017: Radar observations of tornado-warned convection associated with tropical cyclones over Florida. *Wea. Forecasting*, **32**, 165-186.

- May, P. T., A. R. Jameson, T. D. Keenan, and P. E. Johnston, 2001: A comparison between polarimetric radar and wind profiler observations of precipitation in tropical showers. *J. Appl. Meteor.*, **40**, 1702-1717.
- Meischner, P. F., V. N. Bringi, D. Heimann, and H. Holler, 1991: A squall line in southern Germany: Kinematics and precipitation formation as deduced by advanced polarimetric and Doppler radar measurements. *Mon. Wea. Rev.*, **119**, 678-701.
- Melnikov, V., D. S. Zrnić, D. W. Burgess, and E. R. Mansell, 2015: Vertical extent of thunderstorm inflows revealed by polarimetric radar. *J. Atmos. Oceanic Technol.*, **32**, 1860-1865.
- Palmer, R. D., D. Bodine, M. Kumjian, B. Cheong, G. Zhang, Q. Cao, H. B. Bluestein, A. Ryzhkov, T. Yu, and Y. Wang, 2011: Observations of the 10 May 2010 tornado outbreak using OU-PRIME: Potential for new science with high-resolution polarimetric radar. *Bull. Amer. Meteor. Soc.*, **92**, 871-891.
- Payne, C. D., T. J. Schuur, D. R. MacGorman, M. I. Biggerstaff, K. M. Kuhlman, and W. D. Rust, 2010: Polarimetric and electrical characteristics of a lightning ring in a supercell storm. *Mon. Wea. Rev.*, **138**, 2405-2425.
- Romine, G. S., D. W. Burgess, and R. B. Wilhelmson, 2008: A dual-polarization-radar-based assessment of the 8 May 2003 Oklahoma City area tornadic supercell. *Mon. Wea. Rev.*, **136**, 2849-2870.
- Ryzhkov, A. V., and D. S. Zrnić, 1994: Precipitation observed in Oklahoma mesoscale convective systems with a polarimetric radar. *J. Appl. Meteor.*, **33**, 455-464.
- Snyder, J. C., H. B. Bluestein, D. T. Dawson II, and Y. Jung, 2017: Simulations of polarimetric, X-band radar signatures in supercells. Part I: Description of experiment and simulated phv rings. *J. Appl. Meteor. Climatol.*, **56**, 1977-1999.
- Snyder, J. C., H. B. Bluestein, D. T. Dawson II, and Y. Jung, 2017: Simulations of polarimetric, X-band radar signatures in supercells. Part II: ZDR columns and rings and KDP columns. *J. Appl. Meteor. Climatol.*, **56**, 2001-2026.
- Tanamachi, R. L., H. B. Bluestein, J. B. Houser, S. J. Frasier, and K. M. Hardwick, 2012: Mobile, X-band, polarimetric Doppler radar observations of the 4 May 2007 Greensburg, Kansas, tornadic supercell. *Mon. Wea. Rev.*, **140**, 2103-2125.
- Tanamachi, R. L., and P. L. Heinselman, 2016: Rapid-scan, polarimetric observations of central Oklahoma severe storms on 31 May 2013. *Wea. Forecasting*, **31**, 19-42.
- Tang, B., M. Vaughn, R. Lazear, K. Corbosiero, L. Bosart, T. Wasula, I. Lee, and K. Lipton, 2016: Topographic and boundary influences on the 22 May 2014 Duanesburg, New York, tornadic supercell. *Wea. Forecasting*, **31**, 107-127.
- Thompson, R. L., B. T. Smith, J. S. Grams, A. R. Dean, J. C. Picca, A. E. Cohen, E. M. Leitman, A. M. Gleason, and P. T. Marsh, 2017: Tornado damage rating probabilities derived from WSR-88D data. *Wea. Forecasting*, **32**, 1509-1528.
- Van Den Broeke, M. S., J. M. Straka and E. J. Rasmussen, 2008: Polarimetric radar observations at low levels during tornado life cycles in a small sample of classic southern plains supercells. *J. Appl. Meteor. Climatol.*, **47**, 1232-1247.
- Van Den Broeke, M. S., and C. A. Van Den Broeke, 2015: Polarimetric radar observations from a waterspout-producing thunderstorm. *Wea. Forecasting*, **30**, 329-348.
- Van Den Broeke, M. S., 2016: Polarimetric variability of classic supercell storms as a function of environment. *J. Appl. Meteor. Climatol.*, **55**, 1907-1925.
- Van Den Broeke, M. S., 2017: Polarimetric radar metrics related to tornado life cycles and intensity in supercell storms. *Mon. Wea. Rev.*, **145**, 3671-3686.

- Hail

- Aydin, K., T. A. Seliga, V. Balaji, 1986: Remote sensing of hail with a dual linear polarization radar. *J. Climate. Appl. Meteor.*, **25**, 1475-1484.
- Aydin, K., Y. Zhao, and T. A. Seliga, 1990: A differential reflectivity radar hail measurement technique: Observations during the Denver hailstorm of 13 June 1984. *J. Atmos. Oceanic Technol.*, **7**, 104-113.
- Balakrishnan, N., and D. S. Zrnić, 1990: Use of polarization to characterize precipitation and discriminate large hail. *J. Atmos. Sci.*, **47**, 1525-1540.
- Conway, J. W., and D. S. Zrnić, 1993: A study of embryo production and hail growth using dual-Doppler and multiparameter radars. *Mon. Wea. Rev.*, **121**, 2511-2528.
- Depue, T. K., P. C. Kennedy, and S. A. Rutledge, 2007: Performance of the hail differential reflectivity (HDR) polarimetric radar hail indicator. *J. Appl. Meteor. Climatol.*, **46**, 1290-1301.
- Heinselman, P. L., and A. V. Ryzhkov, 2006: Validation of polarimetric hail detection. *Wea. Forecasting*, **21**, 839-850.
- Hubbert, J. C., and V. N. Bringi, 2000: The effects of three-body scattering on differential reflectivity signatures. *J. Atmos. Oceanic Technol.*, **17**, 51-61.
- Hubbert, J., V. N. Bringi, L. D. Carey, and S. Bolen, 1998: CSU-CHILL polarimetric radar measurements from a severe hail storm in eastern Colorado. *J. Appl. Meteor.*, **37**, 749-775.
- Kaltenboeck, R., and A. Ryzhkov, 2013: Comparison of polarimetric signatures of hail at S and C bands for different hail sizes. *Atmos. Res.*, **123**, 323-336.
- Kennedy, P. C., and A. G. Detwiler, 2003: A case study of the origin of hail in a multicell thunderstorm using in situ aircraft and polarimetric data. *J. Appl. Meteor.*, **42**, 1679-1690.
- Kennedy, P. C., S. A. Rutledge, W. A. Petersen, and V. N. Bringi, 2001: Polarimetric radar observations of hail formation. *J. Appl. Meteor.*, **40**, 1347-1366.
- Ortega, K. L., J. M. Krause, and A. V. Ryzhkov, 2016: Polarimetric radar characteristics of melting hail. Part III: Validation of the algorithm for hail size discrimination. *J. Appl. Meteor. Climatol.*, **55**, 829-848.
- Picca, J. and A. Ryzhkov, 2012: A dual-wavelength polarimetric analysis of the 16 May 2010 Oklahoma City extreme hailstorm. *Mon. Wea. Rev.*, **140**, 1385-1403.
- Ryzhkov, A. V., M. R. Kumjian, S. M. Ganson, and A. P. Khain, 2013: Polarimetric radar characteristics of melting hail. Part I: Theoretical simulations using spectral microphysical modeling. *J. Appl. Meteor. Climatol.*, **52**, 2849-2870.
- Ryzhkov, A. V., M. R. Kumjian, S. M. Ganson, and P. Zhang, 2013: Polarimetric radar characteristics of melting hail. Part II: Practical implications. *J. Appl. Meteor. Climatol.*, **52**, 2871-2886.

- Microbursts and Downbursts

- Kuster, C. M., P. L. Heinselman, and T. J. Schuur, 2016: Rapid-update radar observations of downbursts occurring within an intense multicell thunderstorm on 14 June 2011. *Wea. Forecasting*, **31**, 827-851.
- Mahale, V. N., G. Zhang, and M. Xue, 2016: Characterization of the 14 June 2011 Norman, Oklahoma, downburst through dual-polarization radar observations and hydrometeor classification. *J. Appl. Meteor. Climatol.*, **55**, 2635-2655.

- Wakimoto, R. M., and V. N. Bringi, 1988: Dual-polarization observations of microbursts associated with intense convection: The July 20 storm during the MIST project. *Mon. Wea. Rev.*, **116**, 1521-1539.
- Rainfall Estimation
  - Boodoo, S., D. Hudak, A. Ryzhkov, P. Zhang, N. Donaldson, D. Sills, and J. Reid, 2015: Quantitative precipitation estimation from a C-band dual-polarized radar for the 8 July 2013 flood in Toronto, Canada. *J. Hydromet.*, **16**, 2027-2044.
  - Carr, N., P. E. Kirstetter, J. J. Gourley, and Y. Hong, 2017: Polarimetric signatures of midlatitude warm-rain precipitation events. *J. Appl. Meteor. Climatol.*, **56**, 697-711.
  - Chen, G., K. Zhao, G. Zhang, H. Huang, S. Liu, L. Wen, Z. Yang, Z. Yang, L. Xu, and W. Zhu, 2017: Improving polarimetric C-band radar rainfall estimation with two-dimensional video disdrometer observations in eastern China. *J. Hydromet.*, **18**, 1375-1391.
  - Diederich, M., A. Ryzhkov, C. Simmer, P. Zhang, and S. Tromel, 2015: Use of specific attenuation for rainfall measurement at X-band radar wavelengths. Part I: Radar calibration and partial beam blockage estimation. *J. Hydromet.*, **16**, 487-502.
  - Diederich, M., A. Ryzhkov, C. Simmer, P. Zhang, and S. Tromel, 2015: Use of specific attenuation for rainfall measurement at X-band radar wavelengths. Part II: Rainfall estimates and comparison with rain gauges. *J. Hydromet.*, **16**, 503-516.
  - Friedrich, K., E. A. Kalina, J. Aikins, M. Steiner, D. Gochis, P. A. Kucera, K. Ikeda, and J. Sun, 2016: Raindrop size distribution and rain characteristics during the 2013 great Colorado flood. *J. Hydromet.*, **17**, 53-72.
  - Giangrande, S. E., and A. V. Ryzhkov, 2008: Estimation of rainfall based on the results of polarimetric echo classification. *J. Appl. Meteor. Climatol.*, **47**, 2445-2462.
  - Gorgucci, E., G. Scarchilli, V. Chandrasekar, and V. N. Bringi, 2001: Rainfall estimation from polarimetric radar measurements: Composite algorithms immune to variability in raindrop shape-size relation. *J. Atmos. Oceanic Technol.*, **18**, 1773-1786.
  - Gorgucci, E., and L. Baldini, 2015: Influence of beam broadening on the accuracy of radar polarimetric rainfall estimation. *J. Hydromet.*, **16**, 1356-1371.
  - Henderson, D. S., C. D. Kummerow, and D. A. Marks, 2017: Sensitivity of rain-rate estimates related to convective organization: Observations from the Kwajalein, RMI, radar. *J. Appl. Meteor. Climatol.*, **56**, 1099-1119.
  - Lee, G., 2006: Sources of errors in rainfall measurements by polarimetric radar: variability of drop size distributions, observational noise, and variation of relationships between R and polarimetric parameters. *J. Atmos. Oceanic Technol.*, **23**, 1005-1028.
  - Matrosov, S. Y., P. C. Kennedy, and R. Cifelli, 2014: Experimentally based estimates of relations between X-band radar signal attenuation characteristics and differential phase in rain. *J. Atmos. Oceanic Technol.*, **31**, 2442-2450.
  - Pei, B., F. Y. Testik, and M. Gebremichael, 2014: Impacts of raindrop fall velocity and axis ratio errors on dual-polarization radar rainfall estimation. *J. Hydromet.*, **15**, 1849-1861.
  - Ryzhkov, A. V., and D. S. Zrnić, 1996: Rain in shallow and deep convection measured with a polarimetric radar. *J. Atmos. Sci.*, **53**, 2989-2995.
  - Ryzhkov, A. V. and D. S. Zrnić, 1998: Polarimetric rainfall estimation in the presence of anomalous propagation. *J. Atmos. Oceanic Technol.*, **15**, 1320-1330.
  - Ryzhkov, A., D. S. Zrnić, and R. Fulton, 2000: Areal rainfall estimates using differential phase. *J. Appl. Meteor.*, **39**, 263-268.
  - Ryzhkov, A. V., S. E. Giangrande, and T. J. Schuur, 2005: Rainfall estimation with a polarimetric prototype of WSR-88D. *J. Appl. Meteor.*, **44**, 502-515.

- Ryzhkov, A. V., R. J. Schuur, D. W. Burgess, P. L. Heinselman, S. E. Giangrande, and D. S. Zrnić, 2005: The Joint Polarization Experiment: Polarimetric rainfall measurements and hydrometeor classification. *Bull. Amer. Meteor. Soc.*, **86**, 809-824.
  - Scharfenberg, K. A., D. J. Miller, T. J. Schuur, P. T. Schlatter, S. E. Giangrande, V. M. Melnikov, D. W. Burgess, D. L. Andra, M. P. Foster, and J. M. Krause, 2005: The Joint Polarization Experiment: Polarimetric radar in forecasting and warning decision making. *Wea. Forecasting*, **20**, 775-788.
  - Wang, Y., P. Zhang, A. V. Ryzhkov, J. Zhang, and P.-L. Chang, 2014: Utilization of specific attenuation for tropical rainfall estimation in complex terrain. *J. Hydromet.*, **15**, 2250-2266.
  - Williams, C. R., and P. T. May, 2008: Uncertainties in profiler and polarimetric DSD estimates and their relation to rainfall uncertainties. *J. Atmos. Oceanic Technol.*, **25**, 1881-1887.
- Winter Weather
    - Andrić, J., M. R. Kumjian, D. S. Zrnić, J. M. Straka, and V. M. Melnikov, 2013: Polarimetric signatures above the melting layer in winter storms: An observational and modeling study. *J. Appl. Meteor. Climatol.*, **52**, 682-700.
    - Bechini, R., L. Baldini, and V. Chandrasekar, 2013: Polarimetric radar observations in the ice region of precipitating clouds at C-band and X-band radar frequencies. *J. Appl. Meteor. Climatol.*, **52**, 1147-1169.
    - Bringi, V. N., P. C. Kennedy, G.-J. Huang, C. Kleinkort, M. Thurai, and B. M. Notaroš, 2017: Dual-polarized radar and surface observations of a winter graupel shower with negative Zdr column. *J. Appl. Meteor. Climatol.*, **56**, 455-470.
    - Bukovčić, P., D. Zrnić, and G. Zhang, 2017: Winter precipitation liquid-ice phase transitions revealed with polarimetric radar and 2DVD observations in central Oklahoma. *J. Appl. Meteor. Climatol.*, **56**, 1345-1363.
    - Bukovčić, P., A. Ryzhkov, D. Zrnić, and G. Zhang, 2018: Polarimetric radar relations for quantification of snow based on disdrometer data. *J. Appl. Meteor. Climatol.*, **57**, 103-120.
    - Crowe, C. C., P. Market, B. Pettigrew, C. Melick, and J. Podzimek, 2006: An investigation of thundersnow and deep snow accumulations. *Geophys. Res. Lett.*, **33**, L24812.
    - Griffin, E. M., T. J. Schuur, A. V. Ryzhkov, H. D. Reeves, and J. C. Picca, 2014: A polarimetric and microphysical investigation of the Northeast blizzard of 8-9 February 2013. *Wea. Forecasting*, **29**, 1271-1294.
    - Griffin, E. M., T. J. Schuur, and A. V. Ryzhkov, 2018: A polarimetric analysis of ice microphysical processes in snow, using quasi-vertical profiles. *J. Appl. Meteor. Climatol.*, **57**, 31-50.
    - Kumjian, M. R., 2013: Principles and applications of dual-polarization weather radar. Part II: Warm- and cold-season applications. *J. Operational Meteor.*, **1**(20), 243-264.
    - Kumjian, M. R., A. V. Ryzhkov, H. D. Reeves, and T. J. Schuur, 2013: A dual-polarization signature of hydrometeor refreezing in winter storms. *J. Appl. Meteor. Climatol.*, **52**, 2549-2566.
    - Kumjian, M. R., and A. D. Schenkman, 2014: The curious case of ice pellets in Middle Tennessee on 1 March 2014. *J. Operational Meteor.*, **2**(17), 209-213.
    - Kumjian, M. R., and K. A. Lombardo, 2017: Insights into the evolving microphysical and kinematic structure of Northeastern U.S. winter storms from dual-polarization Doppler radar. *Mon. Wea. Rev.*, **145**, 1033-1061.

- Kumjian, M. R., S. A. Rutledge, R. M. Rasmussen, P. C. Kennedy, and M. Dixon, 2014: High-resolution polarimetric radar observations of snow-generating cells. *J. Appl. Meteor. Climatol.*, **53**, 1636-1658.
  - Kumjian, M. R., and W. Deierling, 2015: Analysis of thundersnow storms over northern Colorado. *Wea. Forecasting*, **30**, 1469-1490.
  - Matrosov, S. Y., R. Cifelli, A. White, and T. Coleman, 2017: Snow-level estimates using operational polarimetric weather radar measurements. *J. Hydromet.*, **18**, 1009-1019.
  - Matrosov, S. Y., C. G. Schmitt, M. Maahn, and G. de Boer, 2017: Atmospheric ice particle shape estimates from polarimetric radar measurements and in-situ observations. *J. Atmos. Oceanic Technol.*, **34**, 2569-2587.
  - Picca, J. C., D. M. Schultz, B. A. Colle, S. Ganetis, D. R. Novak, and M. J. Sienkiewicz, 2014: The value of dual-polarization radar in diagnosing the complex microphysical evolution of an intense snowband. *Bull. Amer. Meteor. Soc.*, **95**, 1825-1834.
  - Ryzhkov, A. V. and D. S. Zrnić, 1998: Discrimination between rain and snow with a polarimetric radar. *J. Appl. Meteor.*, **37**, 1228-1240.
  - Ryzhkov, A. V., D. S. Zrnić, and B. A. Gordon, 1998: Polarimetric method for ice water content determination. *J. Appl. Meteor.*, **37**, 125-134.
  - Schneebeli, M., N. Dawes, M. Lehning, and A. Berne, 2013: High-resolution vertical profiles of X-band polarimetric radar observables during snowfall in the Swiss Alps. *J. Appl. Meteor. Climatol.*, **52**, 378-394.
  - Schrom, R. S., M. R. Kumjian, and Y. Lu, 2015: Polarimetric radar signatures of dendritic growth zones within Colorado winter storms. *J. Appl. Meteor. and Climatol.*, **54**, 2365-2388.
  - Schrom, R. S., and M. R. Kumjian, 2016: Connecting microphysical processes in Colorado winter storms with vertical profiles of radar observations. *J. Appl. Meteor. Climatol.*, **55**, 1771-1787.
  - Schuur, T. J., H. Park, A. V. Ryzhkov, and H. D. Reeves, 2012: Classification of precipitation types during transitional winter weather using the RUC model and polarimetric radar retrievals. *J. Appl. Meteor. Climatol.*, **51**, 763-779.
  - Tobin, D. M., and M. R. Kumjian, 2017: Polarimetric radar and surface-based precipitation-type observations of ice pellet to freezing rain transitions. *Wea. Forecasting*, **32**, 2065-2082.
  - Van Den Broeke, M. S., D. M. Tobin, and M. R. Kumjian, 2016: Polarimetric radar observations of precipitation type and rate from the 2-3 March 2014 winter storm in Oklahoma and Arkansas. *Wea. Forecasting*, **31**, 1179-1196.
  - Williams, E. R., and Coauthors, 2015: Measurements of differential reflectivity in snowstorms and warm season stratiform systems. *J. Appl. Meteor. Climatol.*, **54**, 573-595.
- Non-meteorological Scatterers, Tornado Debris, and Data Quality Considerations
    - Achtemeier, G. L., 1991: The use of insects as tracers for "clear-air" boundary-layer studies by Doppler radar. *J. Atmos. Oceanic Technol.*, **8**, 746 – 765.
    - Bodine, D. J., M. R. Kumjian, R. D. Palmer, P. L. Heinselman, and A. V. Ryzhkov, 2013: Tornado damage estimation using polarimetric radar. *Wea. Forecasting*, **28**, 139–158.
    - Bodine, D. J., R. D. Palmer, and G. Zhang, 2014: Dual-wavelength polarimetric radar analyses of tornadic debris signatures. *J. Appl. Meteor. Climatol.*, **53**, 242-261.

- Bodine, D. J., R. D. Palmer, T. Maruyama, C. J. Fulton, Y. Zhu, and B. L. Cheong, 2016: Simulated frequency dependence of radar observations of tornadoes. *J. Atmos. Oceanic Technol.*, **33**, 1825-1842.
- Bunkers, M. J., and M. A. Baxter, 2011: Radar tornadic debris signatures on 27 April 2011. *Electronic J. Oper. Meteor.*, **12**, 1-6.
- Chilson, P. B., W. F. Frick, J. F. Kelly, K. W. Howard, R. P. Larkin, R. H. Diehl, J. K. Westbrook, T. A. Kelly, and T. H. Kunz, 2012: Partly cloudy with a chance of migration: Weather, radars, and aeroecology. *Bull. Amer. Meteor. Soc.*, **93**, 669-686.
- Friedrich, K., U. Germann, and P. Tabary, 2009: Influence of ground clutter contamination on polarimetric radar parameters. *J. Atmos. Oceanic Technol.*, **26**, 251-269.
- Giangrande, S. E., and A. V. Ryzhkov, 2005: Calibration of dual-polarization radar in the presence of partial beam blockage. *J. Atmos. Oceanic Technol.*, **22**, 1156-1166.
- Griffin, C. B., D. J. Bodine, and R. D. Palmer, 2017: Kinematic and polarimetric radar observations of the 10 May 2010, Moore-Choctaw, Oklahoma, tornadic debris signature. *Mon. Wea. Rev.*, **145**, 2723-2741.
- Hall, W., M. A. Rico-Ramirez, and S. Krämer, 2016: Offshore wind turbine clutter characteristics and identification in operational C-band weather radar measurements. *Q. J. R. Meteor. Soc.*, **143**, 720-730.
- Houser, J. L., H. B. Bluestein, and J. C. Snyder, 2016: A finescale radar examination of the tornadic debris signature and weak-echo reflectivity band associated with a large, violent tornado. *Mon. Wea. Rev.*, **144**, 4101-4130.
- Krause, J. M., 2016: A simple algorithm to discriminate between meteorological and nonmeteorological radar echoes. *J. Atmos. Oceanic Technol.*, **33**, 1875-1885.
- Kumjian, M. R., 2013: Principles and applications of dual-polarization weather radar. Part III: Artifacts. *J. Operational Meteor.*, **1**(21), 265-274.
- Lang, T. J., S. A. Rutledge, and J. L. Smith, 2004: Observations of quasi-symmetric echo patterns in clear air with the CSU-CHILL polarimetric radar. *J. Atmos. Oceanic Technol.*, **21**, 1182-1189.
- Lakshmanan, V., C. Karstens, J. Krause, K. Elmore, A. Ryzhkov, and S. Berkseth, 2015: Which polarimetric variables are important for weather/no-weather discrimination? *J. Atmos. Oceanic Technol.*, **32**, 1209-1223.
- Melnikov, V. M., M. J. Istok, and J. K. Westbrook, 2015: Asymmetric radar echo patterns from insects. *J. Atmos. Oceanic Technol.*, **32**, 659-674.
- Murphy, T. A., R. A. Wade, and B. C. Carcione, 2016: Observations and operational considerations of the 4 June 2013 chaff event in northern Alabama. *J. Operational Meteor.*, **4**, 34-45.
- Ryzhkov, A. V., T. J. Schuur, D. W. Burgess, and D. S. Zrnić, 2005: Polarimetric tornado detection. *J. Appl. Meteor.*, **44**, 557-570.
- Ryzhkov, A. V., 2007: The impact of beam broadening on the quality of radar polarimetric data. *J. Atmos. Oceanic Technol.*, **24**, 729-744.
- Ryzhkov, A. V., D. S. Zrnić, 2007: Depolarization in ice crystals and its effect on radar polarimetric measurements. *J. Atmos. Oceanic Technol.*, **24**, 1256-1267.
- Schultz, C. J., L. D. Carey, E. V. Schultz, B. C. Carcione, C. B. Darden, C. C. Crowe, P. N. Gatlin, D. J. Nadler, W. A. Petersen, and K. R. Knupp, 2012: Dual-polarization tornadic debris signatures part I: Examples and utility in an operational setting. *Electronic J. Oper. Meteor.*, **13**, 120-137.



- Schultz, C. J., S. E. Nelson, L. D. Carey, L. Belanger, B. C. Carcione, C. B. Darden, T. Johnstone, A. L. Molthan, G. J. Jedlovec, E. V. Schultz, C. C. Crowe, and K. R. Knupp, 2012: Dual-polarization tornadic debris signatures part II: Comparisons and caveats. *Electronic J. Oper. Meteor.*, **13**, 138-150.
  - Van Den Broeke, M. S., 2013: Polarimetric radar observations of biological scatterers in Hurricanes Irene (2011) and Sandy (2012). *J. Atmos. Oceanic Technol.*, **30**, 2754-2767.
  - Van Den Broeke, M. S., and S. T. Jauernic, 2014: Spatial and temporal characteristics of polarimetric tornadic debris signatures. *J. Appl. Meteor. Climatol.*, **53**, 2217-2231.
  - Van Den Broeke, M. S., 2015: Polarimetric tornadic debris signature variability and debris fallout signatures. *J. Appl. Meteor. Climatol.*, **54**, 2389-2405.
  - Van Den Broeke, M. S., and H. Alsarraf, 2016: Polarimetric radar observations of dust storms at C- and S-band. *J. Operational Meteor.*, **4**, 123-131.
  - Van Den Broeke, M. S., 2017: Potential tornado warning improvement resulting from utilization of the TDS in the warning decision process. *J. Operational Meteor.*, **5**, 121-133.
  - Zrnić, D. S., and A. V. Ryzhkov, 2004: Polarimetric properties of chaff. *J. Atmos. Oceanic Technol.*, **21**, 1017-1024.
- Algorithms
    - Carlin, J. T., A. V. Ryzhkov, J. C. Snyder, and A. Khain, 2016: Hydrometeor mixing ratio retrievals for storm-scale radar data assimilation: Utility of current relations and potential benefits of polarimetry. *Mon. Wea. Rev.*, **144**, 2981-3001.
    - Chang, W., J. Vivekanandan, K. Ikeda, and P-L. Lin, 2016: Quantitative precipitation estimation of the epic 2013 Colorado flood event: Polarization radar-based variational scheme. *J. Appl. Meteor. Climatol.*, **55**, 1477-1495.
    - Chen, H., V. Chandrasekar, and R. Bechini, 2017: An improved dual-polarization radar rainfall algorithm (DROPS2.0): Application in NASA IFloodS field campaign. *J. Hydromet.*, **18**, 917-937.
    - Elmore, K. L., 2011: The NSSL hydrometeor classification algorithm in winter surface precipitation: Evaluation and future development. *Wea. Forecasting*, **26**, 756-765.
    - Giangrande, S. E., J. M. Krause, and A. V. Ryzhkov, 2008: Automatic designation of the melting layer with a polarimetric prototype of the WSR-88D radar. *J. Appl. Meteor. Climatol.*, **47**, 1354-1364.
    - Hall, M. P. M., J. W. F. Goddard, and S. M. Cherry, 1984: Identification of hydrometeors and other targets by dual-polarization radar. *Radio Sci.*, **19**, 132-140.
    - Hengstebeck, T., K. Wapler, D. Heizenreder, and P. Joe, 2017: Network radar-based detection of mesocyclones at the German Meteorological Service. *J. Atmos. Oceanic Technol.*, in press.
    - Krause, J. M., 2016: A simple algorithm to discriminate between meteorological and nonmeteorological radar echoes. *J. Atmos. Oceanic Technol.*, **33**, 1875-1885.
    - Liu, H., and V. Chandrasekar, 2000: Classification of hydrometeors based on polarimetric radar measurements: Development of fuzzy logic and neuro-fuzzy systems, and In Situ verification. *J. Atmos. Oceanic Technol.*, **17**, 140-164.
    - Mahale, V. N., G. Zhang, and M. Xue, 2014: Fuzzy logic classification of S-band polarimetric radar echoes to identify three-body scattering and improve data quality. *J. Appl. Meteor. Climatol.*, **53**, 2017-2033.

- Ortega, K. L., J. M. Krause, and A. V. Ryzhkov, 2016: Polarimetric radar characteristics of melting hail. Part III: Validation of the algorithm for hail size discrimination. *J. Appl. Meteor. Climatol.*, **55**, 829-848.
- Park, H., A. V. Ryzhkov, D. S. Zrnić, and K. Kim, 2009: The hydrometeor classification algorithm for the polarimetric WSR-88D: Description and application to an MCS. *Wea. Forecasting*, **24**, 730-748.
- Park, S.-G., J.-H. Kim, J.-S. Ko, and G. Lee, 2016: Identification of range overlaid echoes using polarimetric radar measurements based on a fuzzy logic approach. *J. Atmos. Oceanic Technol.*, **33**, 61-80.
- Porcaccia, L., P. E. Kirstetter, J. J. Gourley, V. Maggioni, B. L. Cheong, and M. N. Anagnostou, 2017: Toward a polarimetric radar classification scheme for coalescence-dominant precipitation: Application to complex terrain. *J. Hydromet.*, **18**, 3199-3215.
- Ribaud, J.-F., O. Bousquet, S. Coquillat, H. Al-Sakka, D. Lambert, V. Ducrocq, and E. Fontaine, 2015: Evaluation and application of hydrometeor classification algorithm outputs inferred from multi-frequency dual-polarimetric radar observations collected during HyMeX. *Q. J. R. Meteor. Soc.*, **142**, 95-107.
- Ryzhkov, A., P. Zhang, H. Reeves, M. Kumjian, T. Tschallener, S. Trömel, and C. Simmer, 2016: Quasi-vertical profiles—A new way to look at polarimetric radar data. *J. Atmos. Oceanic Technol.*, **33**, 551-562.
- Snyder, J. C., A. V. Ryzhkov, M. R. Kumjian, A. P. Khain, and J. Picca, 2015: A  $Z_{DR}$  column detection algorithm to examine convective storm updrafts. *Wea. Forecasting*, **30**, 1819-1844.
- Snyder, J. C., and A. V. Ryzhkov, 2015: Automated detection of polarimetric tornadic debris signatures using a hydrometeor classification algorithm. *J. Appl. Meteor. Climatol.*, **54**, 1861-1870.
- Starzec, M., C. R. Homeyer, and G. L. Mullendore, 2017: Storm labeling in three dimensions (SL3D): A volumetric radar echo and dual-polarization updraft classification algorithm. *Mon. Wea. Rev.*, **145**, 1127-1145.
- Straka, J. M., D. S. Zrnić, and A. V. Ryzhkov, 2000: Bulk hydrometeor classification and quantification using polarimetric radar data: synthesis of relations. *J. Appl. Meteor.*, **39**, 1341-1372.
- Thurai, M., K. V. Mishra, V. N. Bringi, and W. F. Krajewski, 2017: Initial results of a new composite-weighted algorithm for dual-polarized X-band rainfall estimation. *J. Hydromet.*, **18**, 1081-1100.
- Vivekanandan, J., D. S. Zrnić, S. M. Ellis, R. Oye, A. V. Ryzhkov, and J. Straka, 1999: Cloud microphysics retrieval using S-band dual-polarization radar measurements. *Bull. Amer. Meteor. Soc.*, **80**, 381-388.
- Wang, Y., and T. Yu, 2015: Novel tornado detection using an adaptive neuro-fuzzy system with S-band polarimetric weather radar. *J. Atmos. Oceanic Technol.*, **32**, 195-208.
- Wen, G., A. Protat, P. T. May, W. Moran, and M. Dixon, 2016: A cluster-based method for hydrometeor classification using polarimetric variables. Part II: Classification. *J. Atmos. Oceanic Technol.*, **33**, 45-60.
- Wolfensberger, D., D. Scipion, and A. Berne, 2015: Detection and characterization of the melting layer based on polarimetric radar scans. *Q. J. R. Meteor. Soc.*, **142**, 108-124.
- Xie, X., E. Evaristo, S. Troemel, P. Saavedra, C. Simmer, and A. Ryzhkov, 2016: Radar observation of evaporation and implications for quantitative precipitation and cooling rate estimation. *J. Atmos. Oceanic Technol.*, **33**, 1779-1792.