ATMO 689
Polarimetric Radar Meteorology

Course Syllabus, Fall 2004

Instructor

Dr. Larry Carey
Office: O&M Building, Room 1108c
E-mail: larry_carey@tamu.edu
Phone: 847-9090
Office Hours: TR 2:00 – 3:00 PM (or by appointment)

Course Objectives

Polarimetric radars take advantage of the polarimetric state of the transmitted and received electromagnetic wave, in addition to the magnitude and phase as with conventional Doppler radars. As a result, polarimetric radars can deduce information regarding the size, shape, phase (e.g., ice vs. water), and orientation of precipitation hydrometeors. Polarimetric radar techniques can also be used to quality control radar data, remove artifacts caused by ground clutter, anomalous propagation and clear air, provide a self-consistent calibration, and correct for attenuation. Because of these advantages, the fields of operational and research Radar Meteorology are currently experiencing a shift in precipitation measurement paradigms; transitioning from conventional power-based measures of precipitation rate and coverage, to more accurate and complete dual-polarimetric estimates of bulk hydrometeor types (e.g., rain vs. hail) and amounts (rain rates and water contents) in the radar resolution volume.

As such, this course on *Polarimetric Radar Meteorology* will cover the theory behind radar polarimetry (including particle scattering in a linear polarimetric basis), the instrumental characteristics of dual-polarized radar systems, including the collection, and physical interpretation of dual-polarimetric radar variables. Although the theoretical background will be rigorous, the theoretical emphasis will be on understanding implications for practical meteorological applications rather than the mathematical methods used for developing the theory. Emphasis will be placed on hydrometeorological applications, specifically, precipitation measurement and hydrometeor identification in distributed weather targets. Due to the applied, "hands-on" nature of the course, grades will be based on home work (including applied problem sets and critical literature reviews), and a final class project (case study paper and presentation) due at the end of the semester.

Course Schedule

Lecture: TR 12:45 – 2:00 PM, O&M 1209

Prerequisites

Undergraduate-level exposure to basic electromagnetism (e.g., undergraduate physics, electromagnetism, or remote sensing class) and radar meteorology (e.g., in a radar meteorology, severe weather, mesoscale meteorology, remote sensing or instrumentation class), which is roughly equivalent to material contained in Chapters 1-8 of Rinehart (1997) (see below), are recommended but not required. Students with little or no previous experience in radar meteorology can enroll in the class if they are willing to read and familiarize themselves with the above material in Rinehart (1997) prior to or during the start of the semester. Note – Rinehart is very readable and succinct so this requirement is not as bad as it sounds!

Required Textbook

Bringi, V. N. and V. Chandrasekar, 2001: *Polarimetric Doppler weather radar: principles and applications*, Cambridge University Press.

Recommended Textbooks

Doviak, Richard J. and Dušan S. Zrnić, 1993: *Doppler radar and weather observations,* 2nd Ed, Academic Press.

Stephens, Graeme L., 1994: *Remote sensing of the lower atmosphere: An introduction*, Oxford University Press.

Recommended Undergraduate-level Textbook for Review

Rinehart, Ronald E., 1997: *Radar for meteorologists*, 3rd Ed, 1997, Rinehart Publications.

Recommended Reference Books

Atlas, David (Ed.), 1990: *Radar in meteorology: Battan Memorial,* American Meteorological Society.

Wakimoto, Roger M. and Ramesh Srivastava (Eds.), 2003: *Radar and atmospheric science: A collection of essays in honor of David Atlas*, American Meteorological Society.

Other Reference Material:

Several professional journals published by the American Meteorological Society (e.g., Journal of Applied Meteorology, Journal of Oceanic and Atmospheric Technology, Bulletin of the American Meteorological Society, Monthly Weather Review, Journal of Atmospheric Sciences and Journal of Hydrometeorology), the American Geophysical Union (e.g., Journal of Geophysical Research – Atmospheres, Radio Science) and others contain useful information on radar meteorology theory, methods and applications.

Tentative Course Outline

WEEK 1: *Doppler radar refresher*

Quick review of basic Doppler radar history, hardware, scanning, electromagnetic waves, refractivity, radar equation, radar reflectivity (η), radar reflectivity factor (Z), effective radar reflectivity factor (Z_e), simple block diagram of a Doppler radar, Doppler radial velocity (V_r), maximum unambiguous range and velocity, range and velocity aliasing, dual-Doppler synthesis of the three-dimensional wind field (U, V, W), and miscellaneous Doppler observations (Z, V_r, U, V, W) of various storm phenomena including tornado signature, mesocyclone, hail, heavy rain, and bright band.

WEEK 2: *Motivation and introduction to radar (wave) polarization*

Why polarization? Review method and implications of single parameter radar approach to estimation of rainfall (R) and liquid water content (M): Z-R and Z-M relationships. Qualitative definition and benefits of wave and radar polarization. Brief history of polarization radar theory, radars, and applications. Review wave polarization – physical and mathematical basis. Polarization ellipse and types of polarization (linear, circular, elliptical). Stokes vector and the Mueller matrix.

WEEK 3: *Radar range equation in the linear polarization basis and radar observables*

Basics of antenna radiation and reception. Dual-polarized antennas in a linear polarization basis. Voltage equation and scattering matrix for dual-polarized antenna. Radar range equation for a single particle in a linear polarization basis. Radar backscatter cross-section. Reduction to conventional radar range equation. Ensemble-averaged Mueller and covariance matrices. Radar observables (from backscattering) in a linear polarization basis (Z_h, Zdr, LDR, ρ_{hv}).

WEEK 4: *Hydrometeor scattering*

Dielectric properties of hydrometeors and implications (e.g., bright band revisited). Rayleigh scattering by a dielectric sphere. Scattering matrix for sphere and spheroid in the Rayleigh-Gans approximation. Mie solution for scattering. Low-frequency approximation to Mie scattering. Calculation of radar observables for different hydrometeor types (e.g., rain, hail, graupel, snow) using theory (Rayleigh-Gans, Mie). Preliminary basis for polarimetric identification of hydrometeor types.

WEEK 5: *Dual-Polarized Wave Propagation*

Forward scattering and coherent wave propagation. Transmission matrix. Radar range equation with transmission matrix. Attenuation, differential attenuation, and differential phase associated with oriented hydrometeors (e.g., rain). Effect of attenuation and differential attenuation on backscatter-based radar observables. Radar observables from forward scattering in a linear basis (K_{dp}). Calculation of K_{dp} using Rayleigh-Gans theory in rain and other hydrometeors (e.g., hail, ice crystals).

WEEK 6: *Dual-polarized Radar Systems and Signal Processing Algorithms*

General system aspects. Single transmitter and receiver - transmitter aspects, receiver aspects. Ferrite and Rotary switches. Dual receiver and dual transmit systems. Block diagrams and characteristics of polarimetric research radars (e.g., NCAR S-POL, CSU-CHILL, BMRC C-POL). Antenna performance characteristics. Radar calibration. Estimation of covariance matrix and variance of the estimates in 1) alternate polarization pulse mode, and 2) hybrid mode (simultaneous transmit and receive of both polarizations).

WEEK 7: *Polarimetric Radar Data Processing*

Rejection of non-hydrometeor echo (clutter, anomalous propagation, clear air returns, non-meteorological targets such as insects and birds) using polarimetric techniques (ρ_{hv}; differential phase, Φ_{dp}). Practical estimation of specific differential phase (K_{dp}) – filtering, linear regression. Calibration of Z_{dr} (vertically pointing scans, empirical approach in drizzle or snow at high elevation angle). Calibration of Z_h using self-consistency among $Z_h/Z_{dr}/K_{dp}$. Estimation and correction of attenuation and differential attenuation in rain using differential phase (Φ_{dp}). Theoretical basis and issues. Simple implementation – fixed coefficients and empirical approach. Phase-based propagation correction using constraints. Examples of techniques at various wavelengths (S-band, C-band, X-band).

WEEK 8: *Polarimetric Basis for Characterizing Precipitation – Part I, Rain*

Properties and models of rain important for polarimetric radar methods – raindrop shape, size distribution, and orientation. Physical interpretation of polarimetric observables (Z_h, Z_{dr}, K_{dp}, LDR, ρ_{hv}) in rainfall. Equilibrium rain drop shape vs. observations – effect of drop oscillations on polarimetric parameters. Simulation of polarimetric observables in rain using T-matrix and Mueller matrix approach. Effect of rain (drop size distribution, shape, orientation), radar (wavelength, elevation angle), and environmental (temperature) properties on polarimetric observables. Observed horizontal and vertical structure of polarimetric properties in convective rainfall.

WEEK 9: *Polarimetric Basis for Characterizing Precipitation – Part II, Hail*

Properties and models of hail important for polarimetric radar methods – hail shape, size distribution, and orientation. Physical interpretation of polarimetric observables (Z_h, Z_{dr}, K_{dp}, LDR, ρ_{hv}) in hail. Simulation of polarimetric observables in hail using T-matrix and Mueller matrix approach. Effect of hail (drop size distribution, shape, orientation, dielectric), radar (wavelength, elevation angle), and environmental (temperature) properties on polarimetric observables. Observed horizontal and vertical structure of polarimetric properties in hailstorms. Polarimetric signatures of melting hail. Mie resonance effects on polarimetric observables. Techniques for differentiating rain from hail and their mixtures (Z_h/Z_{dr} – "Z_{dr} hole," K_{dp}, H_{dr}, LDR, ρ_{hv}). Techniques for approximate estimation of hail size (e.g., small versus large using Z_h, Z_{dr}, LDR and ρ_{hv}).

WEEK 10: *Polarimetric Basis for Characterizing Precipitation – Part III, Other Ice (e.g., Ice Crystals, Snow, Graupel)*

Observed horizontal and vertical structure of polarimetric properties in cold and mixed-phase clouds for both convective and stratiform precipitation. Polarimetric signatures of melting ice (graupel and snow) – "polarimetric bright band" and comparison to conventional radar reflectivity bright band. Polarimetric methods for differentiating ice from rain – difference reflectivity (Z_{dp}) and K_{dp} methods. Polarimetric signatures of vertically oriented ice crystals in a strong electric field (K_{dp}).

WEEK 11: *Hydrometeor Classification*

Synthesis of weeks 7-10. Empirical algorithms using threshold boundaries and Boolean decision trees. Application to observations at S-band and C-band. Fuzzy logic classification – theory and configuration using polarimetric data. Examples and comparison with in-situ aircraft and surface observations.

WEEK 12: *Polarimetric Radar Rainfall Estimation*

Physically based parametric rain rate (R) and water content (W) algorithms – (Z_h, Z_{dr}), (K_{dp}), (K_{dp}, Z_{dr}). Error structure and practical issues in polarimetric rain rate estimation. Combined/optimal approach. Comparison with conventional Z-R approach. Polarimetric tuning of Z-R relations. Applications and comparisons with rain gauges at various wavelengths (S-, C-, X-band).

WEEKS 13 and 14: *Selected Applications of Polarimetric Radar Methods in the Atmospheric Sciences*

Cloud/precipitation physics studies and combination with traditional multi-Doppler techniques for integrated storm kinematic and physics studies (multicell, supercell, hailstorms, mesoscale convective systems, snow storms, flash flooding, cloud electricity and lightning, and latent heating estimation). Transition of polarimetric radars and techniques to the operational weather community (J-POLE, NSSL KOUN). Future technologies and approaches.

Grading Policy

Percentage	Item
10%	Classroom *attendance and participation in discussion* (that is based on reading assignments from the text, assigned journal articles, and other supplementary handouts as provided in class.)
20%	*Homework* as assigned in class, including some computer work (i.e., modifying and running FORTRAN or IDL code) that will require *basic* knowledge in UNIX and programming. Anticipate roughly four assignments that will be short and applied in nature (i.e., *not* derivations).
20%	*Student led critical review of an assigned journal article* in the field of polarimetric radar – 15-20 minute oral summary and assessment of key background, data/methodology, results, and conclusions of the journal article using electronic means (e.g., MS PowerPoint or other convenient slideshow format). Student led paper reviews will be integrated into lecture during weeks 4-11. Directions, including suggestions regarding content and style, and paper assignments will be given during week 3.
50% (30/20 written/oral)	*"Hands-on" group radar project* - self-directed case study of an interesting meteorological event (e.g., hail storm, heavy rain/flash flood, winter storm, supercell, mesoscale convective system) using research quality polarimetric radar data and state-of-the-art viewing and analysis tools. Students will be paired into groups of two. Evaluation of your group's case study will be based on a detailed written report (i.e., approximately 8 to 10 pages of double-spaced, 12-point font text, *not* including figures and tables, in MS Word or PDF format) and an oral presentation (15-20 minutes in MS PowerPoint or other convenient electronic slideshow format) describing the key background information, data/methodology, results, and conclusions of your project. Project orientation and selection will occur during week 7. Written reports are to be turned in by 5:00 PM on Thursday, 9 December 2004 and will count toward 30% of your overall grade. Groups will present their project findings collectively during a "Workshop on Polarimetric Radar Meteorology," which is tentatively scheduled during the final exam slot assigned by the University (8:00 – 10:00 AM, Wednesday, 15 December 2004). You must provide your oral presentation file (e.g., .ppt file) via electronic means (i.e., either via e-mail, ftp, or common storage device) by 5:00 PM on Monday, 13 December 2004. Oral presentations will account for 20% of the overall grade; evaluation will be based on scientific content, communication skills, and demonstrated knowledge during the presentation and question-and-answer session afterwards.

There will be *no* quizzes or exams.

Letter grades will be assigned based on the following approximate guidelines:

90 - 100%	A
80 - 89%	B
70 - 79%	C
60 - 69%	D
<60%	F

Aggie Honor and Plagiarism

The Honor Code, based on the long-standing affirmation that An Aggie does not lie, cheat, or steal or tolerate those who do, is fundamental to the value of the A&M experience. Know the Code. Aggie Code of Honor "An Aggie does not lie, cheat, or steal or tolerate those who do." http://www.tamu.edu/aggiehonor/

The materials used in this course are copyrighted. These materials include but are not limited to syllabi, quizzes, exams, lab problems, in-class materials, review sheets, and additional problem sets. Because these materials are copyrighted, you do not have the right to copy the handouts, unless permission is expressly granted.

As commonly defined, plagiarism consists of passing off as one's own the ideas, words, writings, etc., which belong to another. In accordance with this definition, you are committing plagiarism if you copy the work of another person and turn it in as your own, even is you should have the permission of that person. Plagiarism is one of the worst academic sins, for the plagiarist destroys the trust among colleagues without which research cannot be safely communicated.

If you have any questions regarding plagiarism, please consult the latest issue of the *Texas A&M University Student Rules*, http://student-rules.tamu.edu, under the section "Scholastic Dishonesty."

Accommodations

The Americans with Disabilities Act (ADA) is a federal anti-discrimination statute that provides comprehensive civil rights protection for persons with disabilities. Among other things, this legislation requires that all students with disabilities be guaranteed a learning environment that provides for reasonable accommodation of their disabilities. If you believe you have a disability requiring an accommodation, please contact the Department of Student Life, Services for Students with Disabilities in Room B118 of Cain Hall, or call 845-1637.