

**ATMO 489/689**  
**Radar Meteorology**  
**Fall 2005**  
**STUDY GUIDE – Exam #3**

- Date:** Friday, 12/2/05
- Time:** Class period: 50 minutes, 12:40 – 1:30 PM. Please arrive a few minutes early to allow time to hand out exam.
- Location:** O&M, Room 1210
- Type:** Closed book and notes. *You must work independently!*
- Form of Exam:** Approximately three major questions with sub-parts. Midterm exams can be a mixture of objective (e.g., multiple choice, true/false) and/or subjective (e.g., short answer/definition, problem solving, derivation) questions. A typical midterm might include 1) multiple choice/true-false questions (10 minutes, 20%), 2) short answer questions (20 minutes, 40%), and 3) a problem solving/derivation question with sub-parts (20 minutes, 40%).
- Material Covered:**
- Lecture notes, lab notes, and web-page lecture materials (Chapters 6, 7, 8 and 10) from 10/26/05 to 11/30/05, inclusive.
  - Lab assignments # 6 and 7.
  - Assigned reading from the class text book, Rinehart (2004) – all of chapters 6, 7, and 8 and some of chapter 10 (specifically polarimetric basics and applications on p. 208 – 233).

**Instructional/Learning Objectives**

- 1) Identify the mathematical relationship between Doppler frequency shift and Doppler velocity. Identify the mathematical relationship between Doppler frequency shift and the time rate of change of the phase. Utilizing these two relationships, calculate the Doppler frequency shift and velocity given the phase at time  $t$  and time  $t + PRT$ .
- 2) Identify the key components of a Doppler radar system (e.g., transmitter, receiver mixer, modulator, computer/signal processor, locking mixer, COHO, STALO, phase detector, IF amplifier), explain (in layman's terms) how these components function to transmit, receive and process electromagnetic radiation in order to produce the Doppler radial velocity.
- 3) Explain why a zero Doppler velocity does not necessarily imply a zero wind velocity.
- 4) Explain in your own words the terms "Unambiguous (Doppler) Velocity" and "(Doppler) velocity folding (or aliasing)."
- 5) Given the relationship between Doppler velocity and frequency shift and another relationship between the Doppler frequency shift and the time rate of change of the phase, derive an expression for the maximum unambiguous Doppler velocity. Given the PRF and  $\lambda$ , calculate  $V_{\max}$ .
- 6) Describe in your own words the term "maximum unambiguous range" and "range folding."

- 7) Derive an expression for the maximum unambiguous range ( $r_{\max}$ ). Given the PRF (or PRT), calculate  $r_{\max}$ . (Note: This item is review but you are expected to know the material for exam 3).
- 8) List and explain four factors that limit the use of Doppler radar data ( $z$  and  $V_r$ ) at very long ranges (e.g., say 400-500 km).
- 9) Describe the “Doppler Dilemma.” Assuming the speed of light ( $c$ ) is constant, identify the one property of a radar system that dictates the relationship between  $V_{\max}$  and  $r_{\max}$  (or, list a relationship relating  $V_{\max}$  and  $r_{\max}$ ). Using this relationship, calculate  $V_{\max}$  or  $r_{\max}$  if given the other.
- 10) Describe the procedure for identifying range aliased or velocity aliased data. Explain the physical principles behind the procedure.
- 11) Explain the implication of choosing a  $V_{\max}/r_{\max}$  pair on the spatial resolution, cost and portability of a radar system?
- 12) Given a specific radar research objective (e.g., typical target - required spatial resolution, typical maximum velocities, minimum and maximum reflectivity etc) a budget for an antenna, and the cost of an antenna per square meter, design the specifications for your new, optimal radar antenna.
- 13) Describe the relationship between a non-zero wind field and the isosurface of zero Doppler radial velocity.
- 14) Given simple (i.e., simulated) PPI (Plan Position Indicators) images of Doppler radial velocity, qualitatively describe the inferred three dimensional wind field (in words or sketches such as wind profiles or with wind barbs on the PPI).
- 15) In your own words and mathematically, describe the Doppler spectrum and the “spectrum width” ( $\sigma$ ). List a mathematical definition of the Doppler radial velocity as a function of the Doppler velocity spectrum.
- 16) List and describe (in detail) the physical factors that will increase  $\sigma$ .
- 17) Define attenuation of a radar wave.
- 18) Identify the primary atmospheric constituents and/or hydrometeors that cause attenuation of radar waves.
- 19) Describe the dependence of attenuation (i.e., attenuation coefficients) on frequency and dielectric (i.e., water vs. ice).
- 20) Identify which atmospheric constituents and hydrometeors are capable of causing significant attenuation for S-band, C-band, X-band,  $K_a/K_u$ -band and W-band radars. Explain why and under what conditions.
- 21) Given an expression for attenuation loss and a simplified form of the radar range equation, derive a logarithmic form of the radar range equation that compensates for attenuation losses.
- 22) List equations for the “linear” loss ( $l$ ) and the logarithmic loss ( $L$ ) in terms of the attenuation coefficient ( $k$  or  $K$ ).
- 23) Given four of the following five parameters, apply the radar range equation to calculate the fifth parameter (radar reflectivity factor, received power, radar constant, attenuation loss, range).
- 24) Given a relationship for the precipitation attenuation coefficient ( $K$ ,  $\text{dB km}^{-1}$ ) in terms of rainfall rate or radar reflectivity factor [e.g.,  $K(R)$  or  $K(z)$ ] and a range profile of  $R$  or  $z$ , calculate the two-way attenuation associated with the modeled precipitation over a specified range. If also given an expression for the attenuation coefficient for

atmospheric gas, solve for the total two-way attenuation along the specified path. Using this information, diagnose the impact of the attenuation on the radar reflectivity and estimate of rainfall rate.

- 25) Identify attenuation in PPI or other radar reflectivity observations.
- 26) Describe the physical quantity called “rain rate” (R) in your own words, using a sketch if helpful. Derive a mathematical expression for rain rate. Given an inverse exponential size distribution model for rainfall and assuming that  $0 < D < \infty$ , calculate the rainfall rate in mm/hour.
- 27) Describe in your own words what a disdrometer is and what it measures. Outline the procedure for calculating radar reflectivity factor ( $z$  and  $Z$ ) and rain rate (R) from disdrometer measurements of the rainfall size distribution (i.e., given binned values  $N(D)$ ,  $D$ ,  $\Delta D$ ).
- 28) Outline the procedure for deriving an empirical  $z$ -R relationship (i.e., power law of form  $z=aR^b$ ) from disdrometer measurements. Discuss the impact of bias error and random error in using this relationship in radar rainfall mapping (Hint: see your lab results).
- 29) Explain why there are multiple  $z$ -R relationships in the literature (e.g., plot of 69  $z$ -R relationships from Battan, 1973). Identify some typical  $z$ -R relationships and the associated storm type. For example, list the  $z$ -R relationship utilized by the WSR-88D on a routine basis. Explain why the WSR-88D utilizes a different set of coefficients ( $a$ ,  $b$ ) during tropical rainfall and list the relationship.
- 30) List and describe potential sources of error in the estimation of rain rate (R) from reflectivity ( $z$ ). (There are about ten).
- 31) Describe the radar “bright band.” Explain the physical mechanisms responsible for the bright band and rank them in order of importance in two zones: 1) from snow to bright band and 2) from bright band to rain. Identify the type of precipitation in which bright bands are most common and explain why.
- 32) Define VIL (vertically integrated liquid) mathematically and in your own words. Describe the relationship between VIL and severe convective weather and the physical origin(s) of this relationship.
- 33) Explain what a WSR-88D Volume Coverage Pattern (VCP) is in general and explain its impact on vertically integrated derived quantities like VIL.
- 34) Explain why VIL might vary geographically and explain the impact on the operational use of VIL to diagnose severe storms.
- 35) Describe the key behavioral difference between the hail kinetic energy flux and the liquid water content (used to calculate VIL) as a function of  $Z$ . (Hint: part of the answer lies in the dBZ weighting function for the hail kinetic energy flux).
- 36) If given the hail kinetic energy flux, define the severe hail index (SHI) mathematically. Describe the purpose of the height weighting function in your answer.
- 37) Explain the purpose of the optimal weighting function (WT) of SHI and how it is used in the Probability of Severe Hail (POSH) algorithm.
- 38) Describe the Maximum Expected Hail Size (MEHS) and show the functional relationship to SHI either graphically or with an equation (i.e., square root functionality).
- 39) Define the polarization of a radar wave in your own words and with a sketch.
- 40) Describe the pulsing of polarization agile radar with your own words and a sketch.
- 41) Describe (with words and a sketch) the shape vs. size relationship of a rain drop and explain how this is important for the polarimetric radar technique of remote sensing.

- 42) Describe the basic physical properties of hailstones. Explain how they differentiate from rain drops and how this is important for the polarimetric radar detection of hail vs. rain.
- 43) Define the differential reflectivity ( $Z_{dr}$ ) and linear depolarization ratio (LDR) in words and mathematically.
- 44) Describe the differential phase ( $\phi_{dp}$ ), specific differential phase (Kdp), and correlation coefficient ( $\rho_{hv}$ ) qualitatively in your own words (or mathematically if that is more meaningful for you).
- 45) List typical  $Z_h$  and  $Z_{dr}$  values for rain and hail. Describe the “hail hole” in RHI and PPI scans and explain how it can be used to diagnose the presence of hail or differentiate rain from hail. List typical ranges of values for Kdp,  $\rho_{HV}$ , and LDR in rain and hail. Synthesize the results and define a rain vs. hail identification algorithm if given observations of  $Z_h$ ,  $Z_{dr}$ , Kdp, LDR and  $\rho_{hv}$ .
- 46) Describe in broad terms the two general approaches to polarimetric radar identification of hydrometeor types (i.e., Boolean logic vs. fuzzy logic approach).
- 47) Explain in broad terms how polarimetric radar measurements (i.e.,  $Z_{dr}$  and Kdp in addition to  $Z_h$ ) can help improve the accuracy of rain rate estimation.