

ATMO 489/689
Radar Meteorology
Fall 2005
STUDY GUIDE – Exam #2

- Date:** Wednesday, 11/2/05
- 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 4-5) from 10/3/05 to 10/25/05, inclusive.
- Lab assignments # 3, 4, and 5.
- Assigned reading from the class text book, Rinehart (2004) – Chapters 4-5 and Appendix A.

Instructional/Learning Objectives

- 1) Derive an expression (i.e., the radar range equation) for the received power (p_r) in terms of the transmitted power (p_t), antenna gain (g), wavelength (λ), slant range (r), and backscattering cross-sectional area (σ) for a point target.
- 2) Given p_t , g , λ for a given radar and σ (or an expression for σ) for a given point target, apply the radar range equation to calculate the maximum range of detection given the minimum detectable signal (MDS) power. If given the saturation power, use the radar equation to calculate the minimum range of detection.
- 3) Using the radar range equation for a point target, explain in your own words the effect of modifying radar characteristics (i.e., the antenna gain, transmitter power, or transmitter wavelength) on the received power for a given target at a given range.
- 4) Explain the difference between backscattering of electromagnetic energy by spheres in the Rayleigh, Mie and large particle regions.
- 5) Given the wavelength of a radar wave and the size of a particle, determine what scattering region the particle belongs in. Describe the relationship between the geometric area and the backscattering cross-sectional area of spheres in each backscattering regime.
- 6) List and describe typical maximum errors in σ associated with assuming Rayleigh scattering for $D < 0.1\lambda$ for both water and ice spheres.
- 7) If one instead defines the Rayleigh scattering regime as the maximum diameter (D_{ray}) for which the absolute error in estimating $\sigma < 25\%$, list D_{ray} for water at S-band ($\lambda = 10$ cm)

and X-band ($\lambda = 3.2$ cm). Discuss why D_{ray} is different for each wavelength. List D_{ray} for ice spheres at S-band. Explain why the definition of the “Rayleigh Scattering Regime” should be different for ice and water spheres.

- 8) List an expression for the backscattering cross-sectional area (σ) for a sphere of diameter (D) in the Rayleigh scattering regime. From this expression, describe the dependence of σ on the dielectric function $|K|^2$, diameter (D), or wavelength (λ). Given values for $|K|^2$, D , and λ , calculate σ .
- 9) Discuss the dependence of the complex index of refraction ($m = n-ik$) on the temperature, wavelength, and composition (i.e., water vs. ice).
- 10) Given the refractive index (n,k) for water or ice at S-band or W-band, calculate the dielectric function $|K|^2$ and utilize the value in the estimation of σ from the Rayleigh expression. Discuss the consequence of using the wrong $|K|^2$ in the estimation of the Rayleigh σ (e.g., using the S-band value when radar is W-band or water value when hydrometeor is ice).
- 11) Distinguish between a point and distributed target. Determine when to utilize the point or distributed target forms of the radar equation.
- 12) Describe and derive an approximate form of the radar sample volume (V) for a uniformly illuminated main lobe. Given the range (r), beamwidth (θ), pulse width (τ), estimate V . Given typical cloud (or rain) droplet concentrations, estimate the typical number of cloud or rain particles in V .
- 13) List an expression for the sample volume for a Gaussian shaped beam and explain why it is different than for a uniformly illuminated beam.
- 14) Define in your own words and list a mathematical expression for the total backscattering cross-sectional area (σ_t) for a distributed target.
- 15) From the radar equation for a point target (see 1) above), the expression for a sample volume (V) for a Gaussian shaped beam (see 13) above), and the expression for σ_t (see 14) above), derive the radar range equation for a beam-filling meteorological (i.e., distributed) targets.
- 16) Define the “time to independence” or “decorrelation time” ($t_{0.01}$) and describe its significance for measuring p_r and hence estimating σ_t (or η or z).
- 17) List the properties of the radar or meteorological targets that modify the decorrelation time. Describe how these properties affect the decorrelation time.
- 18) Given a decorrelation time (or λ and an expression for the decorrelation time as a function of λ), estimate a range of sample times (or frequency) that should be used to obtain independent samples while maximizing the sample rate. Given typical pulse repetition frequencies (PRF) of Doppler radars, explain what implication this sampling rate for independence has on how radar meteorologists use the radar range equation to measure p_r and hence estimate σ_t (or η or z).
- 19) Define the radar reflectivity (η) and list typical units. Show how η can be estimated from the radar range equation for a beam-filling meteorological targets (see 15) above).
- 20) Define the radar reflectivity factor (z) and list typical units. Show (i.e., derive) how z can be estimated from the radar range equation for a beam-filling meteorological targets (see 15) above) after making the Rayleigh scattering approximation. Define key assumptions associated with assuming Rayleigh conditions.

- 21) Derive the relationship between η and z . Demonstrate that z is a function of hydrometeor properties only while η depends on both hydrometeor and radar properties.
- 22) List two formal mathematical definitions for the radar reflectivity factor (z): 1) the definite integral and 2) the discrete forms of z .
- 23) Given a particle concentration per unit volume ($N(D)$, where D is diameter) and size (D) of monodisperse (i.e., same size) rain drops, define, calculate and interpret the reflectivity factor (z or Z) in either typical linear units ($\text{mm}^6 \text{m}^{-3}$) or in logarithmic units, dBZ, using the appropriate definition from 22) above. Convert from $\text{mm}^6 \text{m}^{-3}$ to dBZ and vice versa.
- 24) Repeat 23) if given discrete bin concentrations per volume, $N(D)$, as a function of D .
- 25) Repeat 23) above if given an inverse exponential form of the particle concentration per unit volume ($N(D)$). Note: the definite integral solution provided in class would be provided in the exam.
- 26) Define the equivalent radar reflectivity factor (z_e or Z_e) and explain when one uses this parameter in the radar range equation.
- 27) If given measured $N(D)$ of ice particles, repeat 23) – 25) above to calculate z and Z . Next, estimate z_e and Z_e for the same ice particles. Determine which parameter (Z or Z_e) would be used to compare to actual typical radar measurements and explain why.
- 28) Describe how signal power is lost from the radar to a meteorological target and back. Define the loss or attenuation term (l) and describe how it is implemented in the radar range equation.
- 29) Given the radar range equation from 20) above (with or without the loss term [l]; see 28), derive the logarithmic form of the radar equation in terms of the radar reflectivity factor (Z , dBZ), the radar constant (C_3 , dB), the received power (P_r , dBm), the range (r , km) and, if required, the logarithmic loss term (L , dB).
- 30) Define the noise power, signal-to-noise ratio (SNR), dynamic range, saturation power, minimum detectable signal (MDS) power, minimum detectable reflectivity (MDR), and saturation or maximum detectable reflectivity.
- 31) Utilize the logarithmic form of the radar range equation (see 29) above) to calculate the parameter of interest if given the other required terms. For example, if given the minimum detectable signal (MDS) power in dBm and the radar constant (dB), calculate the minimum detectable reflectivity (MDR) factor (Z , dBZ) at a specified range. Other applications related to the saturation power, saturation or maximum radar reflectivity factor, dynamic range, signal-to-noise ratio (SNR), and the loss factor (L) are possible.