ASEN 6519. Lidar Remote Sensing

HWK Project #4 – Lidar Simulation for Range-Resolved Signals with Error Analysis

This project is to simulate the range-resolved Na Doppler lidar signals with temperature and wind error analysis by integrating the knowledge we gained through the lidar class. The knowledge includes our understanding of (1) different scattering processes; (2) the lidar equation and the lidar remote sensing procedure; (3) the roles of atmospheric number density and atomic specie density in the lidar equation; (4) the signal-to-noise ratio (SNR) related to the uncertainty caused by photon noise; (5) the ratio technique for temperature and wind derivation; (6) temperature and wind error analysis for photon-noise-induced uncertainty, etc.

This project contains the following tasks (related parameters are listed at the end of the assignment) –

(1) Simulate the range-resolved photon count return from 30-150 km by a Na Doppler lidar, considering Rayleigh scattering signal from all altitudes, Na resonance fluorescence signal from 75-115 km, and background photon counts for all altitudes. Plot the range-resolved photon count profiles. (Put altitude to x-axis)

The Na Doppler lidar uses 3-frequency technique (see our textbook and lecture notes for the details). Please simulate the entire 30-150 km profiles for the peak frequency and simulate the Na signals from 75-115 km for all three frequencies.

The atmospheric number density and temperature profiles are taken from a MSIS00 model profile (posted at the class website). The Na layer can be simulated using a Gaussian distribution with the peak at 91.5 km, rms width of 4.6 km, and column abundance of 4 x 10^9 cm^{-2}. The background count is 10/1000shots/km. The temperature profile in the Na layer is taken from the same MSIS00 model profile. The vertical wind in Na layer is V_R = 0 m/s and the zonal wind is given by a model profile.

(2) Add the photon noise with Possion distribution to the range-resolved lidar profile (30-150 km) for the peak frequency to simulate the actual lidar returns with photon noise. Try this for 10, 1000, 10,000 shots of integration. Plot the photon count profiles. (Put altitude to x-axis)

(3) Derive the signal-to-noise ratio (SNR) equation when considering the Rayleigh, Na, and background photon counts, and then calculate SNR for the range-resolved photon count profile from 30-150 km. Plot the SNR profile in absolute number and dB, respectively. (Put altitude to x-axis)

(4) Calculate the temperature metrics from the simulated 3-frequency Na signals and from the calculated effective cross sections using equation (1) and (2). Plot the two R_T versus altitude side by side (put altitude to y-axis). Are they the same?

$$R_T = \frac{N_+ + N_-}{N_a} \quad (1), \qquad R_T = \frac{\sigma_{eff}(f_+, T, V_R) + \sigma_{eff}(f_-, T, V_R)}{\sigma_{eff}(f_a, T, V_R)} \quad (2)$$

(5) Using Eq. (2) of R_T, derive the temperature error coefficient $\frac{R_T}{\partial R_T / \partial T}$. It is easy to derive this numerically. Again, the temperature profile in Na layer is from the MSIS00 profile.

Plot the temperature error coefficient versus altitude and side-by-side plot the temperature versus altitude (put altitude to y-axis)

You may also realize that this temperature error coefficient is the reciprocal of temperature sensitivity S_T, which you have derived for the Na Doppler lidar in Project #3.

(6) Derive the following error equation for $\Delta R_T/R_T$ (i.e., Eq. (5.83) in our textbook), and then calculate and plot $\Delta R_T/R_T$ versus altitude from photon counts.

$$\frac{\Delta R_T}{R_T} = \frac{\left(1+\frac{1}{R_T}\right)^{1/2}}{\left(N_{f_a}\right)^{1/2}}\left[1+\frac{B}{N_{f_a}}\frac{\left(1+\frac{2}{R_T^2}\right)}{\left(1+\frac{1}{R_T}\right)}\right]^{1/2} \qquad (3)$$

(7) From Steps (7) and (8), derive the temperature error caused by the photon noise. Plot the temperature error ΔT vs altitude, and side-by-side plot the Na photon count profile.

The temperature error is given by

$$\Delta T = \frac{\partial T}{\partial R_T}\Delta R_T = \frac{R_T}{\partial R_T/\partial T}\frac{\Delta R_T}{R_T} \qquad (4)$$

Plot the temperature T with errors (i.e., $T\pm\Delta T$) profile vs altitude (put altitude to y-axis). Try this for 1000, 20,000, and 100,000 shots of integration to see how the temperature errors change.

With this code, you may also vary lidar parameters, e.g., the telescope diameter, the detector quantum efficiency, or laser power, etc. to see how they affect the temperate errors under the same integration shots.

(8) In real data processing, we usually simplify the temperature error coefficient, i.e, do not count in the coefficient variation with operating points (i.e., T and V values) but use a nominal coefficient at T = 200 K and V_R = 0 m/s to estimate the errors. This nominal temperature coefficient is 202.8 for the Na Doppler lidar. Thus, the Na lidar temperature error can be estimated as Eq. (5), where $\Delta R_T/R_T$ is also given by Eq. (3)

$$\Delta T = 202.8\times\frac{\Delta R_T}{R_T} \qquad (5)$$

Please implement Eq. (5) into your Project #3 data processing code to calculate the Na temperature error and then plot the temperature with error bars for .001 profile. (Put altitude to y-axis) The photon counts used in the error analysis should be raw photon counts, i.e., without PMT, chopper, and range corrections.

Related atomic parameters: see the textbook

Related CSU Na Doppler lidar parameters are

- Laser pulse energy: 20 mJ
- Laser repetition rate: 50 Hz
- Laser wavelength: 589.1582 nm (in vacuum)
- Transmitter mirror reflectivity: 99% for each mirror and total of 3 mirrors
- Telescope primary mirror diameter: 75 cm
- Telescope primary mirror reflectivity: 90%
- Telescope secondary mirror reflectivity: 90%
- Fiber throughput: 75%
- Transmission of receiver optics: 90%
- Interference filter peak transmission: 85%
- PMT quantum efficiency: 40%
- Geometric factor for above 20 km: 1
- Lidar station base altitude: 1.6 km

Related atmosphere parameters are

- Lower atmosphere transmission at 589 nm: 70%
- Atmospheric transmission from 30 to 75 km: 100%
- Atmospheric number density: taken from MSIS00 number density
- Atmospheric temperature: taken from MSIS00 number density
- Mean sodium column abundance is 4×10^9 cm^{-2}
- Na layer: Gaussian, peak at 91.5 km, rms width of 4.6 km

You are required to show your MatLab or equivalent code with your simulation results.