ASEN 6365. Lidar Remote Sensing
HW #7 -- Na Lidar Data Processing

The lidar raw data can be accessed from our class website, named "NaLidar_AR1102". The folder includes many datasets obtained by a Na wind and temperature lidar for an entire night on April 11, 2002 at Maui Haleakala Mountain by Dr. Xinzhao Chu. Note: bin resolution "7" in the data header means 160 ns of bin width. The file "TPNDMauiAR1102.dat" contains the MSIS00 temperature, pressure, and number density data. All data are in ASCII format.

This project is to give students quantitative ideas of how lidar raw data look like, how to obtain necessary information (e.g., date, UT time, range bin, base altitude, zenith or off-zenith angle, azimuth, etc) from raw data, and how to convert raw photon counts into meaningful physical quantities (temperature, wind and Na density) for a single profile. You are required to process "AR1102.001" (zenith pointing) and "AR1102.009" (30 degree off-zenith pointing to East) profiles for the first portion of HW#7.

In the second portion of HW#7, you will process all profiles, plot the temperature and wind contours through the night, and also calculate the temperature and wind errors. This portion provides students quantitative ideas of how to process the entire night of data on April 11, 2002 and distinguish different pointing directions, how to convert line of sight (LOS) wind to zonal, meridional and vertical winds (DBS mode), and how to do error analysis for photon-noise-induced measurement uncertainties of temperature and wind.

The entire project is divided into five sub-projects:
1) Compute the calibration curve of R_T versus R_W
2) Pre-process and profile-process to obtain normalized photon counts,
3) Main process to obtain temperature, wind and Na density for profiles .001 and .009.
4) Process the entire datasets and plot temperature, wind and Na density results.
5) Temperature error analysis.

Subproject 1: Compute and plot the calibration curves (R_T versus R_W) for the Na Doppler lidar with the following temperature and wind metrics:

1). $R_T = \dfrac{\sigma_{eff}(f_+)+\sigma_{eff}(f_-)}{\sigma_{eff}(f_a)}$, $R_W = \dfrac{\sigma_{eff}(f_-)}{\sigma_{eff}(f_+)}$

2). $R_T = \dfrac{\sigma_{eff}(f_+)+\sigma_{eff}(f_-)}{\sigma_{eff}(f_a)}$, $R_W = \dfrac{\sigma_{eff}(f_+)-\sigma_{eff}(f_-)}{\sigma_{eff}(f_a)}$

3). $R_T = \dfrac{\sigma_{eff}(f_+)+\sigma_{eff}(f_-)}{\sigma_{eff}(f_a)}$, $R_W = \dfrac{\ln\left[\sigma_{eff}(f_-)/\sigma_{eff}(f_+)\right]}{\ln\left[\sigma_{eff}(f_-)\times\sigma_{eff}(f_+)/\sigma_{eff}^2(f_a)\right]}$

where σ_{eff} is the effective cross section of Na D_2 line, frequencies f_a = -651.4 MHz, f_+ = -21.4 MHz, and f_- = -1281.4 MHz (relative to the line center). Assume the laser line shape is a Gaussian with rms width of 60 MHz. The temperature and wind ranges are T = 100 to 300 K and V_R = -100 to +100 m/s at resolutions of 10 K and 10 m/s.

Subproject 2 contains the following assignments –
1) Draw a flowchart for your data processing code to show the pre-process and profile-process procedures.

Note: you may refer to our lecture notes, but I do want you to write a flowchart for your own code, because it helps you to keep a clear mind in writing such a complicated code.

2) Read in the lidar raw data and plot raw-data profiles for three frequencies versus bin number and altitude for both .001 and .009 profiles.

Note: pay attention to how to convert bin number to range (the actual distance from lidar to the scatter) and then to altitude (the height above the mean sea level).

3) Do PMT/discriminator saturation correction and plot the peak-frequency data profiles after this correction. Sample MatLab code is provided at our website.
4) Do chopper correction and plot the peak-frequency data profiles after this correction. Note: chopper profiles are in the same folder as the data.
5) Subtract background and plot the peak-frequency data profiles after this step.
6) Remove range dependence and plot the peak-freq data profiles after this step.
7) Add base altitude and then take Rayleigh signal @ 40 km as the Rayleigh normalization signal. Plot the Rayleigh fitting and the Rayleigh signal for the peak-frequency data profiles.
8) Normalize the entire profile by the Rayleigh normalization signal and plot the normalized profiles for all three frequencies.

Subproject 3 contains the following assignments –

1) Draw a flowchart for your data processing code to show the whole procedure how you process the data. This is to add the main procedure to your previous flowchart.
2) From the normalized photon count profiles at all three frequencies to derive the temperature and wind ratios R_T and R_W, and then infer temperature and wind from these ratios for each altitude (either by look-up table method or iteration method).

Note: Pay attention to the extinction caused by the Na absorption, and the subtraction of Rayleigh signals from the Na altitude range.

3) Then derive Na density for each altitude.

Use the following metrics to calculate the ratios

$$R_T = \frac{\sigma_{eff}(f_+) + \sigma_{eff}(f_-)}{\sigma_{eff}(f_a)}, \quad R_W = \frac{\ln\left[\sigma_{eff}(f_-)/\sigma_{eff}(f_+)\right]}{\ln\left[\sigma_{eff}(f_-)\times\sigma_{eff}(f_+)/\sigma_{eff}^2(f_a)\right]}$$

<u>Conditions:</u> Three laser frequencies are f_a = -651.4 MHz, f_+ = -21.4 MHz, and f_- = -1281.4 MHz (relative to the line center), the laser lineshape is a Gaussian with a linewidth (rms) of 60 MHz, and PDA frequency offset is 10.27 MHz for the night of April 11, 2002.

Please show the following plots as the products of your code for the first portion of HW#7:

1) Ratio R_T versus altitude for .001 and .009 profiles
2) Ratio R_W versus altitude for .001 and .009 profiles
3) Derived temperature T versus altitude for .001 and .009 profiles
4) Derived radial wind V_R versus altitude for .001 and .009 profiles when PDA frequency offset is 0 MHz.
5) Derived radial wind V_R versus altitude for .001 and .009 profiles when PDA frequency offset is set to 10.27 MHz.
6) Derived zonal wind u versus altitude for .009 profiles when PDA frequency offset is set to 10.27 MHz.
7) Derive Na density versus altitude for .001 and .009 profiles when PDA frequency offset is set to 10.27 MHz.

Subproject 4 – Process the entire datasets and plot temperature, wind and Na density results.

1) Process the entire datasets for April 11, 2002, using loop and distinguishing different pointing directions of the lidar beam.
2) Calculate zonal, meridional and vertical wind from the derived LOS wind.

Note: Let's use the notion of LOS wind moving away from the lidar beam is positive, and eastward, northward and upward winds are positive.

3) Plot a contour of temperature versus UT time and altitude.
4) Plot a contour of zonal wind versus UT time and altitude.
5) Plot a contour of meridional wind versus UT time and altitude.

Subproject 5 -- Temperature error analysis.

Temperature ratio is defined as

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

The temperature error caused by photon noise is given by

$$\Delta T = \frac{\partial T}{\partial R_T}\Delta R_T = \frac{R_T}{\partial R_T / \partial T}\frac{\Delta R_T}{R_T} \quad (3)$$

1) Derive the temperature error coefficient $\frac{R_T}{\partial R_T / \partial T}$ using Eq. (2) of R_T. It is easy to derive this numerically. Plot the temperature error coefficient versus altitude and side-by-side plot the temperature versus altitude (put altitude to y-axis) for profile 001.

Note: The temperature error coefficient is the reciprocal of temperature sensitivity $S_T = \frac{\partial R_T / \partial T}{R_T}$.

2) 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 "raw photon counts" for profile 001.

$$\frac{\Delta R_T}{R_T} = \frac{\left(1 + \frac{1}{R_T}\right)^{1/2}}{\left(N_{f_a}\right)^{1/2}}\left[1 + \frac{B}{N_{f_a}}\frac{\left(1 + \frac{2}{R_T^2}\right)}{\left(1 + \frac{1}{R_T}\right)}\right]^{1/2} \quad (4)$$

3) From above steps, calculate the temperature errors caused by photon noise for profile 001. Plot the temperature error ΔT vs altitude, and side-by-side plot the Na photon count profile and temperature profile.

4) 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. (4)

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

5) Please implement Eq. (5) into your data processing code so that you can calculate the Na temperature error for every profile. (Put altitude to y-axis)

Note: The photon counts used in the error analysis should be raw photon counts, i.e., photon counts without PMT, chopper, and range corrections.

Extra assignments (not required):

(1) Wind error can be analyzed in similar way as the temperature errors (see our textbook and lecture notes). You may derive and then add wind error analysis to your Na lidar data processing code.

(2) You may also add the temperature and wind error analyses to your range-resolved lidar simulation code. Once this is done, you can check how the measurement errors vary with the lidar and atmospheric parameters.

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

The first due date for HW#7 is Friday, April 15, 2016 – please show preliminary results of the first portion to the professor so that the instructor can help you judge if you are on the right path for the data processing. As this project is extensive, please start right away, and you are encouraged to show preliminary results earlier once you get some.

The final due date for HW#7 is Friday, April 22, 2016.