Combining Laser Radar and Radiosonde Measurements to Study the Planetary Boundary Layer

Seth Gagnon (seth.gagnon@my.ccsu.edu), Marcus Alcantara-Silva, Adrian Parnell, Dr. Nimmi Sharma, Dr. Amin Kabir

Why study the planetary boundary layer?

The planetary boundary layer (PBL), also called the atmospheric boundary layer, is the lowest part of the atmosphere, and its behavior directly affects the surface of the earth. Convection, driven by heat from the surface rising through this layer can drive large scale motions and mixing in the PBL. PBL dynamics can affect transport of pollutants like smoke or dust. The transport of pollutants like smoke, which is made up of harmful components such as CO_2 and CO, can have large implications on public health. PBL height and characteristics are also crucial inputs for atmospheric models of climate, precipitation and weather. Most suspended particulates in the atmosphere (aerosols) reside in the PBL so mapping aerosol distributions with altitude provides insights on the structure of the PBL.

Instruments: CLidar

CLidar is a remote sensing technique that is used to study the lower atmosphere. As shown below, a laser, located D meters from a CCD camera detector, is fired vertically into the atmosphere. Light scatters off air molecules (molecular scattering) and suspended particles (aerosol scattering). The light scattered at scattering angle θ is detected by the CCD camera. To find the aerosol scattering at each altitude, the molecular scattering is modeled and subtracted from the total signal. Converting the resulting aerosol scattering at angle θ to total aerosol scattering over all angles (by assuming an aerosol "phase function") and correcting for atmospheric transmission, we derive the aerosol extinction as a function of altitude.

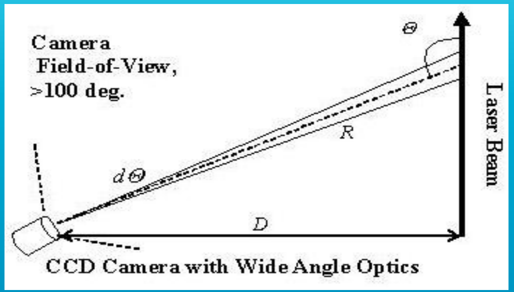

Figure 1: CLidar apparatus

Instruments: Radiosonde

A radiosonde is an instrument attached to a weather-balloon that collects atmospheric data as it rises through the atmosphere. Among these measurements are relative humidity and potential temperature, which were used to study the PBL. Relative Humidity (RH) is the percentage ratio between the amount of water vapor in the air and the saturation vapor at the same temperature. Potential temperature is the temperature that a parcel of fluid would reach if brought adiabatically to a standard pressure, generally 1 bar.

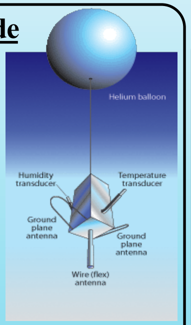

Figure 2: Radiosonde apparatus

Experiment

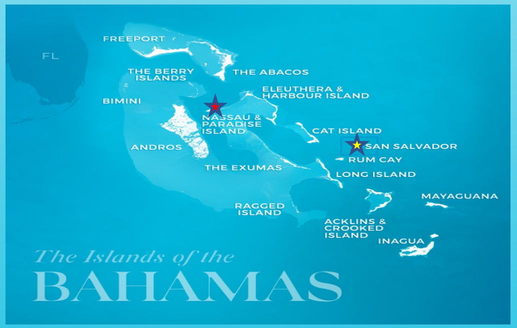

Figure 3: Bahamas Map

In a collaboration between Central Connecticut State University and The University of The Bahamas in Nassau, Clidar measurements were taken at Gerace Research Center in San Salvador. See Figure 3. CLidar is limited to being run only at night, so the data in Figure 4 correspond to the night of November 23, 2019, on San Salvador island. Measurements from about 9 pm to about 11 pm were averaged to provide the CLidar aerosol extinction. The Radiosonde data were collected at Nassau airport. The weather balloons are sent up every day at noon and midnight, so the data in Figure 5 correspond to 12 AM of November 24, 2019, in Nassau, which is the time closest to the CLidar measurements.

Results

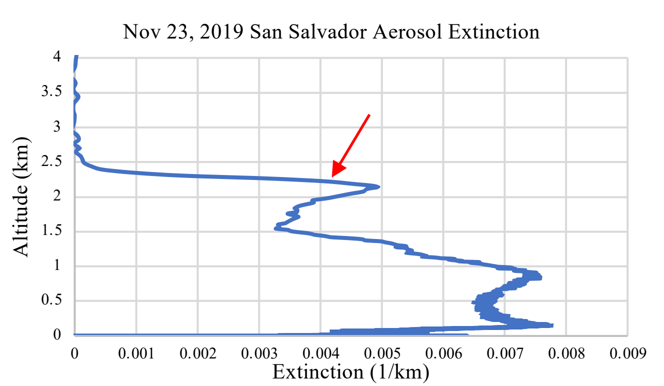

Figure 4: San Salvador Extinction Plot

Figure 4 is a time-averaged plot of extinction data collected from about 9 PM to about 11 PM on November 23, 2019, on San Salvador island in the Bahamas. Atmospheric aerosol extinction is a measure of how much our laser beam's energy is being scattered (extinction) by aerosols in the air at a certain altitude. More aerosols in the air will yield a larger extinction, therefore, extinction provides information on atmospheric aerosols. We can use this information to find the top of the planetary boundary layer, which will be indicated by a steep drop off in extinction (shown by the red arrow). Most of the particles in the atmosphere are contained within the PBL, therefore, the steep drop off in the extinction indicates the top of this layer.

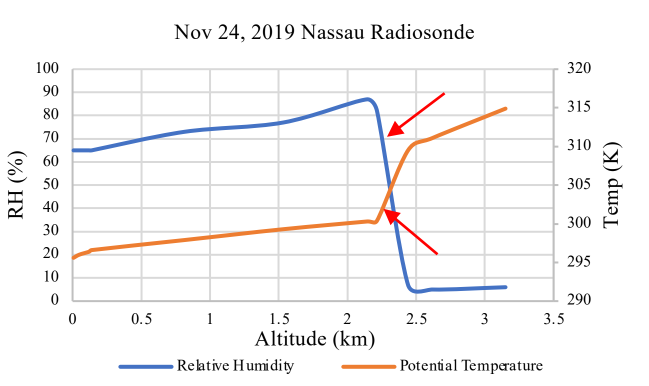

Figure 5: Nassau Radiosonde Plot

The PBL is often a well-mixed layer due to convection, therefore, the relative humidity and potential temperature are mostly constant with altitude. Above the PBL, where there is no convective mixing, the air is drier, thus, creating a sharp drop in relative humidity.

The potential temperature is a function of temperature and pressure, with pressure being the dominating term. An approximation of potential temperature (derived from the ideal gas law) is given by

$$\theta = T\left(\frac{p_0}{p}\right)^{0.286},$$

where θ is the potential temperature, T is the temperature, p_0 is standard pressure, and p is the pressure. Therefore, the sharp decrease in pressure, and thus increase in potential temperature, indicates the top of the PBL.

Conclusion/Future Work

The proposed boundary layer height from CLidar measurements (Figure 4) and from radiosonde data of RH and potential temperature (Figure 5) show excellent agreement for a 2.2 km PBL height. The extinction plots produced by CLidar are thus good tools for computing the PBL height. The CLidar experiment demonstrated good agreement with the radiosonde data on a night when RH and potential temperature radiosonde data were relatively uncomplicated. However, relative humidity and potential temperature are also dependent on other factors that can obscure the PBL height. Thus, atmospheric phenomena, as simple as clouds, can create multiple layers in the radiosonde plots, which may frequently make estimating the top of the PBL using radiosonde data challenging. The single time measurement of the radiosonde also does not allow for studies of temporal evolution of the PBL, while the CLidar can produce time series images to allow for studies of PBL dynamics. In the future we plan to take much more data in multiple locations to study the dynamics of the boundary layer further. One such project that is underway involves studying the seasonal variation of the PBL.

References:

[1] 2.6 Stability and Buoyancy | METEO 300: Fundamentals of Atmospheric Science. (n.d.). Retrieved October 17, 2021, from www.e-education.psu.edu website: https://www.e-education.psu.edu/meteo300/node/557

[2] University of Wyoming College of Engineering (n.d.). Retrieved from http://weather.uwyo.edu/upperair/sounding.html

[3] Aryee, J., Amekudzi, L., Preko, K., Atiah, W., & Danuor, S. (2020). Estimation of planetary boundary layer height from radiosonde profiles over West Africa during the AMMA field campaign: Intercomparison of different methods. *Scientific African, 7*. doi:10.1016/j.sciaf.2019.e00228

[4] Kovalev, V. A., & Eichinger, W. E. (2004). *Elastic lidar: Theory, practice, and analysis methods*. Hoboken, NJ: Wiley-Interscience.

[5] Sharma, N. C., Kabir, A., & Barnes, J. E. (2021). Camera Lidar Collaboration for Undergraduate Education [Education]. *IEEE Geoscience and Remote Sensing Magazine, 9*(2), 112-116. doi:10.1109/mgrs.2021.3064921