5-2018

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Sodium Lidar for Mesopause Temperature and Wind Studies

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Abstract
In 1990 Dr. Chiao-Yao She developed a narrowband Na Temperature lidar in Colorado State University (CSU), it immediately became an important instrument to measure the temperature in mesopause region (80-105 km in altitude): the atmospheric layer between mesosphere and thermosphere [Krueger et al., 2015]. Led by Dr. Tao Yuan, this system was relocated to Utah State University (USU) in summer 2010 and has been continuing its exploration of upper atmosphere. This report will give a brief introduction to the theory and application of Sodium Lidar.

1. Introductions
Mesopause, the atmospheric layer with the lowest temperature in the entire earth-atmosphere system, is located between about 80 km to 110 km from sea level. For this altitude, regular temperature and wind measuring methods such as using helium balloons and aircraft fall short. Thus, the ground-based Na lidar has been created by utilizing the Na atoms in mesopause region. After nearly 30 years of development, the ground-based Na lidar’s capability has evolved from the nighttime Na density measurement only to both wind and temperature measurements in full diurnal cycle [Krueger et al., 2015].
2. Theory and Structure

Because Na atoms in mesopause region have less than 1 mm mean free path, the Na atoms with air around are considered in a thermal equilibrium condition. Based on this assumption, the main idea of Na lidar is exciting the Na atoms to a certain energy level, which will emit photons with specific wavelength when these atoms come down to the ground state. After collecting those photons with the ground-based telescope, the motion of Na atoms at mesopause could be revealed by analysis the Doppler shifts of photons with respect to the initial wavelength. At the same time, the temperature is derived based upon the Doppler broadening of the Na spectrum. In order to create the photon emitting with a process, called laser-induced
fluorescence, the seed laser with wavelength 589.159 nm has been used to excite the Na atoms.

Figure 2. Na lidar measured nocturnal Na density (top left), temperature (top right) wind (bottom left) and Brunt–Väisälä frequency (bottom right).
After Fricke and von Zahn built the very first Na lidar in 1985 [Krueger et al., 2015], various upgrades have been developed around the globe to this lidar technique. Two of the most significant upgrades are the wind measurement capability upgrade in 1994 and daytime measuring upgrade in 2002, both of which were led by CSU group In general, by pointing the laser beam to certain angle off zenith direction and accurately controlling the laser frequency and bandwidth, the Na lidar is capable of not only measuring the temperature but also the horizontal wind velocity of mesopause region, as shown in Figure 2. In 2002, a pair of robust Faraday filter has been developed and deployed into the lidar system. This device using the combination effect of Faraday rotation of the returning signal polarization and Zeeman Effect produced by a strong magnetic field in each filter. The result is that the non-resonant noise majorly generated by sunlight gets rejected by the two crossed polarizers on either end of the filter, while the Na signals pass through the filter with minimum loss [Cai. 2017].

The main structure of the Na lidar is shown in figure 3 below
3. Summary and Conclusion

The Na lidar is widely used in various studies of atmospheric dynamic and chemistry in mesopause region. It provides the information of temperature and horizontal wind velocity to advance our understanding of the geophysical processes in the upper atmosphere, including both short-term variability and long-term trend. Its measurements also provide critical calibrations to several ground-based and space board remote sensing instruments [Pautet et al., 2014; Xu et al., 2006].


