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RESEARCH ON THE RELATIONSHIP BETWEEN CLOUD TEMPERATURE AND OPTICAL DEPTH USING ROTATIONAL AND VIBRATIONAL RAMAN LIDAR

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ABSTRACT

Clouds play a key role in the climate system, for they can result in a warming or a cooling effect according to their characteristics and altitudes. Raman Lidars have been proven to be a very useful remote sensing tool to characterize cloud properties and locations. In this paper, cloud temperature and optical depth are obtained using rotational Raman (RR) and vibrational Raman techniques. Results of cloud temperature and optical depth (OD) observed by the Hampton University (HU) Rotational-Vibrational Raman Lidar are presented. The paper discusses the influence of cloud OD on temperature of the cloud base and top. From these measurements, the relation of low-altitude cloud OD and temperature is summarized. These analyses are unique in that they combine simultaneous measurements of these quantities that can lead to an improvement in the understanding of cloud radiation transfer and effects.

1. INTRODUCTION

The study of clouds is very important in the understanding climate change. Reliable measurements of cloud temperature and optical depth are important for improving our understanding of cloud physics, cloud dynamics, and for validating cloud-resolving models [1, 2]. Raman Lidars have been proven to be a very useful remote sensing tool to measure cloud properties. Atmospheric temperature can be measured using RR lidars [3-4]. Moreover, the capabilities of RR technique are extended to the measurement of cloud temperature. Behrendt et al. developed the multi-cavity polychromator to measure cloud temperature using RR lidar when cloud backscatter ratio is smaller than 45 [3]. Su et. al present a technique to obtain cloud temperature by correcting for the influence of the residual elastic-signal on RR channels [4]. And cloud OD can be independently obtained from a nitrogen vibrational Raman signal. In this paper, cloud temperature and OD are both obtained using the RR and vibrational Raman techniques. Results of cloud temperature and OD observed by the Hampton University (HU) Rotational-Vibrational Raman Lidar are presented. The paper discusses the influence of cloud OD on temperature of cloud base and top. From these measurements, the relation of low-altitude cloud OD and temperature is summarized. These analyses are unique in that they combine simultaneous measurements of quantities that can lead to an improvement in the understanding of cloud radiation transfer and effects.

2. METHODOLOGY

2.1. Rotational Raman method to obtain temperature

Cloud temperature can be derived from two RR signals and written as[4]:

$$T(z)=\frac{a}{In\left(\frac{X_{r1}^{L}(z,\lambda_{r1})-k_1X_e(z,\lambda_e)}{X_{r2}^{L}(z,\lambda_{r2})-k_2X_e(z,\lambda_e)}\right)+b} \quad (1)$$

where the subscripts of X_e, X^L_{r1} and X^L_{r2} refer to one elatic and two RR backscattering signals; λ is wavelength; z is altitude; T is temperature; a and b are calibrated coefficients obtained using a balloon-sounding's temperature; k_1 and k_2 are two RR channels' transmission for elastic backscatter signals from HU lidar elastic channel.

2.2. Vibrational Raman method to obtain OD

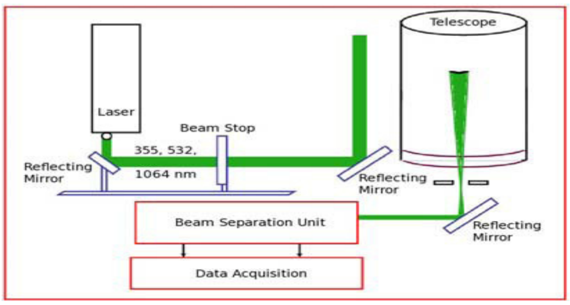
Cloud OD can be derived from Nitrogen vibrational Raman signals and written as:

$$OD=\frac{In\left[\frac{X_r(z_{top})}{X_r(z_{base})}\times\frac{m(z_{base})}{m(z_{top})}\right]}{-2}-\sum_{z=base}^{z=top}T_m(z)dz \quad (2)$$

Where the subscripts of *r, m, top* and *base* refer to Raman, molecular, cloud top and base; *X* is the lidar signal; *z* is altitude; *OD* is optical depth; *T* is molecular extinction; *dz* is lidar range resolution.

3. Equipment

The HU lidar system includes three parts: laser system, receiver telescope and detector system, and data acquisition and analysis system. The Nd:YAG laser emits three laser beams with wavelengths of 1064, 532 and 355 nm. The lidar system can measure high-resolution (7.5 m) vertical profiles of elastic backscatter at the three operational wavelengths, and Raman scattering in the near-UV that are collected by a Cassegrain-configured telescope with a 48 inch diameter and 1~4 mrad field-of-view. The lidar has a non-coaxial configuration and detects return signals between the ranges of 1 km and approximately 30 km. Four photomultiplier tubes are used for the detection of the backscattered signals (532 nm and 355 nm) and Raman backscattered signals, while an avalanche photodiode is used to detect the backscattered 1064 nm signal. This provides the ability to retrieve aerosol backscatter and extinction coefficients [5-7] from the elastic measurements, and temperature [4] and H_2O from the rotational and vibrational Raman measurements, respectively, with a vertical range that extends from the near-surface to the top of the troposphere (~15km) depending on atmospheric conditions. Fig.1 shows the structure and filter system of HU lidar.



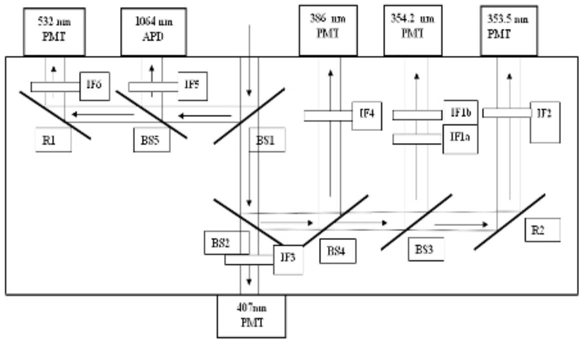
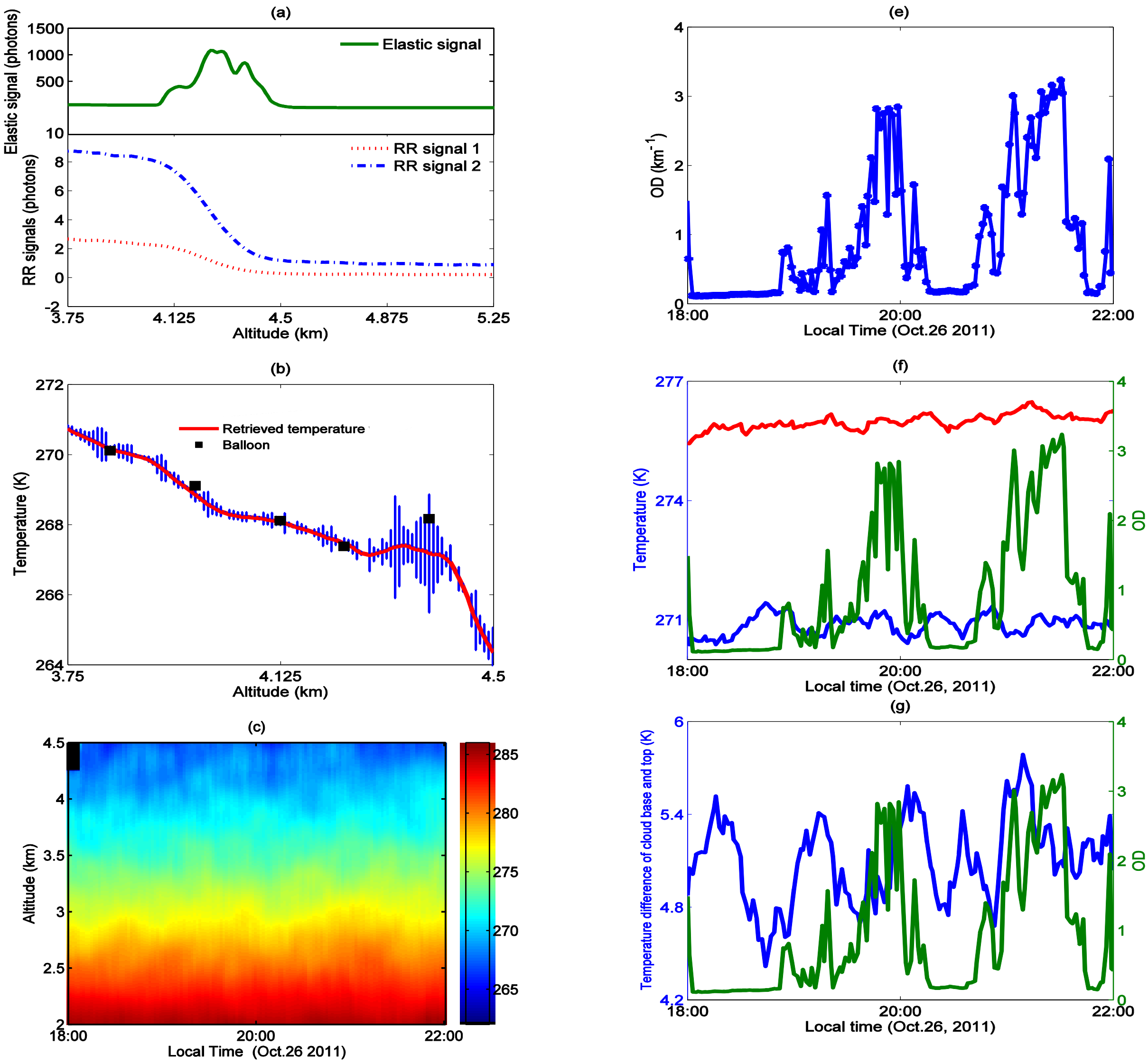


Fig.1 The detector system.

4. RESULTS

The example for a cumulus cloud is demonstrated with this technique. Fig. 2(a) shows a 5-min average of elastic backscatter returns at 354.7 nm, as well as two channel RR returns at 22:10 (local time) on October 26, 2011. Fig. 2(a) shows that the cumulus clouds appear at approximately 4.0 to 4.5 km altitude; 2(b) presents the HU lidar temperature results derived with the RR-signals (red line) and balloon-sounding's temperature results (square symbols). The blue bars are error bars of temperature retrieved using RR signals. Clearly, the lidar-derived cloud temperatures agree well with balloon-sounding's results. Presented in Fig. 2(c) is the temporal variation of HU lidar temperature results for a time period of 18:00–22:00 on October 26, 2011. Fig. 2(d) shows HU lidar range-corrected signals for the same time period., For this case, the clouds show stable heights, depths and a few hours life-time at 18:30 – 20:00 and 20:20 – 22:00. Fig 2. (e) shows corresponding cloud OD variation obtained by HU lidar. Fig. 2(f) shows the corresponding results of temperature of cloud base and top and cloud OD. It is found that the temperature of cloud base (red line) has a slight increasing trend. It means night cloud can reflect Earth radiation and warms the air below the cloud. Fig. 2(g) shows the corresponding results of temperature difference of cloud base and top and cloud OD. It is found that the higher the cloud OD is, the higher the difference of temperature of the cloud base and top is. These results indicated that the technique is feasible.



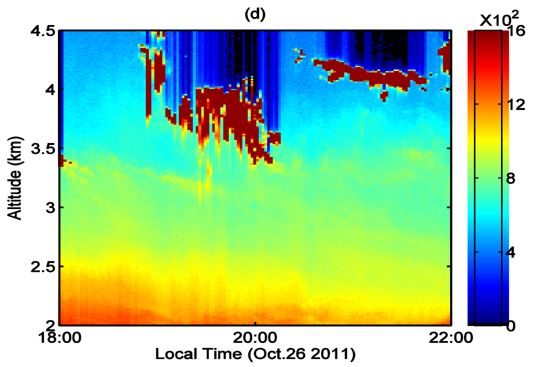


Fig.2 (a) elastic backscatter returns at 354.7 nm and two channel RR returns at 22:10 (local time) on October 26, 2011; (b) HU lidar temperature results (solid line) and a balloon-sounding's temperature results (square symbols) launched at HU; (c) Temporal variation of HU lidar temperature for a time period of 18:00–22:00 22:00 on October 26, 2011; (d) HU lidar range-corrected signals for a time period of 18:00–06:00 22:00 on October 26, 2011; (e) cloud OD variation measured by the HU lidar for a time period of 18:00–22:00 on October 26, 2011; (f) Temperatures retrieved of cloud base (red line) and cloud top (blue line), and cloud OD (green line) over the same period; (g) Temperature difference between cloud base and cloud top, as well as the cloud OD.

5. CONCLUSIONS

This work has developed a new method to research the relationship between cloud temperature and cloud OD using a Raman Lidar. Cloud temperature and optical depth are obtained using the rotational Raman and vibrational Raman techniques. A nocturnal result of cloud temperature and optical depth observed by the HU Rotational-Vibrational Raman Lidar are presented. The results of cloud temperature base and top, and cloud OD, are analyzed. . It is found that the higher the cloud OD, the higher the difference of temperature of the cloud base and top. . We will continue studying this outcome in the future.

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REFERENCES

[1] Sinkevich AA, and Lawson RP. A Survey of Temperature Measurements in Convective Clouds. J. Appl. Meteor 2005; 44: 1133-1136.

[2] Albrecht BA, Cox SK, and Schubert WH. Radiometric measurements of in-cloud temperature fluctuations. J. Appl. Meteor 1979; 18: 1066-1068.

[3] Behrendt A, and Reichardt J. Atmospheric temperature profiling in the presence of clouds with a pure RR lidar by use of an interference-filter-based polychromator. Appl. Opt 2000; 39: 1372-1376.

[4] Su. J., McCormick, M. P., Wu, Y., Lee III, R. B., Lei, L., Liu, Z., & Leavor, K. R. (2013). Cloud temperature measurement using rotational Raman lidar, Journal of Quantitative Spectroscopy & Radiative Transfer, 125, 45-50.

[5] Tao, Z., Liu, Z., Wu, D., and McCormick, M. P. (2008a). Determination of aerosol extinction-to-backscatter ratios from simultaneous ground-base and spaceborne lidar measurements, Optics Letters, 33, 2986-2988.

[6] Su, J., M. P. McCormick,, Z. Liu,, K. Leavor,, R. B. Lee III,, J. Lewis, M. T. Hill, 2010: Obtaining ground-based lidar geometrical form factors using coincident spaceborne lidar measurements, *Appl. Opt*, **49**, 108-113.

[7] Su, J., McCormick, M. P., Liu, Z., Lee III, R. B., Leavor, K. R., & Lei, L. (2012). Transmittance ratio constrained retrieval technique for lidar cirrus measurements, Optics Letters, 37, 1595-1597.