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Raman/DIAL Technique for Ozone Measurements

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Abstract

The Lidar Atmospheric Profile Sensor (LAPS) instrument is capable of simultaneously measuring profiles of ozone, water vapor, temperature, and optical extinction. The measured profiles are integrated, for user selected intervals, to calculate and display the real-time atmospheric profiles with their associated errors, $\pm 1\sigma$ standard deviation. Profiles of ozone are obtained from a Differential Absorption Lidar (DIAL) analysis of the Raman shifted scatter of N_2 and O_2. The LAPS instrument uses the "solar blind" portion of the ultraviolet spectrum to obtain measurements during daytime periods when large background limits visible measurements.

Introduction

Penn State University has developed the Lidar Atmospheric Profile Sensor (LAPS) as a prototype instrument for the U.S. Navy. The LAPS instrument is capable of providing real-time data products of meteorological properties to determine the refractive conditions in the atmosphere. Several sub-systems have been specifically designed into the LAPS instrument in order to make the instrument simple to operate. User friendly software has been written for the LAPS instrument to constantly monitor the subsystems as well as display a real-time data product. With little training an individual can operate the instrument effectively to produce a data output.

The LAPS instrument uses molecular scattering properties of the species in the lower atmosphere to simultaneously measure profiles of ozone, water vapor, temperature, and optical extinction due to aerosol/particle contributions [1,2]. The profiles are currently obtained each minute, with a vertical resolution of 75 meters from the surface to 7 km. In the near future, the vertical resolution will be improved to the range of 3 to 15 meters using a new fast electronics package that has been demonstrated as a single channel prototype in our laboratory.

Measurement Technique

Ozone profiles are obtained from a DIAL (Differential Absorption Lidar) analysis of the Raman shifted scatter of N_2 (285 nm) and O_2 (276 nm) which occur on the steep side of the Hartley absorption band of ozone (see Figure 1). The tropospheric ozone can be measured during both the daytime and nighttime because of the capability of the instrument to use the "solar blind" portion of the ultraviolet spectrum from the 4^{th} harmonic of the Nd:YAG laser. The day sky background wavelengths are dark because of stratospheric ozone absorption The process used to obtain the ozone profile is illustrated in Figure 2. First, The integrated ozone profile is obtained by taking the ratio of the O_2/N_2 signals. This can be seen in the left panel of Figure 2. .Since photo-multiplier tubes (PMT) are used to detect the backscattered photons, the error bars seen in the left panel of Figure 2 are associated with Poisson statistics, that is, the error is determined from the square-root of the number of photon counts [3]. The ozone profile comes from the differentiation of this integrated measurement and can be seen in the right panel of Figure 2. The ozone profiles must be integrated for 15 to 30 minutes to obtain an acceptable signal to noise ratio.

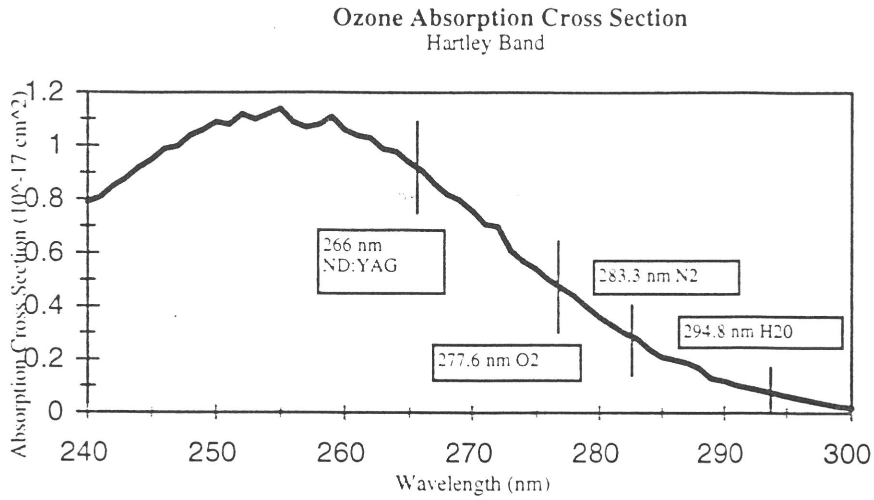


Figure 1. The Hartley band absorption cross-section of ozone is shown with the location of the wavelengths of the 4th harmonic of the ND:YAG laser and Raman shifted wavelengths for N_2, O_2, and H_2O are indicated.

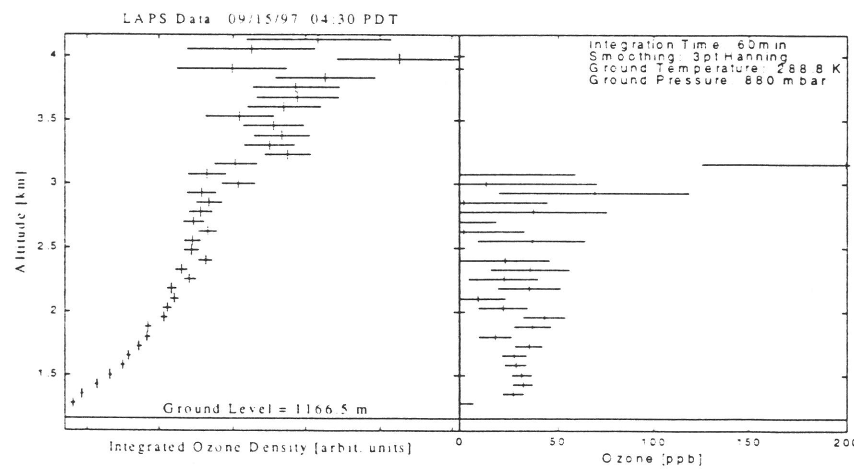


Figure 2: A data sample is used to show how lidar data is analyzed to obtain an ozone profile. The left panel of the figure is the integrated ozone density with arbitrary units. The right panel of this figure illustrates the differentiation to get the final profile.

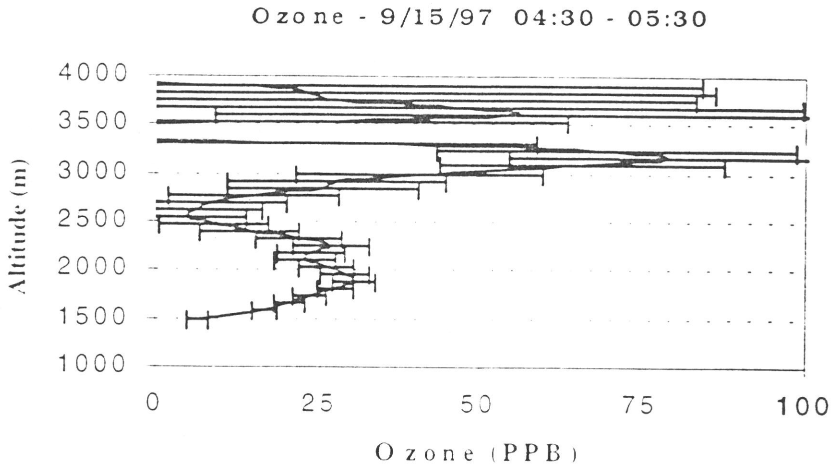
Experimental Data

During August and September 1997 the LAPS instrument was used in the SCOS (Southern California Ozone Study) program to investigate the urban pollution in the Los Angeles area. The PSU lidar field measurement activity in the SCOS'97 program was undertaken to investigate the ozone production in the Los Angeles basin and subsequent transport into the high desert that lies to the east. The instrument was co-located at a site with a RASS (Radio Acoustic Sounding System) instrument at a meteorological station of Radian International Corporation located in Hesperia, California. This site was located in the high desert at the top of the Cajon Pass and was chosen because the Cajon Pass is believed to be a passage which allows ozone to flow from Los Angeles out into the high desert.

During the SCOS campaign the LAPS instrument collected data for nearly 10 hours per day. This was just one of many instruments collecting data during the SCOS '97 campaign. A sample of an ozone profile from the LAPS real-time data display can be seen in Figure 3. This profile was integrated for 60 minutes from 04:30 PDT to 05:30 PDT on 15 September 1997. Figure 4 shows a time sequence plot of ozone for data also obtained on the morning of 15 September. This data was integrated for 30 minutes and updated every 10 minutes. This display illustrates the vertical changes in ozone density as a function of time. The ozone density is ascending as time progresses and is attributed to the lee waves coming from the mountains in the Cajon Pass.

Also during the SCOS'97 campaign, three sets of coordinated measurements were obtained using the LAPS lidar instrument in conjunction with instruments on a University of California, Davis aircraft. On the 18th and 19th of September, the aircraft performed ascending and descending flights which approximately mapped the sides of a square box about 2 km on each side of the lidar beam. Each ascent and descent took approximately 15 minutes. A comparison of the data from LAPS and the airplane can be seen in Figure 5. The LAPS data is integrated for 30 minutes and is centered around the time of
ascent for the airplane.

Figure 3: An example of the real-time display of ozone density shows the graph a controller would see on the LAPS console on 15 September 1997.



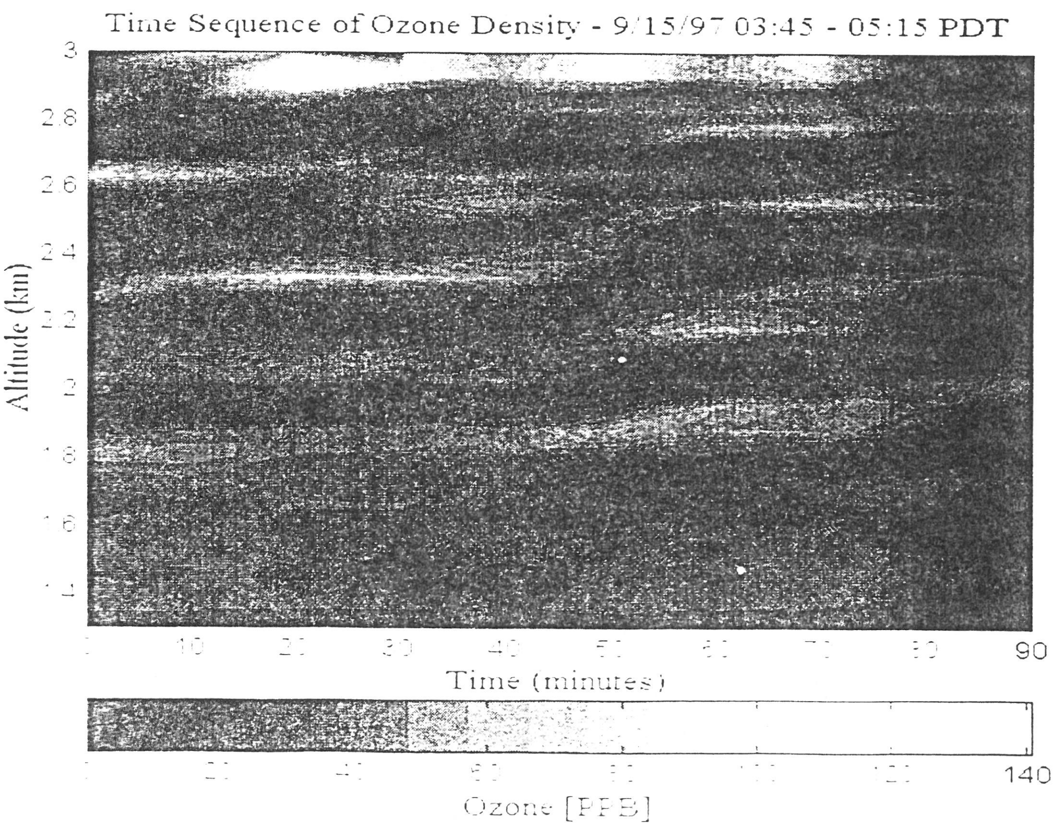


Figure 4: This display shows a time sequence ozone density starting at 3:45 PDT on 15 September 1997 from the LAPS instrument located at the Hesperia CA site

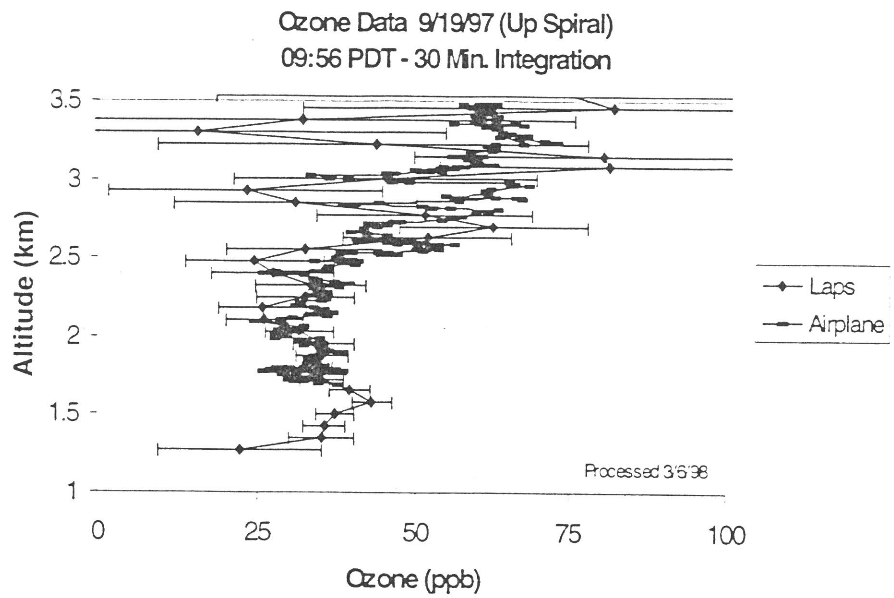


Figure 5: A comparison of ozone data from the LAPS instrument and the University of California, Davis aircraft from 19 September 1997.

Summary

The LAPS instrument uses a DIAL analysis of the Raman shifted scatter of N_2 (285 nm) and O_2 (276 nm) to obtain real-time profiles of ozone density, with a vertical resolution of 75 meters. The minimum integration time for these profiles is 15 to 30 minutes depending on atmospheric conditions. The "solar blind" spectral region is used to obtain profiles of ozone absorption in intense daylight. The LAPS instrument has been compared with other instruments that measured the same atmospheric properties using different techniques and has performed well. This instrument is able to constantly monitor and display absorption properties of tropospheric ozone. This paper shows the preliminary results from the major data set obtained. Simultaneous measurements of water vapor, temperature and optical extinction at three wavelengths was obtained.

Acknowledgments

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References

1. C. R. Philbrick and D. B. Lysak, "Measurement Capability of the LAPS Lidar," Proceeding of the Battlespace Atmospheric Conference, San Diego, California, December 1997.
2. C. R. Philbrick and D. B. Lysak, "Atmospheric Optical Extinction Measured By Lidar," Proceeding of the Battlespace Atmospheric Conference, San Diego, California, December 1997.
3. W. Durbin, "Lidar Measurements of Ozone in the Lower Atmosphere," Masters Thesis, Department of Electrical Engineering, Penn State University, 1997.
4. Balsiger, Franz and C. Russell Philbrick, "Lower-tropospheric Temperature Measurements Using a Rotational Raman Lidar," Optical Instruments for Weather Forecasting, SPIE Proceedings Vol 2832, pg 45-52, 1996.