

HIGH SPECTRAL RESOLUTION LIDAR MEASUREMENTS USING AN I₂ ABSORPTION FILTER

E. W. Eloranta and P. Piironen

University of Wisconsin

1225 W. Dayton St., Madison, Wisconsin

Tel: 608-262-7327 Fax: 608-262-5974

email: eloranta@lidar.ssec.wisc.edu

The University of Wisconsin High Spectral Resolution Lidar (HSRL) measures optical properties of the atmosphere by separating the Doppler-broadened molecular backscatter return from the unbroadened aerosol return^{1,2}. In the past, the HSRL employed a Fabry-Perot etalon with a 0.5 pm bandpass to separate the aerosol and molecular scattering. With careful control of the etalon¹, we were able to maintain a short term (~ 1 hour) calibration stability $\sim 0.1\%$ in the inversion coefficients used to separate aerosol and molecular signals. This provided accurate measurements when the aerosol to molecular backscatter ratio was less than ~ 100 . However, in dense clouds the backscatter ratio often exceeds 10^3 . The etalon provided only a factor of ~ 2 rejection of the aerosol signal incident on the molecular phototube. Thus, the molecular channel signal from inside a dense cloud included ~ 500 times as many photons scattered by aerosols as by molecules. In these cases, a 0.1% error in the inversion coefficients produced a 100% error in the separated molecular return.

She et al³. reported HSRL lidar observations of temperature and aerosol backscattering using a HSRL based on a barium absorption filter and a dye laser. Atomic absorption filters provide more complete rejection of the aerosol signal in the molecular channel. In addition, these filters are much less sensitive to temperature and have little sensitivity to the incidence angle or the divergence of the optical beam. Miles et al.⁴ have used I₂ molecular filters to separate aerosol and molecular scattering for wind tunnel flow visualization and velocity measurements. Molecular iodine has several absorption lines which lie in the thermal tuning range of injection-locked, frequency-doubled Nd-Yag lasers⁵. This eliminates the frequency stabilized dye laser which is required when using a barium absorption cell. Even though the I₂ lines are broadened by hyperfine structure, room temperature operation provides linewidths similar to those provided by the barium cell which must be operated at $\sim 500^\circ\text{C}$.

The HSRL has been modified to use an I₂ absorption cell; the new receiver schematic is shown in figure 1. The signal detected by PMT1 contains both aerosol and molecular scattering. The I₂ filter inserted before PMT2

heavily attenuates aerosol contributions while transmitting the Doppler broadened wings of the molecular spectrum. PMT 3 is used to measure the angular field of view dependence of the signal. The transmitter switches the polarization between parallel and perpendicular on alternate laser pulses. Since the lidar operates at a 4 kHz repetition rate, ratios of alternate lidar returns can be used to accurately determine depolarization in all signal channels.

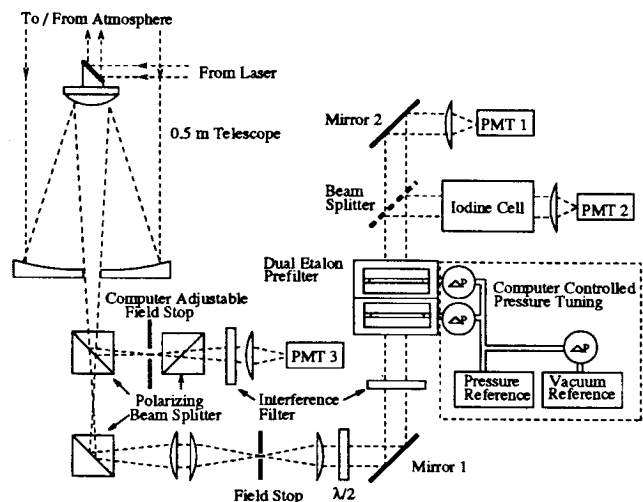


Figure 1. The modified HSRL receiver.

The HSRL transmitter uses a continuously pumped, Q-switched, injection seeded, frequency doubled Nd:YAG laser operating at a 4 kHz pulse repetition rate¹. This laser is tunable over a 124 GHz frequency range by temperature tuning the seed laser under computer control.

An evacuated, 43 cm long cell containing I₂ crystals in a side arm serves as the absorption cell. The cell is maintained at a constant temperature of $27 \pm 0.1^\circ\text{C}$. Figure 2 shows the absorption spectrum of this cell.

For routine operation the HSRL is tuned to line 1109 which provides a large attenuation of the aerosol return and is well isolated from the neighboring lines. However, the laser is sometimes tuned to the notch between lines 1107 and 1108; this provides better separation of aerosol from molecular scattering when the molecular scattering is much larger than the aerosol scattering. Tuning is maintained by a digital servo which monitors the trans-

mission of laser light through a 4 cm long I₂ absorption cell.

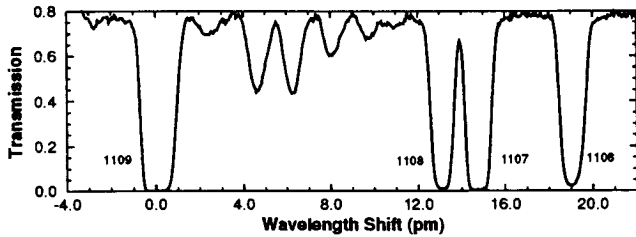


Figure 2. The I₂ absorption spectrum measured by thermally tuning the laser. Spectral lines are identified with numbers from Gerstenkorn and Luc⁶.

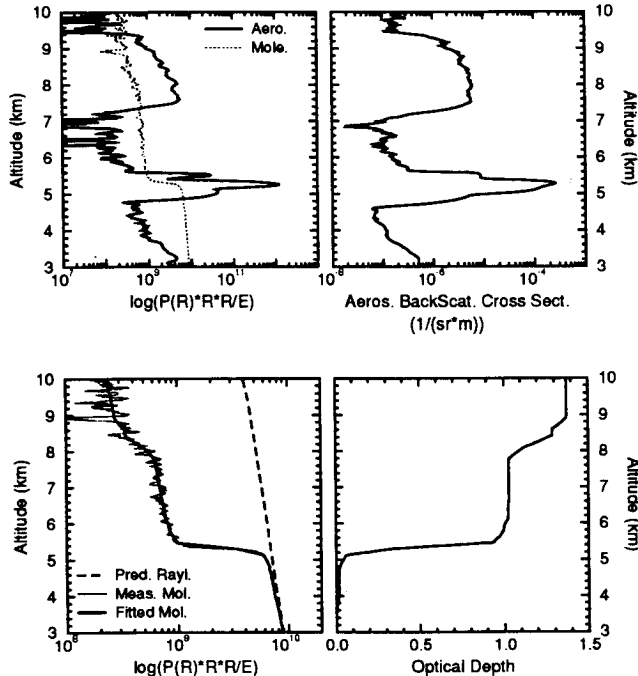


Figure 3. HSRL profiles showing signal returns from aerosols (below 4.8 km and 5.7 - 7.2 km), a water cloud (4.8 - 5.7 km) and an ice cloud (7.2 - 9.5 km). The range-square corrected aerosol (solid line) and molecular (dotted) lidar returns are shown in the upper left. The measured particulate backscatter cross section is shown in the upper right. The measured molecular (thin solid), a constrained nonlinear regression fit to the molecular (bold solid) and the molecular density variation with altitude (dashed) are plotted in the lower left. The measured optical depth profile is plotted in the lower right.

Line 1109 of the I₂ filter provides very clean separation of the molecular lidar return. Only 0.08% of the aerosol return appears in the molecular return. Increasing the cell length does not increase the online rejection of the cell. The rejection may now be limited by the spectral purity of the laser output. Tests show that the spectral transmission of the cell is very stable. Separation of aerosol and molecular returns can be ac-

complished in dense clouds. In the past, the probing of dense clouds was limited by uncertainties in the calibration constants; currently, photon counting statistics appear to provide the dominant error.

The HSRL also includes a Wide-Field-of-View (WFOV) data channel which records the combined aerosol and molecular lidar return simultaneously with the spectrometer channels. The angular field of view of this channel is controlled by the system computer and it can be adjusted from 0.2 mrad to 4 mrad. This channel is rapidly sequenced between several apertures to record the FOV dependence of the multiply scattered lidar return. The system calibration and signals recorded in the spectrometer channels are sufficient to allow removal of the molecular return from the WFOV signal. The depolarization of light received in the WFOV channel is also measured.

Figure 3 provides an example of HSRL profiles measured between 1:29 and 1:34 UT on November 11, 1993. Notice that these measurements have been acquired through clouds with a total one-way optical depth of 1.38. With more uniform clouds, longer time averages have allowed measurements through clouds with an optical depth as large as 3.

ACKNOWLEDGMENTS

This work was supported by grants from the Office of Naval Research (N00014-91-J-1558) and the National Aeronautics and Space Administration (NAG-1-882).

REFERENCES

1. Grund, C.J., and E.W. Eloranta, 1991: University of Wisconsin High Spectral Resolution Lidar, *Optical Engineering*, **30**, 6-12.
2. Piironen, P. and E. W. Eloranta, 1994: Demonstration of an iodine absorption filter based high spectral resolution lidar, *Optics Letters*, **19**, 234.
3. She, C. Y., R. J. Alvarez II, L. M. Caldwell, and D. A. Krueger, 1992: High-spectral-resolution Rayleigh-Mie lidar measurements of aerosol and atmospheric profiles, *Optics Letters* **17**, 541-543.
4. Miles, R.B., W.R. Lempert and J. Forkey, 1991: Instantaneous Velocity Fields and Background Suppression by Filter Rayleigh Scattering, *29th Aerospace Science Meeting*, AIAA paper 91-0357, Reno, NV.
5. J. A. Harrison, M. Zahedi, and J. W. Nibler, 1993: Use of seeded Nd:YAG lasers for high-resolution spectroscopy, *Optics Letters* **18**, 149-151.
6. S. Gerstenkorn and P. Luc, 1978: *Atlas du spectre d'absorption de la molécule d'iode* (Centre National de la Recherche Scientifique, Paris).