Improvements in Raman Lidar Measurements Using New Interference Filter Technology

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Abstract

Narrow-band interference filters with improved transmission in the ultra-violet have been developed under NASA-funded research and used in the Raman Airborne Spectroscopic Lidar (RASL) in ground-based, upward-looking tests. Measurements were made of atmospheric water vapor, carbon dioxide cloud and aerosol and carbon and nitrogen and carbon and carbon dioxide when excited by the frequency-tripled Nd:YAG laser (354.71 nm). The specifications of these 50 mm diameter filters are shown in Table 1.

Interference Filter Technology Development

The objective of this research was to develop processes for fabricating UV filters with significant improvement in throughput, bandwidth, and demonstrate a series of UV filters processing 100 to 250 pm bandwidths and peak transmission of 60-90%. Temperature stability and long lifetime were desired indicating that refractory oxides would be the thin film materials of choice. Among the filters developed under this activity were ones to measure Raman scattering from water vapor, nitrogen and carbon dioxide when excited by the frequency-tripled Nd:YAG laser (354.71 nm). The specifications of these 50 mm diameter filters are shown in Table 1.

Daytime Water Vapor Mixing Ratio Measurements

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Generally Raman lidar measurements of cirrus cloud optical depth and extinction-to-backscatter ratio have not been made in the daytime. The recent use of pure rotational Raman scattering coupled with a Fiji-Peri unit for temperatures profiling has demonstrated the ability to measure cirrus cloud extinction during the daytime. These measurements require working very close to the laser line and can be subject to beamdeeps from the strong cloud scattering. Cirrus cloud optical depth measurements during the daytime using the technologically simpler approach of measuring the vibrational absorption of N2 have not been demonstrated previously due to poor signal-to-noise measurements at cirrus altitudes. Using an interference filter produced under this research with a bandwidth of 6.1 pm centered on the Raman vibrational q branch, Raman lidar measurement of cirrus cloud optical depth and extinction-to-backscatter ratio have been made for the first time using vibrational Raman scattering during the daytime. The figure on the left shows upward-looking RASL measurements of cirrus cloud scattering optical depth and extinction-to-backscatter ratio calculated with 1-sec temporal resolution. The solar zenith angle was approximately 45 degrees during this measurement period. The statistical uncertainty of both the optical depth and lidar ratio retrieval is less than 10%. The filter packet was centered on the absorption of N2 by shifting the filter. The Continuum 9900 laser in use in this experiment was not injection-seeded. We observed changes in the transmitted intensity of the Raman laser due to variations in the laser cooling water temperature to +/-10°C eliminated any noticeable change in the transmitted intensity of Raman scattering measurements as confirmed by the Burleigh pulsed wavelength measurement system. These new cirrus cloud measurements of optical depth will permit Raman lidar systems to provide useful measurements of cirrus optical quantities during both daytime and nighttime.

Summary and Conclusions

Improved Raman lidar measurements were demonstrated using advanced interference filter techniques produced under this research. Measurements of water vapor, nitrogen and carbon dioxide were acquired using those filters, in the Raman Airborne Spectroscopic Lidar (RASL) operating from the ground in an upward-looking configuration. Water vapor measurements were acquired at heights that range between 1.5 and 2 km. The statistical uncertainty of both the optical depth and lidar ratio retrieval is less than 10%. The filter packet was centered on the absorption of N2 by shifting the filter. The Continuum 9900 laser in use in this experiment was not injection-seeded. We observed changes in the transmitted intensity of the Raman laser due to variations in the laser cooling water temperature to +/-10°C eliminated any noticeable change in the transmitted intensity of Raman scattering measurements as confirmed by the Burleigh pulsed wavelength measurement system. These new cirrus cloud measurements of optical depth will permit Raman lidar systems to provide useful measurements of cirrus optical quantities during both daytime and nighttime.

On September 19, 2004, RASL was not for 5 hours acquiring what we believe to be the first simultaneous remote profile measurements of atmospheric CO2 and H2O mixing ratio. The latter value first ground-based lidar measurements of the vertical striping of the image at approximately 16.0 and 19.5 UT are due to clouds that developed at the top of the boundary layer. The residual layer from boundary layer mixing on previous days, is observed to descend from approximately 4.5 km to less than 3 km over the period extending into the free troposphere as well. The CO2 measurements were calibrated based on ground-based measurements of CO2 acquired at the time. The calibration must therefore be considered only approximate. The water vapor measurements were calibrated by using the total precipitable water of the lidar profile to that measured by a collocated GPS sensor. Both the CO2 and H2O have been analyzed such that the vertical resolution is 380 km between 1 and 2 km, 400 km between 2 and 3 km, 500 km between 3 and 4 km, and 600 km above 4 km. The precision of the CO2 mixing ratio measurement obtained with these observations, determined from the signal strength of the CO2 and N2 data assuming Poisson statistics, is found below 1.5 ppm for altitudes less than 4 km. The precision of the CO2 mixing ratio is generally consistent with model predictions.

Table 1. Specifications of interference filter manufactured under this effort, BW refers to the full width half maximum bandwidth of the filter, CWL to the center wavelength, T to the transmission.

<table>
<thead>
<tr>
<th>Filter</th>
<th>CWL (nm)</th>
<th>BW (nm)</th>
<th>T (%)</th>
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</thead>
<tbody>
<tr>
<td>Raman Water Vapor</td>
<td>371.71</td>
<td>0.1</td>
<td>40</td>
</tr>
<tr>
<td>Raman nitrogen</td>
<td>210-1200</td>
<td>0.1</td>
<td>60</td>
</tr>
<tr>
<td>Raman carbon dioxide</td>
<td>210-1200</td>
<td>0.1</td>
<td>40</td>
</tr>
</tbody>
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References