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THE DESIGN AND INITIAL OBSERVATIONS OF A TROPOSPHERIC OZONE LIDAR CAPABLE OF CONTINUOUS RAPID PROFILING DAY AND NIGHT

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The measurement of ozone in the free troposphere by the differential absorption lidar technique (DIAL) has been practiced for more than a decade. The instruments are usually ground-based although aircraft applications have also been quite successful. Measurements are made during the nighttime hours or at low sun angles to decrease the background signal due to solar radiation. As with the stratospheric DIAL method, the tropospheric application requires at least two wavelengths with differing ozone absorption cross sections. A judicious choice of wavelengths provides the sensitivity required to measure accurately the low ozone concentrations present in the troposphere, and under clear sky conditions, allows for rapid profiling 24 hours a day. By retaining flexibility in the choice of wavelengths, errors in the calculated values of ozone due to differential Mie scattering and other absorbing molecular species can also be decreased.

Stratospheric ozone lidar instruments have been producing routine profiles from about 20 km to at least 40 km with a precision sufficient to monitor stratospheric ozone change. Well below these altitudes, tropospheric ozone appears to be also changing, with significant increases reported in a few geographic locations. Tropospheric ozone profiles have been generally provided by balloon-borne ozone sondes launched perhaps once a week at a few locations. Tropospheric ozone is highly variable on much shorter time scales, so such infrequent sampling is not necessarily representative of the one week period. In contrast, the tropospheric ozone lidar that we describe can provide many profiles in rapid succession and examine the statistical fluctuations in ozone distributions on short time scales. The disadvantage for lidar is the requirement of a cloud-free period while taking data. The tropospheric lidar we describe takes full advantage of the lidar technique. It has the capability of rapidly acquiring profiles throughout the free troposphere with high vertical resolution and accuracy, during all clear sky hours of the day.

Wavelengths shorter than 286 nm are attenuated sufficiently in the atmosphere to limit the useful altitude range of ground-based measurement to the lower troposphere. This sets the lower limit for our measurement wavelengths. Considering longer wavelengths, there is sufficient solar radiation beyond about 292 nm to increase the background signal and again limit the maximum altitude range of the measurement. During daylight measurements we use an edge filter to virtually eliminate the solar photons with wavelengths longer than 293 nm, and we restrict our laser wavelengths to be between 286 and 292 nm. Nighttime profiles can be made without the filter, allowing longer wavelengths that can propagate to higher altitudes.

The lasers we use are continuously variable over the wavelength range described above. Each wavelength is produced by an independent laser system, consisting of a Nd:YAG laser that is doubled to pump a dye laser. The resulting visible wavelength emitted from the rhodamine dye is again doubled to produce the required ultraviolet wavelengths. The two lasers are fired at 20 Hz and their output wavelengths are independently variable. By separating the two laser outputs by 400 microseconds, a single photomultiplier detector with the broad-band edge filter described above can be used. This allows the wavelengths to be changed from profile to profile to search for interfering molecular species and to make consistency checks. A wavemeter is used to monitor the wavelengths.

Two independent telescopes and gated photomultipliers are used, one for the near field and the other for the more distant measurements. The signals are hardware averaged by 12-bit analog to digital converters and recorded by a devoted data acquisition computer. Data from an ozone profile can be acquired and stored in as little as one minute, while a preliminary analysis of the data from the previous profile is underway on the data analysis computer. This gives real-time information to the operator.

The resulting system provides vertical profiles in from 1 to 4 minutes up to at least a 12 km altitude with a 1 km altitude resolution. The absolute accuracy of the clear sky measurement can be approximated if one considers statistical uncertainty in the detected signal (up to 3%), uncertainty in the ozone cross section (2%), molecular interferents (2%) and hardware limitations such as laser-telescope alignment, photomultiplier signal-induced bias, and digitizer non-linearities (4%). Null profiles (profiles using two identical wavelengths) are consistent with this conclusion. A simple sum of these sources of possible error reduces to 10%, and we consider it to be a conservative estimate of absolute error. Uncertainties in the wavelength dependence of Mie scattering have not been included in this analysis, however the effect in clear air should be relatively small. Our error analysis needs to be verified by direct comparison with in-situ measurements of known high accuracy.

We now have more than two years of ozone observations using our lidar at Fritz Peak Observatory near Rollinsville, Colorado. The expected seasonal changes in ozone are apparent, reflecting the annual rise and fall of the tropopause and the ozone increase during spring. We have also made a few intensive studies with 12 to 24 hour periods of continuous measurement. The changes that we have observed on these time scales appear to be dynamical rather than chemical in origin.

The ability to independently change wavelengths allows for many new techniques to check for consistency in the reduced data. We have already briefly mentioned the null profiles, where both lasers are tuned to the same wavelength and an ozone profile is calculated using a nominal value for the differential cross section of ozone. Deviations from a zero profile reflect errors that might otherwise go undetected. These can arise from many causes, such as improper alignment of the laser beams with the telescope. Another capability that we have not fully utilized is varying the wavelenths from profile to profile to routinely searched for other molecular species such as sulfur dioxide that could produce an ozone-like absorption signature in DIAL measurements. And finally we might attack the nemesis of lidar, the wavelength dependence of backscatter from particles. Again by systematically varying the wavelengths from profile to profile, and by simultaneously monitoring the aerosol backscatter at another wavelength, regions of high aerosol content can be studied for their ultraviolet backscatter wavelength dependence.