Feasibility Study For A Spaceborne Ozone/Aerosol Lidar System

Richard E. Campbell[1], Edward V. Browell[1], Syed Ismail[1],
Alexander E. Dudelzak[2], Allan I. Carswell[3], and Arkady Ulitsky[4]

1 - NASA Langley Research Center, Hampton, Virginia, USA
E-mail: r.e.campbell, e.v.browell, or s.ismail@larc.nasa.gov
2 - Canadian Space Agency, St-Hubert, Quebec, Canada
E-mail: dudelzaka@sp-agency.ca
3 - York University, Toronto, Canada: carswell@lidar.ists.ca
4 - Optech, Inc. Toronto, Canada: arkady@optech.ists.ca

Abstract. Because ozone provides a shield against harmful ultraviolet radiation, determines the temperature profile in the stratosphere, plays important roles in tropospheric chemistry and climate, and is a health risk near the surface, changes in natural ozone layers at different altitudes and their global impact are being intensively researched. Global ozone coverage is currently provided by passive optical and microwave satellite sensors that cannot deliver high spatial resolution measurements and have particular limitations in the troposphere. Vertical profiling DIfferential Absorption Lidars (DIAL) have shown excellent range-resolved capabilities, but these systems have been large, inefficient, and have required continuous technical attention for long term operations. Recently, successful, autonomous DIAL measurements have been performed from a high-altitude aircraft (LASE - Lidar Atmospheric Sensing Experiment), and a space-qualified aerosol lidar system (LITE - Laser In-space Technology Experiment) has performed well on Shuttle. Based on the above successes, NASA and the Canadian Space Agency are jointly studying the feasibility of developing ORACLE (Ozone Research with Advanced Cooperative Lidar Experiments), an autonomously operated, compact DIAL instrument to be placed in orbit using a Pegasus class launch vehicle.

1 Introduction

Though DIAL techniques have a long history of application in aircraft studies of tropospheric and stratospheric ozone and aerosols [1,2,3,4], technology limitations have precluded operation from a space platform. Recent advances in tunable solid state laser technology have opened the avenue for the development of compact, efficient, high power laser systems [5], and advances in composite materials and other receiver technologies will permit development of large area, light-weight receiver systems. These advanced lidar technology developments have been supported by NASA through the Office of Space Access and Advanced Technology and through SBIR funded research and make possible the transition from aircraft lidar systems to satellite-based DIAL systems.

2 Mission Description

The ORACLE DIAL system will operate in the ultraviolet spectral region (305-320 nm) for the measurement of ozone profiles and columns and provide simultaneous aerosol and cloud profile measurements from the direct lidar backscatter returns in the visible (520-600 nm) and/or near-infrared (960-1060 nm) regions. Table 1 presents an estimate of ORACLE's transmitter and receiver characteristics for an instrument operating at an altitude of about 400 Km.

Table 1 - NASA-CSA Ozone DIAL Parameters

	Transmitter		
Wavelength (nm)	308/320 (DIAL)	524	1047
Pulse Energy (mJ)	500	75	300
Rep. Rate (pps)	7 (Double Pulsed)		
Line Width (pm)	<50		
Stability (pm, Drift & Jitter)	<50		
Spectral Purity (%)	~99		
Beam Divergence (mR)	<0.2		
Pulse Width (ns)	30		
	Receiver		
Area (m^2, effective)	0.7		
Field of View (mR)	0.3		
Filter Bandwidth (nm, FWHM)	BB Cut Off UV (Night) BB V/IR (Night) 0.5 nm, UV (Day) 0.05 nm V/IR (Day)		
Overall Optical Eff. (%, Night/Day)	0.72 (Night)/0.45 (Day); UV/NIR 0.2; Visual, Night/Day		
Detector Quantum Eff. (%)	25 UV, 20 V (Both PMT)		
Noise Eq. Power ($w/Hz^{1/2}$, System)	0.15E-14		
Excess Noise Factor (APD)	1.0		

These parameters are based on the use of a limited capability booster that defines the maximum satellite weight and size that can be launched and on the predicted capability of a solid-state UV laser now under development at NASA’s Langley Research Center. The parameters were used to provide an assessment of the measurement capability of ORACLE under a wide range of atmospheric and solar background conditions. Figure 1 shows a typical range of tropospheric ozone distributions; these were used in the experiment simulations.

Figure 2 shows the ozone measurement accuracy for these different ozone distributions for night-time operations. The percentage measurement accuracy is better at the higher ozone levels, and yet the absolute ozone error stays about the same at ~5 ppbv for all the ozone profiles. The vertical resolution in the lower stratosphere can be less than 1 km with a horizontal resolution of 100 km and still maintain an accuracy better than 10%. Simultaneous aerosol and cloud measurements can be made with high vertical (<100 m) and horizontal (<1 km) resolutions, and these aerosol data can be used to focus the ozone measurements across the boundary layer and across layers in the free troposphere and lower stratosphere. This data is of particular importance to atmospheric process studies related to the influence of aerosol and clouds on the chemistry and transport of ozone in the atmosphere.

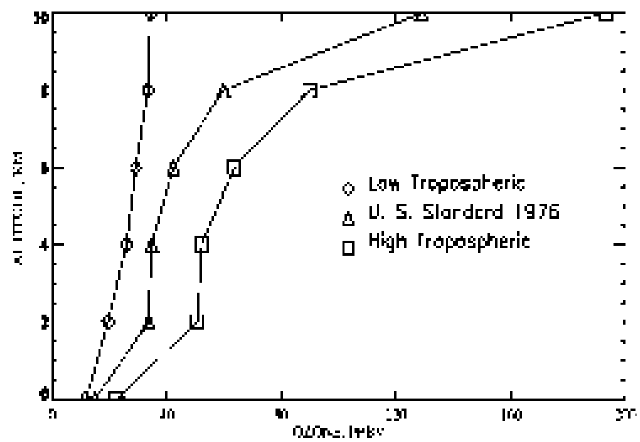

Figure 1- Tropospheric Ozone Model Profiles

These DIAL simulations indicate a need for a 40-50% improvement, especially for daytime operation, in overall system performance in order to meet all of the science objectives. NASA and CSA are currently performing a systems analysis that will include a trade study to determine the most likely areas for improvement. These areas include, but are not limited to: laser output power, pulse repetition rate, telescope diameter, improved signal to noise ratio in the receiver, increased optical efficiency and decreased altitude of operation. None of the potential improvements will be achieved easily. Simply orbiting at a lower altitude, for example, will improve the overall system performance; however, this would also require an increase in the size and weight of the fuel tank required to provide fuel to the thrusters needed to keep the satellite from re-entering the earth’s atmosphere due to increased drag. It would also be a relatively easy task to increase the pulse repetition rate by increasing the power available to the laser. This extra power, however, can only be generated by increasing the size of the solar collectors and batteries, again adding size, weight and drag to the spacecraft. Based on early trade study results, therefore, it seems likely that our efforts will be concentrated in improving the electrical-to-optical efficiency of the laser and in exploring innovative ways to increase the effective area of the receiving telescope.

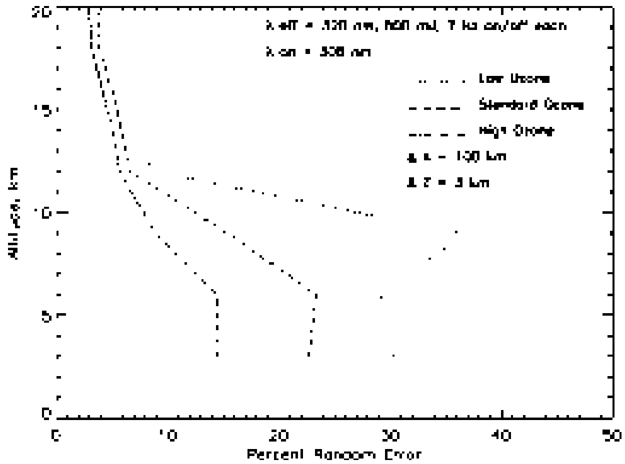

Figure 2 - NASA - CSA DIAL Simulations, Night, Three O_3 Models

3 Conclusion

When completed, the ozone DIAL system will provide a new active remote sensing capability from space that is important to many atmospheric investigations supported by NASA's Office of Mission to Planet Earth and Canada's Atmospheric Environment Service. This system will provide the first global, high-resolution measurements of ozone and aerosols in the troposphere and lower stratosphere. These measurements will also complement and enhance ozone measurements obtained from satellite-based passive remote sensors. Simultaneous ozone, aerosol, and cloud profiles will help in understanding of many processes related to global change, atmospheric chemistry, atmospheric dynamics and meteorology. The development of the ORACLE system will make a significant contribution to spaceborne remote sensing capabilities and enhance international cooperation.

References

1. Browell, E. V., et al., NASA multipurpose airborne DIAL system and measurements of ozone and aerosol profiles, Appl. Opt., 22, 522-534, 1983.
2. Browell, E. V., G. L. Gregory, R. C. Harriss, and V. W. J. H. Kirchhoff, Tropospheric ozone and aerosol distributions across the Amazon Basin, J. Geophys. Res., 93, 1431-1451, 1988.
3. Browell, E. V., C. F. Butler, S. A. Kooi, M. A. Fenn, R. C. Harriss, and G. L. Gregory, Large-scale variability of ozone and aerosols in the summertime Arctic and Subarctic troposphere, J. Geophys. Res., 97, 16,433-16,450, 1992.
4. Browell, E. V., et al., Ozone and aerosol distributions and air mass characteristics over the South Atlantic Basin during the burning season, J. Geophys. Res., 1995.
5. Barnes, J. C., et al., Solid State Laser Technology Development for NASA DIAL and Lidar Systems, AIAA Space Technologies Conference, Sept. 1995.