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WAVELENGTH DEPENDENCE OF COHERENT AND INCOHERENT SATELLITE-BASED LIDAR MEASUREMENTS OF WIND VELOCITY AND AEROSOL BACKSCATTER

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INTRODUCTION

Global profiling of Earth's wind from a satellite would provide numerous civilian, commercial, military, and scientific benefits. In addition, satellite-based measurements of aerosol and cloud backscatter are of great interest. Studies sponsored by the Defense Meteorological Satellite Program (DMSP) have shown the feasibility of measuring the global wind field using a satellite-based pulsed coherent CO_2 laser radar [1]. RCA Corp. has recently completed a study for an Earth-orbiting lidar to measure aerosol backscatter and cloud top heights using a Nd:YAG and doubled Nd:YAG laser operating in an incoherent mode. The Nd:YAG wavelengths at 1.06 and 0.53 microns are in a wavelength region where strong consideration must be given to eye safety. Only coherent CO_2 laser radars, which operate in the 9-11 micron wavelength region, have demonstrated accurate long-range remote wind velocity measurements to date. However, solid-state laser technology has progressed to the point where it should also be considered. Stanford University researchers have built a solid-state Nd:YAG lidar and have recently demonstrated coherent return signals from clouds and aerosols. Solid-state laser systems, compared to CO_2 systems, will be smaller, lighter, may require less power, may not require cooled detectors, and have the potential of several years lifetime in space. A technology assessment has shown the feasibility of fabricating a ground-based Nd:YAG solid-state coherent lidar system at this time for wind velocity and aerosol backscatter measurements [2]. Research is progressing at Stanford University and elsewhere on eyesafe solid-state sources suitable for coherent lidar measurements. The "modular" nature of solid-state systems would allow for the eventual upgrade of Nd:YAG systems to an eyesafe wavelength as the technology permits.

This paper presents the results of a capability study of Earth-orbiting lidar systems, at various wavelengths from 1.06 to 10.6 microns, for the measurement of wind velocity and aerosol backscatter, and for the detection of clouds [3]. Both coherent and incoherent lidar systems were modeled and compared for the aerosol backscatter and cloud detection applications.

COMPUTER SIMULATION

The Coherent Technologies, Inc. lidar computer simulation was used to estimate the performance of a satellite-based laser radar system [1]. A set of satellite base parameters was selected which was used in an earlier analysis by NOAA to determine global wind velocity monitoring feasibility at 9.11-micron wavelength. The wavelength dependence of several of the parameters was reviewed and incorporated in the simulation. The wavelength and height variation of the atmospheric extinction was modeled through the use of the 1982 AFGL atmospheric absorption line parameters compilation. A simplified wavelength**(-2.5) dependence of the aerosol backscatter coefficient was adopted after reviewing recent modeling results and measurements. A factor of 2 was used at 9.11 microns (vs 10.6 microns), instead of 1.5, due to the predicted and measured enhancement at that wavelength. Atmospheric refractive turbulence is modeled in the computer simulation but was found to have a negligible impact even at 1.06 microns. A pulse duration of 6.67 microseconds was used at 10.6 and 9.11 microns yielding a 1 km range resolution and a Gaussian pulse Fourier transform-limited radial wind velocity resolution of approximately 1 m/s. The pulse duration at other wavelengths was made proportional to wavelength in order to preserve a constant velocity resolution.

WIND VELOCITY PERFORMANCE

An example of the satellite-based coherent lidar performance in measuring the horizontal wind velocity component along the track of the satellite is shown in Figure 1 for a wavelength of 2.10 microns. The pulse duration and 10.6-micron backscatter profile multiplying factors are shown in the figure. The corresponding along-track RMS error at 9.11 microns (not shown) varied between 0.8 and 2 m/s for altitudes between ground level and 20 km. The CO2 isotopic laser wavelength at 9.11 microns is a strong candidate due to the lower atmospheric CO2 absorption and due to the enhanced aerosol backscatter coefficient. The eyesafe wavelength at 2.10 microns also has relatively low atmospheric absorption and is a promising solid-state laser wavelength [3].

Using the backscatter multiplier of 60 at 2.10 microns, we see in Figure 1 that the wind velocity error is much greater than at 9.11 microns. Adding a further backscatter enhancement of 10 for a total enhancement of 600 results in better performance at 2.10 microns than at 9.11 microns and much better than is needed. The aerosol model assumed in the computer simulation is the most uncertain parameter in the performance estimate. Aerosol backscatter measurements at several eyesafe wavelengths in addition to the CO2 laser wavelengths are needed. The performance curves in Figure 1 do not include any range-gate averaging. The factor of 5 shorter pulse duration at 2.10 microns would allow the averaging of 5 range gates while preserving range and wind velocity resolutions equal to those at 9.11 microns. This would reduce the wind errors shown in Figure 1.

BACKSCATTER PERFORMANCE

An example of satellite-based coherent and incoherent lidar cloud detection performance at 1.06 microns is shown in Figure 2. The 10.6-micron aerosol backscatter profile was multiplied by a factor of 316 above 5 km altitude. To simulate a cloud, the backscatter coefficient below 5 km was set to a value of 1.0E-5 1/m 1/sr. The correct SNR expression for incoherent detection depends on the type of detector in use, how it is used, the measurement scenario, and whether detection is in the pulse-counting or current-measurement mode. No SNR expression covers all cases. Realistic device parameters were inserted into an equation for non-avalanche photodiodes and the results are shown in Figure 2 as curve A. A state-of-the-art SNR expression, which allows variation of wavelength and detection bandwidth, is shown as curve B. The effect of the cloud on the SNR is clear for all 3 curves. Detection should be possible with either coherent or incoherent systems.

REFERENCES

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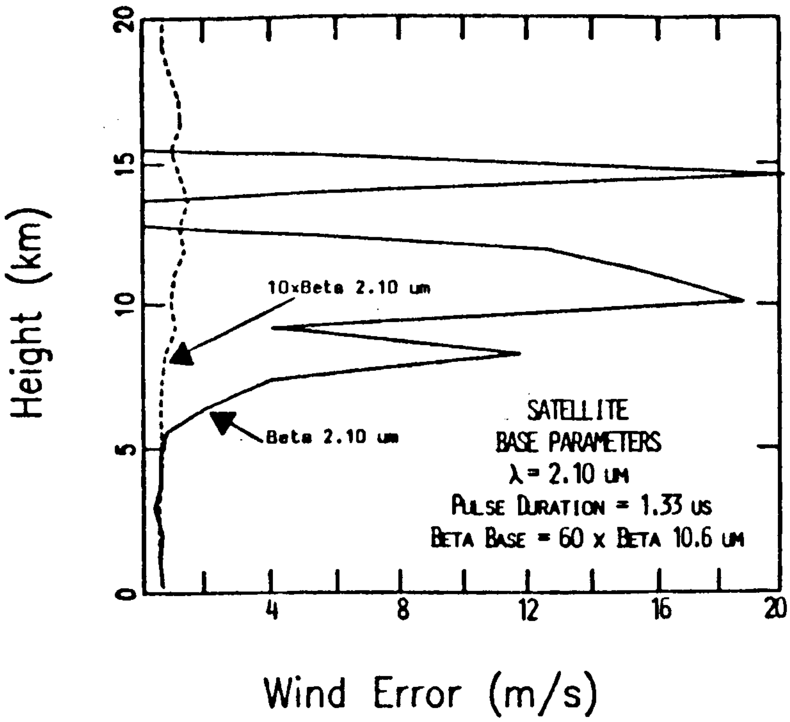

FIGURE 1

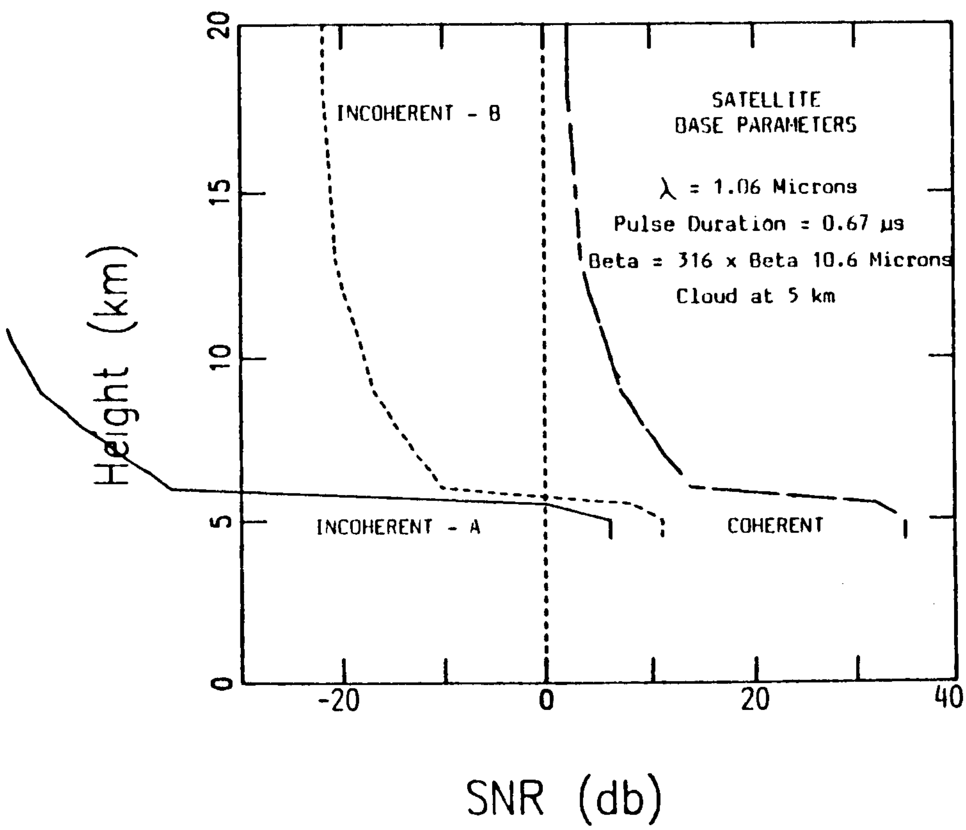

FIGURE 2