Cloud Microphysical and Radiative Properties Measured by Combined Lidar, Radar, and Infrared Radiometer

W. L. Eberhard and J. M. Intrieri
National Oceanic and Atmospheric Administration
Environmental Technology Laboratory
Boulder, Colorado

K. P. Chan and G. Feingold
Cooperative Institute for Research in Environmental Sciences
Boulder, Colorado

Introduction

The goal of our research in the Instrument Development Program (IDP) is to provide experimental descriptions of the bulk, microphysical, and radiative parameters of clouds (especially cirrus) and the relationships between these properties, for use in developing and validating climate models. The strategy of the Atmospheric Lidar Division of our laboratory is to develop remote sensing techniques to simultaneously measure important cloud parameters and to apply these new methods and older ones in case studies and statistical investigations. Our division participated with the University of Utah on technique development during the first three years of IDP including field tests locally and at FIRE II. The Atmospheric Radiation Measurement (ARM) Program also helped fund demonstration of new technology at the Atlantic Stratocumulus Transition EXperiment (ASTEX). Our current research under a new, independent grant comprises four tasks, which are summarized in the following sections.

Characterize Cloud Signatures Obtained by CO_2 LIDAR

A CO_2 lidar operates on a transition line selectable over the range of 9-11.5 µm, with the most common operating wavelength at 10.591 µm. Signals from clouds at these wavelengths are distinguished from lidars operating in or near the visible (“shortwave lidars”) in several ways. The most important difference is the strong absorption by water and ice particles in the infrared. Scattering parameters are also an order of magnitude smaller. These features make simple approximations in scattering calculations adequate for some applications, e.g., Eberhard (1993a). They also provide some unique capabilities, especially the technique described below for measuring drop sizes.

One of the four IDP tasks is to characterize cloud signatures obtained by CO_2 lidar. For instance, our earlier work discovered that depolarization from ice particles was almost always very small (Eberhard 1992). Hence, the polarization technique used so successfully by shortwave lidars (Sassen 1991) fails for a CO_2 lidar. We also studied the phenomenon of enhanced backscatter from oriented ice crystals when pointed near the zenith (Eberhard 1993b). Our current investigations emphasize the backscatter intensity and vertical Doppler motions.

One important technical characteristic of CO_2 lidar is coherent detection, i.e., mixing the scattered radiation with a local oscillator beam, which enables Doppler measurements and also achieves sensitive detection. However, coherent detection requires considerably more complex hardware than direct detection. Coherent CO_2 lidar is equally sensitive day or night and can scan very near the sun without harm or degradation of signal. CO_2 systems also have the asset of complete safety of the radiation transmitted out of the telescope.

Develop a Robust CO_2 LIDAR

Most of our research has relied on a powerful but recalcitrant system that uses transverse-excited atmospheric pressure

(TEA) lasers. Our second IDP task is further development of a robust, user-friendly lidar that incorporates radio-frequency (RF) excitation of the laser gas. A separate paper at this meeting discusses this high-pulse-rate, low-pulse-energy system.

Develop New Cloud-Sensing Techniques

We have performed thorough theoretical feasibility studies under IDP on two cloud-sensing techniques that use only CO_2 lidar measurements.

One method, first introduced by Platt and Takashima (1987), obtains the mode radius of the drop size distribution averaged over the penetration path of the lidar pulse. Eberhard (1993c) showed that better results can be obtained for the mean or effective radius. He also reported the first field application, which gave reasonable but unverified results.

Another theoretical study (Eberhard 1995) showed that the ratio of backscatter at two different CO_2 lidar wavelengths should give useful information on cloud phase as an alternative to the shortwave polarization method.

The most important element of our technique development work involves the synergistic use of simultaneous measurements from multiple sensors for observation of cirrus clouds. Intrieri et al. (1993) showed that the ratio of backscatter cross sections measured by mm-wavelength radar and CO_2 lidar provides a good estimate of the effective radius r_{eff} of the cirrus particle size distribution as a function of height. Comparison with limited in situ measurements was very encouraging. The technique was expanded in Eberhard et al. (1994) to retrieve profiles of ice water content and of the particle number density and to examine the impact of measurement errors on the retrieved parameters.

Our third task in current research concentrates on refinement, extension, and validation of this technique. The effect of nonspherical ice particles on the measurements and the interpretation of results are key issues. Further error analysis will be performed. Some intercomparisons are being made from FIRE II data, which were partly funded through IDP.

We are marrying the lidar-radar method with the lidar-radiometer (LIRAD) method (Platt and Dilley 1981), which combines lidar backscatter profiles, infrared radiometer radiance measurements, and temperature profiles to obtain the emissivity, absorption optical depth and (for CO_2 lidar) the infrared optical depth of ice clouds. LIRAD also provides the means to correct the lidar data in the lidar-radar method for attenuation by the cloud.

The cirrus parameters that can be retrieved from the combined measurements, listed approximately in order of decreasing percentage accuracy, are

Cloud base height	z_{base}
Emissivity	ε
Cloud top height	z_{top}
Absorption optical depth	δ_a
Infrared optical depth	δ_c
Effective radius profile	$r_{eff}(z)$
Ice water content profile	$IWC(z)$
True lidar backscatter cross section profile	$\beta(z)$
Total particle cross section area profile	$A_c(z)$
Total particle surface area profile	$A_s(z)$
Particle number density profile	$N(z)$

Vertical and space (=time) averages, which may be more appropriate for developing algorithms for models, can also be obtained.

Participate at Cloud Remote Sensing IOP

The fourth task is participation in the Cloud Remote Sensing intensive observing period (IOP) at the Oklahoma Cloud and Radiation Testbed (CART) site during April 1994. We will test a new, two-wavelength version of the RF-excited CO_2 lidar that incorporates improvements and design changes based on experience with the first version during ASTEX. We will also evaluate the accuracy of our new techniques by comparison with in situ measurements by aircraft and with other remote measurements, e.g., shortwave lidar polarization. We plan tests of the average drop size method; of ice/water discrimination with two CO_2 wavelengths; and of all the parameters possible from the combined lidar, radar, and infrared radiometer measurements.

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