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ON THE USE OF IR LIDAR AND K_a-BAND RADAR FOR OBSERVING CIRRUS CLOUDS

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I. Introduction

Advances in lidar and radar technology have potential for providing new and better information on climate-significant parameters of cirrus. Consequently, the NOAA Wave Propagation Laboratory is commencing CLARET (Cloud Lidar And Radar Exploratory Test) to evaluate the promise of these new capabilities. Parameters under investigation include cloud particle size distribution, height of cloud bases, tops, and multiple layers, and cloud dynamics revealed through measurement of vertical motions. The first phase of CLARET is planned for September 1989 at the Boulder Atmospheric Observatory (BAO) near Erie, Colorado.

II. Lidar and Radar Capabilities

The CO_2 coherent lidar operating at 10.6 um wavelength is a relative newcomer in the arsenal of cirrus remote sensors. It differs from the other lidars commonly used for cirrus studies in several important respects. First, its wavelength is an order of magnitude larger, so size parametes for scattering are smaller. Second, absorption by cloud particles is substantial. Third, the CO_2 lidar operates in the atmospheric window, whereas others are in or near the visible. And fourth, it has Doppler capability for observing cirrus dynamics. Some introductory research on cirrus with this lidar has already been accomplished (Gross et al., 1984; Hall et al., 1988; Sassen et al., 1990). Recently, however, the stability of the transmitter frequency has been improved for better Doppler estimates, and the pulse can now be shortened to approximately 50 m range resolution instead of exceeding 300 m (Eberhard et al., 1989). This eyesafe instrument is now much more suited to cirrus measurements.

The longer wavelength of a sensitive radar can provide a somewhat different perspective on cirrus. The ice content can be estimated from the backscatter, but depends strongly on size distribution (Sassen, 1987). A radar can penetrate optically thick clouds to reveal the height of cloud top and the presence of multiple layers. During the first phase of CLARET we are limited to the use of an X-band radar (3.2 cm wavelength), but we will use extensive coherent averaging to detect weak signals. Preliminary data sets have shown that this radar can detect some cirrus. Our considerably more sensitive K_a-band radar (0.86 cm wavelength) will be available after renovation and testing are completed within a year. Both radars have Doppler capability to study the dynamic structure of cirrus clouds.

CLARET will explore what new kinds of information on cirrus can be extracted from measurements by these two instruments operating individually and in combination with each other and with more common instruments.

III. CLARET Experiment

The CO_2 lidar and the X-band radar will operate in a coordinated fashion when cirrus appears. They will be joined by a ruby lidar (694 nm wavelength; Eberhard and McNice, 1986) with polarization discrimination and perhaps an additional 347 nm wavelength.

Other instruments at the BAO site will include a microwave radiometer that measures integrated liquid water and precipitable water. Radiation data from a pyranometer, pyrgeometer, and pyrheliometer (shortwave and longwave channels) will help in interpreting the results. A narrow-field radiometer with bandpass centered at 10.7 um will point parallel to the lidars so the LIRAD (Platt et al., 1987) method can be applied. Time-lapse pictures with an all-sky camera are also planned. Data from twice-daily radiosonde launches from Stapleton Airport 30 km away will be collected.

Data sessions will be coordinated as much as practical with overpasses of the NOAA polar orbiter, and corresponding AVHRR and TOVS data will be stored. Winds at cloud height are needed for using advection to connect satellite data with the ground-based data. The wind profiler at Stapleton, Doppler lidar or radar, and all-sky movies will be used to accomplish this correctly. The cloud signals from the lidars and radar can therefore be compared with the clouds' effects on radiative transfer as measured at the surface and from space.

IV. Parameters to be investigated

The main cloud and instrumental parameters under evaluation in CLARET are as follows.

1) SENSITIVITY FOR DETECTING THIN CIRRUS

Visible lidars have demonstrated detection of optically thin cirrus, including subvisual clouds not observable by eye. The ability of the CO_2 lidar, operating with the short pulse at reduced power (maximum 100 mJ pulse energy), for detecting diffuse cirrus will be compared to that of the ruby lidar. The detection threshold of the radar will be compared to those of lidars and radiation instruments.

2) SIZE DISTRIBUTION FROM MULTIWAVELENGTH BACKSCATTER

The widely varied wavelengths of the two lidars and radar are expected to be sensitive to different parts of a cirrus particle size distribution. We therefore anticipate that simultaneous measurements will give information on the cloud particle size distribution. Another perspective is that the three instruments can indicate the size-dependent balance between ice content, longwave radiation, and shortwave attenuation.

CLARET will provide an opportunity to evaluate this possibility in a preliminary way. The wavelength dependence of the backscatter measured by the two lidars and the radar will be examined for correlation with other indicators of particle size, such as cloud temperature. A first-cut analytical study, using Mie scattering and published results on scattering from nonspherical particles, will also search for size-dependent signatures. Because the radar backscatter cross section of complex-shaped ice particles is nearly equal to the cross section of an ice sphere of equal mass (Marshall and Gunn, 1952), the Rayleigh scatter approximation will easily apply to the radar scatter. If the outcome is positive, further research should ensue using in situ size distribution measurements and perhaps new scattering calculations for nonspherical particles to verify the lidar-radar results.

3) EMISSION PROFILE FROM IR PROFILE OF BACKSCATTER

The absorbing character and large-sized, complicated shapes of ice particles may cause the backscatter of the CO_2 lidar to be related to the effective volume at which the particles radiate in the longwave. If so, the backscatter and temperature profiles could give the emission profile of cirrus. This suggestion will be tested empirically by vertically integrating the backscatter from the CO_2 lidar and comparing this with the emissivity obtained from measurements by the narrow-field IR radiometer.

4) DEPOLARIZATION OF IR BACKSCATTER

The degree of depolarization at visible wavelengths is a useful tool for determining the phase of the cloud particles (Sassen et al., 1989). Depolarization for an IR lidar may be somewhat different because of a smaller size parameter and substantial absorption. Multiple scatter, which contaminates the measurement by most visible lidars, is negligible in the coherent CO_2 lidar. Depolarization at CO_2 and ruby wavelengths will be compared to find what information may be available from the CO_2 lidar data alone and in combination with visible lidar depolarization.

5) WAVELENGTH DEPENDENCE OF ANGULAR WIDTH OF SPECULAR PEAK

The angular width of the enhanced backscatter from oriented ice crystals is believed to depend on the size of the particles through diffraction effects and on the extent of their fluttering motion (Platt, 1978). We will compare the magnitude and angular widths of such scatter at visible and IR wavelengths. Differences may allow a separation of size and flutter effects.

6) VERTICAL DOPPLER MEASUREMENTS

Velocity measurements from the Doppler lidar and radar pointed at the zenith will be examined for consistency, which will that both are trustworthy. Case studies of small-scale vertical motions and the corresponding cloud structure should provide valuable insights about the mechanisms involved in the various stages of cloud evolution.

7) IR EXTINCTION-TO-BACKSCATTER RATIO

The range-averaged ratio of extinction-to-backscatter for a lidar can be obtained from range-integrated measurements on optically thick clouds (Platt, 1979). This method should be particularly straightforward for the coherent CO_2 lidar because multiple scatter is very small. One use of this ratio is to obtain optical depth from the measured profile of backscatter.

8) ECLIPS

CLARET will also be a component of ECLIPS (Experimental Cloud LIdar Pilot Study; WCRP, 1988). The extent of data acquisition and archival will depend on the amount of financial resources that become available.

V. <u>Summary</u>

The CO_2 coherent Doppler lidar and the sensitive K_a-band radar hold considerable promise for providing valuable information on cirrus that is beyond the grasp of current visible lidars.

Some of the possibilities are particularly noteworthy. First, the effective size distribution is a critical parameter in understanding the climate effects of cirrus. A multiwavelength measurement may be able to provide such information as a function of height. Second, a CO_2 lidar can reveal cloud height, probably the phase, and perhaps the long-wave emission profile. If so, addition of these measurements to the proposed space-borne Laser Atmospheric Wind Sounder would be extremely cost-effective and should have high priority. Third, the sensitive K_a-band radar is expected to detect cirrus often, including cloud top and multiple layers. And fourth, the vertical motion and structure information from zenith-pointing Doppler lidar or radar is expected to reveal much about formation and maintenance of cirrus clouds.

These possibilities will be explored in CLARET. Successful methods can be used in Phase II of cirrus FIRE and similar intensive field programs. A suite of lidar(s), radar, and radiation instruments may also be ideal for extended observations of clouds to study their climatic influences.

VI. References

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