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AIRBORNE LIDAR/RADIOMETRIC MEASUREMENTS OF CIRRUS CLOUD PARAMETERS AND THEIR APPLICATION TO LOWTRAN RADIANCE EVALUATIONS

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EXTENDED ABSTRACT

SRI has assembled an airborne lidar/radiometric instrumentation suite for mapping cirrus cloud distributions and analyzing cirrus cloud optical properties. Operation of upward-viewing infrared radiometers from an airborne platform provides the optimum method of measuring high-altitude cold-cloud radiative properties with minimum interference from thermal emission by the earth's surface and lower atmospheric constituents. Airborne installed sensors can also operate over large regional areas including water, urban and mountain surfaces and above lower atmospheric convective clouds and haze layers.

Figure 1 illustrates currently available sensors installed on the SRI Queen Air aircraft. The upward-viewing lidar (ALPHA-2) transmits energy pulses at two wavelengths (0.53 and 1.06 μm) at pulse rates to 10/sec. Backscattered energy is collected in a 14-inch diameter telescope and is wavelength separated into two independent detector systems that produce range-dependent lidar signatures representing a profile of the scattering medium above the aircraft. Because an upward-viewing airborne radiometer views a low-radiance background in the absence of clouds, radiance perturbations introduced by low-density aerosol and cloud layers may be detected by a high-sensitivity infrared radiometer. The upward-viewing 8- to 14-μm infrared radiometer is calibrated for equivalent blackbody temperatures as low as -80° C.

Lidar and radiometric data records are processed for real-time viewing on a color video screen. Figure 2 presents a cirrus cloud data example as a black-and-white reproduction of a color display. Upward-viewing lidar backscatter signatures are plotted as an altitude/distance intensity-modulated display with relative density scale shown to the right of the lidar data display.Aircraft latitude data are overplotted on the lidar display between 10,000 and 15,000 ft. Longitude data are overplotted between 15,000 and 20,000 ft. Downward-viewing solar flux radiometer data are overplotted between 20,000 and 25,000 ft. Downward-viewing infrared radiometer data are overplotted between 25,000 and 30,000 ft. Upward-viewing solar-flux radiometer data are overplotted between 45,000 and 50,000 ft. Upward-viewing infrared radiometer data are overplotted between 50,000 and 55,000 ft.

The data presented in Figure 2 show that at the aircraft altitude of 12,000 ft, the 8- to 14-μm atmospheric radiation background was equivalent to a blackbody temperature of about -60° C and, therefore, the radiometer did not respond strongly to low-density cirrus cloud concentrations detected by the lidar. At an altitude of about 20,000 ft, the radiation background was near -80° C and the radiometric temperature of low-density cirrus clouds could better be measured. For the sensitivity of the radiometer flown on the Queen Air aircraft, an altitude of at least 20,000 ft is required for making optimum cirrus cloud radiance measurements.

Figure 3 presents cloud blackbody temperatures (observed by radiometer) plotted against midcloud temperatures (derived from lidar-observed cloud heights and supporting temperature profiles) for data collected on 30 June and 28 July. The radiation temperatures for 30 June were generally warmer (5° C) than cloud temperatures, indicating an effective cloud emissivity greater than 1.0. Data from optically dense clouds observed on 28 July agree with the 30 June results; while radiation temperatures were significantly lower than cloud temperatures for optically thin clouds, indicating cloud effective emissivities were substantially less than 30 June radiation temperatures were related to cloud base height, while the 28 July radiation temperatures were related to cloud thickness.

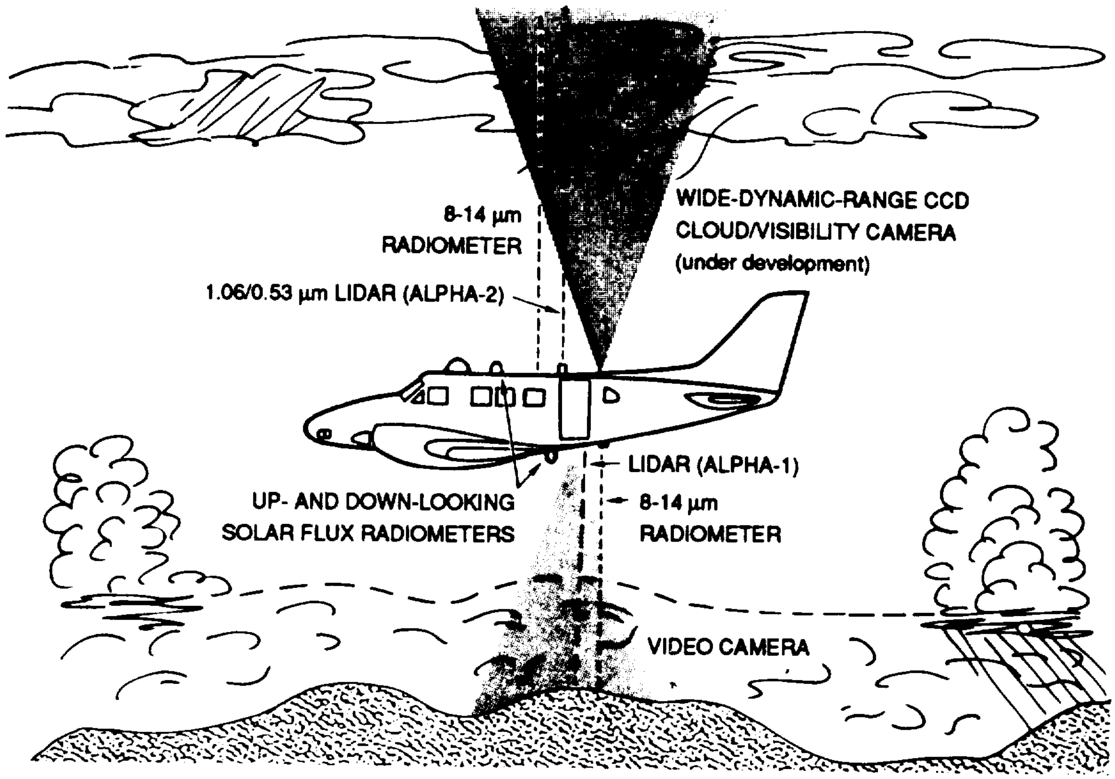

FIGURE 1 SRI QUEEN AIR AND INSTRUMENTS USED FOR OPTICAL CLOUD MAPPING

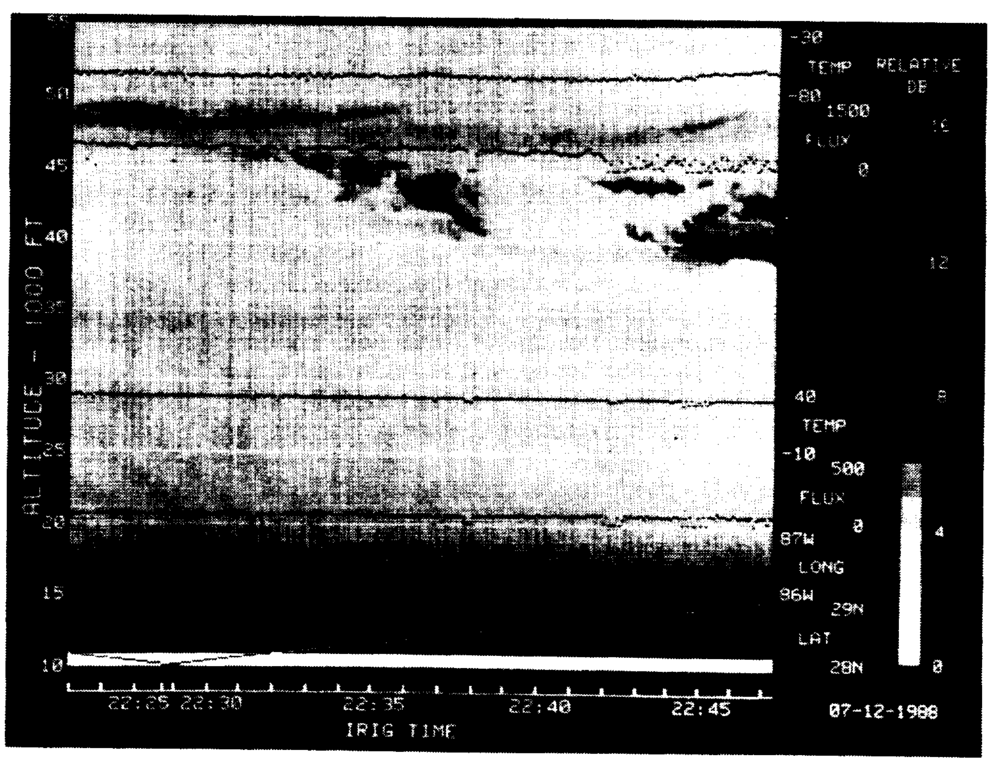

FIGURE 2 AIRBORNE LIDAR RADIOMETRIC CLOUD DATA COLLECTED ON 12 JULY 1988

Table 1

LOWTRAN-7 INPUT PARAMETERS

PARAMETER (WAVELENGTH)	SYMBOL	SOURCE	PARAMETER VALUES		
			30 JUNE (1855 IRIG)	14 JULY (2235 IRIG)	28 JULY (2233 IRIG)
CLOUD BASE ALTITUDE	Z_c	LIDAR	11.9 km	12 km	8.4 km
CLOUD THICKNESS	ΔZ_c	LIDAR	3.0 km	1.5 km	2.1 km
TEMPERATURE PROFILE	T(Z)	SOUNDING	2100 IRIG	2400 IRIG	2400 IRIG
WATER VAPOR PROFILE	W(Z)	SOUNDING	2100 IRIG	2400 IRIG	2400 IRIG
BOUNDARY TEMPERATURE (PRT-5)	T_B	DOWN-VIEWING RADIOMETER	302° K	304.5° K	306° K
CLOUD EMISSIVITY (PRT-5)	ϵ	UP-VIEWING RADIOMETER/ LIDAR/CLEAR AIR LOWTRAN-7	0.80	0.099	0.62
CLOUD ABSORPTION OPTICAL DEPTH (PRT-5)	u_a	$u_a = -\ln(1-\epsilon)$	1.59	0.10	0.97
SINGLE-SCATTERING ALBEDO (11 μm)	ω	PLATT AND STEPHENS (1980)	0.53	0.53	0.53
CLOUD TOTAL OPTICAL DEPTH (PRT-5)	u	$u = u_a/(1-\omega)$	3.38	0.21	2.06
EXTINCTION COEFFICIENT (PRT-5)	σ_e	$\sigma_e = u/\Delta Z_c$	1.13 km^{-1}	0.14 km^{-1}	0.98 km^{-1}
ASYMMETRY PARAMETER (11 μm)	g	PLATT AND STEPHENS (1980)	0.70	0.70	0.70

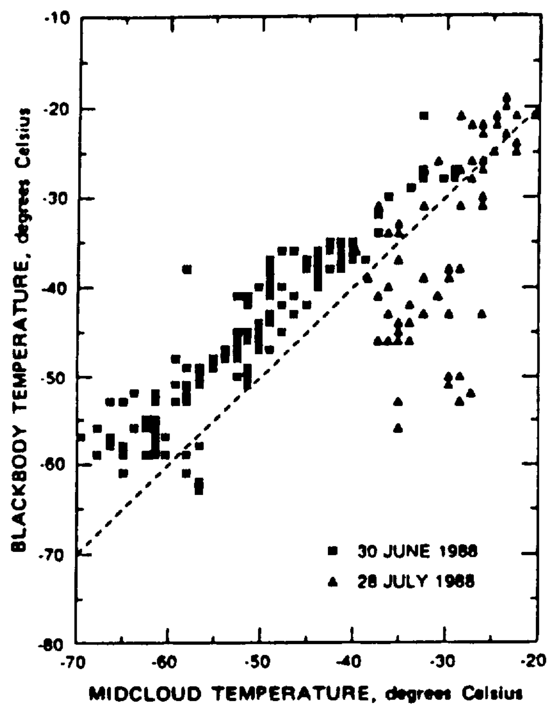

FIGURE 3 OBSERVED CLOUD BLACKBODY TEMPERATURES PLOTTED AGAINST MIDCLOUD TEMPERATURES DERIVED FROM LIDAR CLOUD HEIGHTS AND OBSERVED TEMPERATURE PROFILES

Actual cloud emissivities were evaluated from the measured effective emissivities by applying corrections for (1) clear-air thermal emission from the intervening aircraft-to-cloud base layer as computed from the LOWTRAN-7 radiance code using measured temperature and water vapor profiles as model input and (2) reflection by the cloud of upwelling infrared radiation emitted by the earth's surface and lower atmospheric constituents. The cloud base altitude, cloud thickness, and cloud emissivity can be used as LOWTRAN-7 model inputs to evaluate cloud effects on atmospheric radiances. The LOWTRAN-7 code is attractive as it incorporates wavelength-dependent absorption and scattering parameters, multiple-scattering parameterization, and two new cirrus cloud models. The code is widely used to evaluate atmospheric effects on electro-optical systems. Table 1 presents model parameters derived for three airborne lidar/radiometric measurement periods. It should be noted that the lidar data are used only for deriving cloud height and thickness and not for estimating cloud optical parameters. Because of uncertainties introduced by scattering from the irregularly shaped ice crystals, optical analysis of lidar signatures in terms of cloud optical properties is believed to be less desirable than derivation of cloud emissivity based on radiometer readings. The method of deriving cloud parameters from lidar/radiometer observations has been extensively discussed in a series of papers by Platt (1973).

Figure 4 presents an example of LOWTRAN-7 model simulations for infrared radiometer measurements of the cloud/atmospheric conditions observed on 30 June 1989. In this case, the standard LOWTRAN-7 cirrus cloud model, in which cloud emissivity is based on cloud thickness, gives about half the radiance of the LOWTRAN-7 model using the parameters listed in Table 1. The LOWTRAN-6 model gives radiances about halfway between the two LOWTRAN-7 model results. Using the standard LOWTRAN-7 cloud single-scattering albedo and asymmetry parameters based on spherical scattering particles rather than parameters based on scattering cylinders (Platt and Stephens, 1980) results in lower radiance as observed by the upward-viewing radiometer. The radiometer measurement supports the standard LOWTRAN-7 model, although other cases support the modified LOWTRAN-7 model.

A methodology of applying airborne lidar and radiometer measurements for deriving LOWTRAN-7 radiance model parameters and for predicting cloud effects on atmospheric radiances has been illustrated. This study was supported by the U.S. Air Force, Aeronautical Systems Division, Wright-Patterson AFB.

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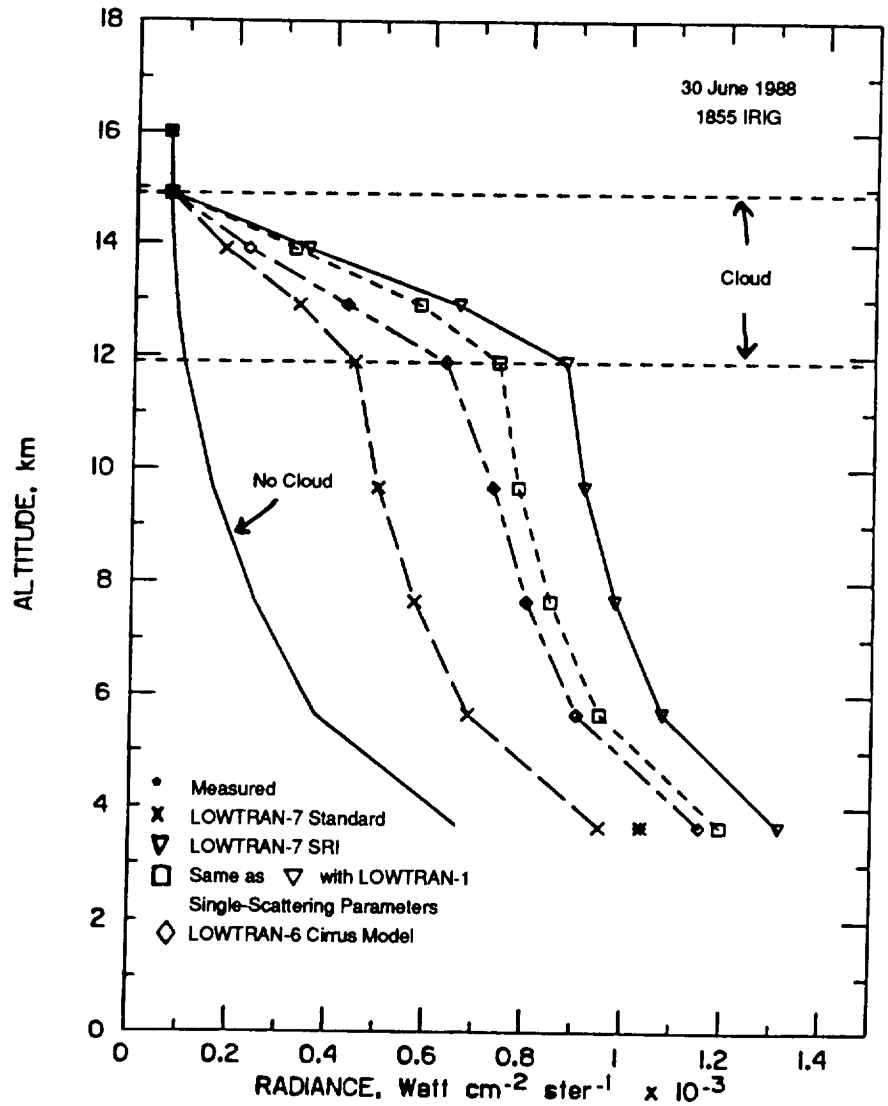

FIGURE 4 RADIANCE SIMULATIONS FOR UPWARD-VIEWING PRT-5 RADIOMETER AS A FUNCTION OF RADIOMETER ALTITUDE.

Simulations are for various LOWTRAN models of cloud conditions observed during a flight test on 30 June 1988.

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