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Spectral Variation of Scattering and Absorption by Cirrus

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1. Introduction

The impact of cirrus clouds on the radiative budget of the earth depends on the microphysics and scattering properties of the clouds. Cirrus clouds have been especially difficult to observe because of their high altitude and complex tenuous structure. Observations by Abakumova *et. al.* (1991) show that the near infrared wavelengths are more sensitive to the cirrus cloud properties than the shorter ultraviolet wavelengths. Anikin (1991) was able to show that collimated spectral measurements can be used to determine an effective particle size of the cirrus clouds. Anikin (1991) also showed that the effect of scattering through cloud causes the apparent optical depth of a 10° field of view pyrheliometer to be roughly half the actual optical depth. Stackhouse and Stephens (1991) have shown that the existence of small ice crystals do dramatically affect the radiative properties of the cirrus, though observations taken during the 1986 FIRE were not totally explained by their presence.

2. The Modelling Study

A forward Monte Carlo model, described by Davis *et. al.* (1979), was used to model the spectral variation of scattering and absorption by a cirrus cloud layer. Runs of the model were performed at four wavelengths (0.45, 0.70, 0.94, 1.38 m), for three optical depths of $\tau(0.70\ m) = 1, 2, 3$ using the equivalent sphere ice particle distributions of C5 (Deirmendjian, 1975), C6 (Deirmendjian, 1975), and CI175 (Griffith *et. al.*, 1980). The distributions are shown in Figure 1. Model irradiances were calculated for a 10° field of view, a zenith of 60° and a cloud positioned between 8 to 10km to allow comparison with pyrheliometric observations.

Figures 2, 3 and 4 show modeled ratios of cloudy to clear sky irradiances (for a 10° field of view) at 0.45, 0.70, 0.94, and 1.38 m. This ratio normalizes the data to the clear sky case. A distinct difference in spectral variation of irradiance ratios between the large particles of the CI175 size and the small particles of the C5 and C6 distributions is seen. In the CI175 distribution the magnitude of the slope of the irradiance ratio versus optical depth decreased with increasing wavelength (with the exception of the 0.70 m data), while for the small particle distributions the opposite was the case. The steepest slope of the ratio lines was seen in the C5 distribution, which contained the smallest particles. The results are summarized in Table 1. The nearly identical slopes of the 0.45 m irradiance ratios result from the method chosen to present the data. Since the ratios are approximately equal to transmittance values, the slopes of the 0.45 m irradiance ratio lines on the log plot are approximately equal to $-\sec(60°)\log_{10}(e)$.

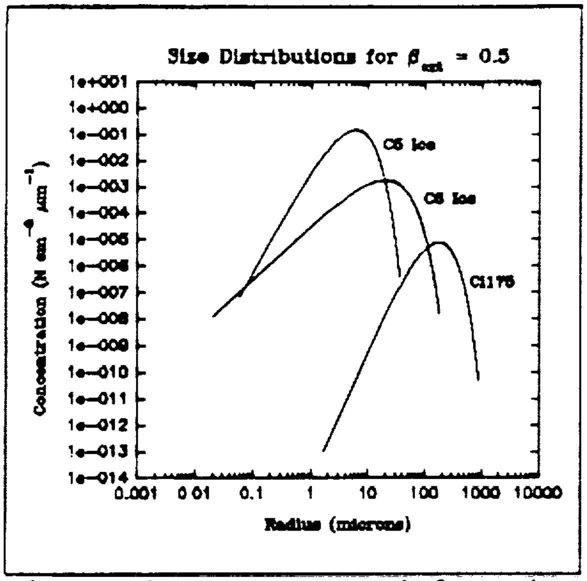

Figure 1 Ice Particle Size Distributions.

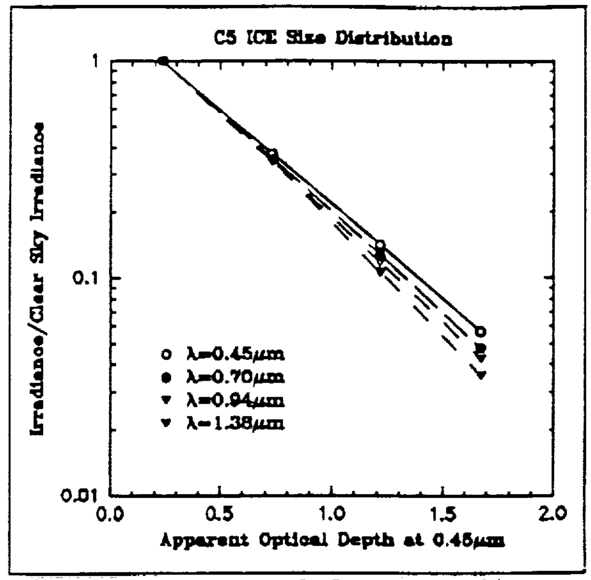

Figure 2 Model Irradiance Ratios from C5 Distribution.

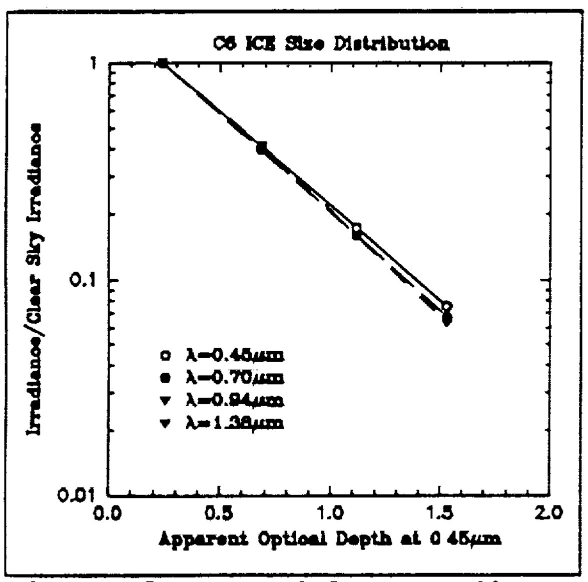

Figure 3 Model Irradiance Ratios from C6 Distribution.

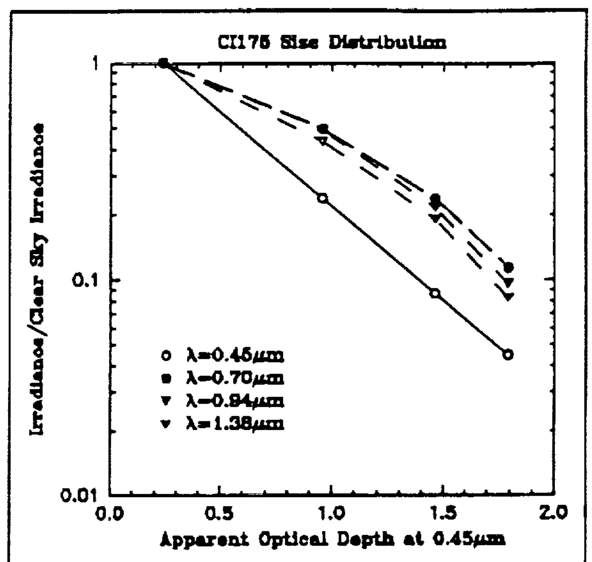

Figure 4 Model Irradiance Ratios from CI175 Distribution.

3. Pyrheliometer Observations

Simultaneous filtered and unfiltered pyrheliometric measurements were taken at Parsons, KS during the FIRE II Cirrus IFO. Longpass 0.53-2.8 m, 0.695-2.8 m and 1.0-2.8 m filters were used. On 26 November 1991, from about 1700 UTC through sunset (about 2300 UTC), the cirrus layer slowly thickened and lowered. The cirrus was too inhomogeneous to allow for a direct comparison between the filtered measurements which were about 23 seconds apart, so the apparent optical depth deduced from measurements by the unfiltered pyrheliometer was used to stratify the filtered data as a function of optical depth so that a comparison would be possible. From the medians of each interval of the filtered irradiances (corrected to a 60° zenith), irradiance values, normalized to clear sky, were calculated for the 0.28-0.53 m, the 0.53-0.695 m, the 0.695-1.0 m, and the 1.0-2.8 m spectral region.

Figure 5 displays these observations in a format similar to the model results shown in Figures 2, 3 and 4. The slopes of the lines are generally consistent with those from the small particle calculations, suggesting that the cirrus clouds observed on 26 November 1991 did contain small ice crystals. Adding a volcanic aerosol layer to the model, did not significantly affect the model results.

Table 1. Size Distribution Parameters and Irradiance Ratio Regression Line Slopes.

		β_{ext}(0.70 m) = 0.5		Irradiance Ratio Regression Line Slopes			
Size Distribution	Modal Radius (m)	Concentration (cm^{-3})	Ice Water Content (g m^{-3})	0.45 m	0.70 m	0.94 m	1.38 m
C5	5	1.1196	0.0030	-0.8686	-0.9203	-0.9577	-1.0108
C6	20	0.0651	0.0150	-0.8686	-0.9073	-0.9280	-0.9280
CI175	175	0.0015	0.0851	-0.8686	-0.5921	-0.6794	-0.6378
Observations from 26 November 1991				0.28-0.53 m	0.53-0.695 m	0.695-1.0 m	1.0-2.8 m
				-0.8686	-1.6363	-1.4534	-1.0598

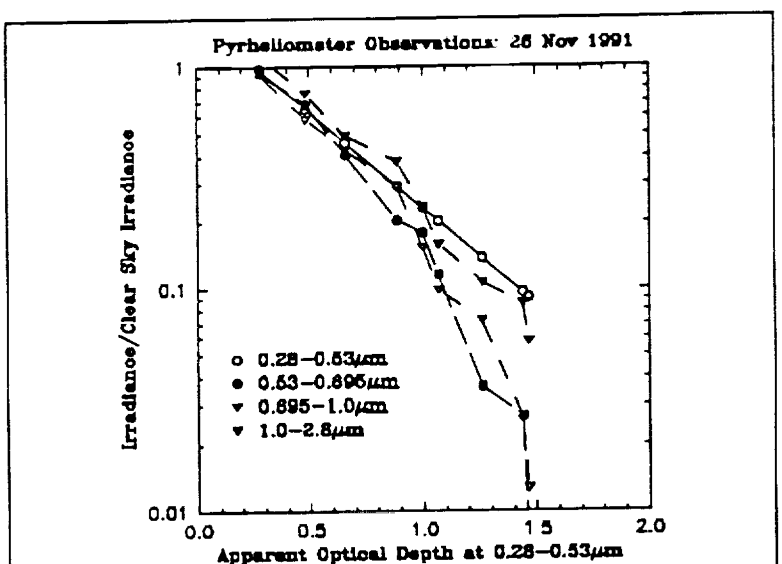

Figure 5 Pyrheliometer observations from 26 November 1991.

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