# 10 to 12 μm Spectral Emissivity of a Cirrus Cloud

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ABSTRACT

A balloon flight made 4 February 1970 with an infrared spectral radiometer system scanning from 10 to 13 μm ascended through an extensive cirrus cloud. This allowed measurements to be made of the spectral radiance of the cloud both underneath and in the cloud as the balloon ascended. The spectra obtained are presented and the data were used to determine the emissivity of the cloud at 11 μm. The value $\epsilon=0.38$ is in reasonable agreement with values found by Kuhn and Weickmann.

## 1. Introduction

The possible effects of cirrus clouds on the radiation budget of the earth is receiving considerable attention, particularly in view of the fact that the cirrus cloud cover might be increased as a result of Man's activities. The amount of experimental data available concerning the radiative properties of cirrus clouds is rather limited. Broad-band measurements have been made from aircraft (Kuhn and Weickmann, 1969; Davis, 1970; 1971) and from the ground (Allen, 1971; Platt and Gambling, 1971; Platt, 1973). During a balloon flight made from Holloman AFB, New Mexico, on 4 February 1970, spectral radiance data were obtained from an extensive cirrus cloud layer as a function of altitude as the balloon ascended up to and through the layer. The purpose of this note is to present these data since they appear to be the only data of this sort available for cirrus clouds. Unfortunately, the infrared data were obtained at night and no observations regarding the short wavelength characteristics of the cloud were made.

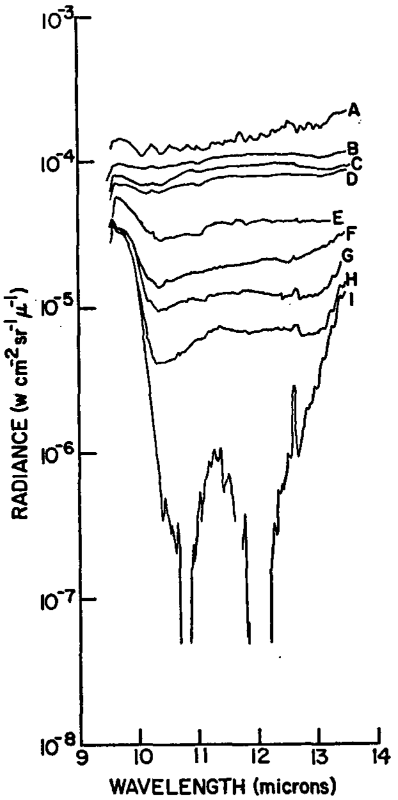


FIG. 1. Atmospheric spectral radiance as observed at various altitudes: A, 1.5 km; B, 8.1 km; C, 8.8 km; D, 9.4 km; E, 10.4 km; F, 11.3 km; G, 11.6 km; H, 11.8 km; I, 12.4 km.

## 2. Instrumentation

The spectrometer used in this study was designed to measure the atmospheric spectral radiance at high altitudes (20–30 km) in the 10–12 μm region. Since the atmospheric radiance in this wavelength region is quite low, the sensitivity of the system had to be made quite high. This was accomplished by cooling the whole spectrometer system by enclosing it in a liquid nitrogen cooled container. The spectrometer entrance slit was used as the entrance aperture for the system and this determined the field of view of the instrument (12°×12°). The instrument was set to look at an elevation angle of 45°. Boil-off dry nitrogen gas was vented into the back of the instrument and out the entrance slit into a baffling system which also acted as an antifrost system. The spectrometer was equipped with a liquid helium cooled, copper-doped germanium detector. The atmospheric radiation was chopped against the liquid nitrogen background of the instrument by means of a tuning fork chopper. The detector signal was synchronously rectified, amplified and recorded on board by means of a digital magnetic tape recorder. This allowed the instrument to be absolutely calibrated by means of a blackbody source whose temperature could be controlled from 80K to room temperature. The instrument is described in more detail in a previous publication (Brooks *et al.*, 1973).

## 3. Results

The instrumentation and balloon was launched at 0313 MST on 4 February 1970. At the time of launch the weather at Holloman was clear. This is evident in the upper spectrum shown in Fig. 1, which shows the water vapor lines which are evident in clear sky spectra obtained from the ground and also the 9.6 $\mu$m ozone emission. As the balloon ascended it also moved out to the east and underneath a cirrus deck which appears to have been fairly extensive and uniform, judging from the radiance data obtained for the next 45 min. The presence of the cirrus layer is evident in the spectra which show a complete absence of spectral detail associated with the molecular emission, but rather are dominated by the greybody emission of the cirrus clouds. There is little change of radiance until the balloon has reached an altitude of 8.1 km. Above that altitude each successive spectrum shows a significant change in radiance. By the time the balloon has reached 10.4 km, the cloud emission has dropped below the emission due to $O_3$ in the 9.5–10 $\mu$m region and the ozone emission attenuated by the cirrus cloud is clearly evident. While the effect of the cirrus cloud is still evident in the spectrum obtained at 11.6 km, the spectrum obtained at 12.4 km shows no evidence of any contribution from the cirrus. At this altitude the spectrum is clearly that due to the atmospheric molecular constituents $O_3$ and $CO_2$ on the short wavelength side, $HNO_3$ in the middle, and $CO_2$ and $O_3$ on the longer wavelength side of the "window" (Murcray *et al.*, 1973).

## 4. Cirrus emissivity

The temperature vs altitude profile for the flight data as obtained from the 0600 MST rawinsonde ascent from Holloman AFB is shown in Fig. 2. As noted from the data in Fig. 1 the cloud appears to extend from about 8.1 km to at least 11.6 km. The ambient temperature varies from −30C at the base of the cloud to −60C at the top of the cloud. In order to compare the results obtained during this flight with those presented by others, an effective emissivity was determined at 11 $\mu$m on the following basis:

$$\epsilon(11\,\mu\text{m}) = N(11\,\mu\text{m})/B(11\,\mu\text{m},\ -45\text{C}),$$

where $N(11\,\mu\text{m})$ is the observed radiance at 11 $\mu$m and $B(11\,\mu\text{m},\ -45\text{C})$ is the blackbody radiance at −45C. This gives the effective emissivity of the cloud as $\epsilon=0.42$. Here −45C was used as the equivalent blackbody temperature for the cloud since the major emission comes from the region where the atmospheric temperature is between −35 and −55C. This emissivity is based on the observed radiance and represents the effective emissivity of the cloud when viewed at a 45° angle rather than vertically. Since the emissivity is not a linear function of optical path, the zenith emissivity would not be given by dividing the observed emissivity by sec45°. The study by Hall (1968) indicates that the factor should be 1.1–1.2, giving a zenith emissivity of 0.35–0.38. This value is in reasonable agreement with values found by Kuhn and Weickmann (1969) as the average emissivity for the 8.5–13.0 $\mu$m region for a cloud of 3.5 km thickness. It appears that the top of the cloud layer and the tropopause occur at close to the same altitude.

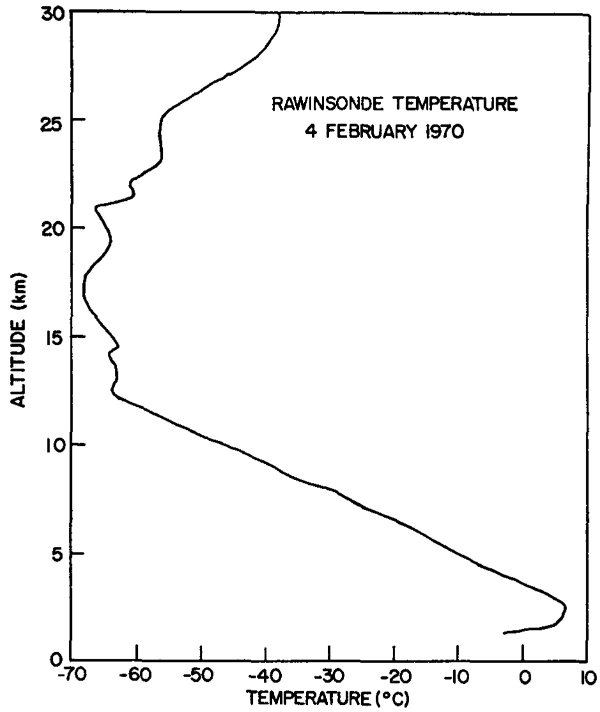


Fig. 2. Atmosphere temperature profile taken from Holloman AFB at 0600 MST 4 February 1970.

Since data were obtained as the balloon ascended through the cloud it is possible to determine the change in emissivity with distance through the cloud. The emissivity values for each cloud layer were determined in succession starting with the radiance as observed at the top of the cloud according to the basic radiative transfer equation for a layered atmosphere with no scattering (Murcray *et al.*, 1973). The calculation was performed for 11 $\mu$m. The results obtained indicate that to within the scatter of the data the cloud was uniform with a gradient of emissivity of 0.10 per kilometer.

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