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U.S. DEPARTMENT OF COMMERCE
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National Environmental Satellite Service

Calculation of Clear-Column Radiances Using Airborne Infrared Temperature Profile Radiometer Measurements Over Partly Cloudy Areas

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WASHINGTON, D.C.

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CALCULATION OF CLEAR-COLUMN RADIANCES USING AIRBORNE INFRARED TEMPERATURE PROFILE RADIOMETER MEASUREMENTS OVER PARTLY CLOUDY AREAS

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CALCULATION OF CLEAR-COLUMN RADIANCES USING AIRBORNE INFRARED TEMPERATURE PROFILE RADIOMETER MEASUREMENTS OVER PARTLY CLOUDY AREAS

William L. Smith

ABSTRACT. In June 1970, a brassboard version of the Infrared Temperature Profile Radiometer (ITPR) was flown on the NASA Convair-990. This flight was made primarily to obtain measurements to test the hypothesis that radiance propagating from clear portions of a partly cloudy field could be calculated directly from the total radiance measurement over the field. Such clear-column radiances are needed if one is to determine the temperature and water vapor profiles of the atmosphere to the earth's surface. Sample results presented herein show these calculations are feasible, and indicate that measurements from the medium resolution scanning radiometers to be used on future polar-orbiting satellites can be used to provide global soundings.

INTRODUCTION

Future Nimbus and ITOS weather satellites are programmed to carry an Infrared Temperature Profile Radiometer (ITPR) for making indirect measurements of the vertical profiles of temperature and water vapor in the earth's atmosphere. The radiation from clear columns of air is required for the derivation of temperature and moisture profiles down to the earth's surface. However, at any given time, most of the earth has broken cloud cover. Since clear columns are few, a method is needed for estimating the equivalent clear-column radiance for the many cases where the radiometers' field of view is partially covered by clouds. Smith (1968) developed a method for calculating the clear-column radiance from the observed total radiance. The brassboard version of the ITPR was flown on the NASA Convair-990 during June 1970 to collect data for the purpose of testing this procedure.

The brassboard ITPR measures radiance in five narrow spectral channels centered at: (1) 18.8μm, (2) 11.1μm, (3) 13.4μm, (4) 13.7 μm, and (5) 14.1μm. The radiance measured in channel (1), a semi-transparent region of the rotational water vapor band, is a strong function of the water vapor content of the troposphere. The radiance measured in channel (2), the atmospheric "window" region, is a function of the surface temperature, and the temperature and amount of any clouds within the field of view. The radiances measured in channels (3), (4), and (5), semitransparent spectral regions of the 15μm CO_2 band, are strongly dependent on the temperature of the lower, middle, and upper troposphere, respectively. The brassboard instrument measures independent upward radiances in these spectral channels every four seconds with a relative accuracy of 0.5 percent. The absolute accuracy is believed to be 1 percent.

DETERMINATION OF CLEAR-COLUMN RADIANCE

The solution for the clear-air radiance contribution to the total radiance measured over a partly cloudy atmosphere was first presented by Smith (1968). A detailed description of the solution and its application to satellite measurements is contained in a subsequent report by Smith (1969). Briefly, the clear-column radiance for any frequency ν is obtained from two spatially independent radiance measurements through the solution of

$$I_{clr}(\iota) = \frac{I_1(\nu) - N^* I_2(\nu)}{(1-N^*)} \qquad (1)$$

where $I_{clr}(\nu)$ is the clear-column radiance and $I_1(\nu)$ and $I_2(\nu)$ are the two spatially independent radiance measurements. The parameter N^* is the ratio of the fractional cloud cover of the two fields of view. N^* is determined from corresponding atmospheric "window" radiometric observations, I(w). It follows from (1), applied to the window region, that

$$N^* = \frac{N_1}{N_2} = \frac{I_{clr}(w) - I_1(w)}{I_{clr}(w) - I_2(w)} \qquad (2)$$

where the clear-air radiance for the window region is assumed to be known. $I_{clr}(w)$ is obtained from high resolution window measurements (Smith et al, 1970) or approximated from surface temperature estimates. Elements 1 and 2 are chosen such that $I_1(w) \geq I_2(w)$ which restricts N^* to $1 \geq N^* \geq 0$.

The above solution for the clear-column radiance is valid only when the geographical variation of observed radiance is due to a variation of cloud cover. A variation of atmospheric temperature or cloud height produces erroneous values of N^* and $I_{clr}(\nu)$. Therefore, the two spatially independent observations should be geographically close to each other so that the observed radiance variation will tend to be due to cloud cover variations. High spatial resolution and contiguous scanning ensure that observations will be close together geographically, increase the probability of clear fields of view, and produce a large number of independent estimates of clear-air radiance over a given area.

The noise level of the deduced clear-air radiances will be larger than the measurement noise. In fact, it can be seen from equation (1) that the clear-air radiance level is about $1/(1-N^*)$ times as large as the measurement noise. Consequently, the measurement noise level must be relatively low. On the other hand, the spatial resolution must be sufficiently high so that N^* is generally much less than unity. The satellite versions of the ITPR and VTPR temperature sounding radiometers have been designed to scan spatially and contiguously with an instantaneous resolution of 15 and 30 n.mi., respectively, and still achieve a relatively low noise level less than 0.5 percent.

AIRCRAFT RESULTS

On June 12, 1970, high altitude (41,000 ft) ITPR radiance observations were obtained above broken altocumulus and stratocumulus clouds over the Pacific Ocean (46°N, 133°W). Clear-air measurements were obtained on either side of the broken cloud region. Clear-air radiances were calculated from the cloud contaminated observations.

Figure 1 shows the measured window radiances (ergs cm^{-2}-s^{-1}-$sr^{-1}cm^{-1}$) during the period. Clear observations were obtained near 23:37:20 and 23:44:20 (Hr:Min:Sec) GMT. The clear-air window radiance measured was about 84.0 ergs cm^{-2}-s^{-1}-$sr^{-1}cm^{-1}$ (279°K). Cloud contaminated radiances measured in the window channel were as low as 50 ergs cm^{-2}-s^{-1}-$sr^{-1}cm^{-1}$ (250°K).

Assuming a clear-air window radiance of 84.0, N^* was calculated for the adjacent fields of view which are spaced about 4 seconds apart. Figure 2 shows the resulting distribution of N^*. Clear-column radiances were then calculated from the adjacent observed radiances in the three temperature sounding CO_2 channels. The values for $N^* \leq 0.8$ are shown together with the measured radiance distributions in figures 3, 4, and 5.

It can be seen from figures 3, 4, and 5 that some of the inferred clear-air radiances are erroneous, particularly in the region where a large amount of cloudiness exists (e.g., 23:38 to 23:44 GMT). Some erroneous values are expected since N^* is relatively high (greater than 0.5 between 23:38 and 23:44 GMT), and there are cases where the variation of radiance is due to a cloud height variation rather than cloud amount variation (the field of view contained both altocumulus and stratocumulus). However, most of the estimates of clear-column radiance are in close agreement with the observed clear-air radiances measured at 23:37:20 and 23:44:20 GMT.

To further illustrate this point, figures 6, 7, and 8 show histograms of the clear-column radiances deduced from the highly cloud contaminated radiances measured between 23:38 and 23:44 GMT. It is shown that the values of the most frequently occurring estimates are in very close agreement with the observed clear-air radiances. The mean clear-column radiance values, $I_{clr}(\nu)$, defined as the frequency-weighted average of the mode value and values of the two adjacent class intervals, agree with the measured clear-air radiance values to within the measurement noise.

CONCLUSION

The aircraft test results presented here indicate that the clear-air radiance contribution to radiances observed with a partial cloud cover within the field of view can be deduced with the accuracy needed for calculating temperature profiles down to the earth's surface. (This conclusion applies as well to numerous other parameters not presented here.) Since the earth's atmosphere, when viewed on a synoptic scale (i.e., horizontal scale of 300 to 500 km), has a broken cloud cover, this solution, when applied to the appropriate satellite measurements, should make possible the determination of atmospheric temperature distribution on a synoptic scale over the entire globe.

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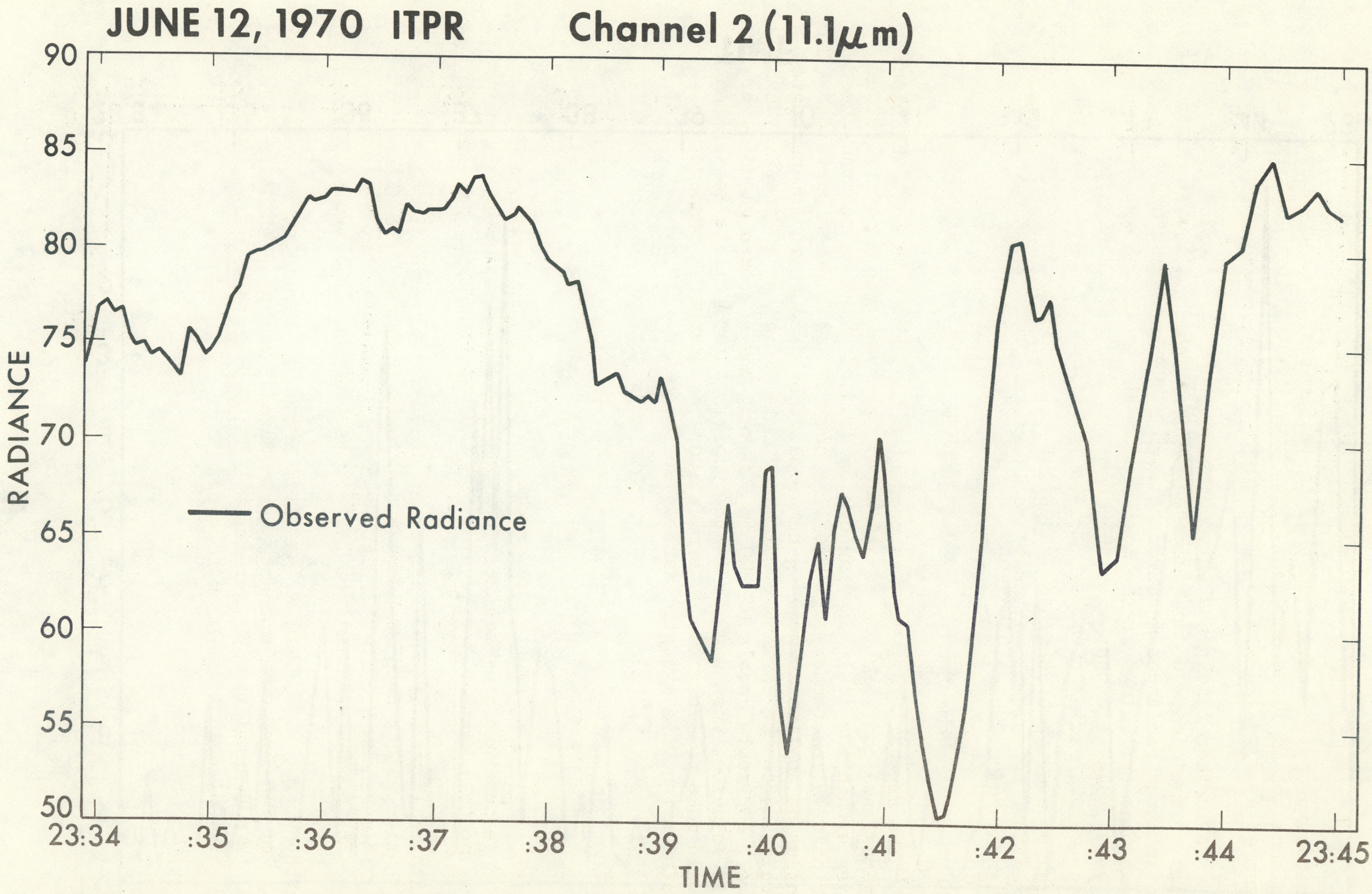

Figure 1.--"Window" radiances measured by ITPR 11.1 μ m CO_2 channel.

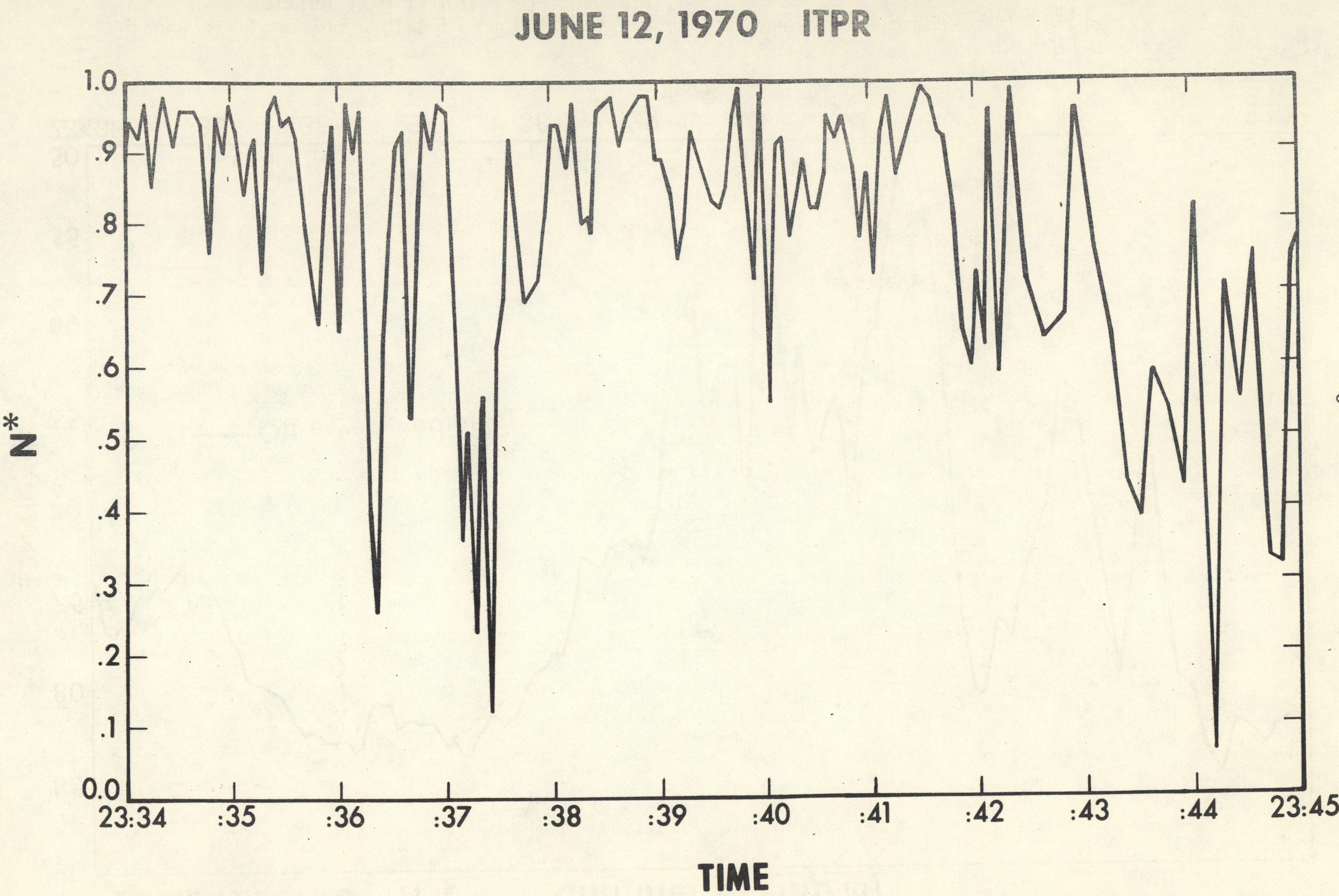

Figure 2.--N* distribution calculated for adjacent fields of view from 11.1 μ m radiance measurements.

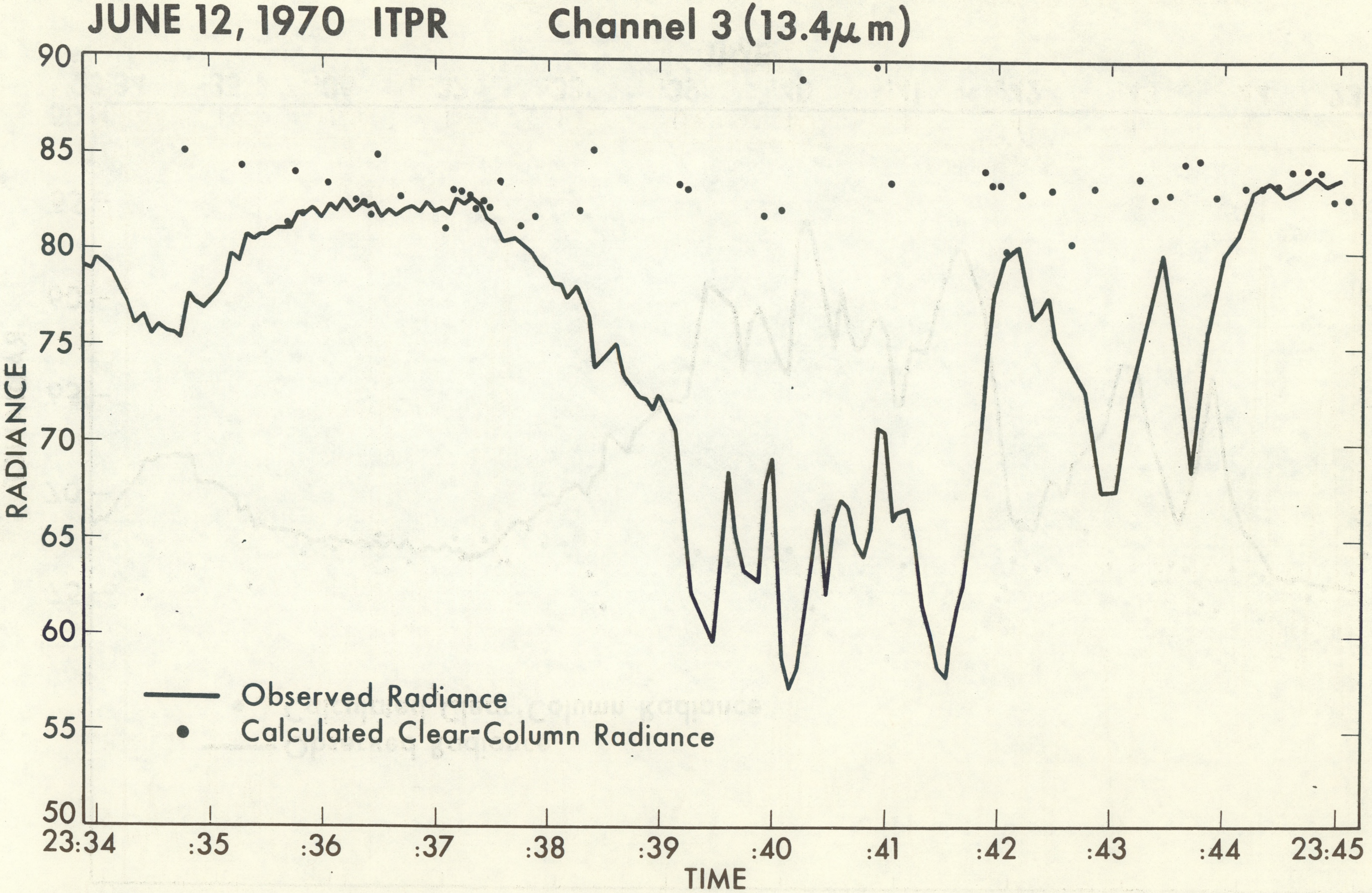

Figure 3.--Observed radiances (solid line) and calculated clear-column radiance (dots) for the ITPR 13.4 μ m CO_2 channel.

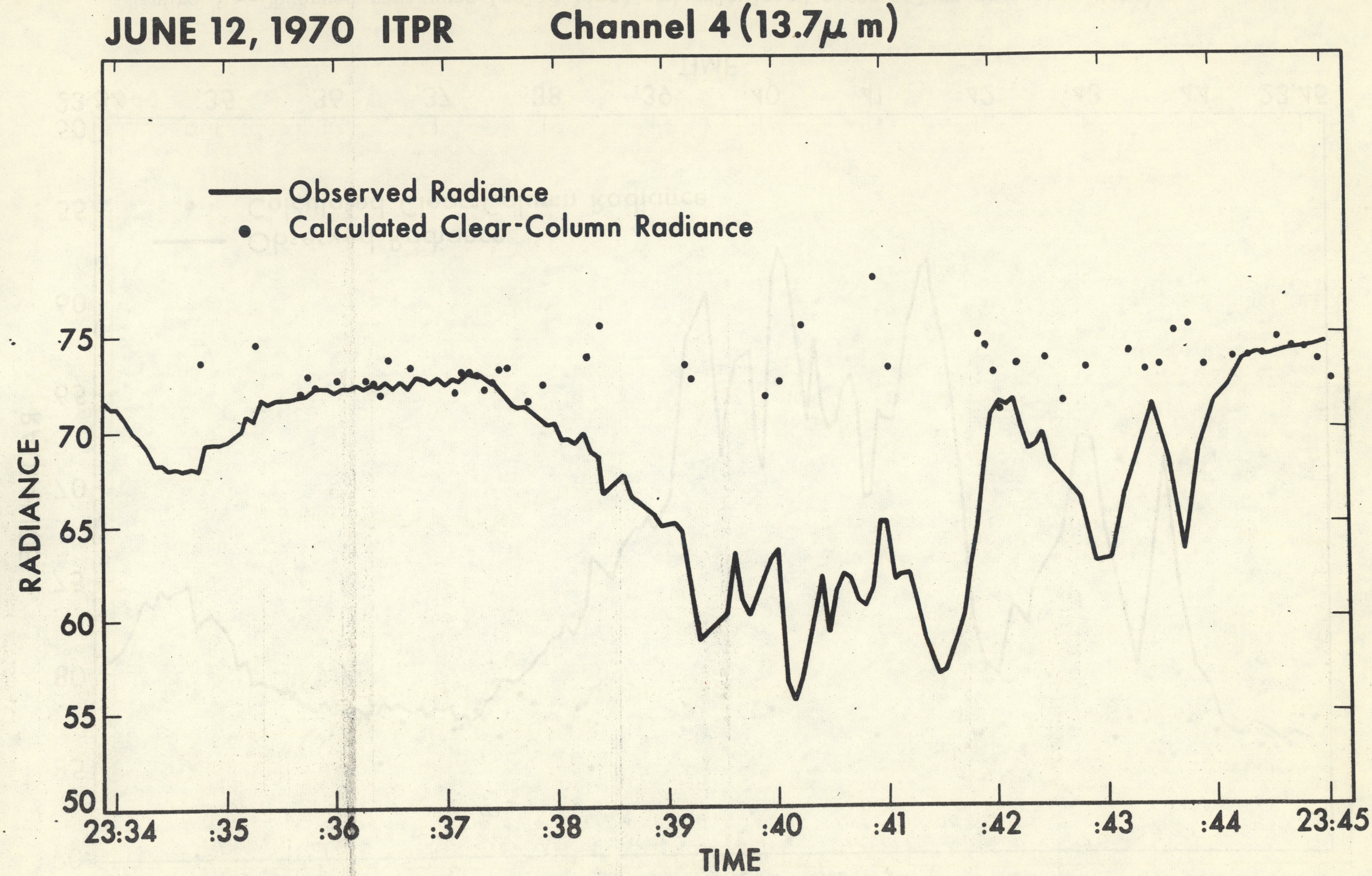

Figure 4.--Observed radiances (solid line) and calculated clear-column radiance (dots) for the ITPR 13.7 μ m CO_2 channel.

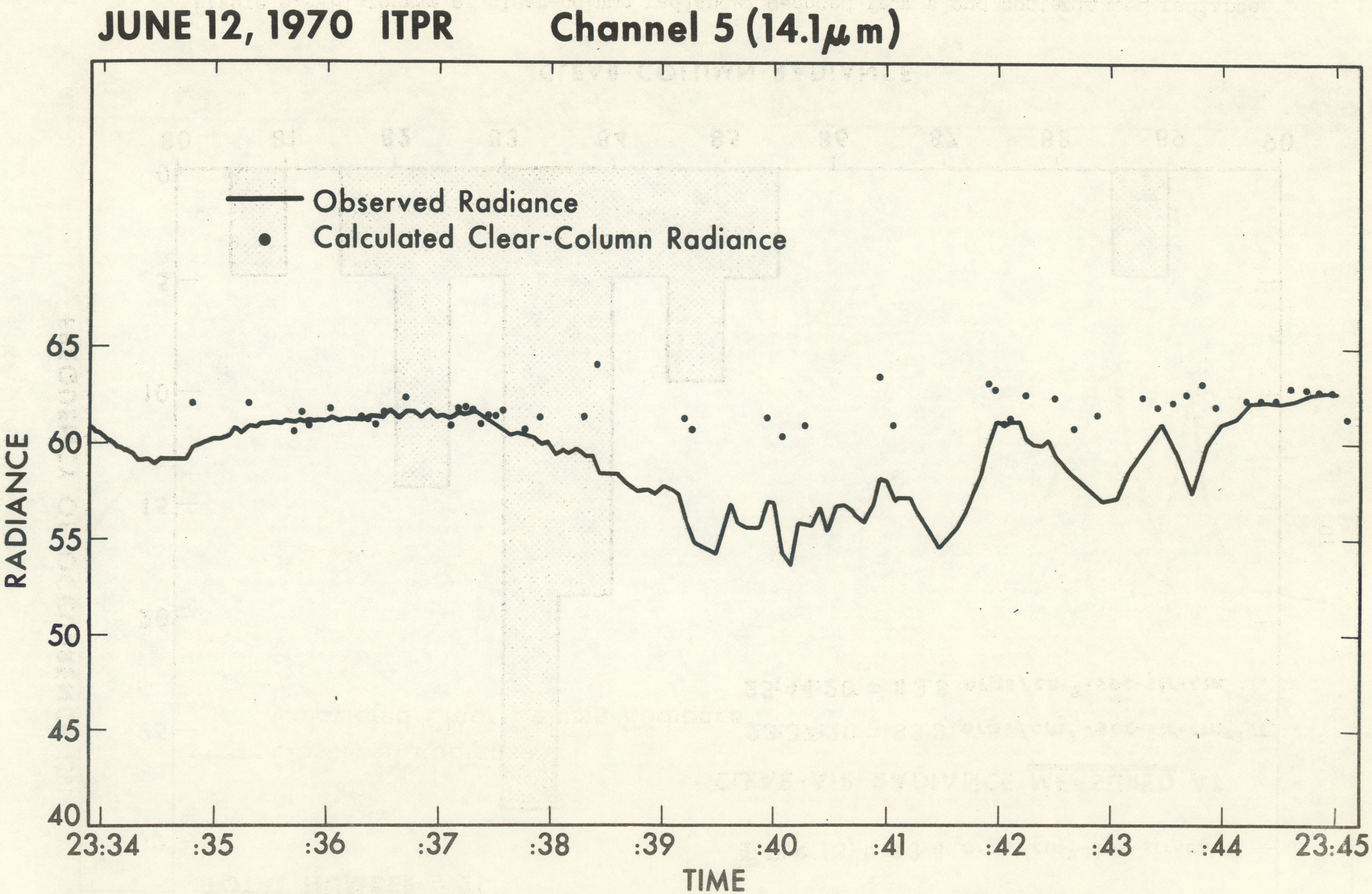

Figure 5.-- Observed radiances (solid line) and calculated clear-column radiance (dots) for the ITPR 14.1 μ m CO_2 channel.

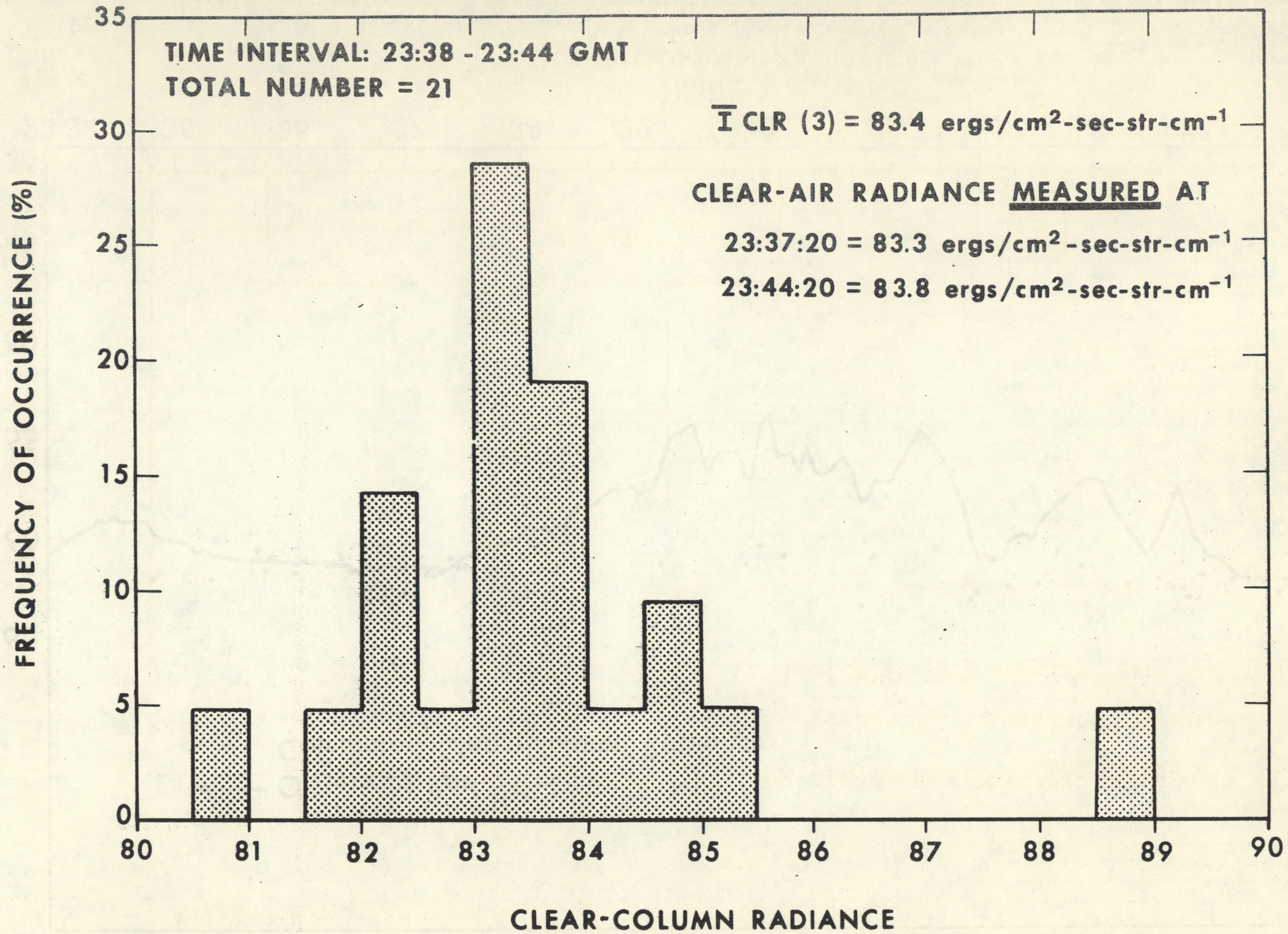

Figure 6.--Histogram of clear-column radiances deduced from cloud contaminated radiances measured in the 13.4 μm CO_2 channel.

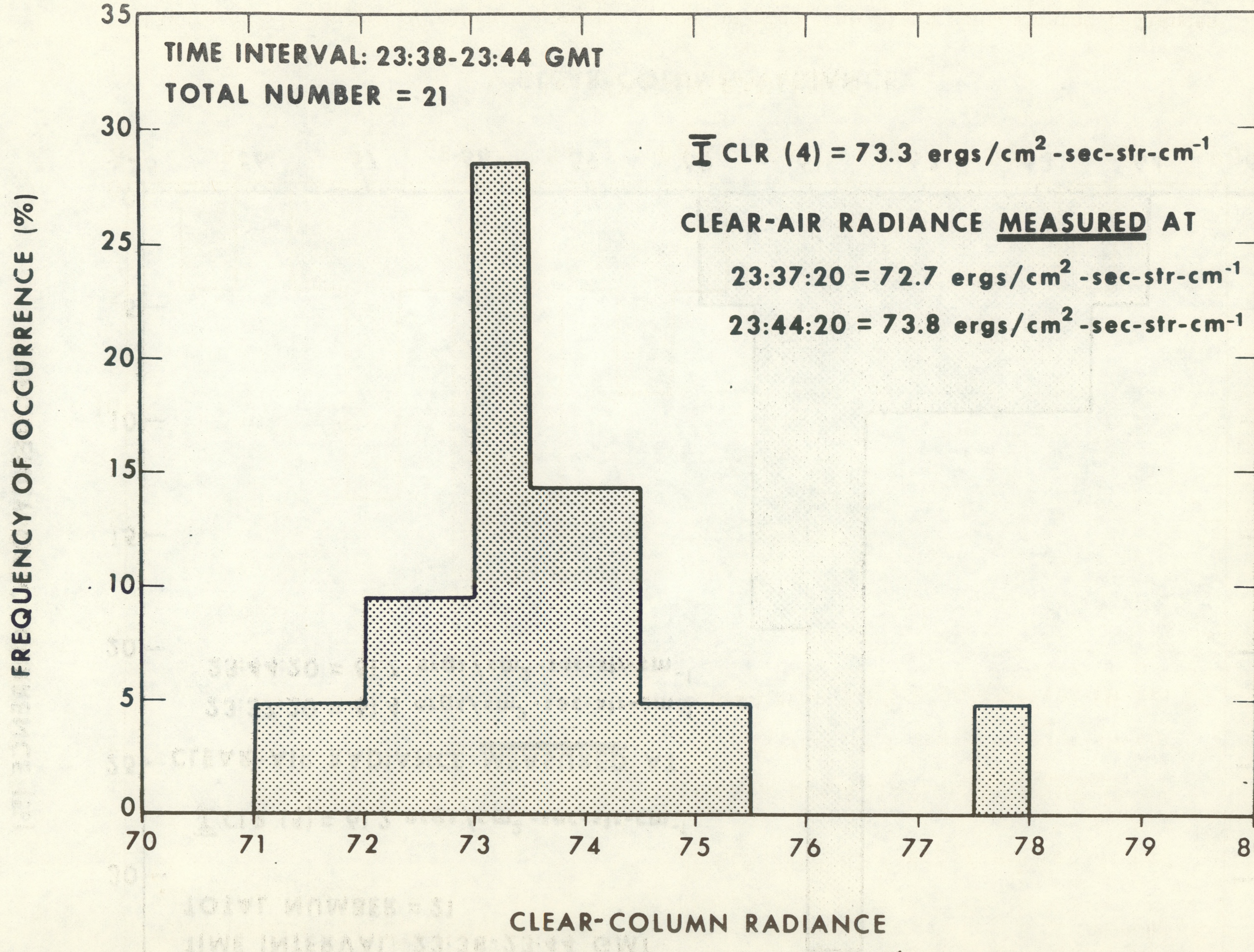

Figure 7.-- Histogram of clear-column radiances deduced from cloud contaminated radiances measured in the 13.7 μ m CO_2 channel.

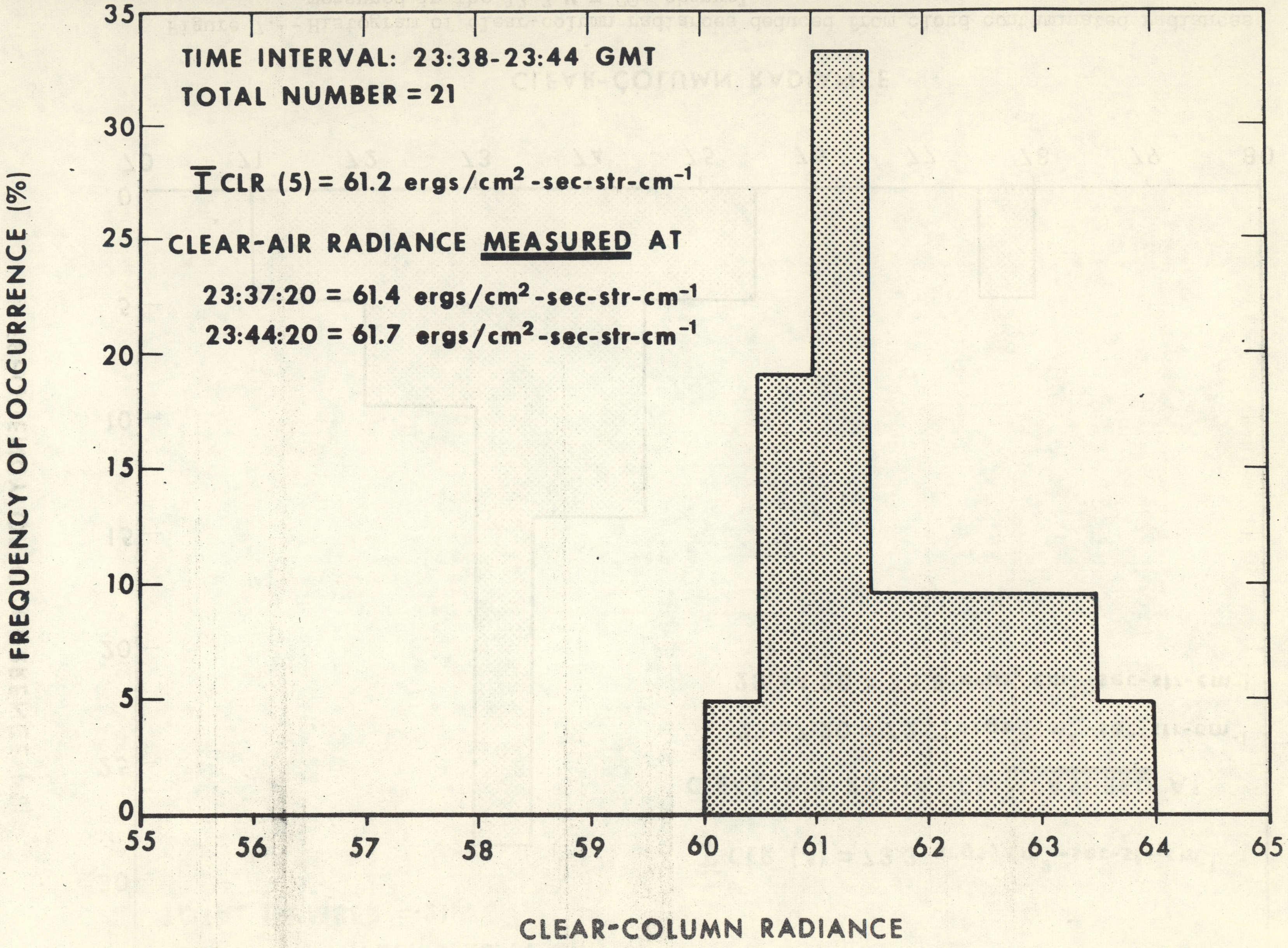

Figure 8.--Histogram of clear-column radiances deduced from cloud contaminated radiances measured in the 14.1 μm CO_2 channel.

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