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DETERMINATION OF AEROSOL CONTENT IN THE ATMOSPHERE FROM LANDSAT DATA

Progress Report No. 4

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Period Covered: November 1, 1975 to January 31, 1976

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ACCOMPLISHMENTS

In this fourth reporting period, more theoretical calculations were made, Volz measurements were made at both test sites, and an analysis of the usefulness of urban areas for aerosol observations was made.

Theoretical Calculations

Calculations were made with the Dave program to determine the effect of a different type of size distribution on the radiance aerosol content relationship. The Dave program is able to handle a log-normal distribution such as reported by Russell and Grams (J. Appl. Meteorol. 14, 1037, 1975):

$$n(r) = [\sigma r (2\pi)^{1/2}]^{-1} \exp [-(\ln r - \ln r_m)^2/2\sigma^2]$$

Using the same particle radius limits as our previous calculations for the Junge distribution, i. e., r_{min} = .03 μm and r_{max} = 8.5 μm, we find that σ = .7058 and r_m = .505 μm. This distribution is compared to the Junge (ν = 2) distribution in Figure 1.

The results of the calculation for MSS 6 are plotted in Figure 2 in comparison with the previous calculations for the Junge distribution. It is seen that the log-normal distribution gives radiances similar to those for the Junge (ν = 2) distribution, and significantly lower than the measured Landsat 1 relationship which corresponds to a Junge (ν = 3.7) distribution. The calculations were performed for a refractive index of 1.5 + 0i. If aerosol absorption were introduced, the radiance values would decrease, making the difference from the measured data even greater. Hence, the Landsat data suggest that a log-normal distribution, covering this particle size range, does not provide a good description of the backscattering by atmospheric aerosols.

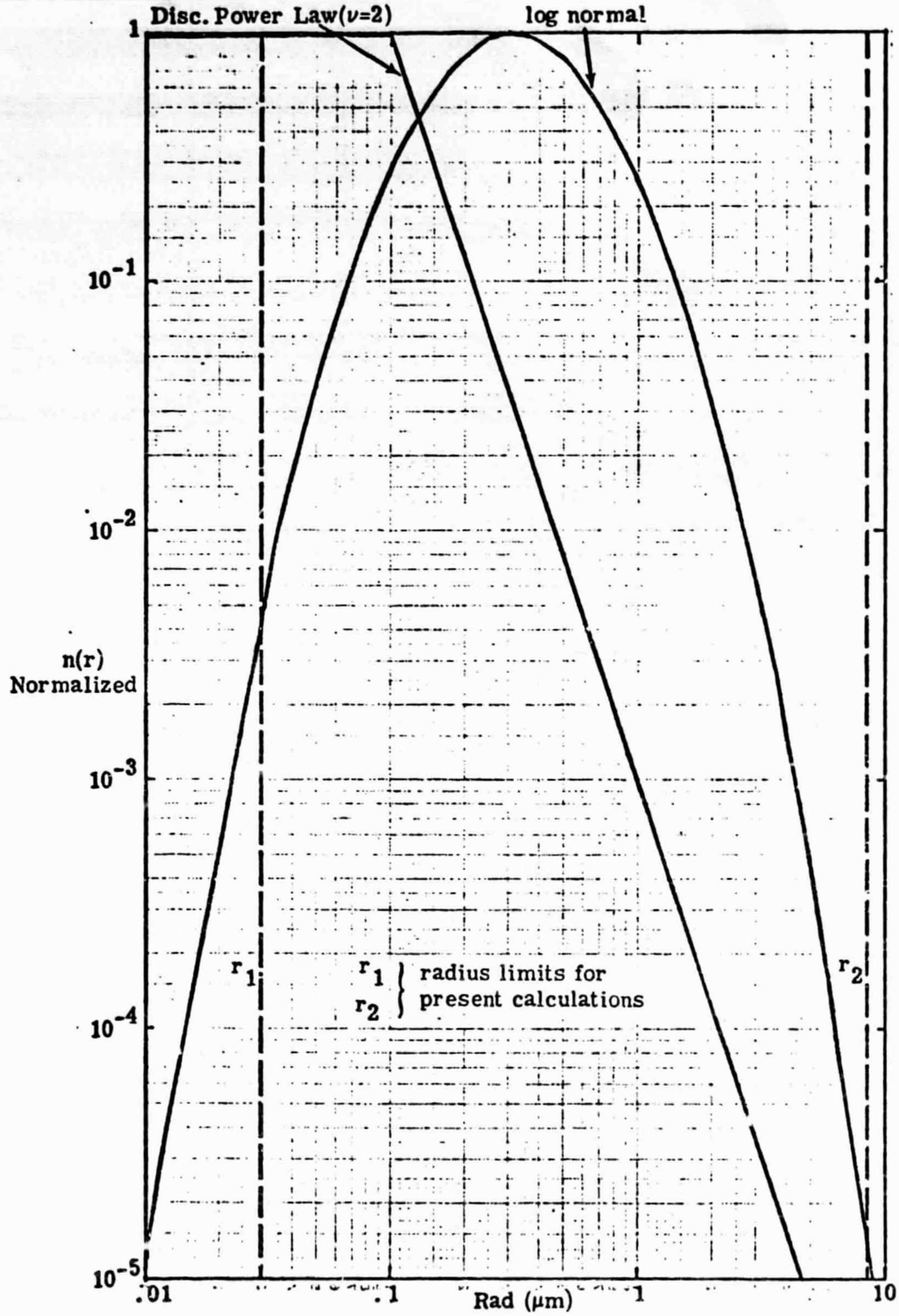

Figure 1. Particle Size Distributions

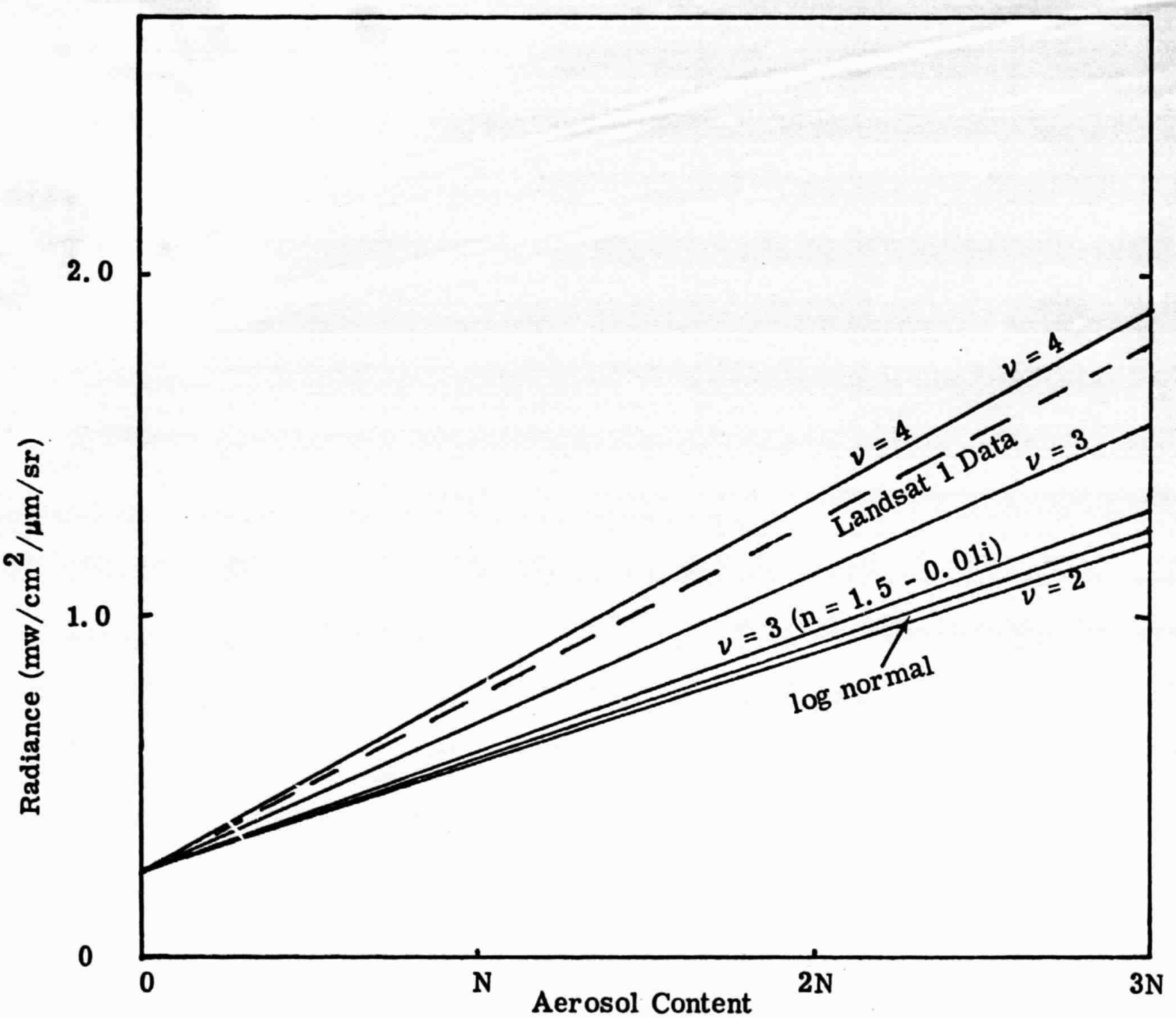

Figure 2. Measured (Landsat 1) and Calculated Radiance for MSS 6

Further calculations were made to confirm that the radiance-aerosol content relationship is independent of the height distribution of the particles. This independence had originally been determined for us by Plass and Kattawar (Appl. Opt. 11, 1598, 1972) using the Monte Carlo technique. Those original calculations had considered only variations below 1 km. The present calculations (for MSS 6), with the Dave program using the log-normal size distribution, are made for several different vertical distributions shown in Figure 3. These distributions are the 1968 Elterman, the 1964 Elterman (the standard in all the comparisons in these theoretical studies), and the 1964 Elterman distribution with single peaks located at different altitudes.

The calculated radiances, shown in Figure 4, confirm that they are essentially independent of the vertical distribution except in the case of a strong 5 km peak [(d) and (e) in Figure 3]. These peaks are 150 and 75 times greater than the normal concentration at 5 km, and would probably not occur in the real atmosphere.

It is clear from a comparison of Figure 2 and Figure 4 that changes in the size distribution or refractive index of the particles are more significant than changes in their vertical distribution.

Use of Urban Areas for Aerosol Observations

Our previous Landsat 1 study demonstrated that the radiance over a desert surface (high albedo ~ 0.3) is not sensitive to aerosol changes, and that the contrast of the water/desert target varies only because of aerosol effects on the radiance over the water surface (low albedo ~ 0). Hence, the contrast measurement does not provide any additional information on aerosols beyond the water radiance measurements. It was

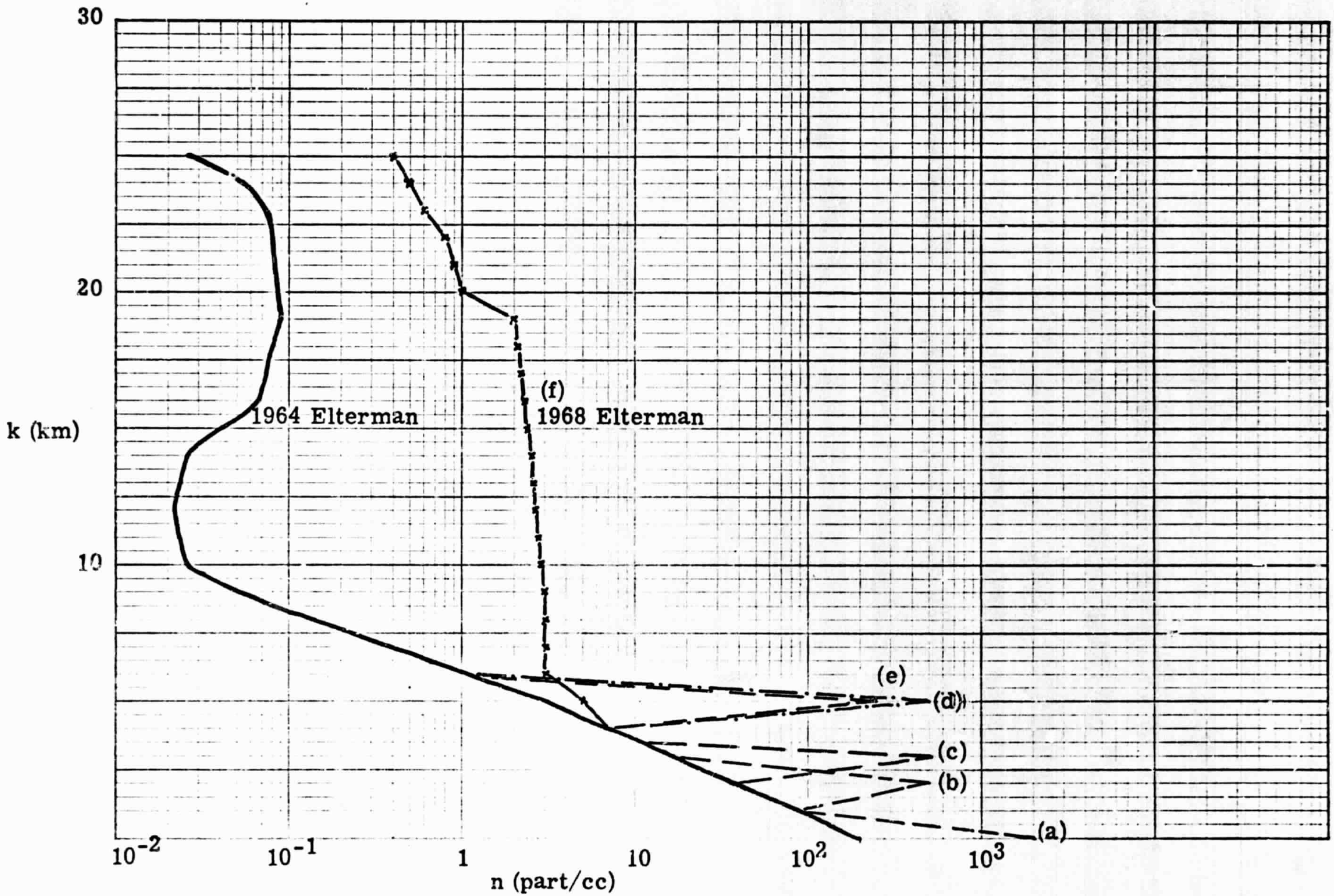

Figure 3. Vertical Aerosol Distributions

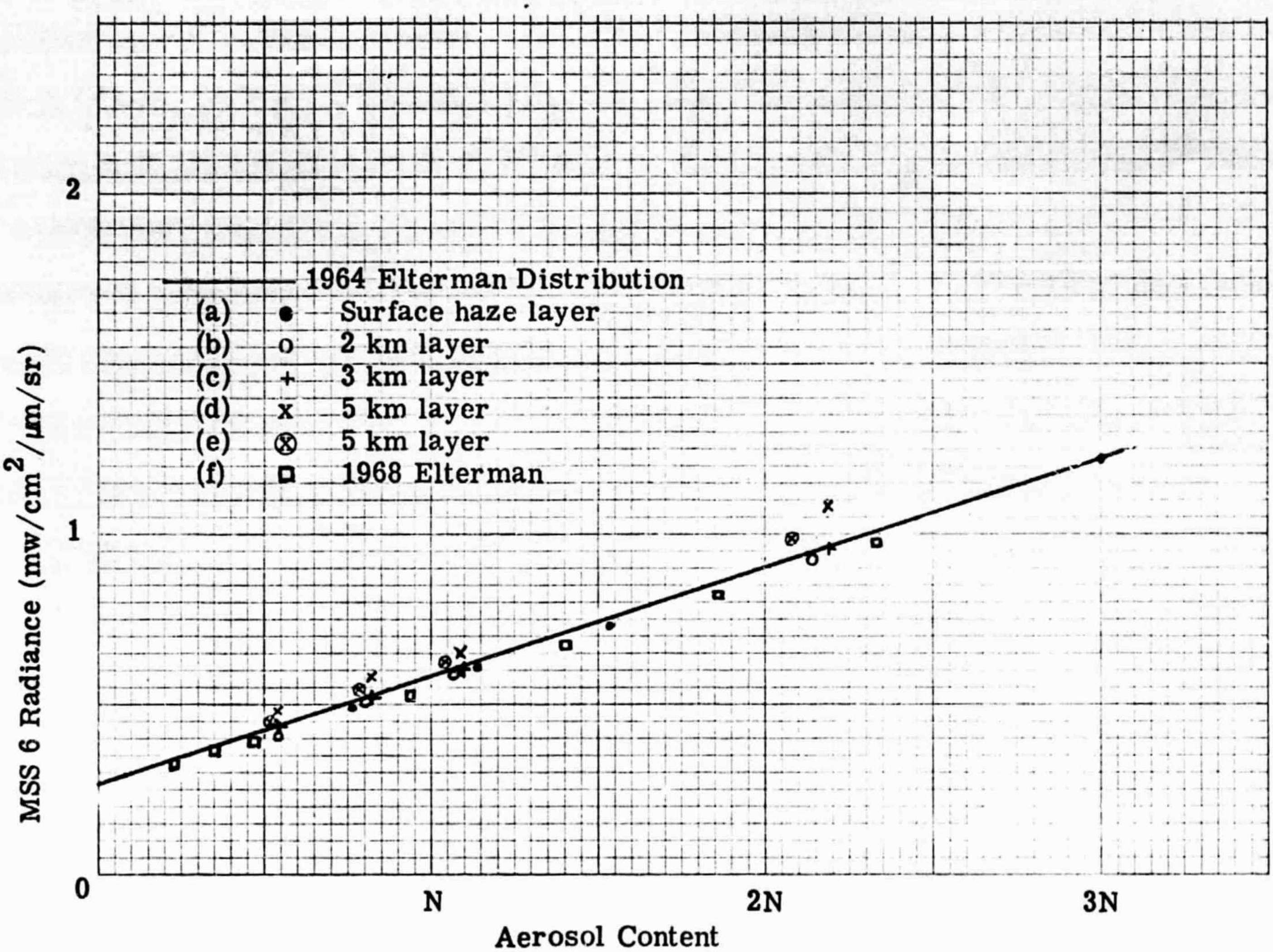

Figure 4. MSS 6 Radiance versus Aerosol Content for Log-Normal Size Distribution

suggested, since urban areas have a lower albedo (.15 - .20) than the desert, that aerosol information might be obtained from radiance and contrast measurements over urban areas. The use of urban areas has been investigated in the present study both theoretically and with Landsat data.

Theory -- Calculations were made for MSS 6 using the Dave program. The upwelling radiance was computed as a function of aerosol content for several surface albedos for a sun angle of $\mu = 0.45$; a size distribution with $\nu = 4$, and a refractive index of $n = 1.5$, were used. The results are presented in Figure 5. It is seen that the radiance is most sensitive to aerosols for $A = 0$, and that at $A = 0.3$ the radiance shows no change with aerosol content, and that the radiance even decreases with increasing aerosol content at $A = 0.4$. The theory is supported by the Landsat 1 data obtained over desert ($A \sim 0.3$) and water ($A \sim 0$) surfaces, also shown in Figure 5. The experimental data shows excellent agreement with the theoretical predictions at high and low albedos. Hence, the theory for intermediate albedos (urban areas) may be assumed to be representative of experimental data, i.e., the radiance over urban areas ($A \sim .15$) does not vary significantly with aerosol content.

The theoretical relationships, of course, assume that the surface albedo is constant. This is a good approximation for unpolluted bodies of water, and to a lesser degree the desert (rain, wind, and vegetation growth can affect the surface properties). However, in urban areas the surface reflectance can change quite rapidly, due to rain or dust-cover, and slowly, due to man-made changes in structures and surfaces. In addition, the effective reflectance will vary with sun angle on a daily basis due to the presence of buildings, and on a seasonal basis due to the presence of vegetation. Hence, it is probable that the radiance over urban areas will vary more due to reflectance changes than to aerosol content changes.

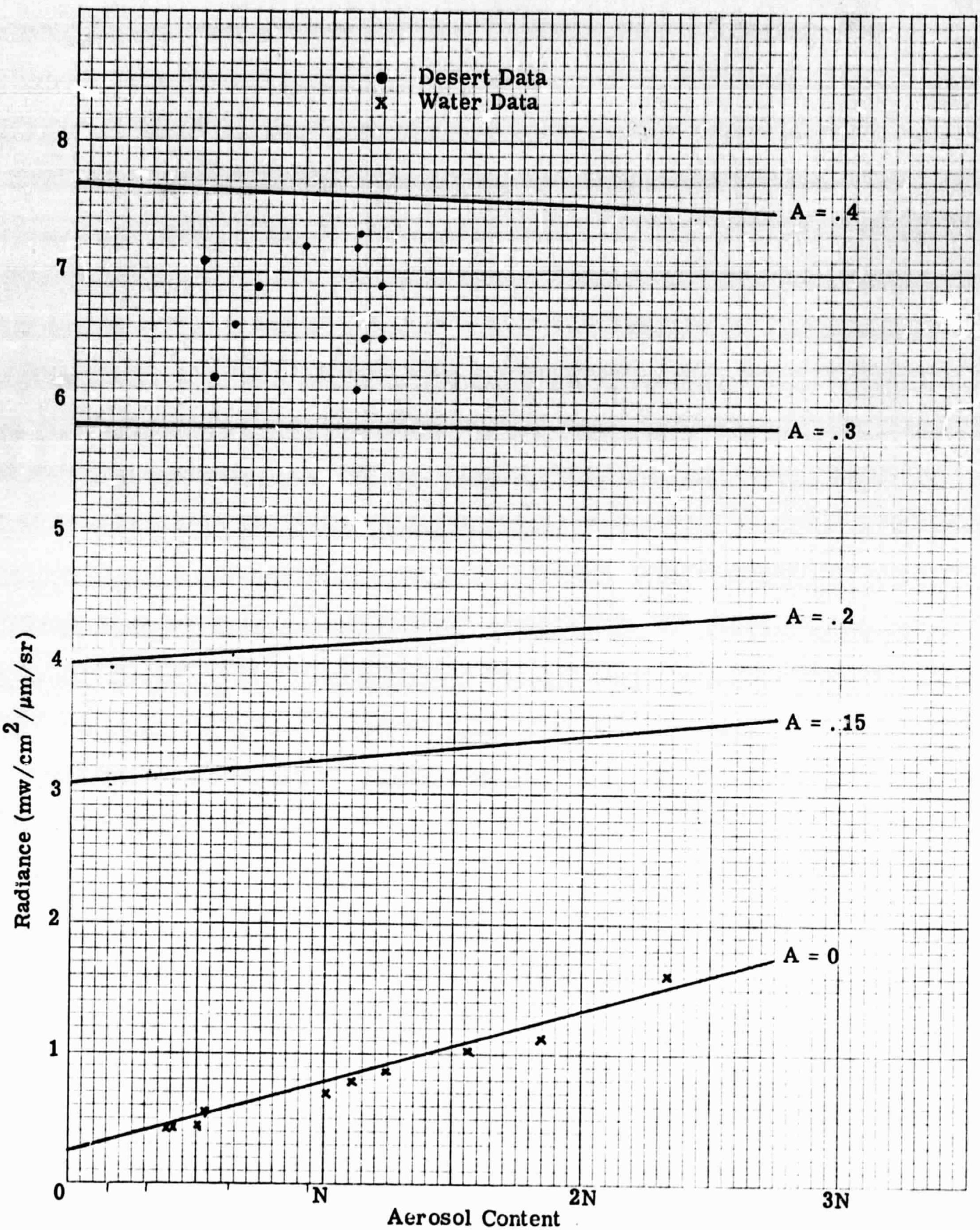

Figure 5. MSS 6 Radiance versus Aerosol Content as a Function of Albedo

Landsat 1 Data -- The radiances over two locations in the San Diego urban area were determined for three consecutive overpasses in the December 1972—January 1973 period. In this period the sun angle was approximately constant (62 - 63° zenith; 146 - 151° azimuth), so no significant effect due to sun angle variation is expected. The radiance in urban areas exhibits considerable spatial variation, and it is very difficult to locate exactly the same areas for each overpass; hence, some differences are expected in intercomparing the overpasses.

The spectral variations for the two locations for the three overpasses are shown in Figure 6. The spectral shapes are similar, but the radiance values show no correlation with the aerosol content for any of the four MSS channels.

Conclusions -- The theory predicts, and the Landsat data verifies, that over urban areas the radiance is not very sensitive to the aerosol content, and in fact is more sensitive to reflectance changes. Thus, it is concluded that the radiance over urban areas cannot be used to determine the aerosol content. Similarly, contrast between the urban area and a water surface cannot be used since, any contrast change, due to aerosols, would be essentially all due to the change in the water radiance; in fact, temporal changes in the urban reflectance would introduce much larger changes in the contrast than would the aerosol content.

Volz Measurements

In this period it was possible to obtain Volz data for three of the six Landsat 2 overpasses at the San Diego test site. Two trips were made to the Salton Sea test site and good data were obtained. No trips were made

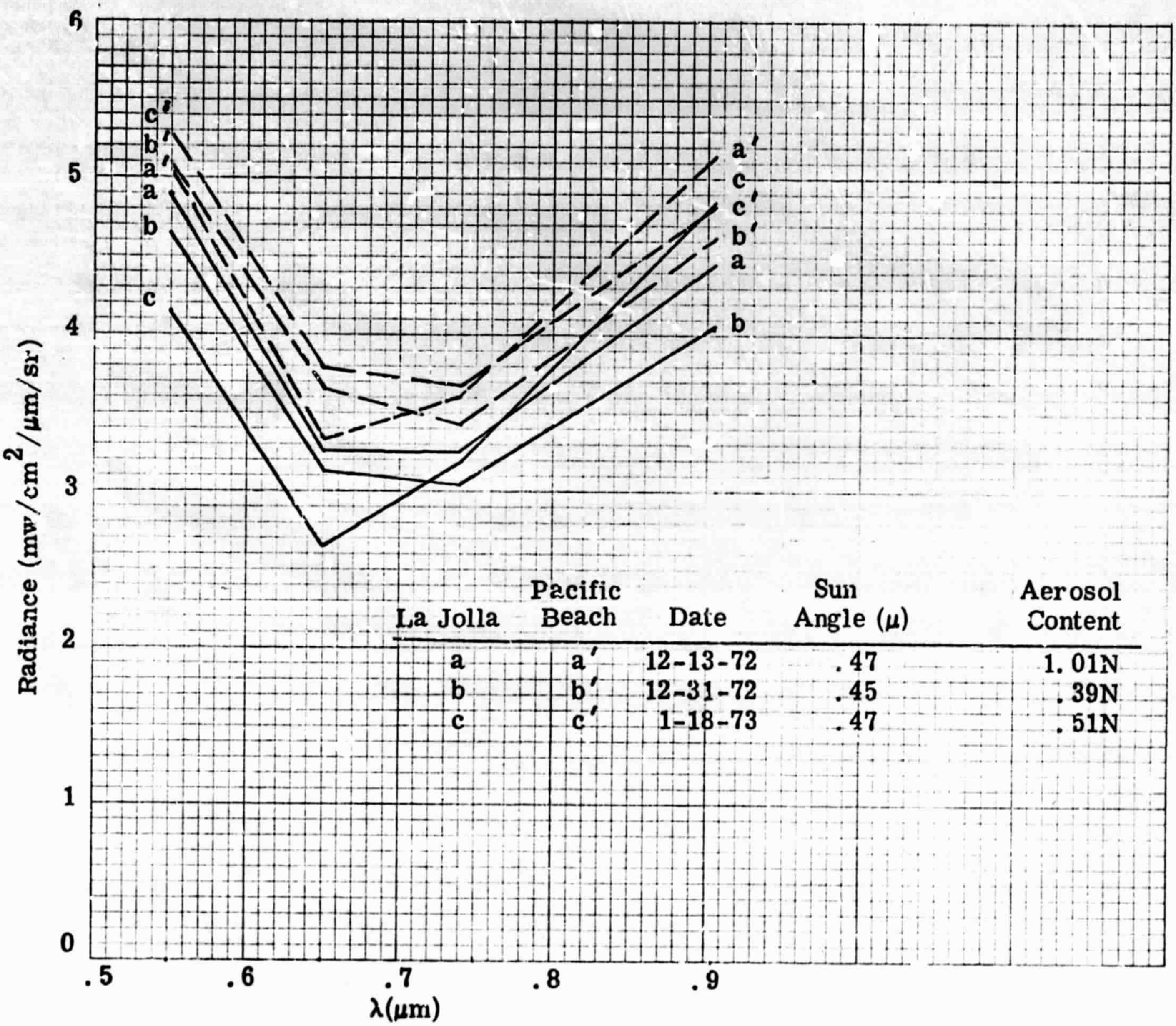

Figure 6. Spectral Variation of Urban Radiance in San Diego Area

to the Salton Sea after 12-6-75 because the CCT's for later overpasses would not be received before submittal of the final report. Data were also obtained for two Landsat 1 overpasses at San Diego. These Volz data are given in Table 1.

TABLE 1. Volz Data

Date	Aerosol Optical Thickness	Aerosol Content
Landsat 2		
San Diego		
11-1-75	.113	.53N
11-19-75	.095	.45N
12-25-75	.157	.74N
Salton Sea		
11-18-75	.235	1.10N
12-6-75	.115	.54N
Landsat 1		
San Diego		
10-23-75	.204	.96N
12-16-75	.080	.38N

Aircraft Measurements

The usefulness of the aircraft measurements reported in Progress Reports No. 2 and 3 was reviewed after receipt of the Landsat digital data. The satellite data are shown in comparison with the aircraft data in Figure 7 and Figure 8; the San Diego measurements look reasonable, but the Salton Sea satellite radiance is less than some of the aircraft values for MSS 6, which is not reasonable. The Landsat data for these days show reasonable agreement with the Landsat 2 aerosol content-radiance relationships, so it would appear that perhaps the aircraft data are in error. However, the Exotech MSS 4 and 7 radiance values are similar at both sites, so there is no reason to doubt the Exotech MSS 5 and 6 values at the Salton Sea. A satisfactory explanation of the Salton Sea data has not been determined. The difference in the spatial resolution of the MSS (200 ft.) and Exotech (26 ft.) does not account for the difference in radiances since the aircraft data were steady for distances of one mile which covers many resolution elements of the satellite data.

The aircraft measurements were originally planned mainly to assist in the contrast investigation discussed in this report. A secondary purpose was to investigate the spectral variation of the ocean radiance with view to eliminating glitter effects should they occur. No evidence of glitter has been found in any of the Landsat data in this program; in addition, the contrast technique for aerosol measurements has proved unsuitable, so it was decided in discussion with Dr. G. Jacobs and Mr. H. Oseroff on their visit to SAI on 11-21-75, that further aircraft flights should not be made in this program.

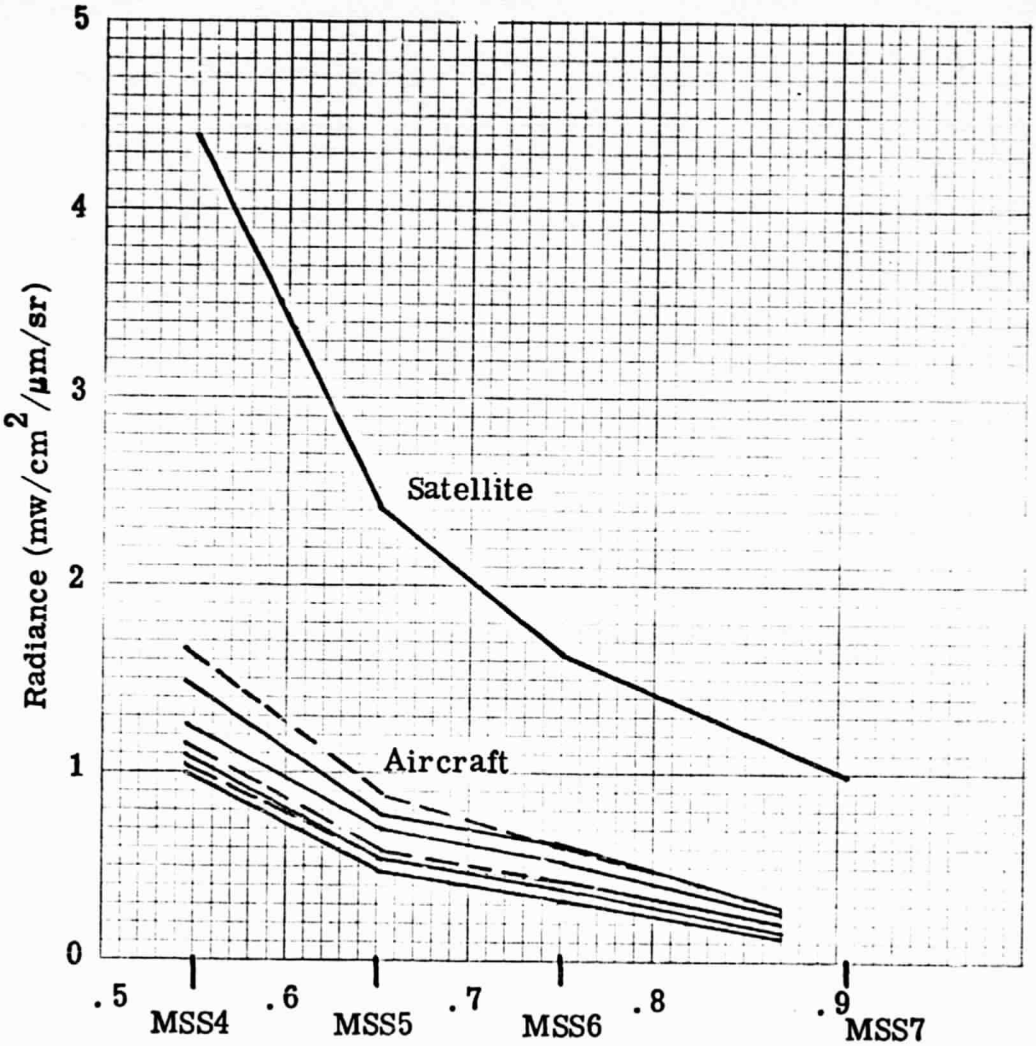

Figure 7. San Diego Radiances Measured from Aircraft and Satellite 7-16-75

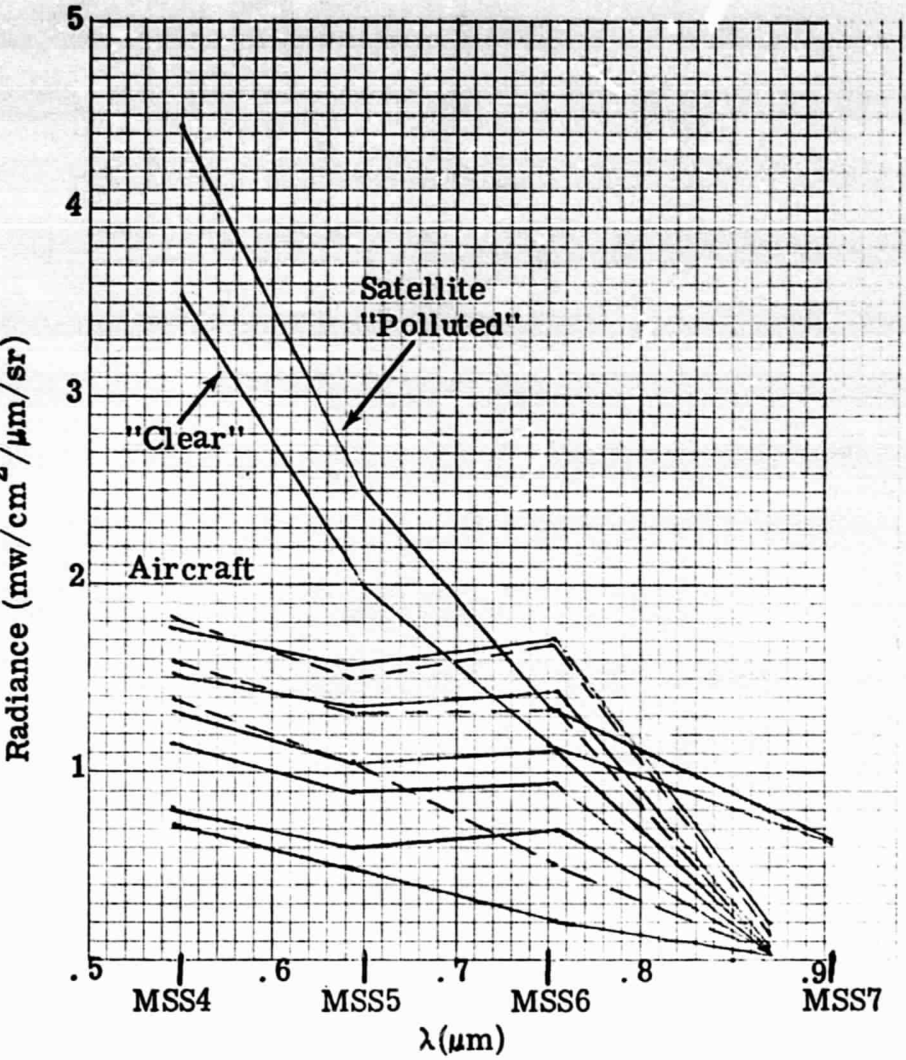

Figure 8. Salton Sea Radiances Measured from Aircraft and Satellite 6-27-75

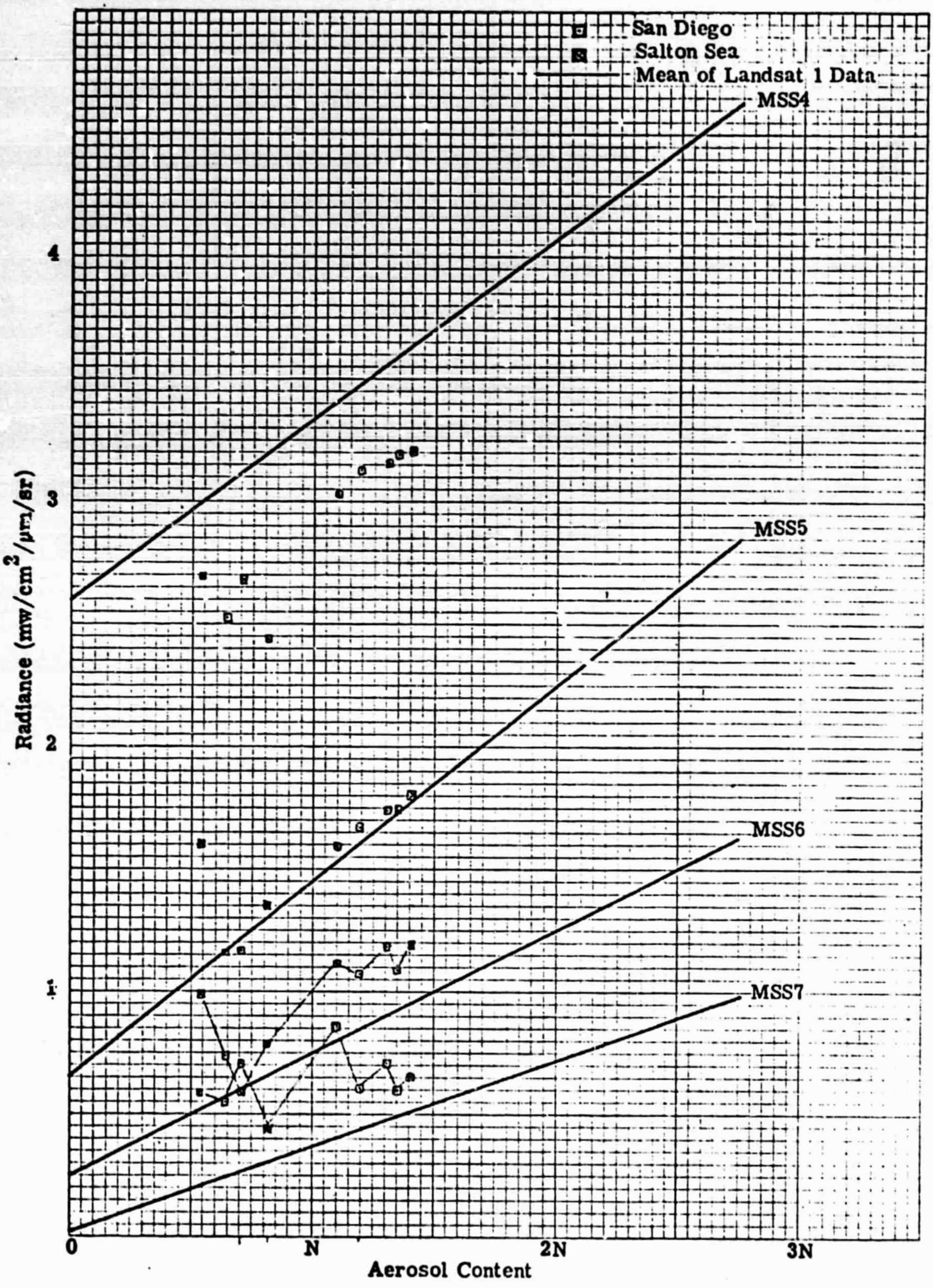

Figure 9. Radiance versus Aerosol Content for Landsat 2

Landsat Data

Digital data for seven Landsat 2 overpasses at San Diego and the Salton Sea have been received and analyzed; CCT's for one Landsat 1 and three Landsat 2 overpasses are on order.

The radiance data analyzed to date are shown in Figure 9 as a function of aerosol content. The figure also shows the empirical relationship determined in the previous Landsat 1 investigation. It is seen that the Landsat 2 radiances show excellent agreement with those of Landsat 1 for MSS 5. The Landsat 2 data for MSS 4 are displaced to lower radiance values suggesting that the radiance calibration is not correct for one (or both) of the satellites. The Landsat 2 data for MSS 6 and 7 do not show the obvious linear relationships found for Landsat 1; this discrepancy is attributed to the method of calibrating Landsat 2, as discussed in Progress Report No. 3.

The point at 0.54N for MSS 5 does not agree with the other data. This point was obtained at the Salton Sea on 10-31-75, and at the time it was observed, and recorded, that small cumulus clouds were forming and rapidly dissolving above the Salton Sea at the time of the overpass. These clouds were not observed in the Landsat imagery. However, it is clear that there probably were increased particle concentrations in the cloud-forming region. These may not have been detected in the Volz measurement since the line-of-sight to the sun is different from the nadir line-of-sight from the satellite. The observed radiances would appear to correspond to an aerosol content of about 1.1N. There was no evidence of significant water pollution in the target area which might also cause high radiance values. Hence, it is concluded, due to the fluctuating nature of the atmosphere, that this data point is not valid and should be disregarded.

In order to analyze the calibration procedures for Landsat 2, a raw data CCT has been obtained from GSFC. This tape contains the data in their uncorrected form, before the outputs of the six detectors in each channel are normalized to avoid striping in the B&W prints. This normalization procedure can distort the radiance values for the low count data which is used in this investigation, particularly in MSS 6 and 7. It is hoped that the raw data will allow true radiance values to be extracted, and possibly eliminate the large scatter of data for MSS 6 and 7.

Plans

Volz data will be taken at San Diego, weather permitting. Analysis of the digital data will continue, and the calibration procedures evaluated with the raw data CCT.

SIGNIFICANT RESULTS

There are no significant results to report in this period.

PUBLICATIONS

No publications were made in this period.

RECOMMENDATIONS

No changes in the program appear necessary at the present time.

DATA USE

Value of Data Allowed	Value of Data Ordered	Value of Data Received
$ 6500.	$ 3575.	$ 2735.

PROBLEMS

No problems exist at the present time.