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GROUND REFLECTANCE MEASUREMENTS FROM THEMATIC MAPPER DATA

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1. Background - Satellite radiance data are measures of solar radiation that has been reflected by the Earth's surface and scattered and absorbed by atmospheric gases and aerosols. Of concern to geologists are the surface reflectance and the degrading effects on surface resolution and albedo contrast introduced by atmospheric phenomena. The objects of the presently-described research have been to: (1) provide an empirical relationship between scanner radiance and ground reflectance allowing interpretation of the satellite data in terms of the surface parameter, (2) assess the precision with which surface spectral reflectance may be recovered from Landsat-4 TM data in the presence of perturbing atmospheric and instrumental factors. Our approach is field-oriented, and utilizes ground observations of surface spectral reflectance with portable spectrometers and radiometers to develop the required empirical relationships.

2. Method - For a satellite scanner system over locally uniform ground with homogeneous atmosphere above the upward directed radiance is given by (Chandrasekhar, 1960; Gordon, 1976; Pearce, 1977).

$$I = I_1 + \frac{R}{1-Rs} I_2 \qquad (1)$$

where the first term (I_1) represents radiation from the atmosphere alone, and the second term radiation that interacts both with the atmosphere and the surface. R is the uniform Lambertian surface reflectance, s is a parameter describing the overall probability of backscatter from the atmosphere after reflection by the ground, and I_2 the overall probability of transmission by the atmosphere after reflection by the ground. All quantities in (1) are functions of wavelength. The determination of R from equation (1) requires measurement of the functions I_1, I_2, and s. In principle this may be carried out by theoretical study of model atmospheres, provided information is available on concentration and distribution of aerosols as well as the absorbing gas species present. These data are not however generally available for the times and places of satellite data acquisition.

We illustrate here an alternative method wherein the required parameters of equation (1) are determined empirically using ground-based measurements of spectral reflectance. The image data set used is the TM scene for Wind River Basin, Wyoming (acquired November, 1982). The scene covers an area of 32,400 km^2 of central Wyoming. The atmosphere is largely free of clouds and haze, which is typical of scenes ordinarily used for geologic remote sensing. Snow blankets higher parts of mountains surrounding the basin.

3. Results for Surface Spectral Reflectance - Field spectral measurements of surface bidirectional reflectance were made for selected targets throughout the Wind River TM scene using a portable reflectance spectrometer (Conel, et al., 1985). Image radiance values, expressed in digital number (DN) were determined for each of the field sites. Scatter plots of image DN versus surface reflectance averaged over bandpasses of the

TM were prepared and are shown in figure 1. After conversion of the DN to energy units the term I_1 is obtained as the intercept value at $R = 0$, and the value of I_2 from the slope. These plots are found to be linear with correlation coefficients of 0.96 or greater for all channels of the TM. It is also possible to obtain good fits using parabolic equations. Quasi-parabolic functional behavior would indicate a contribution to the radiance from the multiple reflection factor $1/(1-Rs)$ and would provide a means for determination of s directly from the curvature term. Based on statistical analysis of these various possible fits to the data, the presence of nonlinear terms in equation (1) cannot be established. For the atmospheric conditions prevailing during time of satellite data acquisition we conclude that the term s is negligible compared to unity, and that the linearized form of equation (1) is appropriate.

To illustrate application of the method for recovery of ground reflectance outside the calibration areas we present a comparison between image-derived spectra and measured field reflectance spectra for five areas throughout the Wind River TM scene (Figure 2). The chronology of events for gathering the data was as follows: (1) the original TM scene was obtained in November, 1982, (2) field measurements were obtained in November of 1983 and used to construct the calibration lines of Figure 1, (3) field measurements using portable spectrometers and a hand-held broadband radiometer of the additional "unknown" areas were obtained in July, 1984. Thus the comparisons involve measurements spanning a period of approximately two years. Agreement between the two sets of observations is excellent to good. It is expected that the comparisons could be improved if the time interval between satellite and field measurements could be shortened. Two additional factors undoubtedly contribute to the differences observed. First, field sites were chosen that were homogeneous and (except for Riverton High School lawn) unvegetated. Despite precautions the best natural targets are always inhomogeneous at the level of a few percent reflectance, and we must rely upon a limited sampling to provide representative reflectance data. Second, some targets are small and it is often difficult to locate them accurately in the images. Factors that are likely to contribute second order effects include those of so-called adjacency effects, phase effects in the surface reflectance, and the comparison of bi-directional versus Lambertian surface reflectance functions. Adjacency effects reduce contrasts between contiguous areas of differing surface reflectance. Kaufman and Joseph (1982) have provided some numerical examples. These problems can be minimized by making measurements far from the edges of large areas of differing albedo, but this is not usually possible in practice. For optically thin conditions (optical depth on the order of 0.2 or less) the effects may amount to a relative change in brightness of a percent (see Kaufman and Joseph, 1982). Relative effects of this magnitude will be difficult to detect (see below) let alone correct for in image data. These effects may influence both the calibration relationships as well as the determined brightness values for isolated pixels in the scene. Phase effects in the surface reflectance can be minimized by taking field measurements at the same phase angle and solar elevation as characterize the satellite observations. The third problem of interpreting satellite-determined reflectance as bi-directional is not considered serious for the present observations since the atmosphere, especially at longer wavelengths, was optically thin.

Considering the possible complications, agreement between measured and satellite-determined reflectance properties is remarkably good. This lends support to the assumption, implicit in Equation 1, of homogeneity of the atmosphere over large areas of the scene during the time of satellite data acquisition. The measured surfaces also appeared to have been stable over the time span of satellite and field data acquisition.

4. Sensitivity of the TM-derived measurements of reflectance - By differentiating Equation (1) with respect to R (Gordon, 1976) a basis is provided for determining what differences in spectral reflectance ΔR may be obtained from TM scanner data, including effects of both atmosphere and precision of scanner irradiance measurements ΔI. The TM system signal-to-noise ratio (i.e., $I/\Delta I_N$ for all visible and near infrared bands can be expressed as a linear function of the irradiance I (Barker, et al., 1983), i.e., $I/\Delta I_N = A + BI$ where the A and B are known constants, and ΔI_N is the noise-equivalent irradiance of the scanner. An expression for ΔR including the signal/noise ratio can then be written down. Figure 3 shows the results of calculations for such noise-limited reflectance differences for all bands of the TM scene of Wind River Basin. The values of I_1 and I_2 are derived from the data given in Figure 1. Based on these calculations, the intrinsic sensitivity of the TM system to detection of changes in reflectance everywhere in the scene less than about 1%.

The actual detectable reflectance differences may be limited by instrumental gain. These differences $\Delta R'$ are given by $\Delta R' = 1/(dDN/dR)$, which is the reciprocal slope of a calibration line in Figure 1. The values of $\Delta R'$ obtained in this way for the calibration data in Figure 1 are comparable to those obtained accounting for the measured pre-flight signal/noise ratio of the TM system together with the atmospheric attenuation factors (Figure 3). The present gain settings of the TM system are thus consistent with the actual noise characteristics of the TM.

5. Significance of Results - We have employed an approximate analysis of the real terrestrial atmosphere and surface (embodied in Equation 1) to investigate the question of recovering surface reflectance from TM radiance data, and to estimate the uncertainties present in such determinations. It was shown that the surface reflectance could in the best examples be recovered to within a few percent, and it is expected that these estimates could in principle be improved by better sampling procedures. The theoretical limit on such determinations was shown to be about a percent for the TM system. Equation 1 and its empirically determined constants can be used in conjunction with sharp edges in the image to estimate the atmospheric portion of the system modulation transfer function (MTF). I_1 and I_2 in Equation 1 can be thought of as functions of the optical depth and phase function for a homogeneous model, and the numerical values obtained as slope and intercept used to estimate these parameters for an optically thin atmosphere. These determinations have been made for the present data set, but space has not permitted a discussion of the results. They along with other results will be set out in forthcoming papers. It also appears possible to provide independent estimates of optical depth and scattering albedo using the so-called "two-halves" method of Kaufman (1982), which will provide an interesting comparison with the present results.

6. Future Research - Despite emphasis placed on interpretation of satellite-acquired scanner data, aircraft scanner systems like TMS and AIS continue to provide essential data sets for the study of many geologic and geobotanical problems. The aircraft observations provide useful high spatial resolution and (for TMS) encompass a wide range of surface viewing directions. We will study the problem of correcting aircraft data for atmospheric effects, and provide methods for looking at directional properties of the surface independent of the atmosphere for one or two test sites. The approach will emphasize "field" determination of atmospheric parameters along lines indicated above, together with observation of directional atmospheric scattering from the aircraft data themselves as inputs to modeling programs.

7. References

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8. Figure Captions

Figure 1: DN vs. Reflectance Calibration Curves. TM-4, Wind River Basin, Wyoming, Nov., 1982.

Figure 2: Comparison of TM-4 and Field Spectra, Wind River Basin, Wyoming.

Figure 3: Noise-Limited Uncertainty ΔR Derived from TM-4, Wind River Basin, Wyoming.

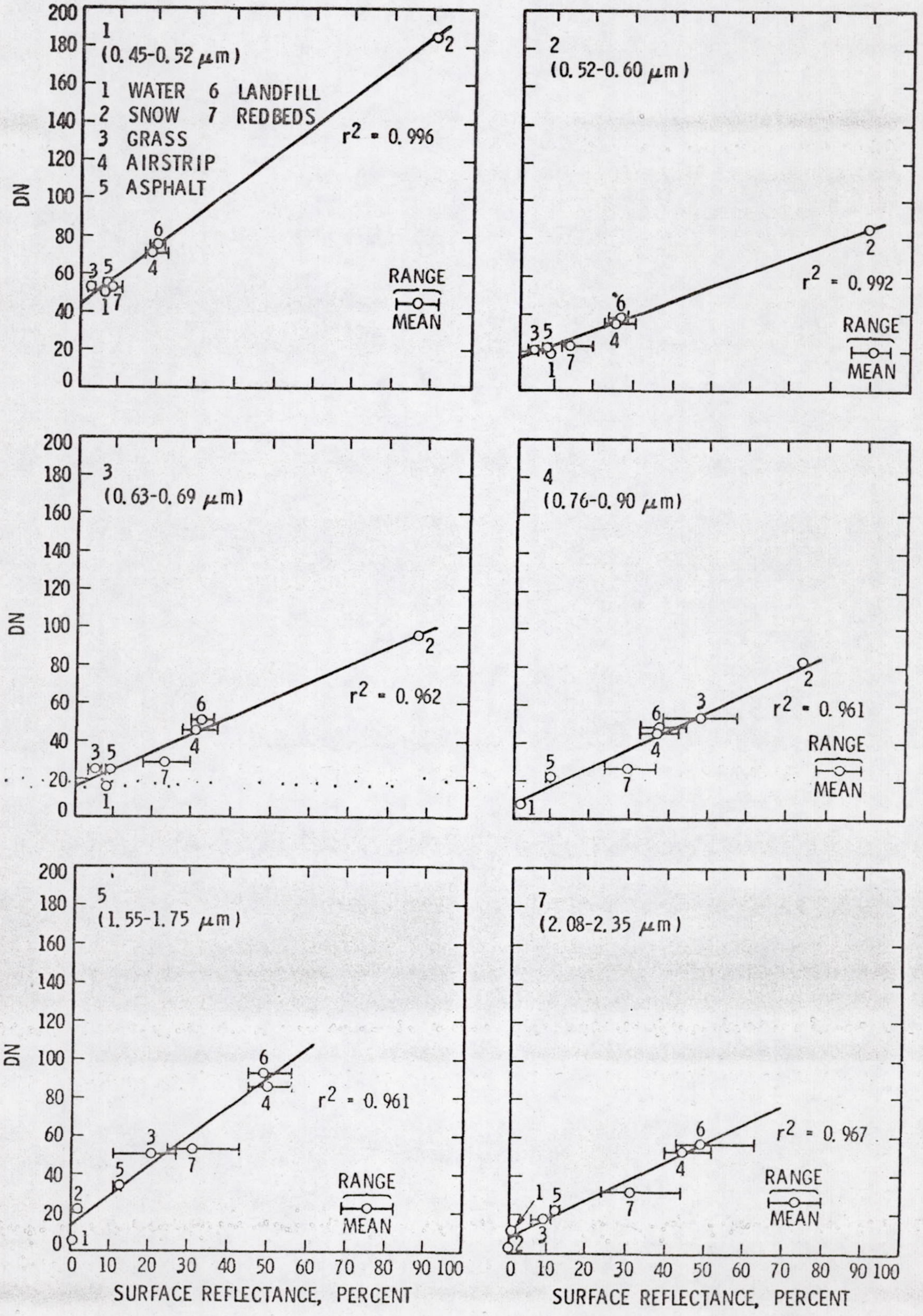
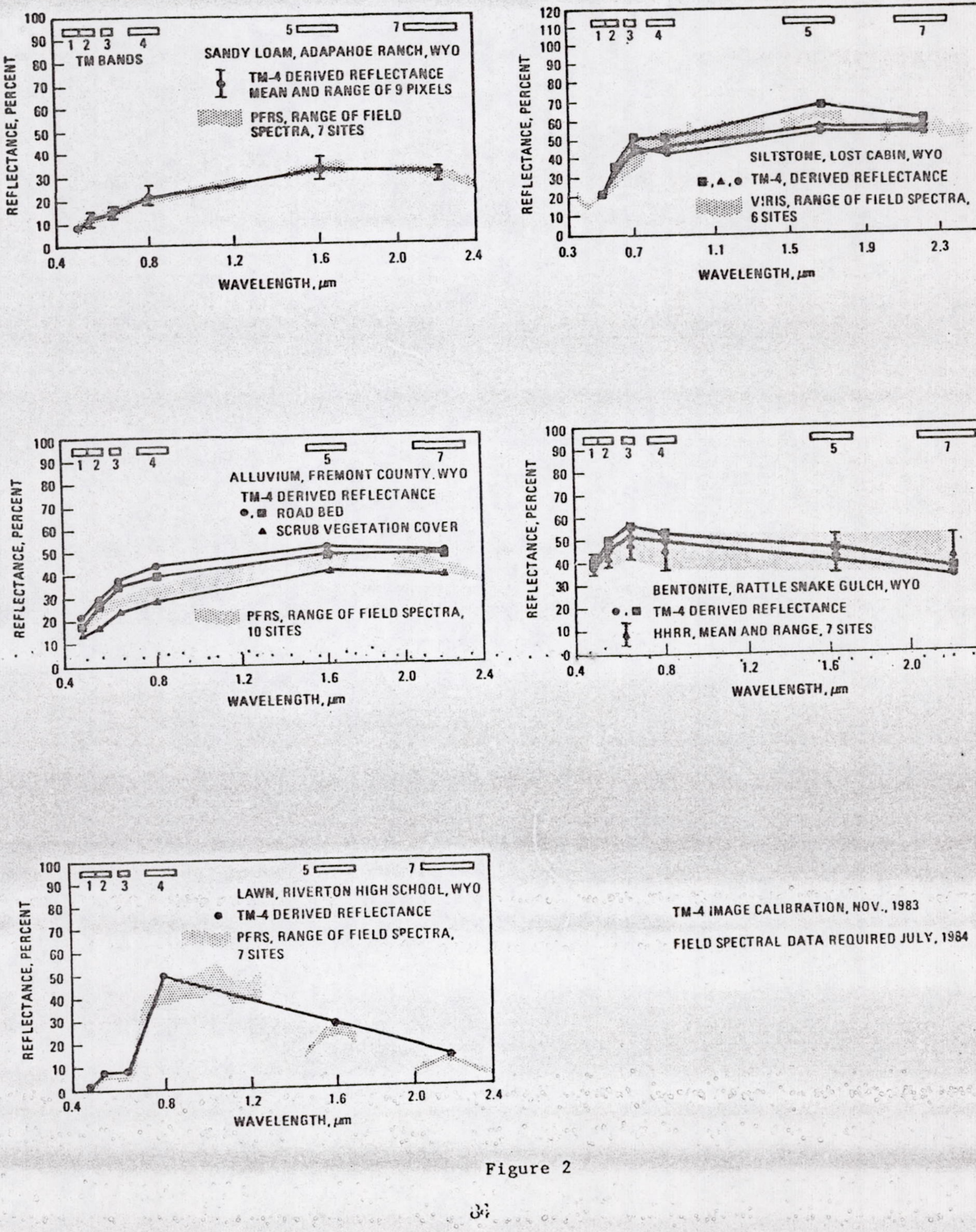

1
(0.45-0.52 μm)
1 WATER
2 SNOW
3 GRASS
4 AIRSTRIP
5 ASPHALT
6 LANDFILL
7 REDBEDS
r^2 = 0.996
2
(0.52-0.60 μm)
r^2 = 0.992
3
(0.63-0.69 μm)
r^2 = 0.962
4
(0.76-0.90 μm)
r^2 = 0.961
5
(1.55-1.75 μm)
r^2 = 0.961
7
(2.08-2.35 μm)
r^2 = 0.967
RANGE
MEAN
DN
0
20
40
60
80
100
120
140
160
180
200
SURFACE REFLECTANCE, PERCENT
0
10
20
30
40
50
60
70
80
90
100

Figure 1

COMPARISON OF TM-4 AND FIELD SPECTRA, WIND RIVER BASIN, WY.



TM-4 IMAGE CALIBRATION, NOV., 1983

FIELD SPECTRAL DATA REQUIRED JULY, 1984

Figure 2

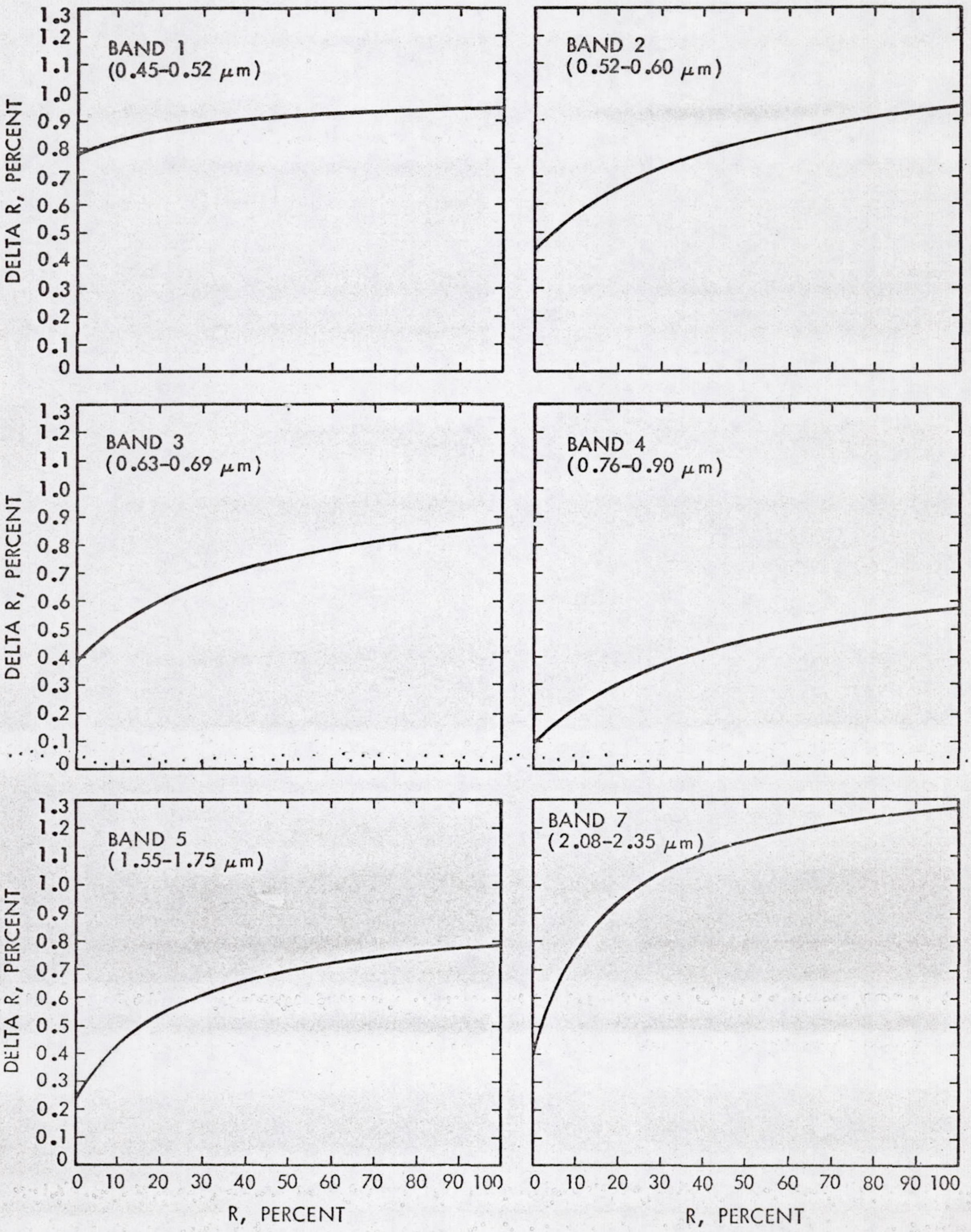

BAND 1
(0.45-0.52 μm)
BAND 2
(0.52-0.60 μm)
BAND 3
(0.63-0.69 μm)
BAND 4
(0.76-0.90 μm)
BAND 5
(1.55-1.75 μm)
BAND 7
(2.08-2.35 μm)
DELTA R, PERCENT
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1.1
1.2
1.3
R, PERCENT
0
10
20
30
40
50
60
70
80
90
100

Figure 3