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14. Abstract/Notes

This paper discusses the fundamentals in the use of Band Ratio techniques to enhance spectral signatures of geologic interest. The path radiance, additive term of the measured radiance at any given wavelength, is almost completely eliminated from LANDSAT images by subtracting the smallest value of the radiance measured in each channel, at shadows caused by topographic relief and clouds, and deep clear water bodies. By ratioing successive spectral channels the effect of solar angle of elevation is minimized and the product expresses, to a first approximation, a relationship between reflectances, which are intrinsic characteristics of the targets. Ratios between noncorrelated channels, such as $R_{7/4}$, $R_{7/5}$, and $R_{6/4}$ are useful to show variations in the vegetation cover, probably related to geobotanical associations.

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ENHANCEMENT OF DIGITAL IMAGES THROUGH BAND RATIO TECHNIQUES FOR GEOLOGICAL APPLICATIONS

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ABSTRACT

This paper discusses the fundamentals in the use of Band Ratio techniques to enhance spectral signatures of geologic interest. The path radiance, additive term of the measured radiance at any given wavelength, is almost completely eliminated from LANDSAT images by subtracting the smallest value of the radiance measured in each channel, at shadows caused by topographic relief and clouds, and deep clear water bodies. By ratioing successive spectral channels, the effect of solar angle elevation is minimized and the product expresses, to a first approximation, a relationship between reflectances, which are intrinsic characteristics of the targets. Ratios between noncorrelated channels, such as $R_7/_4$, $R_7/_5$, and $R_6/_4$ are useful to show variations in the vegetation cover, sometimes related to geobotanical associations.

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1. INTRODUCTION

Data registered by sensing devices, specially those at the orbital level, are strongly dependent on several ambiental variables that introduce spectral noise to the information coming from the target of interest. The most troublesome spectral noises are connected with the relationship between topographic relief and the solar angle of elevation and of azimuth, and by the atmosphere between the sensor and the ground surface.

Since there is little control over the degree of influence of these variables on the spectral response from the target of interest, it is very important to understand the problem so that techniques that minimize these effects could be effectively used. Among these techniques, the most commonly used is the radiance ratio between two different spectral bands. The product obtained is less dependent on the illumination conditions, albedo variation within the same target unit, and on the additive and multiplicative factors related to atmospheric effects.

2. PHYSICAL CONSIDERATIONS

The spectral information derived from the ground surface is recorded by the sensor system in the form of tonal variations representing changes in the integrated radiance of all the features contained in each instantaneous field of view (IFOV) of the sensor.

Equation 2.1 relates the different components that integrate the radiance of targets with Lambertian characteristics, detected by a sensor system at a given wavelength.

According to Dozier and Frew(1981), if all the sensors of the system have the same spectral gain, then the total radiance measured by the sensor system would be expressed by

$$N_{\lambda(SPACE)} = \frac{\tau_\lambda}{\pi} M_\lambda + N_{\lambda(ATM.)} \quad (2.1)$$

$$M_\lambda = \rho_{\lambda(DIF.)} \varepsilon_{\lambda(DIF.)} + \cos Z \, \rho_{\lambda(SOL)} \varepsilon_{\lambda(SOL)} \quad (2.2)$$

where:

$N_{(SPACE)}$ = Measured Spectral Radiance at a given Wavelength

τ = Atmospheric Transmittance

M = Radiant Exitance

$N_{(ATM)}$ = Path Radiance

$\rho_{(DIF)}$ = Bi-hemispherical Reflectance (Albedo to diffuse irradiance)

$\rho_{(SOL)}$ = Directional-hemispherical Reflectance (Albedo to direct irradiance)

$\varepsilon_{(DIF)}$ = Diffuse Irradiance

$\varepsilon_{(SOL)}$ = Direct Irradiance

λ = Wavelength

Z = Solar Zenith Angle

The above equation indicates that the spectral information recorded by a sensing system is dependent on the solar illumination intensity (irradiance), the target reflectance, the atmospheric transmittance and scattering, and the solar illumination

conditions. The path radiance $N_{\lambda(ATM)}$ is the light scattered from space into the detector.

Although not indicated in Equation 2.1, the recorded signal depends also on the spectral gain of the sensor.

3. ATMOSPHERIC EFFECTS

Special attention should be given to atmospheric effects since most of the problems related to the recognition of targets are a consequence of its composition and properties. The atmosphere can scatter, refract and absorb the electromagnetic radiation (EMR) before and after it is reflected by the ground surface. Atmospheric effects are dependent on the path length, the physical and chemical conditions and the wavelengths in consideration, and can be grouped into three main classes. The atmosphere affects the spectral signal:

a) By changing the spectral signal and the spatial distribution of the incident EMR, in function of the solar angles and the topographic relief.

b) By attenuating the reflected signal and introducing spectral changes, due to the wavelength dependent atmospheric absorption, refraction and scattering.

c) By adding to the target signal a scattering EMR component known as path radiance.

The latter is the most effective in disturbing the spectral signature of the target, since the contribution during the trajectory attenuates spectral contrast of ground features, and introduces a different spectral component in the recorded data. The path radiance is a function of the wavelength, the atmospheric conditions, the surface albedo, and the illumination conditions, in function of the solar angles and the

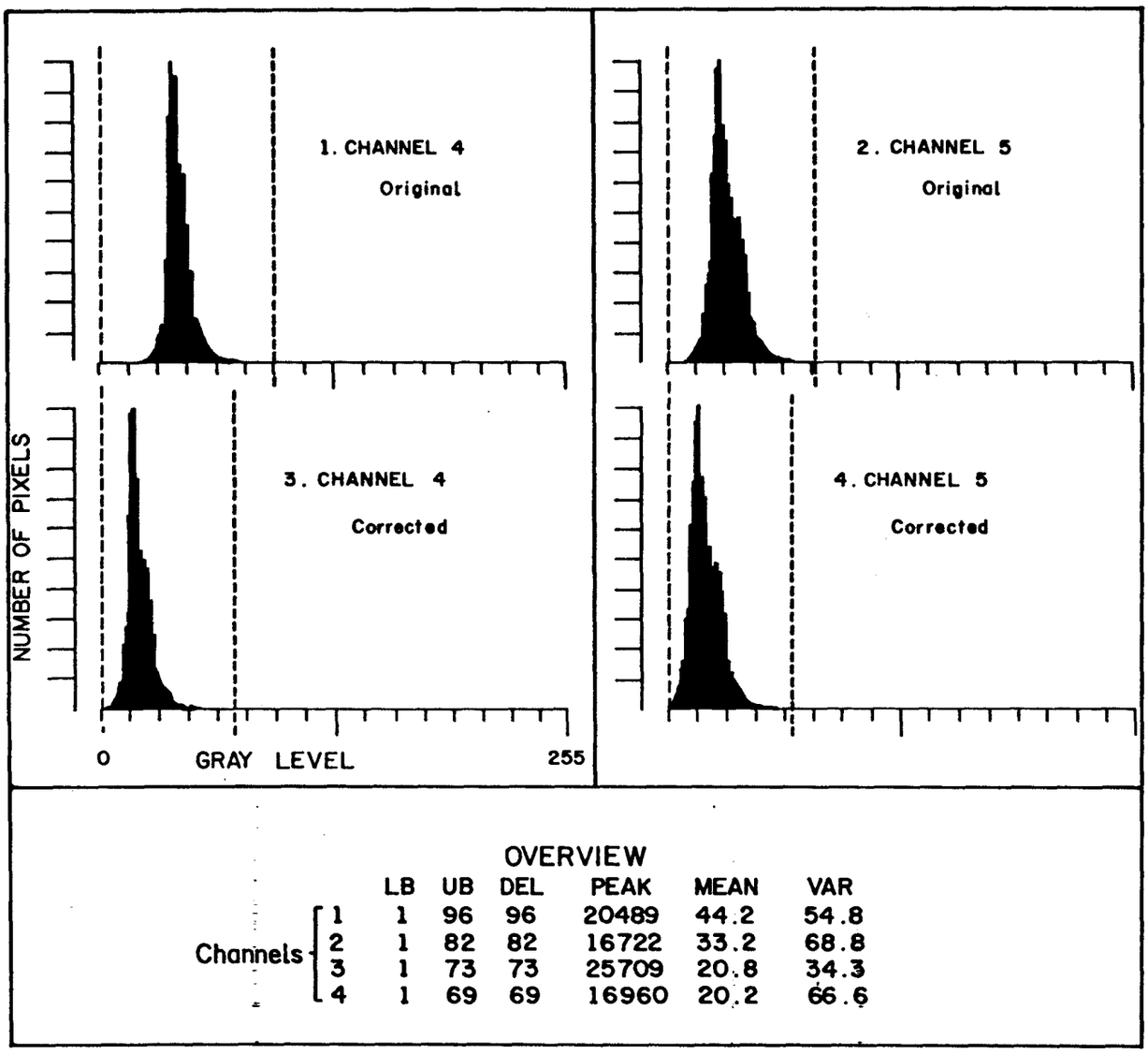
topography (Sharma and Labs, 1972; Taranik, 1977, Malila and Nalepka,1973).

Several algorithms have been developed for the correction of the path radiance, but most of them need atmospheric radiosonde logs, preferably at the same time of the satellite passage. Furthermore, they require extensive computer time to calculate scattering values with an accuracy that usually falls beyond the limits of the uncertainties in the determination of a spectral signature.

A fast and practical way to correct for the additive path radiance is described by Taranik (1977) and consists in the identification in channel 7 of shadows caused by topographic relief and clouds, and deep clear water bodies. The atmospheric scattering is minimum in channel 7 and the measured radiance at these points should be zero or nealy zero. The smallest value of the radiance measured in each channel, at these points, is then subtracted from the gray level values of the entire scene of the respective channel. It is assumed that what remains in each channel is approximately proportional to the reflectance of the ground features. Shadow from topographic relief is always preferred because there might be some diffuse illumination through clouds, in the case of their shadows. In the case of rivers, lakes, etc, the water might be too shallow or loaded with sediments.

Another way to eliminate the additive path radiance is the ratio between band differences, such as the difference of channels 4 and 5, ratioed by the difference between channel 6 and 7 (Lillessand and Kieffer, 1979).

In Figure 1 are shown the histograms of channels 4 and 5 before and after the correction for the path radiance using the above technique. The subtraction of the values corresponding to the atmospheric scattering correction is shown in Figure 1 by the shifting to the left of the histograms of the corrected channels.



OVERVIEW

Channels	LB	UB	DEL	PEAK	MEAN	VAR
1	1	96	96	20489	44.2	54.8
2	1	82	82	16722	33.2	68.8
3	1	73	73	25709	20.8	34.3
4	1	69	69	16960	20.2	66.6

Fig. 1 - Histograms of the original and corrected channel 4 on the upper and lower left side of the diagram respectively, and of the original and corrected channel 5 on the upper and lower right side, respectively. The lower and upper bounds (LB, UB), and their difference (DEL), the number of pixels at the PEAK, the MEAN, and the variance (VAR) of each histogram are shown in the table below the histograms.

The correction for atmospheric scattering is considered to be an enhancement of the image as the subtraction of the necessary values for the correction improves the scene contrasts. The contrast in an image is qualitatively referred as high, medium and low contrast, but quantitatively is frequently expressed by the contrast ratio between the higher and lower gray levels in the scene (Sabins Jr,1978).The contrast ratio usually increases with the subtraction technique.

The two first atmospheric effects a) and b) can not be corrected but can be minimized through the use of band ratio techniques, as will be described in the following sections.

4. TOPOGRAPHIC EFFECTS

The orientation of the topographic features relative to solar illumination, azimuth and elevation has strong effect on the intensity of the signal received by the sensor. If the direction of a given topographic feature is parallel to the solar azimuth, both sides of the topography will be equally illuminated and there will be no serious problem with shadows. On the other hand, if the topographic feature is oblique to the solar ray direction, each side of the topography will have different illumination intensity which will cause important shadow problems. The exitance from the illuminated slope is proportional to the cosine of the incidence angle being stronger when the face of the slope is normal to the incident light beam.

Figure 2 shows three distinct illumination conditions in relation to the solar angle, topography and the atmosphere between the sensor and the ground surface. In area A, incident solar rays fall directly on the topographic face but with a slight inclination, whereas area B faces directly the incident solar rays, having thus, stronger illumination. In area C, the illumination is due to scattered EMR from nearby topography and atmosphere.

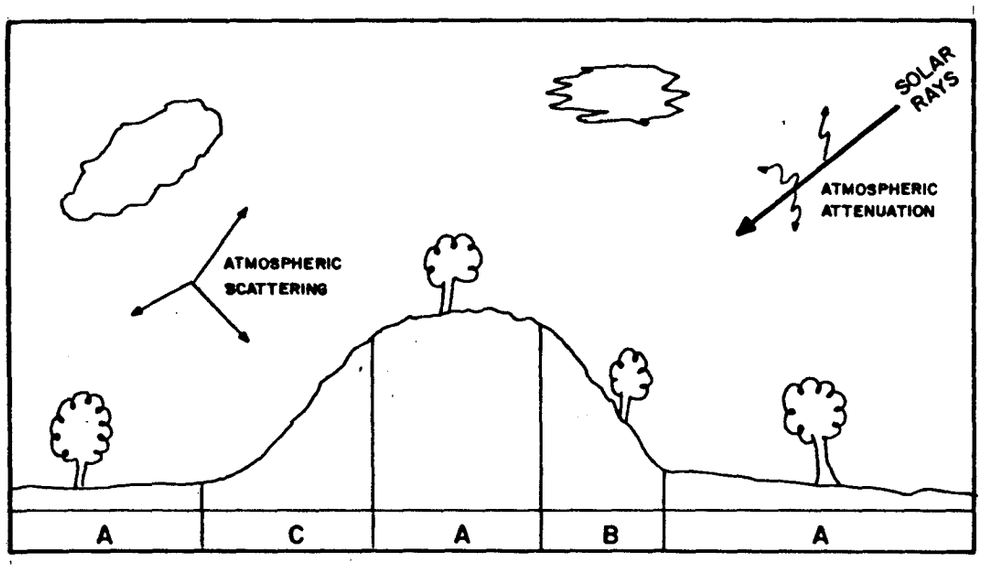


Fig. 2 - Diagrammatic illustration of the path of solar radiation through the atmosphere and interaction with the topography. The illumination intensity on the three different faces are: B > A > C.

From Figure 2 one can notice that the relationship between topography, solar angles and atmosphere can change spatially and spectrally the illumination conditions of the area. Therefore, the same geological target can show distinct spectral behaviour in function of the illumination conditions. Among the techniques that can minimize these topographic effects, the most commonly used is band ratio, described in the next section.

5. IMAGE ENHANCEMENT BY BAND RATIO TECHNIQUE

The main advantage of image enhancement by ratioing of different spectral channels is to create a product less dependent on the variations of illumination conditions. Egbert and Ulaby (1972) have shown the importance of illumination conditions over the reflectivity of natural targets.

The images obtained in spring and summer are more uniformily illuminated than the ones obtained in fall and winter. The latter will show strong shadow effects due to lower angle of solar elevation, and consequently they emphasize topographic features. In this way, fall and winter images are the best for distinguishing texture and pattern characteristics in photogeologic interpretation of the scene. However, in the analysis of tonal variations, representative of the spectral behaviour of different soil-vegetation associations, the variations in illumination are not desirable, since they introduce tonal changes in the same unit. And in this respect, the lower the solar angle, the more intense are the illumination effects. In these conditions, in an area of strong relief,the topographic face directly towards the sun will receive the full incident irradiance whereas in the opposite face, on the other hand, there will be a shadow, illuminated only by the diffuse light from the atmosphere or the neighbouring topographic relief.

To minimize these differential illumination effects, the ratio of channels can be used, after the correction for the path radiance (subtraction of the path radiance), which was described in section 3.

Using the ratio of channels 5 and 4 as an example ($R_{5/4}$), the equation 2.1 becomes

$$R_{5/4} = \frac{N_5}{N_4} = \frac{\tau_5 M_5}{\tau_4 M_4} \qquad (5.1)$$

In areas of diffuse illumination (shadows),equation 5.1 becomes:

$$R_{5/4} = \left(\frac{\tau_5}{\tau_4}\right) \frac{\rho_{5(Dif)} \varepsilon_{5(Dif)}}{\rho_{4(Dif)} \varepsilon_{4(Dif)}} \qquad (5.2)$$

In areas of direct solar illumination, equation 5.1 becomes:

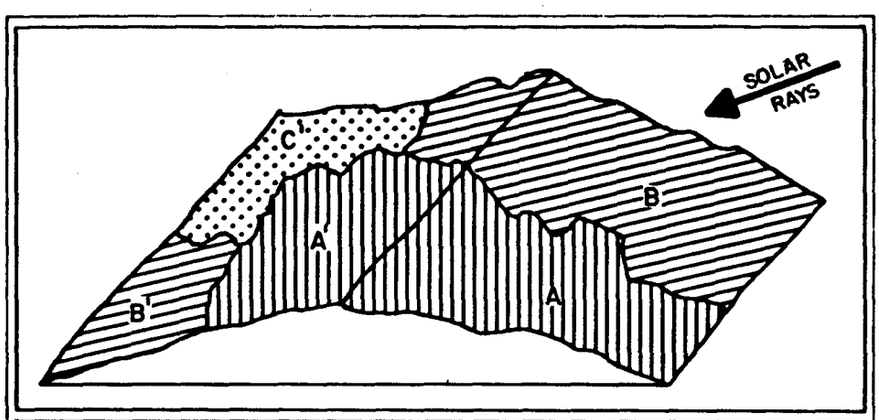
$$R_{5/4} = \left(\frac{\tau_5}{\tau_4}\right) \frac{\rho_{5(Sol)}\ \epsilon_{5(Sol)}}{\rho_{4(Sol)}\ \epsilon_{4(Sol)}} \qquad (5.3)$$

In this case, the effect of the solar angle of elevation ($90^o - Z$) is eliminated. Besides, considering that channels 4 and 5 are spectrally correlated, an assumption can be made that the solar irradiance, ϵ, and the atmospheric transmittance, τ, to a first approximation, are very similar in channel 4 and 5. Therefore, $R_{5/4}$ expresses, to a first approximation, a relationship between reflectances, which are intrinsic characteristics of the targets, and are independent of the illumination conditions:

$$R_{5/4} \approx \frac{\rho_{5(Dif)}}{\rho_{4(Dif)}} \approx \frac{\rho_{5(Sol)}}{\rho_{4(Sol)}} \qquad (5.4)$$

This relationship indicates that geologic targets can be independently characterized by their spectral signatures in ratio products. The ratio can emphasize differences in targets that are spectrally distinct but might appear to be similar in the original images.

In the example of Figure 3, three geologic units (A, B, C), having distinct spectral signatures would show similarities in channel 4 and 5. The gray levels of the units A and B in the side with direct sun illumination are higher (lighter in tone) than their respective sides in the shadow, A' and B'. Furthermore the gray level of the unit C' coincides with A in channel 4. After the application of the ratio $R_{5/4}$, the gray level of each unit becomes similar for the illuminated and nonilluminated side, and quite distinct from the other units.

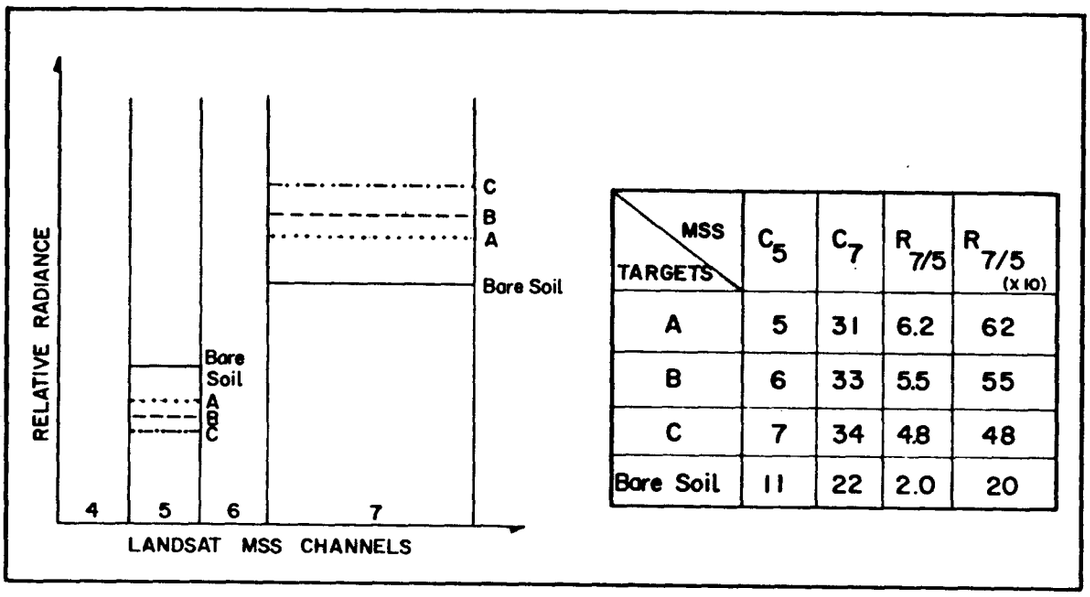


TARGETS \ CHANNELS	C_4	C_5	$R_{5/4}$	$R_{5/4}$ (x 100)
A	35	40	1.14	114
A'	32	37	1.15	115
B	48	63	1.31	131
B'	44	58	1.31	131
C'	35	37	1.05	105

Fig. 3 - Illustration of an example showing elimination of illumination differences in three geologic units, after ratioing (Adapted from Taranik, 1977).

Ratios between noncorrelated channels, such as $R_{7/4}$, $R_{7/5}$ and $R_{6/4}$ are useful to show variations in the vegetation cover, since these ratios are inversely proportional to vegetation density. These ratios are very useful to map geobotanical and/or bio-geochemical associations, as shown by several publications (Lyon, 1975; Raines et al., 1978). This is illustrated in Figure 4 that diagrammatically shows radiance values for each spectrally different region, one with bare soil, and three others (A,B,C) with varying vegetation cover. The region C has a greater vegetation density than B, which in turn is greater than A. In the original channel 5 and 7, the spectral response from the three vegetation densities are almost identical, however, after the application of the ratio $R_{7/5}$ the contrast is significantly improved, which is indicated by the greater

values of contrast ratio between the gray levels of the regions A, B, C, and bare soil, in the new product $R_{7/5}$.



MSS / TARGETS	C_5	C_7	$R_{7/5}$	$R_{7/5}$ (x 10)
A	5	31	6.2	62
B	6	33	5.5	55
C	7	34	4.8	48
Bare Soil	11	22	2.0	20

Fig. 4 - Radiance values for three areas A, B and C with varying vegetation density and one with bare soil, in channels 5 and 7.

6. CONCLUDING REMARKS

The radiation detected by remote sensors travels through some distance of the atmosphere which has a significant effect on the intensity and spectral composition of the energy recorded. The problem is compounded by the effects of the orientation of topographic features on the ground.

The net result of these spectral interferences is that the contrast of the image is reduced, since the spectral components added to the radiance received by the sensor do not contain information of the target of interest. A reduction in image contrast means a reduction of the spatial resolution which in turn reduces the detectability of the image.

Of course, shadow caused by topographic relief is particularly useful in geologic photointerpretation, however, for geological discrimination of different soil-vegetation-rock associations, it is necessary to remove the illumination effects.

There are several techniques for correcting spectral signatures of targets of interest, for atmospheric effects, most of them based on atmospheric models with some parameters difficult to acquire.

The ratioing approach, which involves an initial subtraction step removing the additive spectral term, is a fast and relatively accurate technique to minimize the undesirable effects of the atmosphere or variable scene illumination, by approximately cancelling the multiplicative terms. Unfortunately, spectral ratios can eliminate only extraneous illumination that affect equally in all wavelengths that are being divided. Thus, for the elimination of multiplicative factors, only band ratios of successive channels can be considered as an approximation of a full corresction.

In conclusion, the corrected spectral signature by ratioing is, at worst, less dependent on ambiental variables, and at best, the most accurate technique available for spectral discrimination and identification of targets of interest, than any single-channel image.

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