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ABSTRACT: Techniques were applied to alleviate topographic influences on a TM scene prior to land-cover classification for mobility modeling. Illumination models were created using two different resolutions of DEM data. These illumination models were based on linear regression of the two parts (cosine and sine) of the equation for the incidence angle of the solar beam with the first principal component of the TM data. A topographic normalization procedure was applied to correct the TM data utilizing the derived models. The near IR band required a completely different model because of high correlation between areas of high relief and vigorously growing vegetation. Results are presented showing improved utility for visual interpretation and land-cover classification on the corrected data.

INTRODUCTION

BACKGROUND

THE EFFECTS OF TOPOGRAPHY on MSS data and land-cover classifications derived from them have been widely documented in the literature, and have significantly reduced the efficiency and accuracy of land-cover classifications performed at the Waterways Experiment Station (WES) in support of military mobility. This topographic effect involves differential illumination of surfaces due to slope angle and aspect variations. It has been shown that the angle of the light striking the Earth and reflecting to the sensor has a large effect on the brightness or digital count of each pixel or point on the land surface in areas of high relief. In some cases, parts of the Earth's surface can even be in shadow, drastically affecting the digital count of the pixels involved. Implementation of standard remote sensing data processing techniques without regard to this effect results in commission errors in which differing land-cover types with similar topographic position are grouped together. Likewise, omission errors occur where pixels from the same land-cover type are classified differently.

PURPOSE AND SCOPE

This paper documents research performed at WES and the Mid-America Remote Sensing Center (MARC) at Murray State University concerning the removal of the topographic effect from remotely sensed satellite data. Image processing techniques used previously by WES and other researchers, as documented in the literature, to alleviate this effect are discussed. The Earth Resources Laboratory Applications Software (ELAS) package (Graham *et al.*, 1980) was used exclusively, with modifications made to existing software. An area of North and South Korea containing a part of the Demilitarized Zone (DMZ) was chosen to demonstrate the results from the research. This area was the site of a Brigade/Battalion Battle Simulation (BBS) database developed by the WES in the summer of 1990. The BBS combat model is a training simulation permitting single echelon training of commanders and their staffs. It may also be used as a two-echelon command post exercise for training both the battalion and brigade command groups concurrently. BBS uses a video disc display of the map information as a background. The following terrain parameters are used by the BBS model: (1) Vegetation/Urban Type, (2) Road/Bridge Type, (3) Drainage Type, and (4) Elevation Data.

A land-cover classification was performed on uncorrected, georeferenced Landsat TM satellite data for the entire BBS study area. Traditional methods, commonly used at WES, for alleviating the significant problems caused by the topography, were applied to the classified image to derive land cover for the BBS database. For this study, a classification of an uncorrected subset of the georeferenced BBS area imagery was performed. Techniques developed for this research were applied to the same subset of data to remove or reduce the topographic effect, utilizing two different levels or resolutions of digital elevation model (DEM) data and illumination geometry considerations. A land-cover classification was performed on the resulting topographically corrected imagery for comparison of the results with the classification of the uncorrected data.

LAND-COVER CLASSIFICATION IN HIGH RELIEF AREAS

Data gathered by satellite-based digital scanners, such as Landsat MSS and TM and SPOT systems, contain two different types of information: illumination and surface material reflectance (Pouch and Campagna, 1990). The brightness seen by a sensor is the product of the incident illumination, which is dependent on the topographic slope and aspect in relationship to the sun, and the spectrum of the ground cover. The topographic effect poses several problems in computer-assisted analysis of digital remote sensing data, especially for automated land-cover classification and image segmentation (Civco, 1989). The topographic effect generally results in darker slopes facing away from the sun and brighter sun-facing slopes. In terms of supervised classification problems, in seasons of low sun angles for example, pixels from northerly facing deciduous forested slopes exhibit reflectances lower than the overall true reflectance for this cover type and are often misclassified as a wetland, or even a water, category. Also, pixels from southerly facing deciduous forested slopes exhibit reflectances higher than the mean reflectance for the class and are often falsely assigned to a non-forest category, such as fallow pastures or bare ground. Further, because of the exaggerated variance introduced by the topographic effect, which may be much greater than the variance due to the spectral response, unsupervised classification tends to produce an excessive number of spectral clusters compared to the number of informational classes. Similarly, image segmentation of scenes with a substantial topographic effect tends to produce overly partitioned images (Civco, 1989).

Some techniques which have been used to address this prob-

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lem previously at WES and other remote sensing/image processing facilities have included (1) using digital elevation data and geometrical considerations to remove the topographic effect; (2) using band ratioing or normalization to remove the topographic effect based on the idea that all wavelengths have a tendency to be affected similarly by relief; (3) using vegetation and other indices that are linear combinations of the original bands, hopefully with reduced or eliminated topographic effect; and (4) using simple post-classification raster editing of the high relief areas. Algorithms for applying the first technique are widely available. However, digital elevation data of sufficient quality are difficult to acquire for some areas of interest. Also, results from the application of these algorithms have been mixed at best. The second technique has been used with some limited success at WES. Data processing consisted of band ratios, density slicing, unsupervised statistic collection, and minimum distance classifications on two TM scenes and seven SPOT multispectral images. These techniques proved to be very time and memory intensive for the limited advantages attained. Also, the resulting dataset does not lend itself to the commonly used classification algorithms which are based on statistically multivariate, normally distributed data within a class. The third technique has not been widely used, but does show some promise. The resulting indices have the same type of statistical distribution as the original bands because they are linear combinations of the original bands. They also often provide specific physical interpretation as well as the potential for reduced topographic effect. Probably the most prevalent method used at WES for alleviating the problems caused by the topographic effect has been raster editing of the classified file resulting from an unsupervised classification. The results from this method have been quite successful, though time consuming and tedious. The use of any of these techniques will extend processing time, thus somewhat reducing the cost effectiveness of deriving information from satellite remote sensing data.

Much of the Korean BBS study area contains high relief areas subject to the problems described above. A significant amount of differential illumination due to the topographic effect is shown in Plate 1, an IR composite of the study area. The figure does not adequately represent the topographic effect apparent in the image when displayed on a high resolution image display device. The raw data, from which the images were generated, had been georeferenced to 50 m to reduce disk space requirements, improve the efficiency of image processing, and allow for the comparison of the reduction in topographic effect afforded by the application of the techniques discussed in this report. A reduction in the resolution of TM data from the initial 30 m (pixel size 28.5 m) to 50 m should not significantly impact the quality of the resulting land-cover classification required for the 100-m BBS combat model. A cubic convolution georeference procedure was applied to the TM data in this study prior to the classification process. Attempts to alleviate the topographic effect through the use of DEM data and illumination geometry required that the TM data be transformed to the DEM projection.

After the data were reformatted and georeferenced to a 50-m cell size, the ELAS unsupervised clustering algorithm, modules NVAR and TMTR, were used on four bands (1,3,4,5) of the georeferenced Korean TM imagery. Forty-two spectral classes were generated for the entire BBS area database. Thirty-seven spectral classes were generated for the detailed study area shown in Plate 1. Many of the classes generated by the clustering process were differential illumination based as opposed to representing true spectral differences.

ALGORITHMS TO REDUCE THE TOPOGRAPHIC EFFECT

Most of the studies cited by Civco (1989) attempted to alleviate the topographic effect by modifying the surface digital

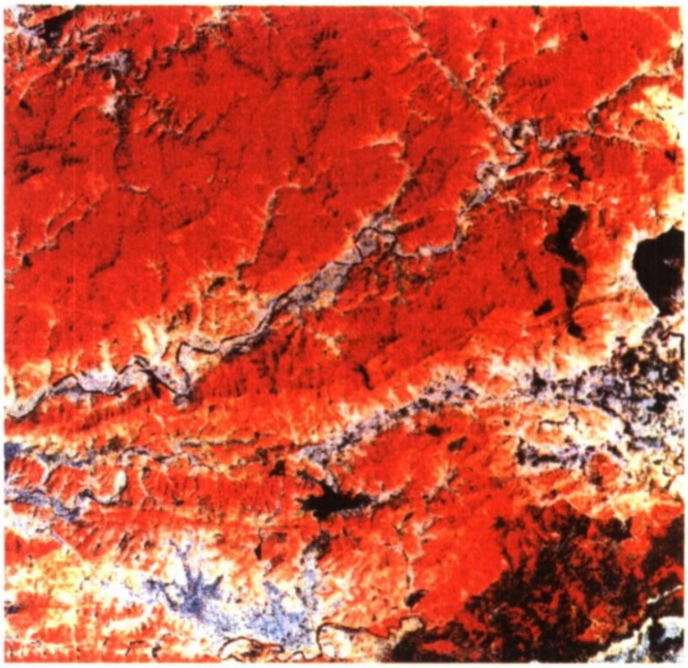


PLATE 1. Infrared composite of L3122-I 1:50,000-scale map area (50-metre resolution).

counts using the cosine of the angle of incidence of the solar beam with a pixel's topographic degree of slope and inclination, as calculated from a registered digital elevation model (DEM). Applications of this technique, assuming Lambertian reflectance, have been ineffective in reducing the topographic effect. However, the cosine of the incidence angle can be used to create an illumination model or shaded relief model from a DEM. The position of the sun, solar zenith angle and azimuth, can be assigned interactively.

Civco (1989) created such an illumination model to be used in alleviating the topographic effect in Landsat TM scenes. *Topographically normalized* TM images were derived through a linear transformation of each of the original TM bands involving the illumination model. These images had reduced variance over the areas that had been affected by the topographic effect. The means and variances of the entire image were essentially retained for all bands. However, the first stage normalization was only partly successful in removing the topographic effect; illumination and shadowing artifacts were not removed completely (Civco, 1989).

A second-stage normalization was then performed by empirically deriving a correction coefficient for each band, based on the results from the first stage and the raw data values for northerly and southerly facing deciduous forested slopes (Civco, 1989). The results from the second-stage normalization were considered highly successful from the standpoint of (1) visual inspection; (2) mean and variance investigations; and (3) a reduction in the number of spectrally separable clusters resulting from an unsupervised clustering technique (Civco, 1989).

Civco (1989) did not use an illumination model which took into account the fact that most natural surfaces are non-Lambertian, having preferred directions of scattering (Justice and Holben, 1979), the diffuse component contribution, the effects of the atmosphere, or the illumination reflected from adjacent slopes. The normalization procedure indirectly accounted for all of these factors except for the latter. Tiellet *et al.* (1982) present several illumination correction equations, some of which attempt to account for all of the above factors except the latter one. Their attempts to apply these equations on Landsat MSS data and airborne MSS data over forested, rugged topography areas in Canada resulted in no significant improvements in classification results. Perhaps if they had applied a normalization procedure similar to Civco (1989) utilizing illumination models derived from their more sophisticated equations, they would have had more success.

Justice and Holben (1979) examined Lambertian and non-Lambertian models for simulating the topographic effect on remotely sensed data. They utilized correlation analysis for the two different models applied to hand-held radiometric data of a uniform sand surface oriented at a complete range of slope angles and aspects collected under several solar elevations. The non-Lambertian model, involving the Minneart constant (K), proved to have higher correlations in all cases than did the Lambertian (Justice and Holben, 1979). The so-called "constant," K, which was known to vary with phase angle (i.e., the angle between the sensor and the light source), land-cover type, and wavelength, was shown by Justice and Holben (1979) to also vary with slope and aspect within a single land-cover type. Thus, the non-Lambertian equation using the Minnaert constant is not satisfactory for alleviating the topographic effect. In analyzing their data for red wavelengths presented in Justice and Holben (1979) and plots of their data for both red and near-IR wavelengths shown in Holben and Justice (1980), an interesting possibility for an empirical non-Lambertian model presents itself where the slope angle would be multiplied by a constant before insertion into the cosine of the incidence angle equation. This constant would be slightly less than 0.5 for the data presented.

APPLICATION OF TOPOGRAPHIC EFFECT REMOVAL ALGORITHMS

Two different resolutions (levels) of DEMs were used. A two-stage technique, similar to that employed by Civco (1989), was applied to perform topographic normalization. First, illumination models were created. Then, linear transformations of each of the four TM bands (1,3,4,5) to be used in a land-cover classification were performed to derive topographically normalized images.

The DEMs mentioned in the previous paragraph are the military versions of DEMs. Level I data are widely available in arc-second format. Each cell represents three seconds of latitude and three seconds of longitude. This corresponds to a resolution of about 90m. Level II data are available for only limited areas. The data are in a UTM projection and have a resolution of 12.5m, roughly eight times the resolution of Level I data.

Because the Level I data were in arc-second format, a georeference procedure was necessary to overlay the elevation data on the georeferenced, UTM projection, TM data. No module was available in the standard multi-byte ELAS package to perform this georeferencing from an arc-second data file to a UTM projection in a more-or-less automatic fashion. Two modules were modified to allow up to third-order mapping equations and cubic convolution resampling. Quadratic, second-order equations were deemed adequate, based on an RMS error of about 3 m, and were used to perform the georeferencing. The cubic convolution resampling was necessary in this case because an approximately 90-m resolution elevation model was being georeferenced to a 50-m resolution. The nearest neighbor technique would have resulted in slopes for every other pixel of zero, while the bilinear technique would have flattened the slopes significantly. Of course, it should be recognized that the georeferenced Level I data did not really have a resolution of 50 m, but the data could be used to generate slopes, aspects, and illumination models at that resolution. The resulting generated datasets would have a reduced accuracy when compared to those derived from an actual 50-m resolution elevation model if one were to exist.

The Level II data were already in the UTM format at a resolution of 12.5m. However, reformatting the data and rotating by 90 degrees were required because each scan line represented a north to south set of elevations, rather than west to east. Slopes, aspects, and illumination models were generated at the 12.5-m resolution for the Level II data instead of degrading the data to 50-m resolution prior to these operations. Because the Level II data, at full resolution, required 16 times as much disk space and computation as it would have at 50 m, and Level II data were not available for the entire BBS area, a subset of the area was chosen for study. The area chosen contained the portion of the BBS area with the most severe relief and would thus be expected to exhibit significant topographic effect problems.

Removal or alleviation of the topographic effect utilizing a method similar to Civco (1989) required the creation of illumination models from the DEMs. New ELAS modules, ILLU and ILL2, were created to generate the necessary data sets. Module ILLU is very flexible in that the user can (1) choose the kernels for the derivation of x and y direction derivatives; (2) output the slope and/or aspect only; (3) output a variety of illumination models (Lambertian, non-Lambertian, modified Lambertian, and the cosine and sine parts of the cosine incidence angle equation); and (4) output topographically corrected images where the raw image data are divided by the chosen illumination model. When creating an illumination model, the user is prompted for the solar elevation angle and azimuth, and, optionally, a Minnaert constant, K, and/or a multiplier for the slope angle part of the cosine incidence angle equation.

Illumination models for the two levels of DEM were created using the modified Lambertian algorithm with a slope multiplier of 0.5. It was obvious when viewing the Level I model that the model was planimetrically correct but was offset in both the x and y directions compared to the TM data. The column and row offsets were determined and the Level I model was adjusted accordingly. Misalignment may have affected the results from the Level 1 data.

It had been noted, in previous attempts to use the method outlined in Civco (1989) to remove the topographic effect from TM data involving high relief, forested terrain, that the given second-stage normalization correction coefficients were not generally applicable and would have to be determined on a scene by scene basis. Preliminary application of the Civco (1989) algorithms to the BBS study area images confirmed the above findings. Given these results and the fact that most land covers do not generally exhibit Lambertian reflectance characteristics, an attempt was made to derive band-specific, empirical, non-Lambertian illumination models. Module ILLU was used to generate two separate illumination channels: the cosine and sine parts of the cosine incidence angle equation. Then linear regression analysis was performed with the four TM bands on the two illumination channels. Correlations from the models derived from the Level II data were remarkably large (near 0.5), while the correlations from the Level I models were equally between those obtained from the simple illumination models and those obtained from the Level II data. The correlations obtained suggest that the Level II models explained somewhat greater than 20 percent of the total variation in the data, while the Level I models explained a little over 10 percent. It was apparent that the band 4 illumination response was significantly different from that of the other bands.

The band-specific illumination models were then used in the first-stage topographic normalization equation from Civco (1989). It was apparent on viewing the resulting normalized bands that the topographic effect had been nearly completely removed, but a significant amount of the variation due to different land-cover types was also removed, especially in band 4. The reason for the removal of land-cover-based spectral variation was probably correlation between the heavily forested areas and the high relief areas. This correlation is apparent in the IR composite shown in Plate 1 where the forested areas are bright red, indicating the highest values in the scene in the near-IR band 4.

The above algorithm removed too much spectral variation due to land-cover differences; therefore, a different technique was applied. The topographic effect should be correlated to a certain extent in all wavelengths. A principal components transformation was applied to the four TM bands. Only the first principal component (PC), which provides the maximum variation possible from a single linear combination of the original bands and often represents the overall brightness of the image, was retained for further study. Linear regressions were then performed with the first PC as the dependent variable and the cosine and sine parts of the cosine incidence angle equation as independent variables.

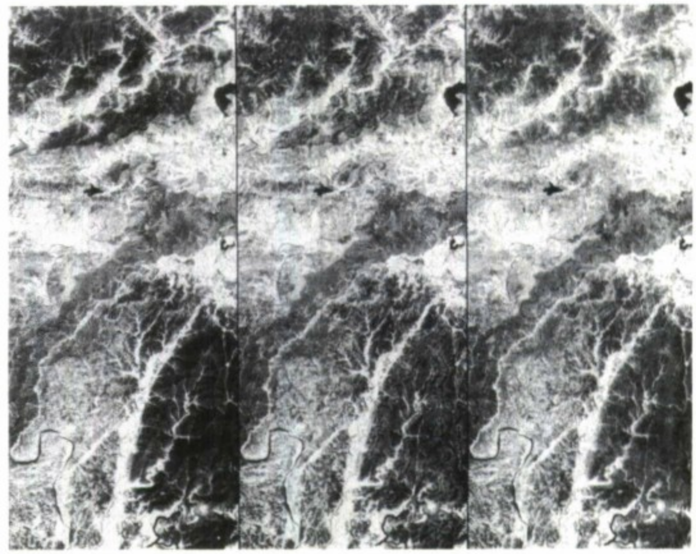
The two resulting PC-based illumination models from the DEM levels were then regressed with the four TM bands as dependent variables for input into the first-stage normalization algorithm. It had been noted in previous research by the authors that performing this regression for each band to build band specific illumination models maximized the removal of the topographic effect without requiring the use of the second-stage algorithm. Correlations between the TM bands and the illumination models were quite large and very similar to those obtained from the algorithm discussed previously for bands 1, 3, and 5. The correlation was however near zero for band 4 with the Level II derived model and was negative for band 4 with the Level I derived model.

It was obvious that the near-IR band 4 presented unique problems for the removal of the topographic effect from the study area image. Two possibilities for proceeding were considered. One possibility was to use the original TM band 4 data in subsequent processing. Another possibility was to utilize an illumination model that did not involve regression. The latter possibility was pursued. The original non-Lambertian illumination model derived from the Level I data using a slope multiplier of 0.5 had shown considerably higher correlation with the band 4 data than the Lambertian model. Thus, the non-Lambertian models derived from the two DEMs were used to perform the topographic normalization of band 4. Figures 1, 2, and 3 show the original images for bands 3, 4, and 5, respectively, along with the corrected images derived from both Level I and Level II DEM data. The Level II corrected data have obviously had much of the topographic effect removed. The Level I corrected data appear to have had some of the topographic effect removed. In some areas the Level I corrected data seems to show added variability. Band 4 results show less topographic effect removal than for the other bands.

An unsupervised classification was performed on the Level II corrected data. The clustering process resulted in fewer separable classes (23) as expected, when compared to the clustering results from the uncorrected detailed study area. The resulting classification showed very few of the problems associated with the classification derived from the uncorrected data.

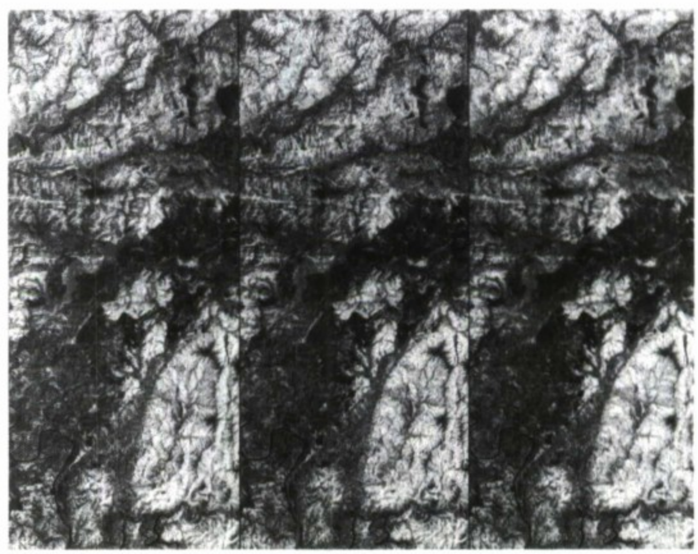
SUMMARY

This paper discusses and documents results obtained from applying DEM data, illumination geometry, and topographic normalization to correct for the topographic effect in Landsat TM data for a high relief area in Korea which includes the Demilitarized Zone (DMZ). Two different resolutions (levels) of DEM were used. The results from the two different levels were compared with each other. The land-cover classification resulting from the Level II corrected data set was then compared with a classification performed on the uncorrected data.



(a) (b) (c)

FIG. 1. TM band 3 uncorrected data (a), corrected using DEM level I (b), and corrected using DEM level II.

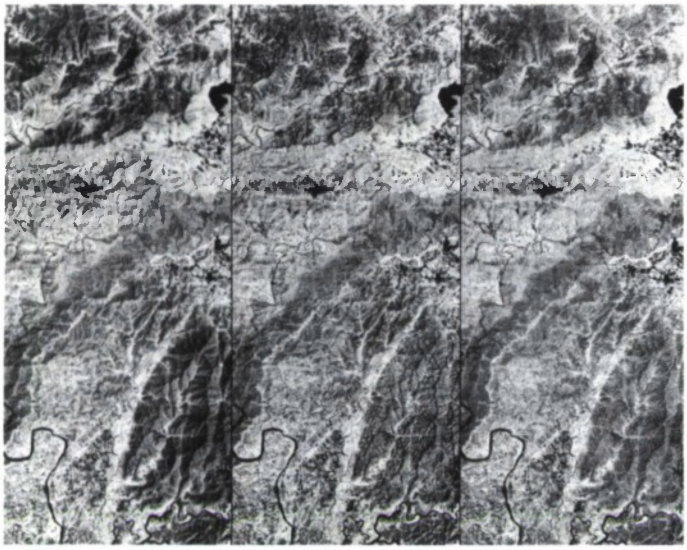


(a) (b) (c)

FIG. 2. TM band 4 uncorrected data (a), corrected using DEM level I (b), and corrected using DEM level II (c)

A two-stage technique was applied to perform the topographic normalization similar to that employed by Civco (1989). First, illumination models were created. Then linear transformations of each of the four TM bands (1,3,4,5) to be used in a land-cover classification were performed to derive topographically normalized images.

Several different methods of deriving illumination models were attempted. Most of the discussion which follows relates to the high resolution Level II DEM (12.5m) data. The method of Civco (1989) appeared to be inadequate for the area involved in this study. Linear regressions with the raw data bands as the dependent variables and the two parts (cosine and sine-aspect) of the equation for the cosine of the incidence angle as independent variables resulted in illumination models for each band. When these models were applied in the normalization proce-



(a) (b) (c)

FIG. 3. TM band 5 uncorrected data (a), corrected using DEM level I (b), and corrected using DEM level II (c).

dure, not only was the topographic effect nearly eliminated, but a considerable amount of the spectral variation due to different types of land cover was removed, a deleterious effect. This was especially true for the near infrared (band 4) data. The reason for the removal of land-cover-based spectral variation was most likely the correlation between the heavily forested areas of the scene with the high slope areas, probably a ubiquitous situation. Because the topographic effect should be correlated to a certain extent in all wavelengths, a principal components transformation was applied to the four TM bands. The first principal component was highly correlated with bands 1, 3, and 5. A linear regression with the first principal component as the dependent variable and the same independent variables as above resulted in an illumination model significantly correlated with bands 1, 3, and 5. The topographic effect was nearly eliminated in these bands utilizing the illumination model in the normalization procedure. Band 4 was normalized with an illumination model consisting of a modified version of the equation for the cosine of the incidence angle. This model did not involve regression with the raw data, but was significantly correlated with band 4. The topographic effect in band 4 was significantly reduced, although not as much as in the other bands. The same techniques were applied utilizing the lower resolution Level I DEM (90 m) data resulting in considerably less removal of the topographic effect.

CONCLUSIONS

In conclusion, the techniques applied for removing the topographic effect were highly successful in providing improved capability for visual interpretation and for land-cover classification utilizing the high resolution Level II DEM data. Some improvement was obtained employing the lower resolution Level I data, although results were significantly less satisfying than for the high resolution data. The near-IR band required special consideration and a very different technique. A full comparison of the accuracies of land-cover classifications obtained from the methods outlined in this paper should be performed to assess the degree of improvement.

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