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Article

A Semi-empirical Topographic Correction Method based on the Relation between Slope-aspect and Mean Radiance.

Kiyoshi Takejima*1, Hiroyuki Sakaue*2, YunQing Lee*3
Satomi Kakuta*4, Yoshio Awaya*5 and Hiromichi Fukui*6

ABSTRACT

This study describes the process and theory behind the development of a topographic correction method for practical application to mountainous forest areas. The algorithm for the method is based on the relation between the slope-aspect and the mean radiance of each slope. First we developed a hypothesis about this relationship by visualizing rugged terrain as an aggregation of cones (representing mountains). From this, it can be observed that the sun facing slope is the brightest, gradually loosing its brightness as the slope-aspect moves to the side facing away from the sun. Then, we verified the hypothesis by applying actual data - IKONOS data taken from a test site in Minami Gifu, and found that the method was able to compensate the topographic effect. Then we checked the method using another sensor, other data sources - Aster, LANDSAT and orthophotos, and another test site. Distinct features of the method are its simplicity and general applicability. We can compensate the topographic effect of a variety of geo-coded data sources (i.e. Aster, LANDAT TM, IKONOS, orthophotos etc) using only digital elevation models. In addition, consistent results can be obtained no matter who operates the method, because the directional and vegetation parameters needed are almost given. With these 2 parameters the compensation will be automatically done from the images.

Keywords: topographic effect, topographic correction, IKONOS, airphoto, slope-aspect

INTRODUCTION

Remote sensing data collected on rugged terrain is influenced by topographic effects (see EKSWARD, 1996; COLBY, 1991; VINCINI and FRAZZI, 2003). Results of supervised classification, cluster analysis, and segmentation are also affected by geographical features (CIVCO 1989). Remote sensing data are often used to make land-use and vegetation maps. Results may not be accurate if the original data has been strongly influenced by significant geographic features (MEYER *et al.*, 1993; GU and GILLESPIE, 1998). Furthermore, time-series analysis using data obtained over a number of seasons may be much more affected by geographic features, in comparison with analysis from data taken in a single season, since the light intensity and shades may vary between the different seasons (HILLS and STURN, 1991). Thus, in order to ensure accurate evaluation of data, it is important to eliminate topographic effects from remote sensing data collected from rugged terrain (CONSE *et al.*, 1993a; PROY *et al.*, 1989). A number of topographic correction methods have been developed and evaluated. The practical use of remote sensing techniques is very important for Japanese forests in particular, which are located predominantly in mountainous area.

Much discussion has surrounded the recent signing of the Kyoto Protocol which came into effect in 17 February 2005. Article 3.3 states that those countries listed in Annex I, including Japan, shall use afforestation, reforestation, deforestation (ARD) activities as a part of measurements in net changes in greenhouse gas. In order to apply, each country

*1 Gifu Acacemy of Forest Science and Culture, Sodai 88 Mino, Gifu 501-3714 Japan
*2 Falcon Co., Ltd., Sakae 2-5-1, Naka-ku Nagoya, Aichi 460-0008 Japan
*3 Japan Space Imaging Corporation, Yaesu 2-8-1 Chuo-ku, Tokyo 104-0028 Japan
*4 Asia Air Survey Co., Ltd., Shinjuku-4-2-18 Shinjuku-ku, Tokyo 160-0022 Japan
*5 Forestry and Forest Products Research Institute, 1 Matsunosato Tsukuba, Ibaraki 305-8687 Japan
*6 Keio University, 5322 Endo Fujisawa, Kanagawa 252-8520 Japan

must specify their ARD activities in the commitment period from 2008 to 2012 in a transparent and verifiable manner. In light of this necessity, the expectations for remote sensing technology to define ARD activities are quite high (ROSENQVIST *et al.*, 2003; YAMAGATA *et al.*, 2002). However, as noted, Japanese forests are predominantly located in mountainous regions, thus it is not easy to use remote sensing for the clarification of ARD activities. Therefore the removal of topographic effects from the data prior to its use in clarifying ARD activities is very important.

Effective methods for topographical effect removal should preferably satisfy the following three conditions:

1. The same result should be obtainable, no matter who does the topographic correction,
2. The process should be able to be run through the algorithm automatically due to the large amount of data needed to target forest cover data from all over Japan, and,
3. Data from a wide range of sensors should be able to be adaptable.

In the light of the fact that conventional methods have been unable to satisfy these three conditions, in this paper we aim to propose a new topographic correction method and argue its validity.

OVERVIEW OF CONVENTIONAL TOPOGRAPHIC CORRECTIONS

A number of topographic correction methods have been developed so far, and a large body of research evaluating their effectiveness has been undertaken (see TEILLET *et al.*, 1982; MEYER *et al.*, 1993; RIAÑO *et al.*, 2003). These methods can be classified into two types. One method for correcting topographic effects uses band ratio and statistical information. The other method uses digital elevation models, which can be divided into two categories including non-empirical and empirical methods. Non-empirical methods use the same formula mechanically applying it to every image. However, empirical methods require scene independent parameters to be determined before applying the algorithm to the data.

Band Ratio and Statistical Transformation Approaches

Band ratios have long been used as a method to compensate topographic effect (LYON, 1975; JENSEN, 1995; HOLBEN and JUSTICE, 1981), and a number of ratios and indexes have been proposed (TUCKER, 1980). For example, the ratio Band5/Band4 is used to evaluate vegetation health while compensating for topographic effect (ROCK *et al.*, 1986; ROCK and VOGELMAN, 1986; VOGELMAN, 1988). Another method employs principle component analysis to remove topographic effect (CONSE *et al.*, 1993b). It is true that if one applies these methods to topography images the topographic effect seems to disappear. However the composite images are pseudo-images, in that the visual details of the landcovers' properties are lost (COLBY, 1991). Furthermore, for single sensor band images, like those using panchromatic data, it is not possible to apply this method

DEM Application Approach

Table 1 shows the list of DEM application approaches. The DEM application approach is commonly used as a topographic correction method (GU and GILLESPIE, 1998; SMITH *et al.*, 1980; TEILLET *et al.*, 1982; COLBY, 1993; MEYER *et al.*, 1993; VINCINI and FRAZZI, 2002). This approach consists of empirical and non-empirical approaches.

Non empirical approaches remove topographic effect by simply applying the same formula to all the data. No pixel sampling is needed to determine the parameters of the formula. If these methods are to be effective for any kind of sensor and topography, they would need to satisfy the three conditions listed previously. The most popular non empirical approach is the cosine method, which assumes that for all light wavelengths the bidirectional reflectance factor is constant and corrects observed radiance according to changes in direct irradiance. However, results usually underestimate the reflection of sun facing slopes and over estimates the reflectance of slopes facing away from the sun (GU and GILLESPIE, 1998). Further more, this method has not been proven to be effective if the incident angle is high (SMITH *et al.*, 1980). Thus the main limitation of this method is that it is effective only in restricted conditions (SMITH *et al.*, 1980; TILLET *et al.*, 1982). Some have pointed out that problems in the method arise from the fact that the actual scattering of properties in natural surfaces are not easily modeled and differ, to varying extents, from Lambertian assumptions (COULSON, 1966; EGDERT and ULABY, 1972). However, others have pointed out that Lambert's assumptions are still possible if aerial conditions are taken into account (PROY *et al.*, 1989). Due to these insufficiencies, this method is not able to be used as conclusively and results are not generalizable.

Another DEM method, the Sun Canopy Sensor (SCS) method was developed for general use in forest areas (GU and GILLESPIE, 1998). This method employs not only the relation between the slope and sun but also the relation between the canopy surface and sun. Research evaluating this method's results and comparing it with other methods have found it to be effective (VINCINI and FRAZZI, 2003; GU and GILLESPIE, 1998). However, each wavelength of light gives a different representation of topographic effect (TEILLET *et al.*, 1982; DEERING *et al.*, 1994; SHOSHARY, 1993; VINCINI and FRAZZI, 2003). That is, the topographic effect is band independent. While SCS can apply the same formula into different bands, the method is not suitable for use in actual field situations. While the cosine and the SCS methods satisfy the first of the 3 conditions mentioned previously, the second and third conditions are not

Table 1 Conventional topographic correction methods.

Non-empirical		Empirical	
Lambertian method	$L_n = L\dfrac{\cos\theta}{\cos i}$	Minnaert method	$L_{\lambda_n} = L_\lambda \dfrac{\cos\theta}{\cos^k i \cos^k e}$
SCS method	$L_n = L\dfrac{\cos\theta\cos\alpha}{\cos i}$	c-cosine method	$L_{\lambda_n} = L_\lambda \dfrac{\cos\theta + c_\lambda}{\cos i + c_\lambda}$
		b-cosine method	$L_{\lambda_n} = L_\lambda \exp\{b_2\lambda(\cos\theta - \cos i)\}$ $L_{\lambda_n} = L_\lambda + (b_1 + x)(\cos\theta - 1)$

L_n	:topographically normalized radiance	L_{λ_n}	:topographically normalized radiance in band (λ)
L	:slope − observed radiance	L_λ	:slope − observed radiance in band (λ)
i	:incident angle with respect to surface normal	k_λ	:minnaert constant in band (λ) k_λ are derived from the following regression line $\log(L_\lambda \cos e) = \log L_\lambda + k_\lambda + k_\lambda \log(\cos i \cos e)$
θ	:sun zenith angle = incident angle for horizontal surface	c_λ	:c-correction factor in band (λ), which are calculated as $a_{1\lambda}/b_{1\lambda}$ $a_{1\lambda}$, $b_{1\lambda}$ are derived from the following regression line $L_\lambda = a_{1\lambda} + b_{1\lambda}\cos i$ $a_{1\lambda}$:interception of the regression line $b_{1\lambda}$:slope of the regression line
α	:slope angle	$b_{2\lambda}$	:b-correction factor in band (λ), which are derived from the following regression line $\ln L_\lambda = a_{2\lambda} + b_{2\lambda}\cos i$ $a_{2\lambda}$:interception of the regression line $b_{2\lambda}$:slope of the regression line

met consistently. That is, these methods are effective on certain scenes and areas only.

Empirical approaches rely on data sampling to extract the parameters. These methods are scene independent. The most common method is the Minneart method which was initially developed to analyze the roughness of lunar terrain. This method was first utilized for LANDSAT Multispectral Scanning Sensor data (Smith *et al.*, 1980), then modified (Colby, 1991; Ekstrad, 1996). One of the parameters, called the Minneart constant k, represents the roughness of terrain surfaces (Smith *et al.*, 1980) and describes the bidirectional reflection distribution function (BRDF) of the surfaces (Colby, 1991). When k is equal to 1, this formula is the same as the cosine method. The k value differs according to each band. If surface topography differs, then k differs also (Richter, 1997). A number of researchers have pointed out the effectiveness of the method (Colby, 1991; Meyer *et al.*, 1993), however, in practical application, the problem lies with the derivation of k. The k is derived from a regression formula using sample data. If the surface is homogeneous, k is derived unambiguously. However if the actual data consists of non homogeneous surfaces, the operator employing the method needs to consciously select pixels from the data which may produce results that differ between operators. A c-cosine method (Teillet *et al.*, 1982), whose results have been evaluated by some as superior to the Minneart method (Meyer *et al.*, 1993, Riaño, 2003), has also been developed. Furthermore, a b-cosine method (Vincini, 2003) has been developed which is made up of two alternative formulas. One formula is for application to the anisotropic reflection behavior band and the other for the isotropic refraction behavior band. The two algorithms are applied to each band and significance levels of each regression are observed. The formula, which has high significance levels, is employed to remove the topographic effect from the band. The procedure for the b-cosine method is somewhat complicated. While these methods have a number of particular advantages and disadvantages, the Minneart, c-cosine and b-cosine methods experience the same problems in practical application of the tools for ARD evaluation as previously stated.

The effect of atmosphere in visible and infrared bands varies (Deering, 1994; Shoshary, 1993) according to the topographic effect on each band (Teillet *et al.*, 1982). If the land cover differs, the reflectance signatures will also differ (Vincini and Frazzi, 2003). As well as this, even if surfaces are relatively homogenous, if the age, species and density vary, differences in BRDF will occur (Gu and Gillespie, 1998). Evaluation of the topographic correction methods available to date reveal that if the procedure is sophisticated, the method is effective in compensating for topographic effect, although detailed information is needed to determine the most suitable parameters. Conversely the use of simple methods tends to result in low quality topographic correction methods.

Topographic correction methods for ARD activity extraction are optimally ones that are both simple and effective. Given the fact that conventional methods have some restrictions regarding sensors, acquisition season, topographic conditions and complexities relating their ease of adaptability, we sought to develop an effective and practical new method.

MATERIALS AND METHODS

Hypothesis and Methodology

First, we set up a hypothesis to develop the algorithm as follows. If one supposes there to be a cone whose surface is covered with a consistent material, when the sun light comes from the south (or north, depending on the hemisphere), the distribution of the brightness of the surface of the cone can be illustrated as appears in Fig.1 (a-1). The direct aerial view of the cone will appear as in Fig.1 (a-2). The brightest slope of the surface is the one which is facing the direction of the sun. The darkest slope is the surface facing away from the direction of the sunlight. The slope gradually loses its brightness moving away from the direction of the sun. The relation between the mean brightness (Y axis) and the slope-aspect (X axis) can be illustrated as in Fig. 1(a-3).

Next, assume that rugged terrain is formed with various sizes of cones (representing mountains) whose surfaces are covered with the same material. Then, if the sun light comes from the south, the distributions of the brightness of each cones surface can be illustrated as in Fig. 1(b-1). The direct aerial view of the cones will appear as in Fig. 1(b-2). We infer that the relation between the brightness and the slope-aspect of cones i.e. mountains will appear as in Fig. 1(b-3). The relation between the slope-aspect and radiance is likely to be consistent with a single cone having a wider range of variance of mean brightness at each slope-aspect. If one can quantify this relation, one can compensate for the difference in the brightness of the cones. Given these suppositions, we made the following hypothesis.

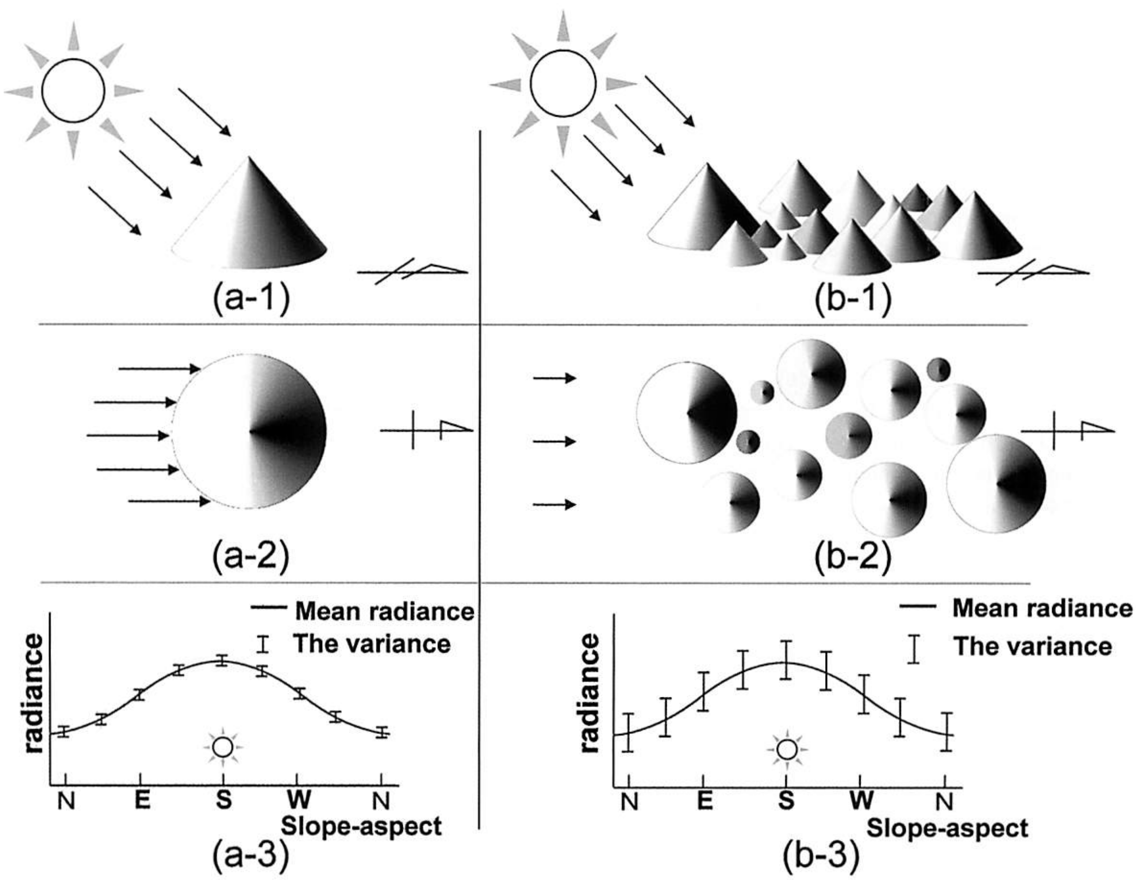


Fig. 1 The relation between radiance and slope-aspect in the simple mountain model

The Hypothesis

If one measure's the radiance of every pixel in a mountainous area using remotely sensed data and calculates the mean radiance of each slope-aspect, there is a quantitative and qualitative relation between the slope-aspect and the mean radiance. That is, the brightest slope-aspect is the slope-aspect which is normal to the direction to the path of sun light, and the radiance will gradually lose its brightness as the slope-aspect move to the opposite side of the brightest slope-aspect.

Methodology

In this paper, we examined actual remotely sensed data to quantify and qualify the relation between the slope-aspect and the mean radiance according to previous hypothesis at a test site in order to develop an algorithm to compensate for topographic effect. We evaluated the validity of the algorithm by applying it practically to data taken from the first test site, then evaluated its effectiveness further by applying it to another sensor, other data sources, and another test site. Finally, we discuss the results in view of the possibility of application of the method to various data sources.

Study Site

Fig. 2(a) shows the location of the first test site. The total area of the site is about 5.5km² and is located in Gifu prefecture, in the center of the Honshu Island in Japan. The site is located at latitude 35° 44' N, longitude 136° 56' E. The elevation varies from 100 to 400 meters. The area is in a warm temperate zone and the trees represented are *Cryptomeria Japonica* and *Chamaecyparis obtusa*. These species cover about 70% of the land area. Most of the stand ages are between 20 and 50 years. The remaining forest is mixed forest with dominant species in the area being *Quercus Serrata, Ilex Pedunculosa* and *Quercus Glauca*. Fig. 2(b) indicates the location of the second test site in Higashi Shirakawa in Gifu prefecture, which has topographic and vegetation conditions differing from that of first test site. The second test site is located at around latitude 35° 35' N and longitude 137° 20' E with the elevation varying from 260 to 1,130 meters. The total

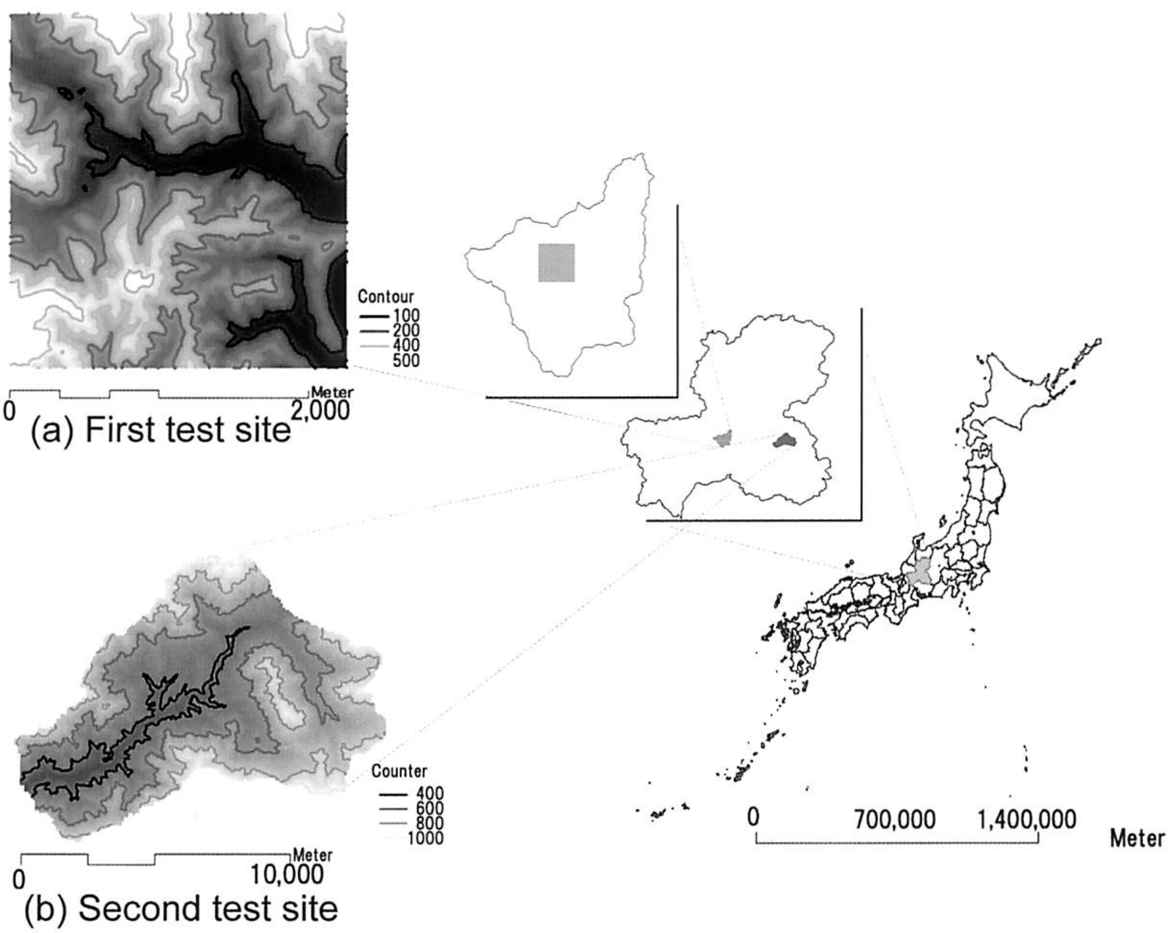


Fig. 2 Location and area of first and second test sites in Gifu

area of the second site is about 100km² and this area is considerably larger than the first one.

Materials

We used IKONOS Multispectral data with 4m spatial resolution, whose positional accuracy is ±3.5m (1σ) for this study. IKONOS Multispectral data is superior to commonly used Landsat Thematic Mapper (TM) data in showing the relation between topographic shadows and mean radiance of the slope, because the spatial resolution is much finer than that of the TM data. Thus, the relation between the slope-aspect and the radiance will be more conspicuous. IKONOS data is suitable for this research also because the rectification accuracy is evaluated at a set of preciseness that does not require attention of the registration between the digital elevation model and remotely sensed data. There seems to be a close relation between the sun elevation angle and the topographic effect, so we used plural season data to see the topographic effect on the IKONOS data. One data set was acquired on September 16 2001 at 10:46. The sun elevation angle was 54.2 degrees and the solar azimuth is 153.32 degrees. The other data set was taken on May 21 2003 at 10:50. The topographic effect was much more conspicuous in the autumn data. The digital number was changed into radiance using the formula from Space Imaging Inc. available on their homepage at http://www.spaceimaging.com /products/ikonos/spectral.html.

The GISMap Terrain digital elevation model from Hokkaido-Chizu Co.Ltd. was used to calculate the slope-aspect. This raster digital elevation model (DEM) was made from a 1/25,000 topographic map, geo-coded, and its spatial resolution was re-sampled into 4m from 10m by bi-linear convolution to adapt to the restrictions of the PCI Geomatica 9.1.7 software. The slope-aspect was calculated from this DEM using the algorithm in the software. The slope-aspect was divided into 16 directions for the convenience of analysis.

RESULTS

In our hypothesis, we assumed that the surfaces of cones were made of the same material. However the surface of an actual mountain is not necessarily made up of the same material, thus the following assumptions were made before analysis could be conducted.

If land cover differs, the characteristics of the spectral response differ. It is natural to think that if species, ages and other details regarding the property of trees differ, the characteristics of the spectral response differ. However, when we examined radiance within the forest, the differences found are extremely trivial compared with the differences between other land cover such as roads, houses, and water. Therefore, we could infer that vegetated land covered by trees and other plants as homogeneous for the purposes of our analysis. To extract the vegetated area from IKONOS images, we used normalized difference vegetation index (NDVI) from Band3 (Red) and Band4 (Near infrared) of each image. The threshold of the index was determined by the visual observation on the image. With this extracted data - including forest, grasses and other vegetated area, we investigated the relation between slope-aspect and mean radiance of each slope-aspect of the IKONOS images. Fig. 3 gives the relationship between slope-aspect and the mean radiance. From the figure we can observe the following:

Observation A: The shape in each curve is convex. Every wavelength had the maximum mean radiance at the same angle of the solar azimuth from the sun when the data was acquired.

Observation B: If the wavelength is longer, the convex shape becomes steeper.

Observation C: If the sun elevation is lower, the convex shape becomes steeper.

From examination of Observation A, we can discuss that the relationship between the slope-aspect and the mean radiance in the data obtained at the test site is the same as that of the hypothesis. That is, we can approximate mountains as cones even if the topographic effect in rugged terrain is very complicated. Observation B shows every wavelength have peculiar topographical influence. This means that if one uses band ratio to compensate the topographic effects, the result is not as good as topographic correction. From this observation, non-empirical topographic correction methods such as cosine and SCS model which does not care the difference of topographic effect in each band cannot be used effectively for topographic correction in mountainous area. Observation C shows that the lower the angle of the solar elevation, the more significant the influence of the geographical feature's shadow is.

The Semi-empirical Topographic Correction

As demonstrated thus far, there was a fixed relation between the slope-aspect and the mean radiance of each slope-aspect in the IKONOS images taken from an actual mountain area. We would like to discuss this relation further. The curve g in the Fig. 3(d) is equivalent to the curve g in Fig. 4(a) which shows the relation between the slope-aspect, radiance and its frequency. From Fig. 4(a) we can observe that the distribution of radiance is similar in each slope-aspect. If the distribution of radiance in each slope-aspect is the same, the difference in radiance from the slope-aspect will disappear. This shows that compensation of topographic effect was successfully achieved on the images. To apply this concept to all the images, we tried to adapt the algorithm, as presented in Fig. 5. The radiance of all slope-aspects are adjusted to the radiance of the highest

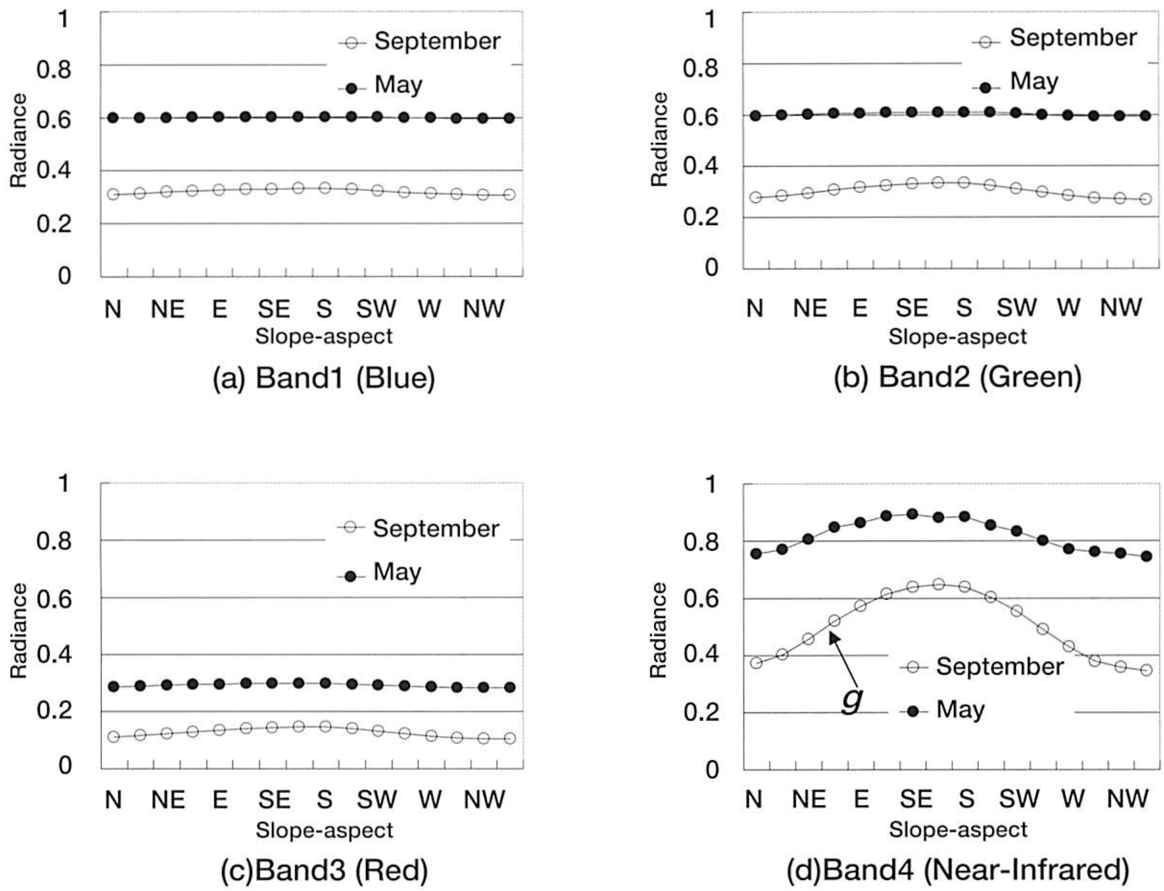
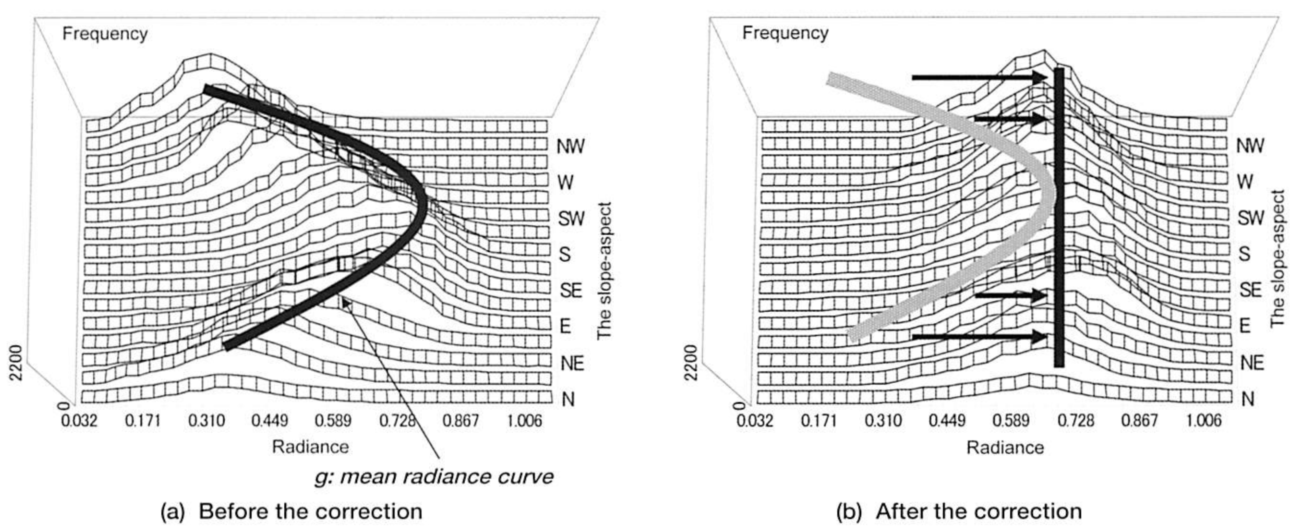


Fig. 3 Relation between the mean radiance and slope-aspect



The brightness of every slope-aspect is adjusted to the brightest slope-aspect by adding the difference of the mean radiance of each slope-aspect.

The relation between radiance, slope and frequency on 16 Sept '05 IKONOS image in band4 (Nir-infrared)

Fig. 4 The fundamental concept of the semi-empirical topographic correction method slope-aspect for convenience. By offsetting the radiance of every slope-aspect, the mean radiance will be the same. When this processing was applied to the data taken from the test site, we obtained the results shown in Fig. 6.

There is a distinct feature in this algorithm which needs discussion. The algorithm contains two parameters. One is NDVI and the other is the number of the class dividing slope-aspect. As for NDVI, we can estimate the approximate threshold value to determine the level of vegetated area beforehand. Since all the pixels are used to determine the amount of offset in each slope-aspect, the little difference in threshold does not affect the corrected images significantly. Furthermore, regarding the class number, if the class is more than 16, there is little difference distinguishable in results obtained. This means that these two parameters can be considered to be a given. That is, if we have DEM we can run the algorithm automatically. Sampling of input values necessary when using the Minneart, b-cosine, c-cosine methods etc. are no longer needed. Furthermore, information such as the sun elevation angle, solar azimuth and other information that are usually necessary are no longer required.

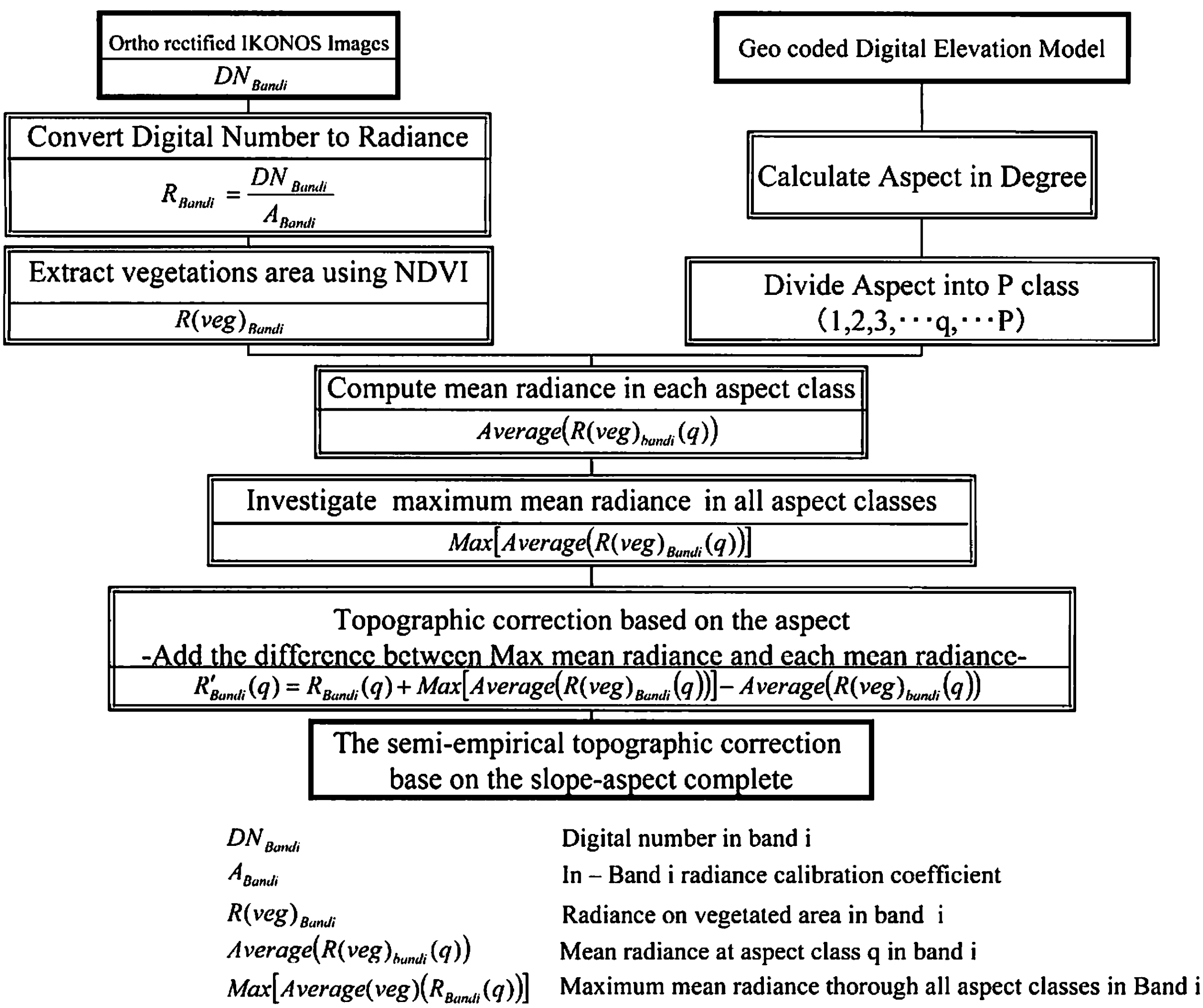
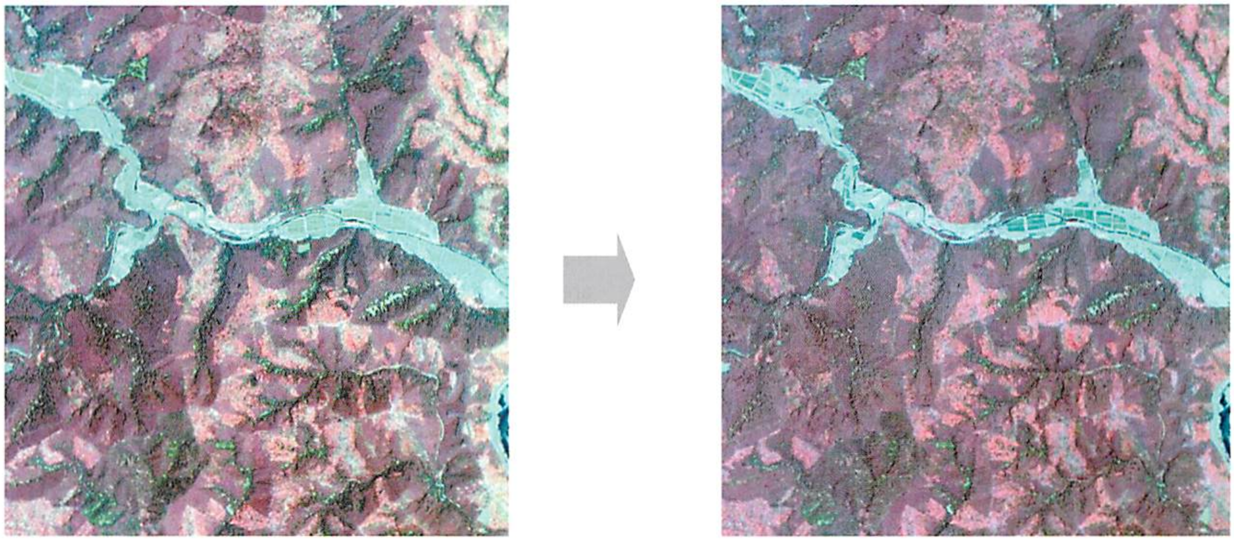
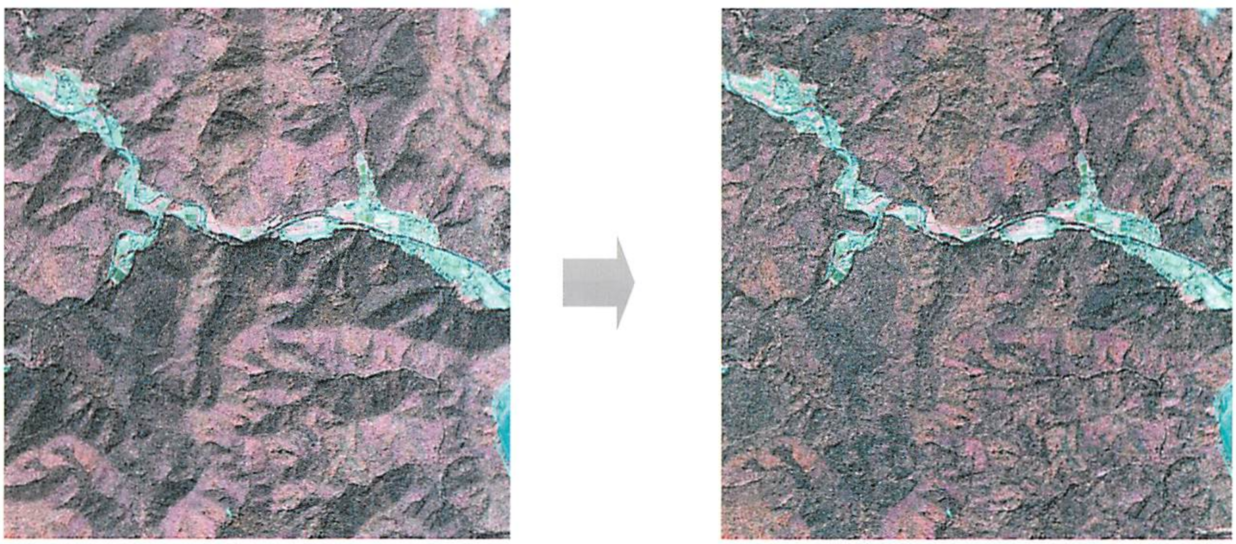


Fig. 5 Flow of the semi-empirical topographic correction method based on the slope-aspect



Mar. 21 '03 IKONOS Multispectral false color images



Sept. 9 '01 IKONOS Multispectral false color images

Fig. 6 Application of the semi-empirical topographic correction method based on slope-aspect to IKONOS Multispectral images

DISCUSSION

The semi-empirical topographic correction method discussed in this paper was devised by an inductive method supplemented by the development of a hypothesis. However, the validity of the algorithm could have held true to the IKONOS images at the first test site only. Therefore we tested the validity of the hypothesis and the effectiveness of the algorithm using another sensor, other data sources and another test site.

Fig. 7 shows the relation between the slope-aspect and the mean radiance of each slope-aspect in the case of three Aster data taken at the second test site. One data set was taken on Sept 19 2003 and its solar angle is 54.1° and the solar azimuth is 160.5°. The second data set was taken on July 10 2000 and its solar elevation angle is 70.7° and the solar azimuth is 131.2° . The last data set was obtained on April 6 2001 under a 58.1° the solar elevation angle and 154.3° solar azimuth. The graph shows that the trend of the relation between the slope-aspect and mean radiance is the same with that of IKONOS images. That is, the shape in each curve is convex, and if the wavelength is longer, the shape of the convex type becomes steeper. Also observed is that when the sun elevation is lower, the shape of the convex becomes steeper. These observations indicate that the topographic effect at the site can be simplified by visualizing the complex mountain shapes into simple cones.

To evaluate the validity of the method, we adapted it into IKONOS Multi-spectral data from the second test site in the same way as in the first test site. Successful results were obtained, thus it is reasonable to assert that the method is generally applicable to correct topographic effect on all mountainous topographic terrain.

As is observed from practical application of the algorithm, it is not necessary to convert the digital number to the radiance. We used the new method to analyze three LANDSAT TM images. The acquisition date of each image is different, and the images were acquired on Oct. 10 1987, Nov. 6 1991 and Nov. 6 2001. The topographic effect in these images is heavy because of a low sun elevation angle - 41° 1 in 1987, 32° 7 in 1991 and 34° 9 in 2000 as shown in Fig. 8. However, the results obtained from application of this method are visually fine. The shadow on rugged terrain seems to disappear significantly. These images were similar to those images gained from the Minneart method. This semi-empirical method needs no sampling. However the results will be similar to images that are found by empirical methods, which are commonly in use.

The National Forest Agency in Japan is now preparing

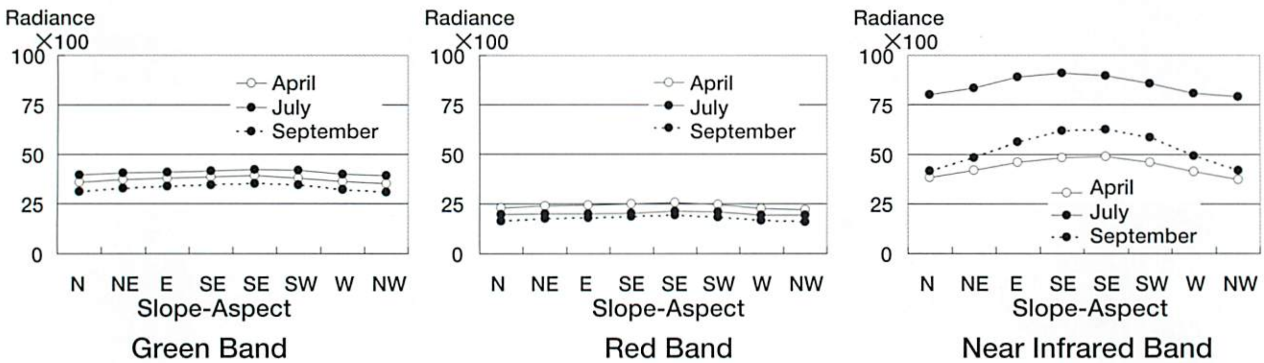


Fig. 7 The relation between radiance and slope-aspect from the ASTER data

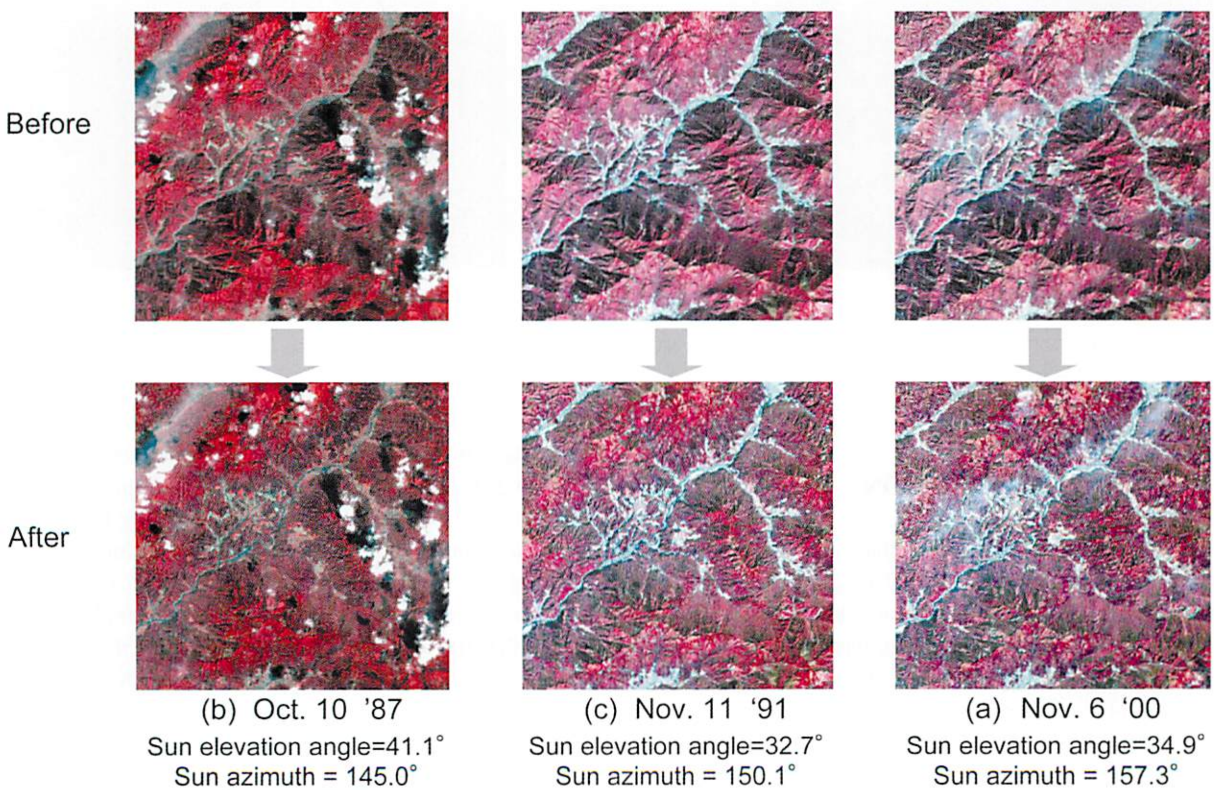


Fig. 8 Application of the semi-empirical topographic correction method based on slope-aspect to Landsat TM images

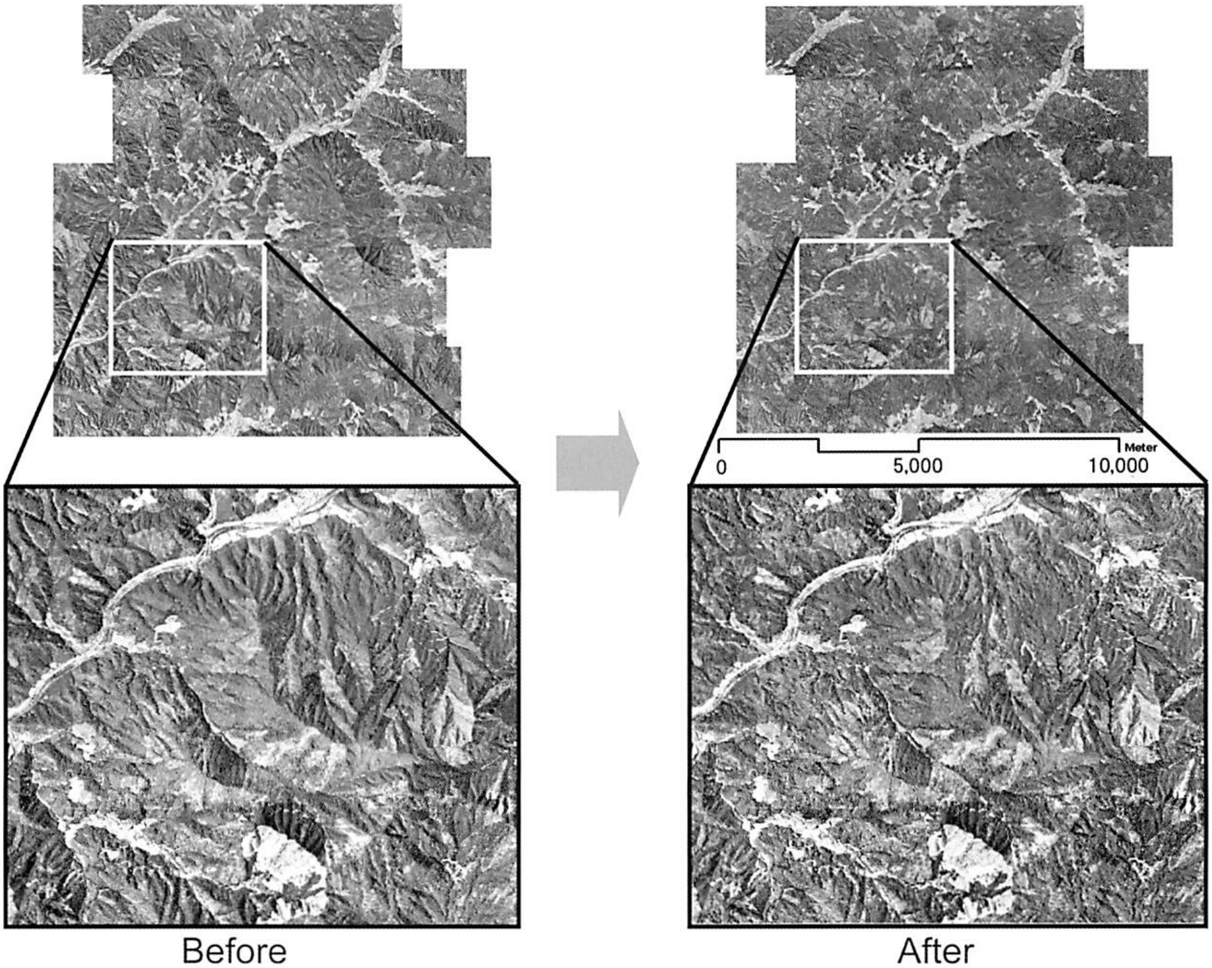


Fig. 9 Application of the semi-empirical topographic correction method based on slope-aspect to mosaiced airphotos

digital mosaic orthophotos to cover the whole area of the country. We adopted this semi-empirical approach to orthophotos in mosaic, which were made up of 10 to 20 orthophotos. There was no information about the date, time and other useful information regarding the acquisition of the orthophotos. When we applied this method to the orthophotos using vegetation areas which were extracted by the IKONOS Multispectral image, the results obtained were shown in Fig. 9. Most of the shadow created by topographic condition were somewhat diminished. It seems that if the acquisition date and time is roughly the same this method will adequately compensate the topographic effect from orthophotos in mosaic.

CONCLUSION

There are two advantages of this method compared with conventional methods. The first one is the simplicity of the procedure in application. Only two parameters - the information of vegetation area and the number of slope-aspects divided into 360 degrees are required. This method provides these two parameters quite simply which gives it significant advantages over using conventional methods which need sampling to determine the parameters. This means that consistent results can be obtained no matter who conducts the analysis, at the same time working flexibly to compensate the topographic effect of the band and the scene independently. Moreover this method does not need atmospheric correction and conversion from digital number of pixels to radiance while conventional methods need these procedures to be conducted before topographic correction can be applied. The second outstanding merit of this method is that it can be applied to many data sources while some conventional methods have some limitations according to the data source. We can use this method even for single band data like panchromatic or monochrome airphotos to compensate the topographic effects.

Despite these advantages, this method has the following limitations. First, this method is only applicable for forest areas in rugged terrain. Non forested areas are not able to be used to adjust the topographic effect. The second is that the pixel value loses its physical information after application. The third is that shadows on ridges of the mountain, deep valleys, very steep slopes, vertical cliffs sometimes cause over or under adjustment. This may be due to the variance with the hypothesis between slope-aspect and mean radiance. The last consideration that needs to be taken into account is that, if particular species are clustered on a certain slope-aspect, the relation between slope-aspects and mean radiance in whole images may be distorted, resulting in the method not working well for these types of vegetation. However, it is possible to cancel the effect in order to adapt the algorithm for use in larger area in such a case.

This semi-empirical topographic correction method has significant advantages and despite a number of disadvantages, the simplicity, effectiveness and versatility of its practical use may over ride the few disadvantages. In addition, this method may be able to compensate the topographic effect of large areas, including that of the whole of Japan, almost automatically, using data from a number of data sources. We would, in conclusion, like to argue that the algorithm that we have developed satisfies the three conditions discussed in the Introduction of this paper and we look forward to evaluation of its application in practical settings in both Japan and overseas.

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