Article

Topographic Correction Effect on Sugi (*Cryptomeria japonica* D.Don) Stand Volume Estimation using Multi Temporal Landsat TM and ASTER Satellite Images in Mountainous Tsugawa Region, Niigata Prefecture

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ABSTRACT

Five images of Landsat Thematic Mapper (TM) and one image of ASTER data at different years were taken to determine the topographic correction effects in the mountainous area in Tsugawa region, Niigata. An *automatic scattergram-controlled regression* approach was applied for radiometric normalization correction using sequence images obtained using the Landsat TM. The forest was classified as either a deciduous, low-middle volume sugi or high volume sugi forest based on its characteristics and volume by separability analysis. We examined four topographic correction methods to reduce the slope-aspect effect in each forest class compared. In order to elucidate the effect of the applied correction method, we also analyzed the correlation between the digital number and ground measurement. The results showed that the specific forest class type should be considered as input when applying a topographic correction method in satellite images analysis. The *two-stage topographic normalization* proposed by CIVCO (1989) and *statistic-empirical* methods appeared to be the best for statistical analyses but were unsuccessful regarding actual correlation for analysis of sugi stand volume. The results indicated that, the *C-correction* for visible bands and MINNAERT correction methods for infrared band are adequate methods for improving the correlation accuracy between derived digital number and sugi stand volume in the Tsugawa region.

Keywords: topographic correction; Landsat TM/ASTER satellite images; sugi

INTRODUCTION

Covered with many mountains, almost all regions in Japan have a steep mountainous terrain and consequently the slope and aspect cause a different illumination condition for evaluating forest cover and has proved to be difficult for image processing analysis. For more than 25 years, topographic effects have been major problems in image processing but have remained unsolved satisfactory. To correct the remotely sensed image due to the illumination effect, many authors have proposed various methods: those based on band ratios and those requiring the digital elevation model (DEM). The former is simple but rarely used due to lack of changes in each

spectral band for diffuse irradiance, whereas the latter (using DEM) has proved useful to minimize effectively the topographic effect.

The first result achieved on topographic correction was a simple normalization based on cosine law. In this approach, the surface is assumed to have Lambertian behavior, but resulting in over-correction especially in weak illuminated regions due to disproportional brightening effect (CIVCO, 1989; COLBY, 1991; MEYER *et al.*, 1993). Several published algorithms have been demonstrated useful for correcting the topographic effect based on the non-Lambertian method such as: MINNAERT correction (SMITH *et al.* 1980; COLBY 1991; EKSTRAND 1996), Running MINNAERT correction (EKSTRAND, 1996), C-correction (TEILLET *et al.*, 1982; MEYER *et al.*, 1993), modified C-correction (RIANO *et al.*, 2003), using digital terrain models (CONESE *et al.*, 1993) and models for high spatial resolution imagery (RICHTER, 1997). Other methods such as the two-stage topographic normalization proposed by CIVCO (1989) and statistical-empirical method (TEILLET *et al.*, 1982; MEYER *et al.*, 1993) also proved to be appropriate methods for reducing the topographic effect based on slope-aspect correction. Moreo-

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ver, for topographic correction on forest images, GU and GILLESPIE (1998) developed a Sun-Canopy-Sensor (SCS) terrain correction model based on the interaction between solar radiation and forest canopy elements. It is necessary to examine the utility of topographic correction methods among many scientific literatures.

Much of regions in Niigata Prefecture contain high topographic relief where sugi as main forest grows. SMITH *et al* (1980) suggested that topographic correction method is inherent to a land cover type. TEILLET *et al* (1982) found that slope-aspect correction in forestry applications must be class-specific and that no correction formula is general enough to accommodate the various forest types by itself, meanwhile HOLBEN and JUSTICE (1980) and LEPRIEUR *et al* (1988) showed that different types of vegetation respond differently. The effect of topography on sugi forest remains unknowable due to the lack on illumination correction information of sugi stand in image analysis especially for estimating its volume. Therefore, the topographic correction effect need to examine for sugi stand in order to achieve better understanding on its implementation and higher accuracy in sugi stand volume estimation.

The objectives of this study were to: (a) examine existing topographic correction methods and suggest the best correction method for topographic correction in mountainous region particularly for sugi forest using Landsat TM and ASTER images; and (b) evaluate of applying topographic correction methods to the accuracy of image analysis in estimating sugi stand volume.

MATERIAL AND METHODS

The study area site is located in the Tsugawa region, Niigata Prefecture, covering approximately 43,200 ha (Latitude 37°38'50" - 37°44'35" N; Longitude 139°26'13" - 139°36'05" E). Tsugawa is covered by forests with a secondary forest consisting of sugi (*Cryptomeria japonica*); as the main coniferous plantation trees and deciduous broad-leaved trees species, such as Buna (*Fagus crenata*) Mizunara oak (*Quercus crispula* Blume), Konara-oak (*Quercus serrata*), Maple species, and Wingnut (*Pterocarya rhoifolia*). The study area in the Tsugawa region is a hilly and mountainous area with elevation

ranging from 41 to 1,031m.

Primary image data sets used in this study were obtained from Landsat-5 Thematic Mapper data imagery in the summer season (June) due to its clear and abundant information for reflecting land cover characteristics to image. The 800-lines by 600-columns (432km²) sub-scene of the Tsugawa region derived from 5-sequence scene images of year 1986, 1989, 1997, 1999 and 2001 of Landsat TM and the 1600-lines by 1200-columns pixels of ASTER image. Digital Elevation Model (DEM) was derived from a 50-meter grid elevation scale made by the Japan Geographical Survey Institute geometrically matched the Landsat TM pixel size (30m) and ASTER image pixel size (15m) for geometric registration. ERDAS IMAGINE version 8.7 was used for image processing. The geometric correction was performed by selecting more than 45 ground control points for each image in the sub-scene image with a root-mean square error (RMSE) of less than 0.5 pixel in the transverse mercator coordinate system.

From ground field measurements, about 50 plots were investigated from 2001 to 2003, based on the Niigata Prefecture Forestry Division. In approximately 0.03 - 0.04 ha per plot (generally used 20 × 20 m), we measured tree diameter at breast height (DBH) and tree height on every plot taken. Radiometric normalization correction was applied to Landsat TM sequence images based on the *An automatic scattergram-controlled regression* approach (ELVIDGE *et al.*, 1995). The effectiveness of radiometric correction was evaluated by visual inspection and calculated using root mean square error (RMSE) in the sample area chosen in order to avoid clouds for the 1997 image.

Forest was classified by the *maximum likelihood classification* method into 3 recognized categories; i.e. "deciduous forest", "low-middle volume sugi forest" with a volume of 0 - 450m³ and "high volume sugi forest" with a volume of more than 450m³ (the decision of volume class depends on separability analysis). Training sites for the classes mentioned above were determined by gathering information from the ground plots investigated (50 plots) and the contextual information provided by satellite image scenes. Mostly 3 × 3 pixel kernels were extracted in each plot as training data areas to divide forest covers especially in sugi forest whereas in some cases only a few neighbor pixels in

Table 1 Satellite acquisition metadata

No.	Satellite	Date	Sun Elevation	Sun Azimuth
1	Landsat	06/10/1986	61	112
2	Landsat	06/02/1989	62	116
3	Landsat	06/24/1997	63	112
4	Landsat	06/14/1999	64	115
5	Landsat	06/03/2001	64	118
6	ASTER	06/02/2005	70	134

plots were used.

Since topographic normalization involves several theoretical and practical considerations, we examined four different topographic normalization methods in mountainous region to reduce slope-aspect effect in Landsat TM and ASTER image data sets regarding the difference of vegetation types: *statistical-empirical* correction method, *a traditional MINNAERT* correction, *C-correction* method and *two-stage topographic normalization* proposed by CIVCO (1989). Many authors have applied these models to forest cover with different degrees of success in application (SMITH *et al.*, 1980; TEILLET *et al.*, 1982; CIVCO, 1989; COLBY, 1991; MEYER *et al.*, 1993; EKSTRAND, 1996; MURAKAMI *et al.*, 1998).

Four methods have been applied to accurately assess the results of topographic normalization; The first method involves direct visual evaluation using bands 2, 4 and 5 in which images ideally appear to be flat and both slope facing the sun and that facing away from the sun reflect the same colors. The second method compares the effect of solar incidence angle before and after correction by using the slope of regression (inclination) and the correlation coefficient (r), whereas slope of the regression line is close to zero (flat slope) and a low (zero) correlation showed that illumination correction has no effect on the images and significantly reduced the topographic effect. In the third method standard deviation (SD), preferably for each forest cover type should be reduced, meaning that a greater interclass homogeneity has been achieved. In the fourth method, by comparing the average digital number of the slope facing away from the sun with that of the slope facing the sun after correction, which should be similar. The digital number for both uncorrected and post-corrected data were imported to SPSS software after converting to ASCII format and analyzed independently for the above purposes.

Sugi Stand Volume Analysis

Regression analysis was applied to *single band images*, *NDVI*, *simple ratio* and *vegetation indices* bands to evaluate the

regression line between estimated sugi stand volume and original digital number as well as derived corrected images using different topographic correction methods on 1999 and 2001 of Landsat TM images including 2005 ASTER image. Thus in order to compare the average sugi stand volume from prediction and volume from ground investigation, the root mean squared error (RMSE) was applied. The smaller RMSE gives a better regression and is related to a more accurate model.

$$RMSE = \sqrt{\frac{\sum_{i=1}^n (\text{ground volume} - \text{estimated volume})^2}{n}}$$

RESULTS AND DISCUSSION

Topographic Correction Approaches

Using transformed divergence analysis (JENSEN, 1986), the accuracies of classification was high for all images in distinguishing among land covers into 7 covers: water (5,308 pixel; 1.11%, based on the 2001 image classification), deciduous forest (286,273 pixels; 59.64%), low-middle volume sugi forest (108,912 pixels; 22.69%), high volume sugi forest (27,504 pixels; 5.73%), agriculture/paddy field (4,257 pixels; 0.89%), resident/building area (36,492 pixels; 7.60%) and open area/bare land (11,272 pixels; 2.35%). The overall accuracy for more than 95% has been resulted for all images operating 5 band combinations (bands 1, 2, 3, 4, and 7) on Landsat images and full bands (bands 1, 2 and 3) on ASTER image.

Visually, images resulted from different topographic correction methods show significant improvements (see its comparison in Fig. 1). In band 1, the MINNAERT correction appears to be overcorrection in all examined images especially in the area of the slope facing the sun whereas it becomes darken. Three other methods were evaluated in the same ways and show slightly similar results in all bands by showing relatively uniform vegetation brightness. Using visual interpretation, the effects of applying topographic correction

Fig. 1 Uncorrected band 2 (left) and statistic-empirical corrected band 2 on 2001 Landsat image, Tsugawa test site (right)

based on specific forest types can be considered improve the images than those in one single forest type.

Slope (m), intercept (b) and correlation coefficient (r) of the various correlations were evaluated for each band in all images before and after corrections were applied. High slope angle of regressions show that the deciduous cover were strongly influenced by the topographic effect, followed by the low-middle volume sugi cover and the high volume sugi cover

(Tables 2 and 3). LEPRIEUR *et al.* (1988) observed that coniferous stands are more dependent on the solar position than the deciduous stand, particularly for near infrared and infrared bands. Using statistical tests, only deciduous forest cover showed a strongly significant correlation; meanwhile both sugi covers generally show significant correlations for visible bands but low correlations for near infrared and short-wave infrared bands. A lower slope angle of regression was

Table 2 Regression analyses between uncorrected digital number and solar incidence angle ($\cos i$) on 2001 on forest cover types in all years of Landsat TM (inclination/slope m , intercept b and correlation coefficient r)

Year of Landsat	Mean <i>Cos i</i>	Band 1			Band 2			Band 3			Band 4			Band 5			Band 7		
		<i>m</i>	<i>b</i>	<i>r</i>	<i>m</i>	<i>b</i>	<i>r</i>	<i>m</i>	<i>b</i>	<i>r</i>	<i>m</i>	<i>b</i>	<i>r</i>	<i>m</i>	<i>b</i>	<i>r</i>	<i>m</i>	<i>b</i>	<i>r</i>
General forest cover (n = 422,671)																			
1986	0.809	10.5	69.2	0.465*	11.8	22.3	0.500*	9.5	16.9	0.429*	96.4	52.4	0.453*	60.2	69.8	0.486*	20.8	7.5	0.486*
1989	0.818	7.3	71.5	0.396*	8.7	24.4	0.482*	7.3	18.0	0.414*	88.8	56.8	0.409*	60.2	34.0	0.435*	15.6	10.9	0.430*
1997	0.822	6.5	72.3	0.311*	6.6	25.9	0.396*	6.8	14.5	0.366*	78.4	63.3	0.322*	49.9	39.8	0.330*	13.4	12.0	0.333*
1999	0.832	5.9	72.5	0.268*	5.2	27.2	0.391*	5.1	20.1	0.300*	79.9	62.8	0.333*	48.3	41.9	0.327*	11.9	13.6	0.336*
2001	0.832	7.8	70.9	0.371*	7.6	25.2	0.401*	6.4	18.7	0.336*	69.7	68.3	0.290*	46.0	42.7	0.307*	12.5	12.9	0.324*
Deciduous forest cover (n = 286,273)																			
1986	0.807	9.6	69.3	0.562*	11.2	22.7	0.606*	7.9	17.7	0.593*	108.7	53.5	0.678*	72.8	29.9	0.679*	20.2	8.6	0.660*
1989	0.813	6.7	71.5	0.442*	8.5	24.5	0.593*	6.5	18.1	0.567*	104.9	54.9	0.642*	65.5	34.3	0.629*	15.9	11.3	0.598*
1997	0.820	7.3	71.2	0.373*	7.4	25.4	0.497*	7.3	17.9	0.567*	104.2	56.7	0.587*	64.3	35.9	0.580*	16.5	11.2	0.545*
1999	0.836	6.2	71.7	0.311*	5.6	26.8	0.469*	4.8	20.1	0.407*	96.9	62.8	0.569*	57.4	42.5	0.554*	13.5	13.9	0.538*
2001	0.833	7.7	70.9	0.466*	8.1	25.2	0.529*	6.0	19.0	0.493*	89.0	67.6	0.568*	57.6	40.8	0.544*	14.6	12.7	0.539*
Low-middle volume sugi forest (n = 108,893)																			
1986	0.829	10.8	71.1	0.359*	12.2	23.2	0.379*	12.7	16.6	0.363*	70.6	57.9	0.338*	63.4	28.3	0.359*	21.8	7.2	0.358*
1989	0.842	6.8	73.4	0.281*	7.1	26.9	0.298*	6.76	20.4	0.266*	57.9	66.2	0.253*	47.2	40.7	0.265*	13.7	13.1	0.259*
1997	0.831	2.9	76.6	0.145	3.3	29.6	0.212*	4.7	21.6	0.210*	16.5	99.9	0.089	15.5	62.4	0.122	5.9	17.7	0.152
1999	0.823	6.9	73.2	0.274*	4.5	28.1	0.298*	7.2	19.4	0.281*	16.3	90.1	0.114	14.9	56.4	0.141	6.8	15.8	0.192
2001	0.830	8.6	71.2	0.308*	7.1	25.4	0.308*	8.1	18.1	0.277*	23.1	81.9	0.145	19.5	54.3	0.145	8.6	14.5	0.202*
High volume sugi forest (n = 27,505)																			
1986	0.758	4.7	71.3	0.373*	2.7	24.7	0.305*	2.1	19.6	0.266*	-5.7	77.0	0.063	-2.6	46.2	0.045	-0.2	13.6	0.000
1989	0.772	3.9	73.0	0.305*	1.8	26.3	0.276*	1.0	20.6	0.187	-9.1	79.6	0.114	-6.2	50.9	0.118	-1.0	15.4	0.063
1997	0.805	4.8	72.0	0.277*	4.5	25.1	0.351*	3.6	18.6	0.308*	1.9	68.7	0.032	-2.0	44.9	0.045	0.0	13.4	0.000
1999	0.829	3.5	74.1	0.202*	2.1	27.9	0.268*	1.5	21.6	0.200*	4.5	67.7	0.055	2.5	41.3	0.055	0.5	13.9	0.032
2001	0.832	4.4	71.3	0.279*	2.9	25.5	0.324*	2.7	19.2	0.283*	4.5	61.4	0.071	3.2	39.0	0.063	1.2	12.4	0.089

*Significant at the 0.05 level;

Table 3 Regression analyses between uncorrected digital number and solar incidence angle ($\cos i$) on 2005 ASTER Image (inclination/slope m , intercept b and correlation coefficient r)

Year of ASTER	Mean <i>Cos i</i>	Band 1			Band 2			Band 3		
		<i>m</i>	<i>b</i>	<i>r</i>	<i>m</i>	<i>b</i>	<i>r</i>	<i>m</i>	<i>b</i>	<i>r</i>
General forest cover (n = 1,692,036)										
2005	0.845	6.9	41.0	0.371*	3.7	18.9	0.401*	14.9	84.3	0.336*
Deciduous forest cover (n = 1,164,485)										
2005	0.841	8.3	40.6	0.391*	4.3	18.5	0.411*	29.8	81.7	0.407*
Low-middle volume sugi forest (n = 406,329)										
2005	0.846	6.6	40.7	0.249*	3.7	19.4	0.200*	2.8	77.5	0.032
High volume sugi forest (n = 121,222)										
2005	0.873	3.6	38.9	0.288*	2.0	18.3	0.295*	3.7	54.3	0.095

*Significant at the 0.05 level;

seen in high volume sugi cover than low-middle volume sugi cover for near infrared and infrared bands (band 4, band 5 and band 7, respectively), it show that reflectance value decrease when sugi stand volume increases. The same result was also obtained by LEPRIEUR *et al.* (1988) using stand age analysis.

As has often been noticed before (HOLBEN and JUSTICE, 1980; LEPRIEUR *et al.*, 1988; TEILLET *et al.*, 1982), the present results showed that using corrected images derived from specific forest types were more effective than those using the forest in general. LEPRIEUR *et al.* (1988) believed that these differences based on different properties of the biological materials (such as: photosynthetic pigments, cell wall materials, water concentrations, etc) and of foliage geometry (leaf and branch shape roughness, internal anatomy, leaf and branch zenith angles, etc).

The relation between mean incidence angle ($\cos i$) and correlation coefficient (r) for regressions derived from the sequences obtained with Landsat TM also showed that a lower mean incidence angle (local solar incident angle) on forest type, the higher the topographic effect to the forest. In the comparison between low-middle volume sugi cover and high volume sugi cover, the apparent reflectance effect due to

topography decreased with the increase in the volume of sugi stand tree, particularly for bands 4, 5 and 7.

In addition, MINNAERT constant values gained from one image varied from those constants gained from other images, and no one fixed value was adequate for all images (see Fig. 2 and 3); a similar result was also obtained for cover type, there being no single fixed value for all cover type which may be highly variable. COLBY (1991) also suggested that the MINNAERT constant gained from sample areas was more accurate than MINNAERT constant gained from corresponding entire scenes.

Tables 4 and 5 show that in most corrected images, slope angle of regression and correlation coefficient was reduced to zero although the topographic effect was nearly completely removed. MURAKAMI *et al.* (1988) reported that no correlation was found after MINNAERT correction and C-correction methods were applied to bands 4 and 5 of Landsat TM data. The best result was obtained by statistic empirical correction and two-stage topographic normalization while the worst result was obtained by MINNAERT correction, which clearly can be seen in visible bands.

In an effort to determine the variants among images after corrections, the standard deviation (SD) was analyzed. Ideally, SD was reduced for successful corrected images since both opposite slopes (slope facing away from the sun and that facing the sun) have similar mean digital numbers. In a deciduous forest type, the decrease of standard deviations showed that all methods were effective and could be defined as suitable methods to correct the illumination effect even though in MINNAERT correction there was less improvement or overcorrection for visible bands. In comparison, the result using a sugi forest type was different, whereas both for low-middle volume sugi cover and high volume sugi cover, there was less improvement; even in the same cases, the correction approach increased its standard deviation. The mean values for both slope facing away from the sun and slope facing the sun were tested statistically. All topographic correction gave significantly reduced the digital numbers on the slope facing the sun and increased digital numbers on the slope facing away from the sun (Table 6).

For the entire analysis of topographic correction, traditional MINNAERT correction was failed to improve topographic correction statistically due to its inconsistencies particularly in visible bands. Other methods showed marked improvements especially the two-stage topographic normalization proposed by CIVCO (1989), but there was only a slight difference among the others as demonstrated by statistical analysis.

Fig. 2 MINNAERT constant values (k) on deciduous forest type

Fig. 3 MINNAERT constant values (k) on high volume sugi forest type

Table 4 Standard deviation (SD) and correlation parameters of original image and corrected image in 2001 Landsat TM image (ideally SD for the corrected is lower than uncorrected, slope and r data is close to zero)

Bands	Correction methods	Deciduous forest (n = 286,273)				Low-middle volume sugi forest (n = 108,893)				High volume sugi forest (n = 27,505)			
		SD	m	b	r	SD	m	b	r	SD	m	b	r
Band 1	Uncorrected	2.19	7.77	70.89	0.466*	3.55	8.59	71.21	0.308*	1.70	4.36	71.32	0.279*
	Statistic Empirical	1.96	-0.21	77.02	0.000	3.39	-0.15	77.95	0.000	1.65	-0.36	74.73	0.032
	MINNAERT Correction	4.05	-9.36	83.81	0.303	4.27	-5.01	83.55	0.148	2.54	-4.52	79.62	0.192
	C-Correction	2.00	1.29	76.42	0.084	3.46	2.65	76.63	0.100	1.68	1.61	73.65	0.105
	Topographic Normalization (Civco)	1.96	-0.25	77.03	0.000	3.39	-0.50	78.23	0.000	1.68	-0.30	74.58	0.000
Band 2	Uncorrected	2.00	8.05	25.22	0.529*	2.94	7.11	25.38	0.308*	0.89	2.90	25.45	0.324*
	Statistic Empirical	1.72	-0.25	31.62	0.000	2.81	0.09	30.72	0.000	0.89	-1.10	28.23	0.134
	MINNAERT Correction	1.98	-2.64	33.94	0.176	2.96	-1.25	32.89	0.055	1.10	-1.48	29.27	0.145
	C-Correction	1.72	1.35	30.97	0.105	2.87	2.08	29.88	0.095	0.88	1.80	26.30	0.221
	Topographic Normalization (Civco)	1.71	-0.32	31.64	0.032	2.78	-0.46	31.14	0.000	0.89	-1.13	28.25	0.138
Band 3	Uncorrected	1.59	5.96	18.96	0.493*	3.70	8.05	18.09	0.277*	0.93	2.70	19.22	0.283*
	Statistic Empirical	1.42	0.65	22.95	0.063	3.57	-0.11	24.37	0.009	0.93	-1.23	21.94	0.145
	MINNAERT Correction	1.56	-1.82	25.12	0.152	3.72	-0.55	25.89	0.046	1.06	-1.43	22.74	0.046
	C-Correction	1.40	1.03	23.05	0.095	3.69	2.45	23.18	0.084	0.93	1.78	19.92	0.036
	Topographic Normalization (Civco)	1.38	-0.11	23.5	0.004	3.54	-0.97	25.03	0.033	0.94	-1.28	21.99	0.002
Band 4	Uncorrected	20.53	88.97	67.62	0.568*	20.33	23.13	81.91	0.145	6.96	4.50	61.39	0.071
	Statistic Empirical	16.90	0.02	141.20	0.000	20.12	0.03	100.59	0.000	6.95	-0.29	64.85	0.045
	MINNAERT Correction	16.80	5.60	144.78	0.045	20.09	2.92	100.45	0.000	7.11	-3.10	68.37	0.000
	C-Correction	16.70	13.5	137.04	0.105	20.37	6.73	97.66	0.045	7.02	1.69	63.78	0.032
	Topographic Normalization (Civco)	16.61	0.682	139.64	0.000	19.93	1.69	99.13	0.000	6.98	-1.01	65.48	0.000
Band 5	Uncorrected	13.89	57.59	40.80	0.544*	16.98	19.51	54.29	0.145	5.24	3.2	39.01	0.063
	Statistic Empirical	11.66	-0.02	88.28	0.000	16.79	-0.02	70.01	0.000	5.24	-0.89	41.87	0.000
	MINNAERT Correction	11.74	4.09	90.28	0.045	16.80	4.27	68.17	0.032	5.36	-1.73	43.37	0.032
	C-Correction	11.63	8.76	85.56	0.100	17.07	5.57	67.58	0.045	5.25	1.76	40.16	0.032
	Topographic Normalization (Civco)	11.51	0.28	87.35	0.000	16.63	0.05	69.86	0.000	5.26	-1.38	42.29	0.032
Band 7	Uncorrected	3.55	14.56	12.72	0.539*	5.43	8.59	14.54	0.202*	1.42	1.19	12.43	0.084
	Statistic Empirical	3.00	-0.14	24.45	0.000	5.33	-0.15	21.29	0.009	1.46	-2.24	14.72	0.167
	MINNAERT Correction	2.97	0.732	25.65	0.032	5.46	1.15	21.21	0.028	1.44	-0.20	13.38	0.002
	C-Correction	2.97	2.24	23.65	0.105	5.48	2.53	20.06	0.055	1.42	0.40	13.02	0.031
	Topographic Normalization (Civco)	2.96	-0.45	24.57	0.001	5.24	-0.66	21.66	0.003	1.46	-2.29	14.76	0.170

* Significant at the 0.05 level;

Table 5 Standard deviation (SD) and correlation parameters of uncorrected image and corrected image in 2005 ASTER image (ideally SD for the corrected is lower than uncorrected, slope and r data is close to zero)

Bands	Correction methods	Deciduous forest (n = 1,164,185)				Low-middle volume sugi forest (n = 406,329)				High volume sugi forest (n = 212,222)			
		SD	m	b	r	SD	m	b	r	SD	m	b	r
Band 1	Uncorrected	2.73	8.31	40.56	0.391*	3.60	6.58	40.66	0.249*	1.03	3.59	38.92	0.288*
	Statistic Empirical	2.53	0.00	47.55	0.000	3.50	0.01	46.23	0.000	1.01	-0.03	42.09	0.000
	MINNAERT Correction	3.01	-4.71	51.39	0.200*	3.72	-2.40	48.87	0.089	1.43	-2.93	45.06	0.207*
	C-Correction	2.50	2.75	45.61	0.141	3.52	2.91	44.23	0.045	1.02	1.25	41.23	0.122
	Topographic Normalization (Civco)	2.51	-0.17	47.67	0.000	3.48	-0.19	46.37	0.000	0.97	0.11	41.96	0.000
Band 2	Uncorrected	1.33	4.25	18.48	0.411*	2.48	3.66	19.42	0.200*	0.68	1.98	18.255	0.295*
	Statistic Empirical	1.26	0.11	21.96	0.000	2.47	0.05	22.45	0.000	0.72	-0.02	19.95	0.000
	MINNAERT Correction	1.41	-1.81	23.54	0.164	2.50	-0.94	23.63	0.055	0.81	-1.29	21.34	0.161
	C-Correction	1.24	1.53	20.96	0.158	2.49	1.67	21.34	0.032	0.73	0.69	19.47	0.095
	Topographic Normalization (Civco)	1.21	-0.12	22.15	0.000	2.43	-0.18	22.65	0.000	0.648	-0.06	20.04	0.000
Band 3	Uncorrected	9.40	29.79	81.72	0.407*	12.21	2.77	77.54	0.032	4.01	3.79	54.32	0.095
	Statistic Empirical	8.58	-0.01	106.78	0.000	12.21	0.00	79.88	0.000	4.00	-0.01	57.63	0.000
	MINNAERT Correction	8.74	-6.79	113.51	0.100	11.92	-1.62	80.62	0.000	4.05	-2.70	60.29	0.071
	C-Correction	8.48	9.9	99.78	0.152	12.20	1.23	79.04	0.000	4.00	1.33	56.75	0.032
	Topographic Normalization (Civco)	8.60	0.97	105.84	0.000	12.20	1.38	78.72	0.000	3.99	-0.15	57.76	0.000

*Significant at the 0.05 level;

Table 6 Comparison of mean DN value on different slopes in 2001 Landsat image (ideally DN values for both of facing away from the sun/shaded side and facing to the sun/sunny side are similar)

Bands	Correction methods	Deciduous forest (n = 286,273)		Low-middle volume sugi forest (n = 406,329)		High volume sugi forest (n = 121,222)	
		Facing away from the sun	Facing to the sun	Facing away from the sun	Facing to the sun	Facing away from the sun	Facing to the sun
Band 1	Uncorrected	76.39	78.11	77.26	79.11	74.56	75.28
	Statistic Empirical	76.91	76.79	77.84	77.82	74.63	74.28
	MINNAERT Correction	77.34	75.00	80.11	78.88	76.56	75.29
	C-Correction	77.38	77.60	78.50	79.06	74.79	75.16
	Topographic Normalization (Civco)	76.90	76.77	77.87	77.77	74.62	74.28
Band 2	Uncorrected	30.92	32.71	30.38	31.93	27.58	28.09
	Statistic Empirical	31.46	31.36	30.79	30.81	27.59	27.09
	MINNAERT Correction	32.09	31.46	31.98	31.77	28.28	27.85
	C-Correction	31.95	32.20	31.38	31.77	27.60	27.97
	Topographic Normalization (Civco)	31.45	31.31	30.82	30.71	27.59	27.09
Band 3	Uncorrected	23.16	24.52	23.71	25.54	21.21	21.68
	Statistic Empirical	23.46	23.51	24.23	24.31	21.22	20.68
	MINNAERT Correction	23.83	23.43	25.39	25.47	21.78	21.37
	C-Correction	23.79	24.01	24.86	25.45	21.21	21.56
	Topographic Normalization (Civco)	23.48	23.37	24.29	24.17	21.22	20.68
Band 4	Uncorrected	130.54	150.33	98.50	102.95	64.62	65.55
	Statistic Empirical	141.01	141.37	100.76	100.51	64.68	64.55
	MINNAERT Correction	148.58	150.11	102.89	102.85	66.21	65.46
	C-Correction	146.79	149.51	102.72	103.62	64.89	65.42
	Topographic Normalization (Civco)	140.21	140.20	100.52	100.53	64.76	64.54
Band 5	Uncorrected	81.52	94.35	68.13	72.16	41.30	41.97
	Statistic Empirical	88.13	88.36	69.96	70.00	41.31	40.97
	MINNAERT Correction	93.05	94.17	71.30	72.01	42.15	41.76
	C-Correction	91.86	93.62	71.59	72.63	41.34	41.85
	Topographic Normalization (Civco)	87.61	87.56	69.90	69.89	41.35	40.97
Band 7	Uncorrected	23.01	26.28	20.57	22.46	13.28	13.54
	Statistic Empirical	24.33	24.34	21.15	21.18	13.23	12.54
	MINNAERT Correction	25.50	25.73	21.97	22.30	13.21	13.21
	C-Correction	25.25	25.72	21.83	22.39	13.28	13.41
	Topographic Normalization (Civco)	24.27	24.13	21.19	21.06	13.26	12.54

The Effect of Applying Topographic Correction Methods on Sugi Stand Volume Analysis

Correlations between DN and ground characteristic information (volume) were analyzed. Regression results obtained from original digital number and observed sugi stand volume on both Landsat TM and ASTER images were found to be generally high with band 2 showing the highest correlation ($r = 0.798$). In 2001 Landsat TM, NDVI calculated from this regression almost similarly resulted with simple ratio bands ($r = 0.467$ and $r = 0.491$, respectively) but weaker than the correlation resulting from vegetation indices ($r = 0.688$). Even though it shows a lower correlation in ASTER images, the same tendency in correlation was found. The strong correlation seen in this study showed that Landsat TM and ASTER images proved to be trustable images for predicting sugi stand volume (see Fig. 4 and Fig. 5).

Almost all band correlations showed that correction using forest type in general resulted in a lower correlation than operating fixed forest types. As expected, the MINNAERT method in band 1 gave the lowest value to volume by

decreasing its correlation. In Landsat TM image, both the statistic-empirical method and two-stage topographic normalization proposed by CIVCO (1989) previously gave statistically better value, resulting a correlation in contrast correlation to sugi volumes (see complete result on Table 7). For visible and near-infrared bands, a better correlation was achieved using C-correction (with band 2 as the highest, $r = 0.802$), meanwhile MINNAERT method for shortwave infrared bands. Slightly different results were obtained from the ASTER image, whereas original DN is better than using corrected DN, mainly for near infrared bands (band 3).

The root mean square error (RMSE) was obtained. The RMS error gained from C-correction showed the smallest value for visible bands (RMSE = 193.71), in contrast to the infrared bands resulting from MINNAERT correction (Table 8). This result indicated that for sugi stand volume analysis, C-correction is the best for visible bands and near infrared band while MINNAERT correction is best for short-wave infrared bands.

Fig. 4 Regression between digital number derived from C-correction method (band 2) and observed sugi stand volume on 2001 image

Fig. 5 Regression between digital number derived from C-correction method (Vegetation Index) and observed sugi stand volume on 2001 image

Table 7 Comparison of correlation coefficient (r) between topographic correction methods and sugi stand volume on 2001 Landsat TM image (n = 50)

Correction methods	Bands								
	Band 1	Band 2	Band 3	Band 4	Band 5	Band 7	NDVI	Vegetation Indices	Simple Ratio
Uncorrected	0.671*	0.798*	0.738*	0.738*	0.754*	0.791*	0.467*	0.688*	0.491*
Statistic Empirical	0.596*	0.774*	0.713*	0.727*	0.751*	0.772*	0.466*	0.680*	0.491*
MINNAERT Correction	0.477*	0.779*	0.703*	0.735*	0.766*	0.797*	0.443*	0.683*	0.468*
C-Correction	0.652*	0.802*	0.742*	0.740*	0.762*	0.781*	0.459*	0.691*	0.486*
Topographic Normalization (Civco)	0.604*	0.768*	0.713*	0.728*	0.752*	0.774*	0.468*	0.682*	0.494*

Table 8 Comparison of Root Mean Square Error (RMSE) using multi bands in estimating sugi stand volume (n = 50)

Correction methods	Bands								
	Band 1	Band 2	Band 3	Band 4	Band 5	Band 7	NDVI	Vegetation Indices	Simple Ratio
Uncorrected	240.39	193.37	213.40	228.20	215.67	219.94	273.88	241.55	270.81
Statistic Empirical	261.85	211.16	225.66	230.60	217.89	223.56	273.90	243.66	270.47
MINNAERT Correction	280.94	213.09	230.63	228.76	212.95	215.39	275.17	241.65	272.21
C-Correction	247.03	193.71	212.66	228.07	214.19	220.34	275.73	241.75	272.20
Topographic Normalization (CIVCO)	258.55	211.72	225.63	230.40	217.48	222.87	273.58	243.46	270.08

Pattern curve of solar incidence angle and digital number from original and DN derived from various methods were also analyzed. DN derived from statistic-empirical correction and two-stage topographic normalization (CIVCO, 1989) was concentrated only on the sunny side (slope facing the sun), while on the dark side (slope facing away from the sun) it was unchanged. Contrasting changes were obtained by MINNAERT correction, whereas for visible bands it showed dynamic changes, even overcorrection in band 1 but slightly for infrared bands. The inconsistency of the results of application of the MINNAERT method and C-correction methods is well known and has been mentioned by many authors (MEYER *et al.*, 1993; GU and GILLESPIE, 1998) but considering the high positive correlation and slight-selective changes for all bands, it shows that both MINNAERT method and C-correction are adequate methods for sugi stand volume estimation analysis even though for different bands.

CONCLUSION

The present study examined the methods for topographic correction of measured value: statistical analysis post-correction and its relation to sugi stand volume estimation. The specific major forest class type should be considered as input when applying a topographic correction method in satellite images analysis. The influence of sugi stand volume on the apparent reflectance distribution appeared as a result: reflectance globally decreased with the increase in stand volume. All topographic correction methods applied in this study were effective for reducing the topographic effect and were suitable for correcting the illumination effect except for MINNAERT correction for visible bands (especially in band 1). Post-corrected statistical analysis is not reliable for determining degree of success until the real effect of applying correction methods on a forest is known.

Topographic effects are scene-dependent and there is no single parameter or model adequate for all scenes and forest types. The two-stage topographic normalization proposed by CIVCO (1989) and statistic-empirical method appeared to be the best for statistical analysis but were unsuccessful regarding actual correlation to sugi stand volume. The present results indicate that using C-correction for visible bands and

MINNAERT correction for short-wave infrared band are adequate methods for increasing the correlation accuracy between derived digital number and sugi stand volume in the Tsugawa region. Further studies using appropriate ground field data are needed at a lower sun elevation angle ($\cos i$) since only a few of the plots had poor illumination conditions. In this study, we found a strong indication of the illumination effect on deciduous forest cover, but further analyses are needed to verify our hypothesis.

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