Analysis of the ASTER Image Topographic Correction Method in Complex Mountain Areas

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Abstract. The phenomenon of "anisotropic reflection" caused by gradient and aspect changes in complex mountain areas has large disturbance on the spectral information of ground feature in remote sensing images, which will further affect the inversion of surface information based on the spectral characteristics of ground feature. Topographic correction is an effective means to weaken the topographical effect and improve the inversion accuracy of spectral reflectance of remote sensing images. Ten topographic correction methods, such as Teillet regression, VECA, Cosine, Cosine-B, Cosine-C, Cosine-T, C, SCS, SCS+C and Minnaert, were used to conduct topographic correction of ASTER remote sensing images in the complex mountain areas of Qulong, and visual effects, statistical results and spectral changes of ground features were used to quantitatively evaluate the correction results. The results show that the topographic effect in the study area is weakened to different degrees. Teillet-regression correction model has the best correction effect and the topographic effect is weakened to the maximum extent. VECA, cosine-c, and Minnaert calibration models followed. Teillet-regression model can be used as topographic correction model in complex mountain areas.

1. Introduction
Located in the southwest of China, the Qinghai-Tibet Plateau was formed due to the strong collision between the Indian plate and the Eurasian plate since 65Ma. The strong uplift since Pliocene has made it become the "roof of the world". Its formation and evolution have a great impact on the natural environment and human activities in itself and adjacent areas [1], which is of great significance in the research of global changes. However, influenced by gravity and universal gravitation in the process of the formation of the Qinghai-Tibet Plateau, the edge of the plateau surface was seriously cut, resulting in broken topography [2]. In complex mountain areas, gradient and aspect changes will lead to the phenomenon of "anisotropic reflection"[3-4], which will further affect the inversion of surface information based on the spectral characteristics of ground feature.

With the combination of DEM and satellite remote sensing image data, the topographic correction model transforms the radiance values of pixels to a certain reference plane through a certain transformation relationship [5], effectively reducing the changes in image radiance values caused by topographic relief, and improving the inversion accuracy of spectral reflectance in remote sensing images [6]. At present, some domestic and overseas scholars have conducted a number of exploration and application for topographic correction model. Zhang Zhaoiming et al improved the Shepherd topographic correction model with a sky scattering radiation calculation method with higher precision, and carried out the surface spectral reflectance inversion experiment in northern mountain areas of...
Beijing with TM image as a data source combined with 6S model [7]. Mu Yue et al. conducted a comparative analysis of the surface reflectance in complex mountain areas calculated with different topographic correction models based on TM images in Fanjing mountain area [8]; Lin Qinan et al. proposed a new semi-empirical topographic correction model, SCEDIL, which takes TM and GF-1 images as data sources to conduct a comparative analysis with the traditional semi-empirical model; Liu Xiao et al. introduced a smoothed terrain model and proposed a "smoothed mountain" correction method suitable for high spatial resolution, and a regional geological mapping test was conducted in the Shetou Mountain area based on GF-1, GF-2 and SPOT6 mountain images [10]. Research on topographic correction model has reached a relative mature level, however, previous studies mostly took Landsat series images as the data sources [11-12], and data from ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer) with 6 SWIR bands were seldom applied. In order to make the image better reflect the spectral characteristics of the surface and establish its relationship with the surface information, this paper adopts DEM data and ASTER image, and takes the complex mountain area of Qulong as the research object, and proposes the topographic correction model based on ASTER remote sensing data. The applicability of each correction model on this data is analyzed, looking forward to providing scientific basis and technical support for the further application of ASTER image data in complex mountain areas.

2. Study area and Data

2.1 Overview of the study area

The complex mountain area of Qulong is located in the southwest of Maizhokunggar County, 84km away from Lhasa, between 29°36′00″N~29°40′00″N, 91°33′30″E~91°37′30″E, with an area of about 38.39km² [13]. The study area is located at the junction of the Nyenchenthanglha Range and the Kailas Range, with complicated geological structure, undulating terrain, steep mountains, harsh environment, Strong geomorphological cutting. Besides The average altitude is above 4000m within air [14].

2.2 Data and Preprocessing

2.2.1 ASTER Data. The ASTER sensor on Terra satellite launched by NASA (National Aeronautics and Space Admin) on December 18, 1999 contains three 15 m resolution VNIR bands, six 30 m resolution short wave infrared bands and five 90 m resolution TIRS bands [15-17]. The ASTER image data used in this paper is L1T products (http://glovis.usgs.gov/), the scene number is AST_L1T_0031129200104439_20150420145105_1906, and the imaging date is November 29, 2001. In the study area, there is no snow basically, covered with a few glaciers, rivers, quaternary system and vegetation. The image is clear, and the bedrock, altered rocks and altered minerals are exposed. It has received Crosstalk correction [18], and preprocessing such as spatial resolution resampling, and radiation correction is still needed.

2.2.2 Topographic Data. The Digital Elevation Model (DEM) is a branch of the Digital Terrain Model (DTM) that only considering terrain components [19], which contains terrain factors such as gradient, aspect, shadow geomorphologic image, profile curvature, horizontal curvature [20]. The topographic correction model uses DEM data to establish the spatial relationship between the actual radiance received by the satellite sensor and the gradient and aspect to reflect the inversion of surface reflectance [5]. DEM data comes from ASTER GDEM V2 product of Geospatial Data Cloud (http://www.gscloud.cn/), with spatial resolution of 30m.

3. Topographic Correction Model

At present, topographic correction methods that can weaken the topographic impact can be roughly divided into spectral band ratio based method, DEM based method and hypersphere based method [21]. In this paper, ten DEM based correction methods including Teillet-regression, VECA, Cosine,
Cosine-B, Cosine-C, Cosine-T, C, SCS, SCS+C and Minnaert model were used to conduct topographic correction for the image of the study area, combining with the solar azimuth, solar altitude and DEM data (Table 1).

**Table 1 Topographic Correction Model [21]**

| No. | Classification | Correction Model | Formula |
|-----|----------------|------------------|---------|
| 1   | Statistical empirical model | Teillet-regression | \( L_{\text{H}} = L - m \cdot \cos i - b + L_a \) |
| 2   |                   | VECA             | \( L_{\text{H}} = \frac{L_a}{m \cdot \cos i + b} \) |
| 3   | Cosine           |                  | \( L_{\text{H}} = L \cdot \frac{\cos \theta}{\cos i} \) |
| 4   | Cosine-B         |                  | \( L_{\text{H}} = (L - b) \cdot (\cos \theta / \cos i) \) |
| 5   | Cosine-C         |                  | \( L_{\text{H}} = L + L \cdot \frac{\cos s \cdot i - \cos i}{\cos s \cdot i} \) |
| 6   | Lambert Reflectivity Model | Cosine-T | \( L_{\text{H}} = L \cdot \cos \theta / \cos i \) |
| 7   | C                |                  | \( L_{\text{H}} = \frac{L \cdot \cos \theta + c}{\cos i + c} \) |
| 8   | SCS              |                  | \( L_{\text{H}} = \frac{L \cdot \cos S \cdot \cos \theta}{\cos i} \) |
| 9   | SCS+C            |                  | \( L_{\text{H}} = \frac{L \cdot \cos S \cdot \cos \theta + c}{\cos i + c} \) |
| 10  | Non-lambert Reflectivity Model | Minnaert | \( L_{\text{H}} = \frac{L \cdot \cos \lambda + S}{\cos \lambda \cdot i} \) |

Note: \( L_H \) refers to the value of the radiance of the corrected pixel; \( L_a \) refers to the average value of the pixel radiance before correction; \( m \) and \( b \) refer to angle of gradient and intercept of the pixel radiance value of \( L \) and the cosi linear regression equation; \( L_\alpha \) refers to the pixel mean before correction; \( \cos \alpha \) is the Cosi mean; \( i \) is the solar incidence angle; \( \theta_s \) is the solar zenith angle; \( S \) is the gradient; \( c \) is the semi empirical coefficient; \( k \) is the Minnaert constant.

**4. Results and Analysis**

**4.1 Visual Effect**

Ten models were applied to conduct topographic correction in the study area, and the correction results are shown in Figure 3. Each correction model weakened the topographic effect of the study area to various extents. Compared with the original image, Teillet-regression, VECA, cosines -C and SCS+C four models show that the topographic effect of shadow area is weakened better, with normalized pixel radiance value, and the shadow area is compensated well; Although the corrected images of the C and Minnaert models also show that the topographic effect is weakened, there is an under-correction phenomenon in areas with big altitude difference, leading to a "black hole", which may be caused by sudden changes of gradient (Figure 1-(h)-1. Figure 1-(k)-1); the correction effect of Cosine-T model and SCS model is similar that the shadow area obtained effective light compensation, however, the light compensation in low-altitude areas is so much that over-correction occurs ; The corrected images of the Cosine and Cosine-B models have intensified over-correction. The reflectance of the shadow surface is higher than that of the original illumination surface after correction. At the same time, there is a "black hole" in the area with steep gradient, which is not suitable for topographic correction of ASTER images in the study area. The order of excellence of these visual analysis models is Teillet- regression >VECA>Cosine-C>SCS+C>Minnaert>C>Cosine-T>SCS>Cosine>B.
4.2 Statistical Results

(1) Discrete analysis  The mean value of images can show the situation of the pixel radiance changes of each band of the image before and after the correction, and the standard deviation reflects the overall tendency that the pixel radiance of the image deviate from the mean value[21]. It can be found from the discrete changes of the image band before and after correction (Figure 2) that the mean value of the image radiance increased after correction, and the standard deviation also changed accordingly. The standard deviation of Teillet-regression model, VECA model, C model, SCS+C model and Cosine-C model decreased significantly, and the mean value of radiance value increased to some extent, indicating that the topographic correction effect was better. Furthermore, although the pixel radiance value of corrected images by Cosine model, Cosine-B, Cosine-T, SCS model, Minnaert model increased to some extent, the corresponding standard deviation also increased, which limits the expression of topographic correction effect. Among them, the standard deviation and mean value of the corrected images through Cosine model increased abnormally, which is consistent with the over correction phenomenon in visual effect.

Figure 2. Image statistical information before and after topographic correction in the study area
(2) Regression analysis. Compared with the linear fitting coefficient of the original image, the correlation between the corrected image radiance value and the illumination coefficient of each model is reduced to a certain extent (Figure. 5). The order of linear fitting determination coefficient is Cosine-T>SCS>Cosine-C>Minnaert> Cosine>Cosine-B> C>SCS+C> VECA> Teillet-regression. Among them, the correction coefficient of Teillet-regression model has the biggest changes, declining from 0.3768 of the original image to 0.0009. The correlation between the corrected image and the illumination coefficient of the model was small, indicating that the topographic effect was well weakened [22]. It can be found through comparison that the determination coefficients of Cosine-B, Cosine, and C models are relatively low with better correction results after correction. However, according to the discrete analysis values, both the corrected mean value and standard deviation increased, which may be caused by over-correction because of ignoring the influence of the scattered radiation of the atmosphere and the surrounding surface features [23].

![Figure 3. Linear fitting of scatter diagram before and after topographic correction (pixels diluting scale 1/10000)](image)

(3) Histogram analysis. Changes in the wave peaks and contrast of image histograms can be used to describe the distribution and variation of pixel radiance in space [24]. It can be seen from the comparative analysis in Figure 4 that before correction, the image wave peaks were relatively scattered, which is inconsistent with the statistical distribution law. The corrected image histograms of the Teillet-regression model, VECA model, C model, SCS + C model and Cosine-C model...
approximate normal distribution, especially the Teillet-regression model, indicating that the pixel radiance of these models is close to random distribution and the corrected image quality is relatively good.

Figure 4. Image histogram before and after topographic correction in the study area (Band 1)

4.3 Spectrum analysis
The main objective of topographic correction is to transform the pixel radiance value in the shady slope area, so as to weaken the "anisotropic reflection" phenomenon caused by topographic relief [4]. The change of spectral reflection curve of pixel before and after topographic correction in shadow area can indicate the weakened topographic effect [25].

Figure 5. Comparison of spectral curves of typical pixels

Vegetation and rock area pixels were selected from the image for a comparative analysis. After analyzing the forms and absorption peaks of the reflection spectra of different corrected image pixels, it can be known that (Figure 5) the spectral curves of the corrected vegetation pixels showed different changes compared with the original images, the reflectance of Cosine-T, Cosine-C, C, Cosine, SCS+C, Minnaert and VECA models have increased or decreased to different extent compared with the
original images, which indicates that spectral distortion happened to the above models to some extent. After the correction of the rock pixel, each model showed the spectral characteristics of kaolinite altered minerals, which conforms to the characteristics that the study area is a super-large porphyry copper deposit. In addition, the absorption characteristics at 2.2 μm are more obvious, which has a better indicating effect on the remote sensing extraction of altered minerals. However, the spectral reflectance of surface features of the Cosine model after the correction suddenly increases, which may be resulted from the spectral distortion of the “sudden change” of the aspect value in the shadow area [26].

5. Conclusion
As an important preprocessing step to express the surface information in areas with huge topographic relief, topographic correction can weaken the topographic effects and improve the inversion accuracy of spectral reflectance. It can be known from the quantitative analysis of vision, statistics, and spectrum that the topographic effects in the study area have been weakened to various extent. Teillet-regression correction model has the best correction effect. The mean value of the corrected image has been increased, the standard deviation has been decreased, and the correlation with the terrain was greatly reduced, therefore, the topographic effect has been reduced to the maximum extent, followed by VECA, Cosine-C and Minnaert correction models. Although C and SCS+C correction models have good correction effects, the correction results cannot be universally applied because the uncertainty of semi-empirical parameter c makes the correction results unstable. Without taking the influences of sky scattering and surrounding terrain into consideration, the Cosine, Cosine-B, Cosine-T, and SCS correction models have poor effects in the study area. Based on the previous research on the image topographic correction models such as Landsat, this paper takes the complex mountain area of Qulong as the research object to emphasize the application of different topographic correction models in ASTER image, to conduct effective evaluation of the correction results by means of visual effects, statistical results and spectral changes of surface features and to obtain a reasonable argument, so as to provide technical support for ASTER image data application in complex mountain areas.

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