Remedy of Spectral and Angular Uncertainties in the Estimation of Broadband Albedo from ETM+ Data

Qiming Qin*, Abduwasit Ghulam, Dongdong Wang, Lin Wang
(Institute of Remote Sensing and GIS, Peking University, Beijing 100871, P.R.China)

Abstract: High-resolution narrowband satellite data such as Enhanced Thematic Mapper Plus (ETM+) contain important information that enables us to map land surface albedos and interrelated phenomenon in high precision. In this paper, land cover of study area is classified into three classes as to surface features so that it is less expensive to eliminate the adjacency effect and to reduce the uncertainty of angular effects caused by Lambertian surface assumption as well as spectral compensation. Then, 6S code is used to atmospheric correction of ETM+ data and to achieve spectral reflectance of different target. Next, to remedy the spectral deficiency of ETM+ data, which has only six bands could be used to calculate broadband albedo, the bandwidths not included in ETM+ sensor are simulated. Finally, spectral albedo is calculated using the ratio of upwelling and downwelling radiance in every spectral range and narrowband to broadband albedo conversion is carried out in total shortwave region (0.3 4 μm) via radiative transfer simulations and conversion formula.

Key Words: 6S model, Quantitative remote sensing, Broadband albedo

1. INTRODUCTION

Broadband albedo is defined as the ratio of total upwelling radiative flux to total downward solar flux in the whole shortwave range (0.3 4 μm) . Land surface parameters such as albedo, vegetation indexes are essential and effective tools in ecological safety monitoring and surface dynamics exploration. It governs the energy balance between the land surface and the atmosphere; therefore, accuracy in the measurement of shortwave broadband albedos directly effect the quality of climate modeling. With the advances of remote sensing technology in the improvement of spatial, spectral and temporal resolution of satellite data, remote estimation of surface albedo becomes the more effective method than field measurements. Remote sensing sensors provide surface information in several discrete wavelengths. For example, Enhanced Thematic Mapper Plus (ETM+) has eight bands but only six bands in visible and infrared range can be used to albedo retrieval; MODIS Moderate Resolution Imaging Spectroradiometer observes the Earth's surface in 36 spectral area, among them the previous seven bands are used to provide three wide range albedo in (0.3-0.7, 0.7-3.0 0.3-5.0 μm) (Barnsley, 2000; Schaaf, 2002). Thus, How can we retrieve broadband albedo using narrow band satellite sensors? Irons (1988) and Zhao (2000) put forward a method to solve the problem that they preceded spectral remedy to discrete band data to albedo calculation.

High-resolution narrowband satellite data such as Landsat-7 Enhanced Thematic Mapper Plus (ETM+) contains important information that enables us to map accurately land surface albedo. The objectives of this paper are to estimate land surface broadband albedo using Landsat-7 ETM+ data. In this paper, 6S (Second Simulation of Satellite Signal in the Solar Spectrum) code is used to atmospheric correction of Landsat-7 ETM+ data and to simulate spectral regions not scanned by Landsat-7 ETM+ sensor. Narrowband albedo is calculated through ratio of reflected and incident irradiance in both measured and simulated bands and surface broadband albedo is estimated.

2. ATMOSPHERIC CORRECTION BY 6S

We used 6S code to eliminate those atmospheric perturbations with surface assumption of non-uniform Lambertian. Correction results show that spectrum brightness in visible bands gets increased. Conversely, noticeable reduction is evident in infrared band. The first case is easy to understand because of Rayleigh scattering and aerosols have a stronger effect on visible bands, and the radiance loss on the

---

*:Corresponding Author: Institute of Remote Sensing and GIS,Peking University, P.R.China,100871,E-mail: qmqin@pku.edu.cn, Phone:86-10-6275-1965; Fax: 86-10-6275-4855

surface-sensor path is remedied after correction. The case of infrared band seems illogical given the recognized fact that atmospheric correction enhances the reflectance attenuated by water vapor absorption. We attribute this result to the meteorological characteristics of the research area, which is extremely dry with annual rainfall of less than 34mm and an immense evaporation rate of 2595.3 mm (Ghulam, 2004). Therefore, it is normal since vapor contribution in infrared channels is negligible compared to that of dust and aerosol scattering. Due to the type of the surface which tends to increase the contrast between low and high reflective targets, the spectral response of these channels is broadened.

3 CALCULATION OF BROADBAND ALBEDO

Surface broadband albdeo is calculated by the following formula (Irons, 1988 and Liang, 2000).

$$A(\theta_i;\Lambda)=\frac{F_u(\theta_i;\Lambda)}{F_d(\theta_i;\Lambda)}=\frac{\int_{\lambda_1}^{\lambda_2}F_u(\theta_i;\Lambda)d\lambda}{\int_{\lambda_1}^{\lambda_2}F_d(\theta_i;\Lambda)d\lambda} \qquad (1)$$

Here, θ_i stands for solar zenith angle, Λ is denoted to be the waveband from wavelength λ_1 to wavelength λ_2, usually λ_1 and λ_2 are specified to 0.3 and 4 μm respectively, since the almost all of the solar energy is distributed within these spectra. F_u represents total upwelling flux (reflected irradiance, in $\mathrm{W\ m}^2$), F_d represents downward solar flux (incident irradiance, in $\mathrm{W\ m}^2$).

To estimate surface broadband albedo from satellite data, spectral compensation should be conducted to cover the whole wavelength range (0.3-4 μm). This is because satellite sensors only scan discrete narrow spectral regions. Spectral compensation for missing bands may be carried out by weighted mean spectral correction method (Zhao, 2000). In this method, the whole wavelength range is divided into certain number of spectral band regions as per the spectral characteristics of given satellite data, and unknown bands are simulated using weights of every band spectra. By the decomposition of equation (1)

$$A(\theta_i;\Lambda)=\frac{\sum_{i=1}^{n}F_{ui}}{\sum_{i=1}^{n}F_{di}}=\frac{F_{u1}}{\sum_{i=1}^{n}F_{di}}+\frac{F_{u2}}{\sum_{i=1}^{n}F_{di}}+\ldots+\frac{F_{un}}{\sum_{i=1}^{n}F_{di}} \qquad (2)$$

It can be transformed into

$$\begin{aligned}A(\theta_i;\Lambda)&=\frac{F_{d1}}{\sum_{i=1}^{n}F_{di}}\times\frac{F_{u1}}{F_{d1}}+\frac{F_{d2}}{\sum_{i=1}^{n}F_{di}}\times\frac{F_{u2}}{F_{d2}}+\ldots+\frac{F_{dn}}{\sum_{i=1}^{n}F_{di}}\times\frac{F_{un}}{F_{dn}}\\&=w_1\times\frac{F_{u1}}{F_{d1}}+w_2\times\frac{F_{u2}}{F_{d2}}+\ldots+w_n\times\frac{F_{un}}{F_{dn}}\end{aligned} \qquad (3)$$

Where, $\sum_{i=1}^{n}F_{di}$ is the total incident irradiance (in $\mathrm{W\ m}^2$) for the whole shortwave range, F_{u1}, F_{u2} … F_{un} and F_{d1}, F_{d2} … F_{dn} are the reflected and incident irradiance (in $\mathrm{W\ m}^2$) in a given spectral band i, respectively, w_1, w_2 … w_n stand for weighted coefficients of band i, respectively. $R_i = {F_{ui}}/{F_{di}}$ denotes to spectral albedo in band i.

Retrieving of surface broadband albedo needs multi-angular data scanned in successive spectral regions. Therefore, it is rather difficult without assumption and determining of some boundary conditions and spectral compensations of wavelengths which are not registered by the satellite since ongoing sensors provide only limited number of discrete band information in one or a few observing directions. Generally, estimation of surface albedo from single angle observed data is based on the Lambertian surface assumption. Yet, Kimes and Sellers (1985) concluded that the Lambertian assumption resulted in the error by 45%. Thereupon, BRDF is used to describe the non-Lambertian characters since surface spectrum is dependent on illumination and viewing directions. Albedo can be calculated by the hemispherical double integral of BRDF, hereby, the accuracy of albedo measurement is determined by the BRDF. However, it is also very expensive to map out the surface BRDF features. Considering these problems, we intend to find a simple method to handle uncertainties posed by angular effect. Results of continual experiments show that angular uncertainties could be reduced when the spectral characters of surface target is simplified. So, satellite image was classified into desert, water and vegetation using maximum likelihood classification method. We conducted radiative simulation and spectral corrections by 6S code via dividing the whole shortwave spectra into 12 representative bandwidths as per spectral bands of Landsat-7 ETM+. To avoid integral operation, here is used the ratio of upwelling and downward radiative flux instead of double integral of BRDF. It is not very difficult to see from the equation (3) hat estimation of narrow band spectral albedo becomes possible if we are able to predict F_{ui} since F_{di} and w_i can be measured by 6S simulation. Supposing that observed radiance by the satellite $L_{v,\lambda}$ it may be expressed by following function.

$$L_{v,\lambda} = L_{\lambda}^{\uparrow} + \tau_{\lambda} L_{g,\lambda} + L_{\lambda}^{d} \qquad (4)$$

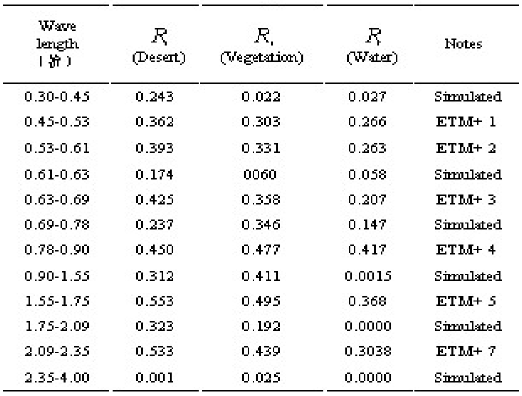
Where $L_{\lambda}^{\uparrow}$ is path radiation in $Wm^{-2}\mu m^{-1}sr^{-1}$ which is reflected by the atmosphere and do not characterize the surface τ_{λ} represents total transmittance in surface to sensor path. $L_{g,\lambda}$ is the radiation in $Wm^{-2}\mu m^{-1}sr^{-1}$ reflected by the surface target L_{λ}^{d} refers the adjacency effect in $Wm^{-2}\mu m^{-1}sr^{-1}$ contributed by surrounding pixels.

Items in the right site of the equation can be obtained by 6S code for both scanned and simulated spectral regions. Assuming the surface is inhomogeneous Lambertian target, then F_{ui} can be written as $F_{ui} = \pi \times L_{g,\lambda_i}$.

4 ESTIMATION RESULTS

To retrieve surface broadband albedo from Landsat-7 ETM+ data: first, the images were classified into typical surface types like desert, water and vegetation. Then, the whole shortwave spectra were divided into 12 spectral regions. Among them, six spectral sections match Landsat-7 ETM+ bands while the other bands match the wavelength range not measured by the sensor. The weights, downward flux and spectral albedos for each surface type are obtained along with synchronous meteorological information of the sensing time in both simulated and measured bands using 6S code(Table 1). Surface broadband albedo were estimated using above-mentioned method over Qira oasis, Xinjiang Uyghur Autonomous Region of China from Landsat-7 ETM+ data acquired on September 13, 1999. The results show that average albedo values for desert 0.344, 0.32 and 0.17 for vegetation and water.

Table 1 Calculation of Measured and Simulated Band Spectral Albedo



Wave length ([illegible])	R (Desert)	R_i (Vegetation)	R (Water)	Notes
0.30-0.45	0.243	0.022	0.027	Simulated
0.45-0.53	0.362	0.303	0.266	ETM+ 1
0.53-0.61	0.393	0.331	0.263	ETM+ 2
0.61-0.63	0.174	0060	0.058	Simulated
0.63-0.69	0.425	0.358	0.207	ETM+ 3
0.69-0.78	0.237	0.346	0.147	Simulated
0.78-0.90	0.450	0.477	0.417	ETM+ 4
0.90-1.55	0.312	0.411	0.0015	Simulated
1.55-1.75	0.553	0.495	0.368	ETM+ 5
1.75-2.09	0.323	0.192	0.0000	Simulated
2.09-2.35	0.533	0.439	0.3038	ETM+ 7
2.35-4.00	0.001	0.025	0.0000	Simulated

5. CONCLUSION AND DISCUSSION

Surface broadband albedo is the critical parameter in the climate and environmental modeling. It affects the regional and global climate via governing the energy exchange mechanism between the Earth and atmosphere. This paper developed a method to estimate surface broadband albedo from Landsat-7 ETM+ imagery. Using 6S code based simulations, Landsat-7 ETM+ data was corrected for atmospheric effects and spectral deficiency. Wavelengths not registered by Landasat-7 ETM+ sensor were simulated. Surface broadband albedo is estimated via the conversion of the narrowband spectral albedo. Although lacking of field observed data posed main limitation to validate the estimation results, it is evident from case study conducted in the Qira region in Hoten prefecture, Xinjiang Uyghur Autonomous Region of China that broadband albedo distribution corresponds to the practical status and surface features of study area. It can be seen from the figure 1 that broadband albedo demonstrated zonal distribution with surface target from water, vegetation surface, ecotone to bald desert; Because of the moisture greatly effects surface albedo, water and wetland albedo values are very low while desert manifested high albedo. We believe that the method developed in this paper is effective.

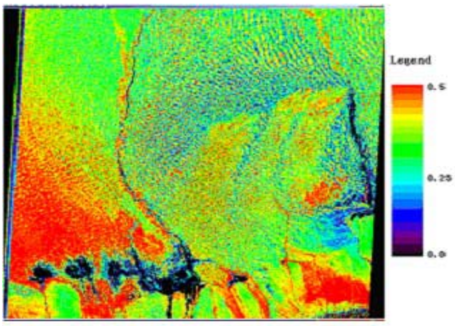


Figure 1 The Land Surface Broadband Albedo Distribution in Qira Oasis and Surrounding Region

ACKNOLEDGEMENTS

This research was supported by the Special Funds for Major State Basic Research Project Grant No: G2000077900 , Hi-tech Research and Development Program of China (Grant No.: 2001AA135110) and NSFC(40071061).

REFERENCES

Barnsley, M. J., Hobson, P. D., Hyman, A. H., Lucht, W. et al., 2000, Characterizing the spatial variability of broadband albedo in a semi-desert environment for MODIS validation. Remote Sensing of Environment 74, pp.58-68.

Ghulam, A., Qin Q., Zhu, L. and Abdrahman, P., 2004a, Satellite remote sensing of groundwater: quantitative modelling and uncertainty reduction using 6S atmospheric simulations. International Journal of Remote Sensing, 25 (23), in press.

Heather E. Henneman, Heinz G. Stefan, 1999, Albedo models for snow and ice on a freshwater lake. Cold Regions and Technology, 29, pp.31-48.

Irons J R, Johnson K J and Daughtry C S T., 1988, Estimating big bluestem albedo from directional reflectance measurements. Remote Sensing of Environment, 25, pp.185-199.

Kimes D S, Sellers P J, 1985, Inferring hemispherical reflectance of Earth′s surface for global energy budgets from remotely sensed nadir or directional radiance values. Remote Sensing of Environment, 18(2), pp.205-223.

Kreible, K T., 1979, Albedo of vegetated surface: its variability with differing irradiances. Remote Sensing of Environment, 8, pp.283-290.

Liang, S., 2000, Narrowband to broadband conversions of land surface albedo: 1 Algorithm. Remote Sensing of Environment, 76, pp. 213-238.

Schaaf, Crystal B., Gao, Feng., Strahler, Alan H., Lucht, Wolfgang et al., 2002, First operational BRDF, albedo nadir reflectance products from MODIS. Remote Sensing of Environment, 83, pp. 135-148.

Wenjing Zhao, Massayuki Tamura, Hidenori Takahashi, 2000, Atmospheric and Spectral Corrections for Estimating Surface Albedo from Satellite Data Using 6S Code. Remote sensing of Environment, 76, pp. 202-212