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To cite this article: L Roupioz *et al* 2014 *IOP Conf. Ser.: Earth Environ. Sci.* **17** 012270

Correction of sub-pixel topographical effects on land surface albedo retrieved from geostationary satellite (FengYun-2D) observations

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Abstract. The Qinghai-Tibetan Plateau is characterised by a very strong relief which affects albedo retrieval from satellite data. The objective of this study is to highlight the effects of sub-pixel topography and to account for those effects when retrieving land surface albedo from geostationary satellite FengYun-2D (FY-2D) data with 1.25km spatial resolution using the high spatial resolution (30 m) data of the Digital Elevation Model (DEM) from ASTER. The methodology integrates the effects of sub-pixel topography on the estimation of the total irradiance received at the surface, allowing the computation of the topographically corrected surface reflectance. Furthermore, surface albedo is estimated by applying the parametric BRDF (Bidirectional Reflectance Distribution Function) model called RPV (Rahman-Pinty-Verstraete) to the terrain corrected surface reflectance. The results, evaluated against ground measurements collected over several experimental sites on the Qinghai-Tibetan Plateau, document the advantage of integrating the sub-pixel topography effects in the land surface reflectance at 1km resolution to estimate the land surface albedo. The results obtained after using sub-pixel topographic correction are compared with the ones obtained after using pixel level topographic correction. The preliminary results imply that, in highly rugged terrain, the sub-pixel topography correction method gives more accurate results. The pixel level correction tends to overestimate surface albedo.

1. Introduction

Land surface albedo, defined as the fraction of incident solar radiation reflected by a surface, is a major parameter controlling the radiative forcing at the land surface and its energy balance. Accurate estimates of albedo at relatively high spatial and temporal resolution can help understanding the impact of climate change on land surface processes, especially in the Qinghai-Tibetan Plateau strongly affected by climate change. The plateau is characterised by an extreme relief and many studies have recognized the importance of topographic effects on albedo retrieved from satellite data [1]. It is then essential to account for topography induced effects to accurately estimate albedo from satellite observations in this area. Physically based albedo retrieval methods using remote sensing observations have been extensively developed at local and global scale [2]. In the case of global surface albedo product, e.g. MODIS or AVHRR, the effect of topography is quoted as an important source of error if retrieval assumes a horizontal surface [3]. Several methods have been developed to account for

IOP Conf. Series: Earth and Environmental Science **17** (2014) 012270 doi:10.1088/1755-1315/17/1/012270

topographic influence on satellite measured data at pixel level [4, 5, 6] and have been proved as successful in improving the quality of the corrected data [7, 8]. In the case of highly rugged terrain and when higher topographic information is available, it is of interest to consider the effect of sub-pixel topography. Besides, it has been highlighted that by neglecting the sub-pixel terrain variability, the albedo derived at different spatial resolutions can appear considerably different even though using the same model [9]. The issue is addressed in Wen et al. [10] where the sub-pixel topographic effects on the surface albedo estimation are illustrated and a correction factor is developed and applied. However, their study did not consider all the effects of topography, e.g. the irradiance coming from adjacent pixels is neglected. In addition, the data used by Wen et al. [10] were resampled from Landsat 30m resolution data to 1km pixel size, which may introduce errors in the conversion. The objective of the present study is to derive sub-pixel topographically corrected surface albedo from 1.25km resolution geostationary satellite FengYun-2D (FY-2D) data combined with a fine resolution Digital Elevation Model (DEM) from ASTER-GDEM2 taking into account the sub-pixel adjacency effect. Geostationary satellites have the advantage of high temporal observations comparing to orbiting satellites, which meet better the requirements of studies on climate and land surface processes on the Qinghai-Tibetan Plateau where clouds cover is often high.

2. Methodology

This section provides a theoretical outline of the approach developed in this study for the estimation of land surface albedo from atmospherically corrected radiance observations by the geostationary satellite. The method accounts for sub-pixel topography induced effects on the retrieval of land surface albedo and can be divided in two major steps as depicted in figure 1: (1) the correction of Bottom Of Atmosphere (BOA) satellite radiance for sub-pixel topographic effects and (2) the use of the terrain corrected BOA reflectance data for albedo retrieval.

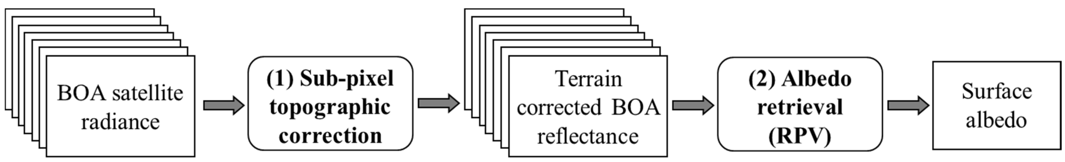

Figure 1. Main steps of land surface albedo retrieval using sub-pixel topographic correction.

2.1. Sub-pixel topographic correction

The topographic correction algorithm used in this study is the one proposed by Sandmeier et al. [11], adapted and applied to correction at sub-pixel level. In order to interpret topographic effects accurately, this method partitions the total solar irradiance for a tilted surface (E) in three components: direct (E_d), diffuse (E_f), and terrain irradiance (E_t). The diffuse irradiance is split into two components, the isotropic and the circumsolar diffuse irradiance [4]. From those components, assuming that the surface is Lambertian, the total solar irradiance affected by the topography is given as:

$$E = \Theta \cdot E_d \frac{\cos\theta_i}{\cos\theta_s} + E_f \left[k \frac{\cos\theta_i}{\cos\theta_s} + (1-k)V_d\right] + E_h \cdot V_t \cdot \rho_{adj} \quad (1)$$

In equation (1), E_h represents the total irradiance on a horizontal surface (W.m^{-2}), Θ is the binary coefficient to control cast shadow, k is the anisotropy index, V_d and V_t are the sky-view and terrain-view factors respectively, ρ_{adj} is the average reflectance of adjacent objects, θ_s is the solar zenith angle (rad) and θ_i is the angle of sun's incidence (rad) relative to the surface of the terrain. The first term of equation (1) shows the cosine law [5] applied to direct irradiance E_d on a horizontal surface and results in the amount of direct irradiance on a tilted target with a certain slope and aspect. The irradiance parameters E_h, E_d, E_f and k are estimated using MODTRAN.

Applied at the resolution of the DEM (30m), equation (1) allows to retrieve the topographically corrected surface irradiance which is then aggregated at the satellite pixel resolution (1.25 km). From the aggregated tilted surface irradiance and the satellite measured surface radiance, the surface reflectance is derived (figure 2). These surface reflectance measurements corrected for sub-pixel topography effects can then be used to estimate surface albedo.

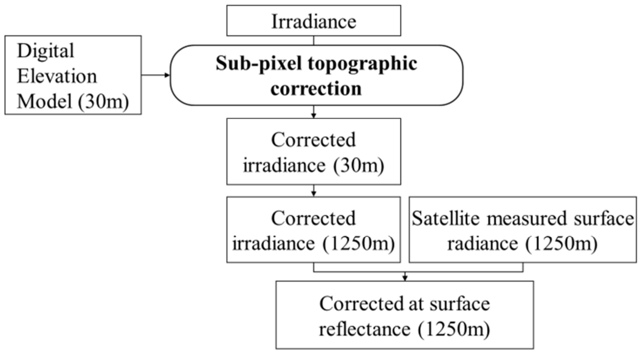

Figure 2. Sub-pixel topography correction steps.

2.2. Surface albedo retrieval

A geostationary satellite allows, over a certain period of time, to accumulate data at different view and illumination angles and therefore offers the possibility to generate the angular observations required as input of a BRDF (Bidirectional Reflectance Distribution Function) model, like the RPV model [12] used in this study. The RPV model is a parametric model that represents the surface anisotropy patterns by approximating the Bidirectional Reflectance Factor (BRF) of an arbitrary surface as a function of the physical and structural properties of this surface as well as the geometry of illumination and observation [13]. RPV expresses the surface bidirectional reflectance factor (ρ_s) as shown below.

$$\rho_s(\theta_s, \theta_v, \Phi; \rho_0, \Xi, k) = \rho_0 \rho_{afs}(\theta_s, \theta_v, \Phi; \Xi, k) \quad (2)$$

In equation (2), four parameters represent the main aspects of the BRDF shape by separating it into overall brightness (ρ_0), bowl-bell shaped anisotropy (k), degree of forward or backward scattering (Ξ), and hotspot (ρ_c) components [12]. The angular field of the surface BRF, ρ_{afs}, is expressed by:

$$\rho_{afs}(\theta_s, \theta_v, \Phi; \Xi, k) = M(\theta_s, \theta_v, k) F_{HG}(g; \Xi_{HG}) H(\rho_0, G) \quad (3)$$

Where θ_v and θ_s are the view and illumination zenith angles respectively. From equation (3), the RPV model can be described as a non-linear model consisting of a modified Minneart function (M), a Henyey–-Greenstein phase function (F_{HG}) to modulate the overall contributions in the forward and backward scattering and a function accounting for the hotspot (H). The inverted version of the model requires a set of bidirectional surface reflectance (BRF) values measured from satellite at different view and illumination angles along with some initial surface parameters values to retrieve the real surface parameters values. The retrieval algorithm delivers then the optimized set of the RPV model parameters characterizing the surface BRDF. The sub-pixel topographically corrected reflectance obtained from the previous step are then used to feed RPV. From the retrieved BRDF parameters the surface albedo is computed.

3. Satellite and ground data

3.1. FY-2D geostationary data

The satellite dataset consists of a series of hourly daytime FengYun-2D full scene images of August 29, 30, 31 2009. Only the visible band is used and the full scene is subset to an area covering part of the Qinghai-Tibetan Plateau where the ground stations used for the validation are located (figure 3). The visible band of FY-2D data spreads from 0.55 to 0.9 μm and is available at 1.25 km resolution. The high temporal measurement frequency of FY-2D allows for the accumulation of a proper reflectance angular sampling over a day [14]. The data are corrected for atmospheric effects prior being used in the presented approach.

3.2. In situ measurements

Ground measurements, from six radiative balance stations located on the Qinghai-Tibetan Plateau (figure 3), are used for evaluating the albedo retrieval results. The Nagqu (BJ) station lies at 4509 m in almost flat terrain with very sparse vegetation. The Nam Co station, at 4730 m, is surrounded by several mountain ranges, the Nam Co lake and an alpine steppe. The Qomolangma (Everest) station lies at 4293 m in a valley enclosed by steep slopes and covered with very sparse vegetation. The MS3478 and Amdo stations lie respectively at 4620 m and 4695 m in a relatively flat area with very sparse vegetation. The D105 station is the highest (5039 m) and North most, surrounded by a gentle relief and sparse vegetation [15].

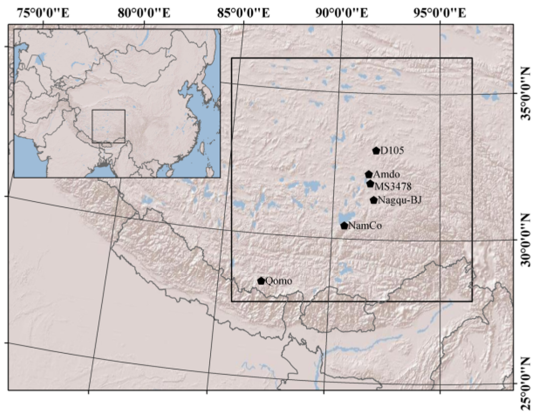

Figure 3. Study area and ground stations.

4. Results

4.1. Sub-pixel corrected reflectance

The correction method is run over the full FY-2D subset. The improvement brought by integrating the sub-pixel topography effects in the reflectance retrieved at 1.25 km is obvious as depicted in the figure 4, in which the three lower maps show: (1) a surface reflectance map without any topographic correction; (2) a surface reflectance map topographically corrected at pixel level, performed using the slope and aspect values degraded from 30m to 1.25 km pixel size; (3) a surface reflectance map topographically corrected at sub-pixel level.

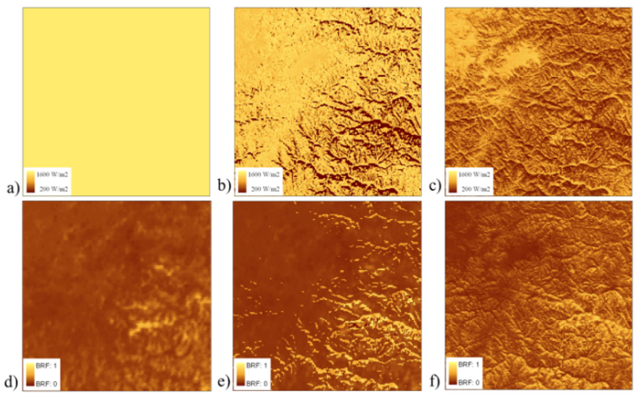

Figure 4. Comparison of the topographic correction at different level. (a) Irradiance with no topographic correction (W.m^{-2}), (b) Corrected irradiance at pixel level (W.m^{-2}), (c) Corrected irradiance at sub-pixel level (W.m^{-2}), (d) Surface reflectance with no topographic correction, (e) Corrected surface reflectance at pixel level, (f) Corrected surface reflectance at sub-pixel level.

It appears that in area where there is a significant topography, a higher level of terrain details is obtained when performing a sub-pixel topographic correction. Concerning the corrected solar irradiance, the main improvement is brought by a better resolution of the shadow binary coefficient and sky view factor. Further analysis is undergoing in a coming paper.

4.2. Surface albedo

Surface albedo is retrieved using the topographic correction at pixel level as well as the correction at the sub-pixel level, presented above, over gentle and rugged relief (figure 5). One should note that strict accuracy assessment of the retrieved albedo at the kilometric level by comparing with ground measurements is not feasible due to the scale mismatch between the two. Several studies stress that a direct comparison is very challenging because of this scale issue and the heterogeneity of the land surface at the satellite measurement scale that reduces the spatial representativeness of ground point measurements [16, 17]. Therefore, the comparison here is only meant to identify which method would give more reasonable result close to the reality.

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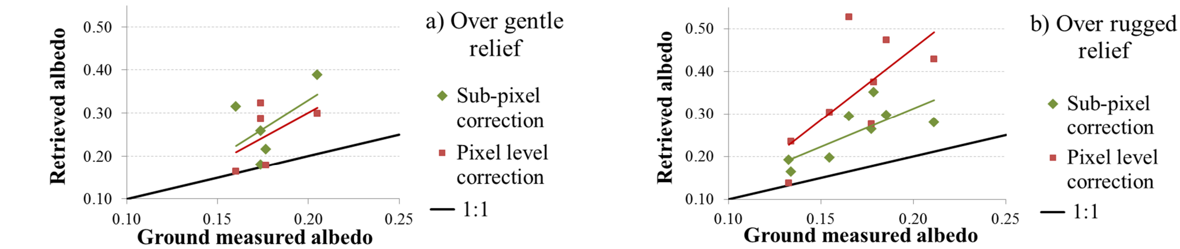

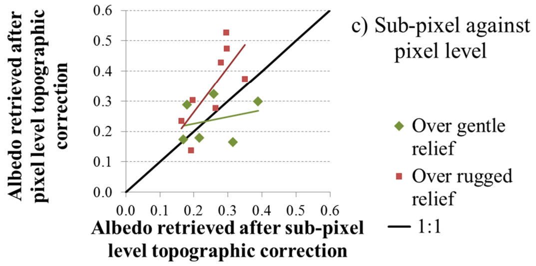

Figure 5. Comparison between the land surface albedo retrieved with pixel level topographic correction and albedo retrieved with sub-pixel level topographic correction: (a) in areas with gentle relief, (b) in rugged areas and (c) sub-pixel level against pixel level correction.

In areas with gentle relief (figure 5a), we can see that the results produced using the topographic correction at pixel and sub-pixel level are relatively similar, say no difference between the two treatments. On the contrary, in rugged areas, difference in the retrieved land surface albedo between pixel level topographic correction and sub-pixel level topographic correction is clearly observed (figure 5b). The sub-pixel topographic correction gives a better agreement with the ground measurements (with RMSE as 0.098) than using pixel level topographic correction (with RMSE as 0.207), the latter tends to over-estimate the land surface albedo (figure 5c). Similar results were also underlined in the study by Löwe et al. [18].

5. Conclusions

The presented methodology is made of two main steps, the sub-pixel topographic correction and the albedo retrieved after this correction. From the first step, it appears that the topographic correction at sub-pixel level leads to improved results of the irradiance and surface reflectance by allowing to integrate in a more detailed way the effects of the underlying topography. From the second step, applying a sub-pixel topographic correction in area presenting a substantial relief has been proven to bring a significant improvement to the retrieved land surface albedo from satellite observations. The main difference in estimating albedo from sub-pixel topographic correction, as compared to pixel level correction, comes from the more detailed irradiance estimates used to derive surface reflectance from measured radiance. When correcting measured radiance for topography effects, the shadow binary coefficient controlling the cast shadow is an essential parameter which defines if a certain pixel receives direct irradiance or not. As it is a binary parameter, it does not consider the possibility of partial shadowing of the pixel, while a significant fraction of the area covered by a kilometric pixel tagged as shadowed might actually see the sun. This can significantly affect the retrieved albedo values whereas 30m resolution computations are much less affected by this discrepancy. Those results are still preliminary and this study should be extended over a longer period of time to be able to conclude on the real dynamic of albedo. However, even if one of the major problems when comparing ground measurements to albedo retrieved from satellite data is the scale issue leading to disagreements in comparison, we can reasonably conclude that, in case of extreme topography, the sub-pixel topography correction method gives the best results. It is also important to quote that the computation time for running sub-pixel topography correction over an area as large as the Qinghai-Tibetan Plateau is significantly higher than using pixel level topographic correction. Then it would be interesting to define the topographic conditions for which the sub-pixel topographic correction significantly improves the land surface albedo retrieval in order to apply this correction efficiently when considering large areas.

Acknowledgments
The work described in this publication has been jointly supported by: the strategic research program KBIV "Sustainable spatial development of ecosystems, landscapes, seas and regions" funded by the Dutch Ministry of Economic Affairs and carried out by Wageningen UR, the EU-FP7 project CEOP-AEGIS (Grant nr. 212921) (http://ceop-aegis.org), the Chinese National Key Programme for Developing Basic Sciences (2010CB951703) and the National Natural Science Foundation of China (Grant No. 41175008). The Nagqu Station of Plateau Climate and Environment of CAREERI/CAS is very thankful for sharing the ground data.

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