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A comparison of methods for estimating fractional vegetation cover in arid regions

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ABSTRACT

We compared a set of methods for estimating the fractional vegetation cover (f_c) of sparse desert vegetation over an arid region of southern Xinjiang, China. Six kinds of remote sensing inversion models (an NDVI regression, a spectral mixture analysis (SMA), a pixel dichotomy model, a three-band maximal gradient difference (TGDVI) model and two modified TGDVI models) were used to derive f_c from remote sensing data, and the results were compared with f_c values measured in the field to select an appropriate model to derive the fractional cover of sparse desert vegetation in arid regions. The NDVI regression based on field f_c and the NDVI for the sampled pixels in September 2006 showed the highest precision, while the results of 2007 showed that the NDVI regression method is inappropriate for depicting vegetation characteristics in other growing season because the empirical model highly depend on the specified *in situ* measurement. The SMA approaches yielded higher precision than the other models, indicating that it is applicable for analysing the coverage of sparse desert vegetation. The pixel dichotomy model can yield a high precision based on finely detailed vegetation maps. However, it requires the measurement of many parameters. The TGDVI model is simple and easy to implement, and the values that it predicted for the coverage of high-density vegetation and barren areas were close to those measured in the field, but the f_c values of sparsely vegetated areas were underestimated. The predictions of the modified TGDVI models were close to the values measured in the field, indicating that these modified models can reliably and effectively extract information on the fractional cover of sparse vegetation in an arid region. We analyzed the models' sensitivity with respect to rainfall because the short-wavelength infrared bands used in the two TGDVI models proposed in this study are sensitive to moisture. The results showed that the modified TGDVI models' accuracy was not affected by increasing soil moisture content caused by rain. However, the NDVI regression, SMA and TGDVI were sensitive to the change of soil moisture content. Moreover, the two modified TGDVI models yielded negative values for water sources, such as reservoirs and rivers, implying that they are effective for characterising water bodies. However, the modified TGDVI models cannot predict f_c in snow- and glacier-covered regions, producing abnormally high rather than zero values. Additionally, the predictions before and after snowfall on the top of a mountain show a linear increasing relationship, suggesting that the short-wavelength infrared band may be useful to predict snow depth.

1. Introduction

Fractional vegetation cover (f_c) is an important variable for describing vegetation quality and reflecting ecosystem changes. It is also a controlling factor in transpiration, photosynthesis and other terrestrial processes (Gutman and Ignalov, 1998; Hirano et al., 2004).The f_c is also a sensitive indicator of land degradation and desertification in arid and semi-arid regions. However, the use of remote sensing to quantify the health and abundance of vegetation in arid environments is made difficult by the combination of the reflectance spectra of bright desert soils and the relatively weak spectral response of sparse vegetation. The aim of this study is to select an appropriate model to derive the f_c values of sparse desert vegetation in an arid region.

Three basic approaches are used in most studies for to estimate f_c values from remote sensing data: empirical methods, SMA and pixel dichotomy methods.

An empirical model establishes the empirical relationship between field observation data and radiance or vegetation indices, such as the normalised difference, soil-adjusted, modified soil-adjusted and transformed soil-adjusted vegetation indices (NDVI,

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SAVI, MSAVI and TSAVI, respectively), to derive f_c (Graetz et al., 1988; Dymond et al., 1992; Pickup et al., 1993; Wittich and Hansing, 1995; Shoshany et al., 1996; Purevdorj et al., 1998; Jakubauskas et al., 2000; Peter, 2002; Gitelson et al., 2002; Patel et al., 2007). Empirical models can produce good results for particular areas but are inappropriate to depict the vegetation characteristics of other regions because they are highly dependent on the specified *in situ* measurement.

SMA method estimates f_c at a sub-pixel level. It has been promoted as an effective method to derive f_c from multispectral and hyperspectral imagery in arid and semi-arid areas (Smith et al., 1990; Roberts et al., 1993; Kenneth et al., 2000; Theseira et al., 2002; Jingfeng and Aaron, 2005; Okin, 2007). This approach decomposes each pixel in an image into a linear component of a reference spectrum, referred to as an endmember. It can be either developed from laboratory or field spectra or derived directly from image data. Kenneth et al. (2000) have used a SMA method based on hyperspectral imagery and three vegetation indices (NDVI, SAVI and MSAVI) to derive the abundance of vegetation in sparsely vegetated areas in an arid environment. They reported that SMA provided significantly better results, with an R^2 of 0.74. More recently, Guerschman et al. (2009) have developed an SMA approach using the NDVI and the cellulose absorption index (CAI) to estimate the f_c of photosynthetic vegetation (f_{PV}), non-photosynthetic vegetation (f_{NPV}) and bare soil (f_{BS}).

Pixel dichotomy models are based on the assumption that pixels are composed of two parts: vegetation-covered and non-vegetation-covered areas. Based on the pixel dichotomy model, Gutman and Ignalov (1998) have presented a uniform-pixel model and mosaic-pixel models (including a dense vegetation model, a non-dense vegetation model and a mixed-density vegetation model) and estimated global f_c from NOAA AVHRR data using the dense vegetation model.

Shihao et al. (2003) have developed a new method referred to as TGDVI to estimate f_c according to the characteristics of soil and vegetation spectra and the definition of the crown cover fraction.

In addition to the methods described above, decision tree classification and artificial neural networks can also be used to estimate vegetation coverage. Using AVHRR and MODIS data, Hansen et al. (2002a,b) have established a decision tree based on the reflectance in red and near-infrared and the NDVI to estimate tree cover in Africa. Goetz et al. (2003) have estimated the tree vegetation fraction using the classification tree method with an accuracy of 97.3%, indicating that this method is suitable for estimating tree vegetation cover. Boyd et al. (2002) have explored the accuracy of vegetation indices, regression analysis and neural networks for estimating coniferous forest cover across the United States Pacific Northwest. In their study, all methods achieved a similar accuracy of forest cover estimation.

In the present study, we developed two simple models based on differences in the spectra of vegetation and bare soil in the red (R), near-infrared (NIR) and short-wave infrared (SWIR) bands. These models are similar in form to the TGDVI model of Shihao et al. (2003). The f_c is calculated by identifying the gradient differences of each pixel in three bands and then scaling the value using the gradient differences calculated for pixels with 100% cover. We analyzed the differences in accuracy and applicability among a SMA method, an NDVI regression model, a pixel dichotomy model, the model of Shihao et al. (2003) and the two models that we developed, and each model's predictions was compared with field survey results.

2. Materials and methods

2.1. Study site

We selected two study sites in the middle and lower reaches of the Tarim River Basin in the northern part of the Taklimakan Desert in China. These study areas are located in the continental warm temperate zone and have an extremely arid desert climate with annual rainfall of less than 50 mm and a potential evaporation of more than 2000 mm per year. Along the main channel of the Tarim River, there are three types of natural vegetation: forest, shrubbery and the herbaceous community. The structure of the vegetation is simple, and its distribution is sparse. The dominant riparian forest species is *Populus euphratica*, and the shrubs in the area mainly consist of *Tamarix hispida*.

The first experimental site, Aqik, is located at the middle reach of Tarim river, approximately 50 km southwest of Yuli county at 86°15′48″N, 41°20′18 E. The second site, Yengisu, is located at the lower reach of Tarim River, approximately 47 km southeast of Tikanlik town at 87°41′32″N, 40°38′30E (see Fig. 1).The vegetation cover at Aqik site varies between natural and cultivated areas. Fig. 2a is a photograph of natural vegetation covered area of Aqik, where the ground cover is characterised by *Populus euphratica* forests accompanied by a few scattered individuals of *Phragmites*, *Tamarix hispida* and *Glycyrrhiza inflata*. In contrast, there is a less ground cover at the Yengisu site (Fig. 2b), where the groundwater level is deeper because floodwater does not reach this area, and exchange between the surface water and the groundwater is reduced. The salt accumulation in the soil at this site is severe, and the plant community is characterised by an open shrub canopy dominated by *Tamarix hispida*,*Lycium ruthenicum*

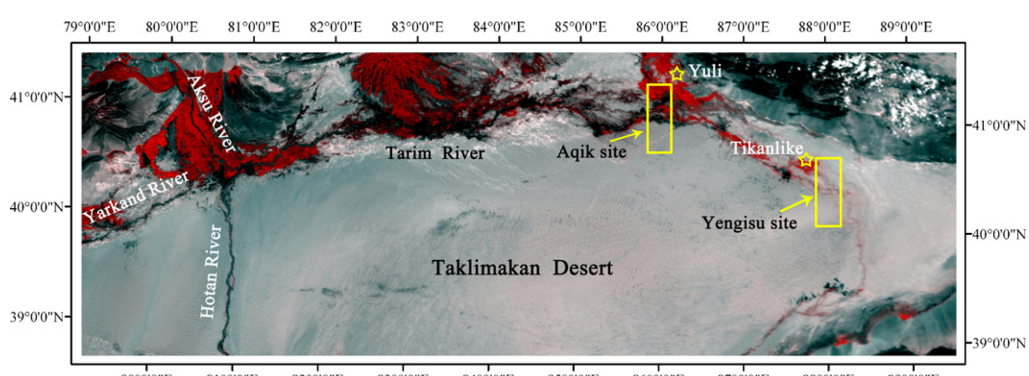

Fig. 1. Locations of study area in the Tarim River Basin. The study sites are noted by yellow rectangles. Aqik site is located at the middle reach of Tarim river, approximately 50 km southwest of Yuli county town (noted by yellow star). Yengisu is located at the lower reach of Tarim River, approximately 47 km southeast of Tikanlik town (noted by yellow star). The MODIS (Moderate Resolution Imaging Spectroradiometer) image covering Tarim River Basin (dated 10 September 2006) were acquired from the Earth Resources Observation and Science Centre website (http://edcsns17.cr.usgs.gov/EarthExplorer/). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of the article.)