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# Evaluating MODIS soil fractional cover for arid regions, using albedo from high-spatial resolution satellite imagery

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Broad-scale high-temporal frequency satellite imagery is increasingly used for environmental monitoring. While the normalized difference vegetation index (NDVI) is the most commonly used index to track changes in vegetation cover, newer spectral mixture approaches aim to quantify sub-pixel fractions of photosynthesizing vegetation, non-photosynthesizing vegetation, and exposed soil. Validation of the unmixing products is essential to enable confident use of the products for management and decision-making. The most frequently used validation method is by field data collection, but this is very time consuming and costly, in particular in remote regions where access is difficult.

This study developed and demonstrates an alternative method for quantifying land-cover fractions using high-spatial resolution satellite imagery. The research aimed to evaluate the bare soil fraction in a sub-pixel product, MODIS Fract-G, for the natural arid landscapes of the far west of South Australia. Twenty-two sample regions, of 3400 sampling points each, were investigated across several arid land types in the study area. Albedo thresholds were carefully determined in Advanced Land Observing Satellite Panchromatic Remote-sensing Instrument Stereo Mapping (ALOS PRISM) images (2.5 m spatial resolution), which separated predominantly bare soil from predominantly vegetated or covered soil, and created classified images. Correlation analysis was carried out between MODIS Fract-G bare soil fractional cover and ALOS PRISM bare soil proportions for the same areas. Results showed much lower correlations than expected, though limited agreement was found in some specific areas. It is posited that the Moderate Resolution Imaging Spectroradiometer (MODIS) fractional cover product, which is based on unmixing using the NDVI and a cellulose absorption index (CAI) proxy, may be generally unable to separate soil from vegetation in situations where both indices are low. In addition, separation is hampered by the lack of ‘pure pixels’ in this heterogeneous landscape. This suggests that the MODIS fractional cover product, at least in its present form, is unsuited to monitor sparsely vegetated arid landscapes.

## 1. Introduction

High-temporal frequency remotely sensed data have received much interest for broad-scale environmental monitoring. Such data are acquired daily by satellite-mounted sensors over most of the earth’s surface, but their low spatial resolution, of 250 m or greater, limits the detail of land-cover information that can be gained. Common approaches to

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interpreting the mixed reflectance signal of such low-spatial resolution imagery include image indices such as NDVI and sub-pixel modelling.

A number of sub-pixel models have been developed from spectral mixture analysis (SMA) early in the history of remote sensing (Huete 1986; Smith et al. 1990; Settle and Drake 1993) to multiple endmember spectral mixture analysis (MESMA) (Roberts et al. 1998) and, more recently, to relative spectral mixture analysis (RSMA) (Okin 2007). Sub-pixel analysis generally separates the data into two to four fractions such as photosynthesizing vegetation (PV), nonphotosynthesizing vegetation (NPV), bare soil (BS), shadow, snow, or other components of interest.

In Australia a MODIS fractional cover product has been developed for monitoring of the northern tropical savanna region (Guerschman et al. 2009). A time series of the product, which unmixes PV, NPV, and BS from the data space defined by NDVI and a cellulose absorption index (CAI) proxy, is made available for the entire Australian continent at 500 m spatial resolution (https://remote-sensing.nci.org.au/u39/public/html/modis/fractionalcover-clw/index.shtml).

For the purpose of this study, we named this product MODIS Fract-G, to distinguish it from other MODIS fractional cover products (G refers to its author, Guerschman). This fractional cover product is proposed to be used across the whole of Australia (Stewart et al. 2011). However, the Australian continent contains a great diversity of climate, soil, and vegetation types (Government of South Australia 2007). To have confidence that MODIS Fract-G gives a true estimate of land cover fractions in regions other than the northern savanna, wider validation is essential.

Limited quantitative validation of MODIS Fract-G was conducted during the development of the product, based on field-collected grassland curing data. This separated dry biomass from green biomass, which were equated to PV and NPV and scaled to 100%. Bare soil values were not available and therefore not explicitly considered in the validation (Guerschman et al. 2009). Additional field-based validation of MODIS Fract-G is in progress and a handbook of methods for field measurement of fractional ground cover has been produced (Muir et al. 2011). In addition, as part of the national Terrestrial Ecosystems Research Network AusCover programme, field data are being collected across Australian rangelands in a format capable of validating satellite data (Foulkes et al. 2011) and field-based evaluation has been performed in the states of Queensland, New South Wales, and to a very limited extent in South Australia (Guerschman et al. 2012). No field validation took place in our region of interest, which covers over 250,000 km$^2$ of the South Australian arid zone.

Validation of satellite image-derived land cover products is most commonly based on field-collected data, using standardized and detailed methods. Field-based validation has several limitations. It is time-consuming and expensive because a large number of widely dispersed field estimates is required (Watson and Novelly 2004; Watson, Novelly, and Thomas 2007). Matching the scale of field data with that of broad-scale remotely sensed data remains challenging (Barnsley et al. 2000; Liang et al. 2002; Morisette, Privette, and Justice 2002; Turner et al. 2004, 2006; Guerschman et al. 2012). Observer differences may introduce additional variation (Friedel and Shaw 1987a, 1987b) and the extent to which the field observations can be extrapolated to the wider landscape is unknown.

This research proposed a different approach for validation, namely the use of high-spatial resolution satellite imagery.

High-spatial resolution imagery provides an objective record in time of land cover and has considerable potential for the validation of coarser-resolution image products. It has been used for the validation of MODIS products in such diverse environments as the Arctic

Circle and southern Africa (Morisette et al. 2003; Montesano et al. 2009). Using satellite data for validation has the advantage that images can be chosen from archives, which enables comparisons between test and validation data for corresponding dates across wide regions, and a large number of revisit dates are on offer. Sample locations can be selected anywhere in the landscape within the imagery and spatially comprehensive assessments made, reducing or eliminating the need for extrapolation from a few field sites. High-spatial resolution satellite data for comparison can also be selected for a single date across an entire satellite path, reducing variables by supplying digital information acquired under identical weather and reflectance circumstances over a very large area, which is nearly impossible to achieve in field assessments due to geographic and time constraints.

This study aims to use high-spatial resolution satellite data to evaluate the bare soil fraction of MODIS Fract-G over the arid regions of South Australia. The bare soil fraction is considered particularly important in the assessment and monitoring of arid and semi-arid land conditions, as it is an indicator of erosion risk and land degradation (Tongway 1995; Nagler, Daughtry, and Goward 2000).

Soil exposure, or conversely vegetation cover, can be detected in satellite imagery where individual trees and shrubs can be distinguished, which allows relative bare soil and cover estimates to be made, similar to those made in the field. This study used the albedo in 2.5 m-spatial resolution ALOS panchromatic imagery as the indicator of relative soil and cover fractions.

Using albedo as indicator of land condition is not new. It has been used to detect changes in land cover (Otterman 1977; Robinove et al. 1981) and to detect degradation from overgrazing (Otterman 1974; Musick 1986). The spatial resolution of Landsat data available for those studies did not allow detection of individual trees and shrubs in the imagery and therefore still required field validation, although aerial photography was at times employed (Foran 1987).

Terrestrial hemispherical photographs revealed a positive relationship between albedo values and soil exposure in a study of broadband albedo for MODIS validation (Barnsley et al. 2000).

Considerable work in Australian arid grazing lands has shown that the reflectance of dry desert soils is consistently higher than that of plants, plant debris, and dry microphytic crust. This is particularly evident in the visible red portion of the spectrum as in Landsat 5TM band 3 (red, 0.62–0.69 μm) or its equivalent in earlier Landsat studies, Landsat MSS band 5 (red, 0.60–0.70 μm) (Graetz and Gentle 1982; Pech et al. 1986; Ringrose and Matheson 1987). ALOS panchromatic imagery, at 0.52–0.77 μm, represents this region of the electromagnetic spectrum.

## 2. Methods

### 2.1. *Study area*

The study was conducted within the 261,180 km$^2$ Alinytjara Wilurara Natural Resources Management (AWNRM) region of South Australia (Figure 1).

This region is a largely natural, mostly non-pastoral, arid area, managed by the traditional Aboriginal owners in cooperation with the South Australian government.

The climate is warm to hot in summer, with annual mean maximum temperature ranging from 24°C along the coast to 29°C inland; and cool to cold in winter with annual mean minimum temperature of 11°C along the coast to 13°C inland (BOM 2012). Mean annual rainfall varies from 250 mm in the south to 150 mm in the central region, and up to 300 mm

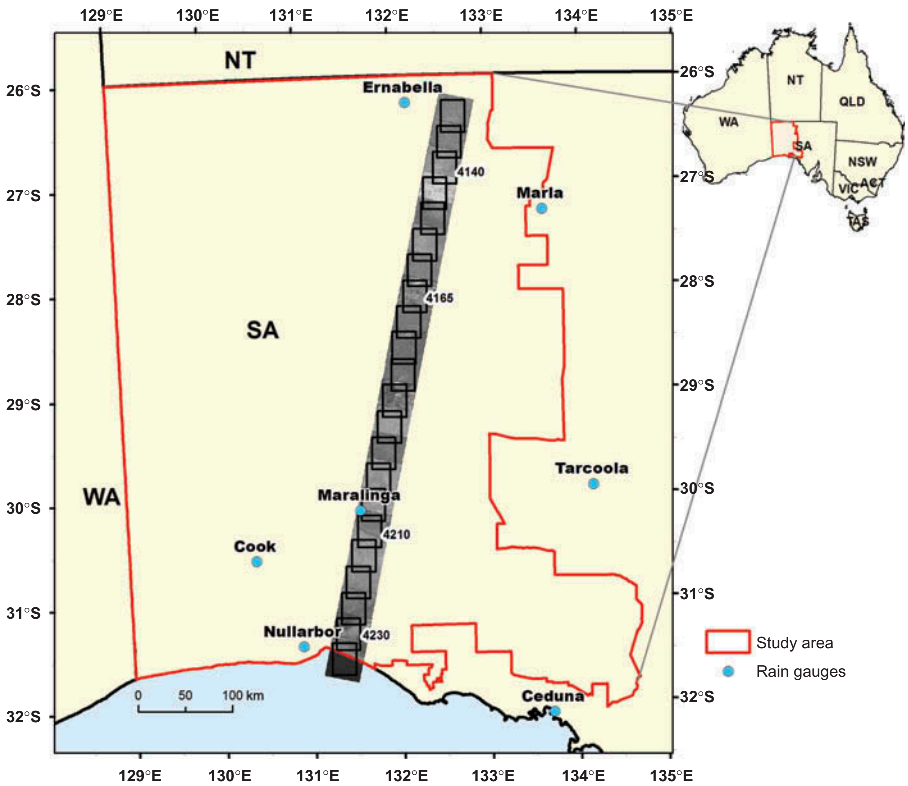


Figure 1. Alinytjara Wilurara Natural Resources Management region forming the study area in South Australia. The ALOS PRISM satellite path used in the study and the 22 25 × 34 km sampling regions north to south within this path are shown. Relevant rain-recording stations are indicated.

in the ranges in the north. Rainfall is non-seasonal and intermittent, often marked by high-rainfall events following long periods of drought. Rainfall records are available but the paucity of recording stations across this vast region has resulted in imprecise interpolation maps (Chappell et al. 2013). Evaporation is extremely high, with an annual mean evaporation of 2400 mm in the south and 4000 mm inland (Government of South Australia 2007).

The landscape consists of a wide variety of landforms and vegetation communities. Dominant landscape features are the Central Ranges in the north descending into alluvial fans and plains with scattered granitic inselbergs and rocky outcrops. The ranges, outcrops, and inselbergs carry a sparse cover of hummock grasses (*Triodia* spp.) and sporadic tall shrubs. The alluvial fans are characterized by low open shrubland of a variety of *Eremophila* and *Senna* shrub species, while the plains support a low woodland of mulga (*Acacia aneura*), needlebush (*Hakea* spp.), and some desert oak (*Allocasuarina decaisneana*). *Eucalyptus* species fringe the dry watercourses.

South of the ranges and plains lie the red dunefields of the Great Victoria Desert. Parallel red dunes rise up to 30 m high and may extend unbroken for up to 100 km. Vegetation on the dunes includes hummock grasses (*Triodia* spp.) and needle bush and sparsely distributed mallee (*Eucalyptus* spp.). Vegetation on the inter-dune flats consists of shrublands of mallee with hummock grass understory and mulga over tussock grasses (*Enneapogon* and *Aristida* spp.). The southernmost part of the study region includes part of the Nullarbor Plain, an extensive flat limestone region carrying bluebush (*Maireana* spp.) and saltbush (*Atriplex* spp.). It is fringed by mallee scrub and ends in a coastline of steep calcarenite cliffs interrupted by areas of white coastal dunes and sandy beaches.

Such a varied landscape naturally contains a variety of soils, including red–brown loams on the northern alluvial plains, red siliceous desert sands of the central region, pale calcareous loamy soils on the Nullarbor, and white sands along the coast. Despite this variety, the common feature is that all soil types present are characterized as 'bright' soils (Viscarra Rossel et al. 2011). Brightness represents the principal source of spectral variance among soils (Huete and Escadafal 1991), and highly reflective soils, referred to as bright soils, are said to occur over most of arid Australia (e.g. Pickup 1989); a fact that is taken advantage of in this research.

Fire is a common occurrence in the study region (Haydon, Friar, and Pianka 2000; Turner, Ostendorf, and Lewis 2008), and fire scars can be readily seen in both moderate- and high-resolution satellite imagery. No permanent surface water is present, although flooding of the dry salt lakes and ephemeral creeks occurs infrequently after heavy rain.

Ecosystems in the region are under pressure through increased mining activities and incursions of feral flora and fauna species, which necessitates close and frequent monitoring for management.

### 2.2. *Estimating the bare soil fraction at high spatial resolution*

The overall aim of this research was to evaluate the bare soil fraction of MODIS Fract-G for the South Australian arid region. To achieve this we developed a method to discriminate the bare soil fraction in high-spatial resolution ALOS PRISM imagery.

The PRISM data were acquired by the sensor on board the ALOS satellite in the wavelengths 0.52–0.77 μm at 2.5 m spatial resolution, over a 35 km swath. ALOS had a revisit cycle of 46 days. A single evaluation date of 10 March 2007 (Table 1) was chosen guided by availability of prolonged dry period cloud-free ALOS PRISM imagery over the study region. The data were in the form of at-sensor radiance recorded as eight-bit digital numbers.

#### *2.2.1. ALOS PRISM scene selection*

For the purpose of this study the following scene selection criteria were used, aiming to maximize the strength and generality of the validation.

(1) The selected scenes covered as many different landscapes and soils as possible.
(2) All scenes were acquired on the same date.
(3) Scenes did not include strongly contrasting soil types.
(4) No significant rainfall was recorded in the two to three months preceding the acquisition date.

An ALOS acquisition path across the study site (path 55, 10 March 2007) (Table 1, Figure 1) was chosen because it covers a wide variety of landscapes including grazed paddocks in the north, linear red sand dunes in the centre, and calcareous saltbush plains and coastal sand dunes in the south. Twenty-two PRISM scenes were available, of which two (scenes 4210 and 4225) were rejected as they did not meet criterion 3.

In regard to criterion 4, rainfall records were available for meteorological stations widely dispersed across the study area, though not all are quality controlled (BOM 2012)

Table 1. Satellite image acquisition dates and attributes.

| Satellite data | Acquisition periods | Spatial res. (m) | Wavelength (μm) | Path | Tiles |
|---|---|---|---|---|---|
| MODIS Fract-G 041 | 10 February 2007–25 February 2007 | 500.0 | – | – | – |
| MODIS Fract-G 049 | 18 February 2007–5 March 2007 | 500.0 | – | – | – |
| ALOS PRISM | 10 March 2007 | 2.5 | 0.52–0.77 | 55 | 4130–4235 |

(Table 2). The most significant rainfalls in the months preceding 10 March 2007 were recorded on 19 and 20 January 2007 at Tarcoola, which is located 300 km east of the southernmost sampling sites and too remote to have an effect on these, and at Ernabella, 50 km west of our northernmost sampling site (Figure 1). Depending on the spatial extent of the Ernabella rain, this may have affected vegetation in the northernmost sampling sites, although during the summer months the high evaporation rate likely minimized this. Other recorded rainfalls were too low to have an effect on vegetation growth (Table 2). No other effective rain was recorded from mid-July 2006 to the evaluation date in March 2007. Rain did fall within days thereafter, resulting in a March monthly rainfall of 63 mm and annual (2007) rainfall of 249 mm (Maralinga), but both evaluation- and evaluated imagery were acquired entirely prior to these rain events and therefore represent prolonged dry period imagery.

Australian arid zone atmospheric conditions are generally clear and are likely to be very similar along a single date path and cloud-free images were selected, hence radiometric and atmospheric corrections were deemed not necessary for the ALOS PRISM imagery. The sun angle contribution to the brightness of the scenes was uniform across all scenes because the acquisition dates were the same. This applied to all satellite imagery used in this study.

All satellite data (Table 1) were co-registered and re-projected using nearest neighbour resampling to South Australian Lambert Conformal Conic.

#### *2.2.2. Sampling regions within scenes*

A rectangular sampling grid of 500 × 500 m cells in 50 columns × 68 rows was created. This 25 × 34 km grid was placed within each of the 20 PRISM scenes so the cells coincided with the MODIS Fract-G 500 m raster. The size of this grid was chosen to give consistent sampling size whilst including the maximum practicable rectangular sampling area within each 35 km ALOS PRISM scene (Figure 1).

#### *2.2.3. Thresholds for soil exposure*

For this study we defined soil cover as all vegetative material, alive, senescent, or in the form of plant debris. This includes microphytic crust, a living organism, which darkens bright soil when intact. Clear boundaries between such cover and bare soil do not, however, exist within the Australian natural arid zone landscape, and pure pixels are uncommon, even at 2.5 m ground resolution. To differentiate between these fractions, pixels are assigned to categories of predominantly covered soil or predominantly bare soil using an albedo threshold.

Table 2. Rainfall records (mm) relevant to the study area. Evaluation date is in bold. (N)QC = (not) quality controlled.

| Station<br>2007 | Ernabella<br>NQC | Marla<br>QC | Cook<br>QC | Maralinga<br>QC | Tarcoola<br>NQC | Nullarbor<br>NQC | Ceduna<br>QC |
|---|---|---|---|---|---|---|---|
| 18 January | 1 | 6 | – | – | 6.4 | – | – |
| 19 January | 28.8 | 3.5 | – | – | 62.2 | – | – |
| 20 January | 1.4 | 4.7 | – | 0.2 | 19.8 | – | – |
| 21 February | – | – | – | – | 21.6 | – | – |
| 25 February | – | – | 2 | 8.2 | 2 | – | – |
| 1 March | 0.8 | – | 7 | 0.6 | 1.2 | – | – |
| 02 March | – | – | 4 | – | – | – | – |
| **10 March** | **–** | **–** | **–** | **–** | **–** | **–** | **–** |
| 13 March | – | – | 11.2 | 2.2 | – | 1.4 | 2.2 |
| 14 March | – | – | 28.6 | 11.8 | 1.4 | 27.4 | 4.2 |
| 19 March | 0.4 | 1.2 | – | 4 | 26.6 | – | – |
| 20 March | 0.4 | – | 6 | 23.4 | – | 16.2 | 42.2 |
| 21 March | 5.4 | – | – | 1.6 | 1 | 0.4 | 2 |

Figure 2. Bare soil colour of the minor roads is similar to that in the surrounding landscape (image: E Lawley – 7/12/2011, 3:30 pm, West of Umuwa).

While the Alinytjara Wilurara landscape is largely without built or invariant features, it is traversed by a small number of survey tracks and unpaved roads leading to small settlements or mining sites. These roads are clearly visible in the ALOS PRISM imagery. The surface material of these roads, providing they are minor tracks not ameliorated by roadworks nor overgrown by grasses, is identical to that of the bare soil surface in the surrounding landscape (Figure 2).

The brightness of these bare soil roads can therefore be used as a guide to determine an albedo threshold value. Thresholds were determined for each 850 km$^2$ sampling area by creating a bare soil/cover classified image using an approximate threshold, visual inspection of the roads in the classified image, and iteration until satisfied that the roads were adequately classified and delineated in the image (Figures 3(*a*)–(*d*)).

Soils in the AWNRM region are all considered bright soils (Pickup 1989; Viscarra Rossel et al. 2011), but some variations in soil albedo naturally occur across the landscape, and therefore a unique threshold was determined for each sampling area. Some minor variation in bare soil albedo within the sampling areas was considered acceptable for the purpose of this study. Images spanning very strongly contrasting soil types were excluded from the analysis, because the different soil reflectance would have required more than one threshold for effective discrimination within those sampling areas. In environments with very heterogeneous soil colours, stratification within the sampling regions and the use of different albedo thresholds may be advantageous.

### *2.2.4. Classification and calculation of bare soil fractions*

The thresholds for each sampling area were used to classify all PRISM 2.5 m pixels with values equal to or below the threshold as soil cover, and all pixels with values above the threshold as bare soil (Figure 3(*e*)). Thresholds ranged from 120 to 140, with the highest value on the Nullarbor calcareous soils. The percentage of PRISM pixels classified as bare soil was calculated for each of the 3400 (500 m × 500 m) sample cells within each sampling area (Figure 3(*f*)). These percentages of bare soil were then available to be used to evaluate the MODIS Fract-G bare soil estimates.

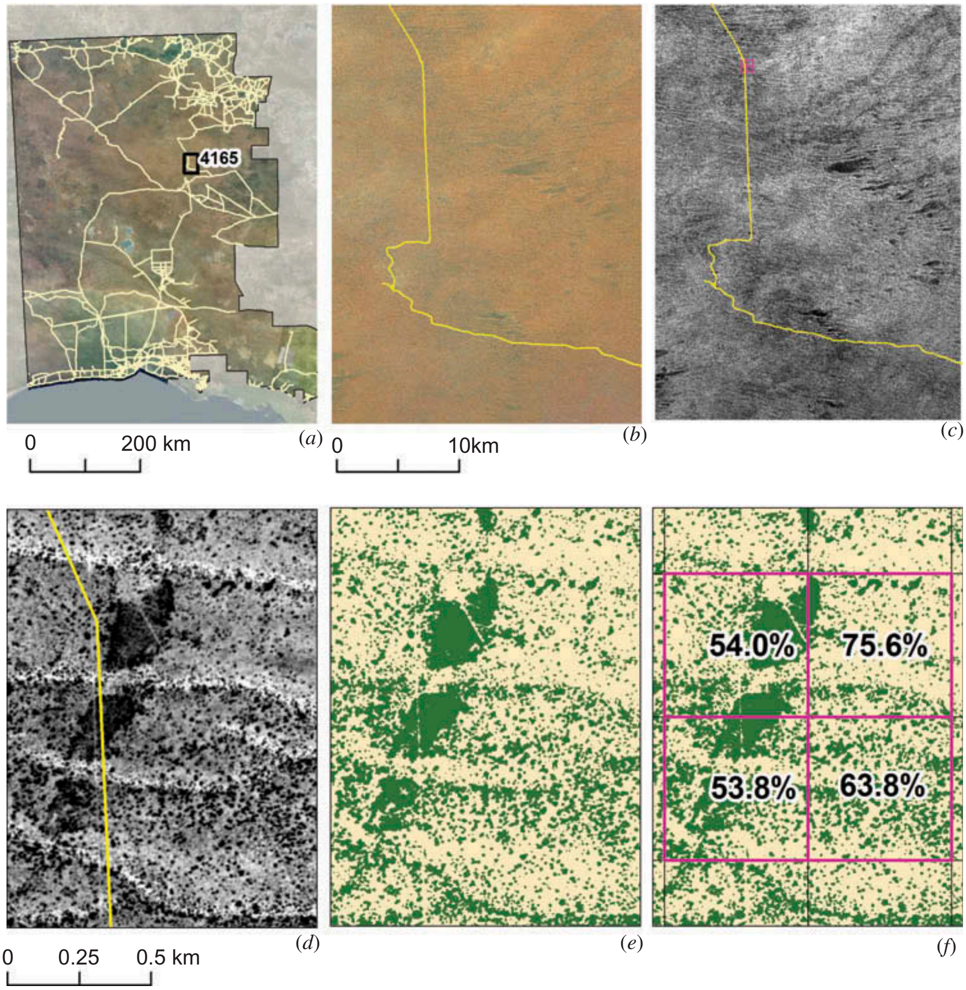


Figure 3. Illustration of the procedure followed to determine the bare soil albedo threshold and percentage of bare soil. (*a*) ALOS scene selected, here 4165 in the Great Victoria Desert region of the AWNRM. (*b*) ALOS sampling area 4165 shown in natural colour with overlay of known road. (*c*) Same area in ALOS panchromatic 2.5 m, indicating subset in magenta. (*d*) Enlarged subset, showing parallel east–west dune crests crossed by minor roads that were used to determine the reflectance threshold for sampling region 4165. (*e*) Same enlargement classified using the threshold; bare soil – yellow, cover – green. (*f*) The image with 500 m grid and percentage bare soil per cell calculated.

Although retrospective field verification is not possible, the use of red band reflectance to distinguish bare soil from covered soil in similar dry desert conditions has been previously demonstrated by field sampling (e.g. Graetz and Gentle 1982).

### *2.3. The MODIS fractional product to be evaluated*

The product to be evaluated was MODIS Fract-G, a time series of fractional cover produced from MODIS MOD43 nadir bidirectional reflectance distribution function

(BRDF)-adjusted reflectance (NBAR) data, and developed for the northern savanna region of Australia. The unmixing scheme of MODIS Fract-G is based on two indices. It uses the NDVI, created from red and near infrared (NIR) reflectance, to reveal the PV fraction (Tucker 1979) and the cellulose absorption index (CAI), created from two short-wave infrared reflectances, to reveal the NPV fraction (Nagler, Daughtry, and Goward 2000). The third dimension in this three-dimensional data space is the bare soil fraction (BS). The unmixing in the NDVI/CAI space is constrained to produce fractions of PV, NPV, and BS totalling 100% (Guerschman et al. 2009).

MODIS Fract-G images represent 16-day compositing periods with sequential periods overlapping by 8 days. The images are tagged day of year (DOY), by the first date of the 16-day period.

We downloaded the product for the year 2007 from <http://www-data.wron.csiro.au/rs/MODIS/products/Guerschman_etal_RSE2009/>, and extracted the bare soil layers.

We selected from this two sequential MODIS Fract-G bare soil images for dates close but prior to the ALOS PRISM acquisition date (Table 1). The MODIS acquisition period being entirely prior to the PRISM acquisition date ensured that no events after this acquisition date, such as rainfall or fire, influenced the MODIS Fract-G composite. The MODIS Fract-G 049 image was chosen for evaluation because it is the image closest to the PRISM acquisition date. The preceding image, MODIS Fract-G 041, was used to appraise the internal consistency of the MODIS Fract-G time series.

The MODIS Fract-G product was re-projected several times: from satellite projection to MODIS sinusoidal and then to Lambert Conformal Conic geographic systems. To counteract the geolocation errors this might cause, we applied a smoothing algorithm (low-pass 3-by-3 filter) to the selected MODIS Fract-G bare soil images. The smoothed images were used in the analysis.

The MODIS Fract-G bare soil percentages were extracted for the cells in each sampling grid. Any pixels in salt lakes and sea, which had been assigned values of 254 and 255 in MODIS Fract-G, were excluded from analysis.

### 2.4. *Evaluation of MODIS Fract-G*

We investigated the internal consistency of the MODIS Fract-G image series by examining correlations between two sequential MODIS Fract-G images (DOY 041 and DOY 049). Because the two images overlapped by 8 days, were based on data acquired during a very dry period over an invariant landscape, and had been smoothed to counter geolocation errors, we expected very high correlations for all sampling areas.

Our main investigation sought to evaluate MODIS Fract-G in order to test it for use across the AWNRM region. We assessed the correlation between the bare soil percentages in MODIS Fract-G and the bare soil percentages as calculated in the high-spatial resolution ALOS PRISM imagery, comparing each of the 20 scenes. Furthermore we assessed whether the degree of correlation was related to the amount of vegetation cover in the scene.

## 3. Results

The relationship between two MODIS Fract-G bare soil images representing part-overlapping periods showed correlation coefficients ranging from $r$ = 0.43 to $r$ = 0.94, with seven sampling areas having correlation coefficients less than 0.75 (Table 3). This revealed lower internal consistency in the MODIS Fract-G time series than expected. The lowest correlation, $r$ = 0.42 for scene 4205 could be explained as an anomaly. The

Table 3. Correlation between two sequential (smoothed) MODIS Fract-G bare soil images showing correlation coefficient (*r*) and RMSE, and correlation between (smoothed) MODIS Fract-G 049 and ALOS PRISM bare soil values showing (*r*) and RMSE. For image dates see Table 1.

| Sampling areas | Correlation (*r*) between MODIS Fract-G 041 and 049 | RMSE | Correlation (r) between MODIS Fract-G 049 and ALOS PRISM | RMSE |
|---|---|---|---|---|
| 4130 | 0.76 | 4.24 | 0.04 | 20.51 |
| 4135 | 0.82 | 3.37 | −0.03 | 28.37 |
| 4140 | 0.90 | 3.07 | 0.47 | 22.09 |
| 4145 | 0.83 | 4.26 | 0.35 | 23.38 |
| 4150 | 0.72 | 5.37 | −0.30 | 27.65 |
| 4155 | 0.74 | 5.42 | 0.04 | 17.81 |
| 4160 | 0.79 | 4.18 | 0.25 | 11.75 |
| 4165 | 0.78 | 3.93 | −0.07 | 15.83 |
| 4170 | 0.85 | 4.38 | −0.24 | 25.83 |
| 4175 | 0.87 | 3.71 | −0.47 | 57.88 |
| 4180 | 0.82 | 4.26 | 0.00 | 58.70 |
| 4185 | 0.74 | 5.11 | −0.09 | 51.87 |
| 4190 | 0.73 | 5.05 | 0.13 | 30.13 |
| 4195 | 0.63 | 3.58 | 0.04 | 42.47 |
| 4200 | 0.87 | 4.25 | −0.27 | 41.97 |
| 4205 | 0.43 | 5.81 | 0.31 | 31.82 |
| 4215 | 0.91 | 1.43 | 0.01 | 31.25 |
| 4220 | 0.80 | 2.40 | 0.27 | 30.16 |
| 4230 | 0.94 | 2.28 | 0.75 | 21.08 |
| 4235 | 0.64 | 6.19 | 0.26 | 20.13 |

first image showed a fire that had not completely burnt out in the first week of the first image period (DOY 041). This fire appeared complete by the second week, as evidenced by the fire scar of comparable extent in the second MODIS Fract-G image (DOY 049) and in the corresponding PRISM bare soil image. No fires were detected in the remaining scenes that could account for the low internal consistency of the MODIS Fract-G data, in this otherwise invariant landscape.

Evaluation of the MODIS Fract-G bare soil fraction using the ALOS PRISM bare soil percentages revealed almost no correlation over most of the sample regions. Correlation coefficients less than 0.30 were common and some of these were negative. Only four of the 20 areas, 4140, 4145, 4205, and 4230, registered correlation coefficients >0.30 (Table 3). High RMSE was noted in particular over the Great Victoria Desert area covered by scenes 4175–4200. The strongest correlation ($r$ = 0.75) was found in sampling area 4230 (Table 3) (RMSE = 21.08). This area contains two contrasting vegetation associations, one of predominantly chenopod shrubland, open scrub, and open heath over brownish calcareous earth, and the other of open red mallee scrub and open woodland of black oak and myall over red calcareous earth (Department of Environment 2011). This contrast is clearly visible in the PRISM and MODIS bare soil imagery (Figure 4). This sampling area also had the strongest internal consistency for MODIS Fract-G (Table 3, Figures 4(*d*) and (*e*)). Scene 4230 is located not far from the coast (Figure 1).

The next strongest correlation between MODIS Fract-G and PRISM bare soil fractions occurred in sampling area 4140 at $r$ = 0.47 (Figure 1). Area 4140 includes hills and ridges of a variety of rock types separated by undulating plains of red massive earths, reddish siliceous sands, and red duplex soils. The vegetation comprises low open woodland of mulga and grasses, open tussock grasslands, low shrubland of witchetti bush, senna, and

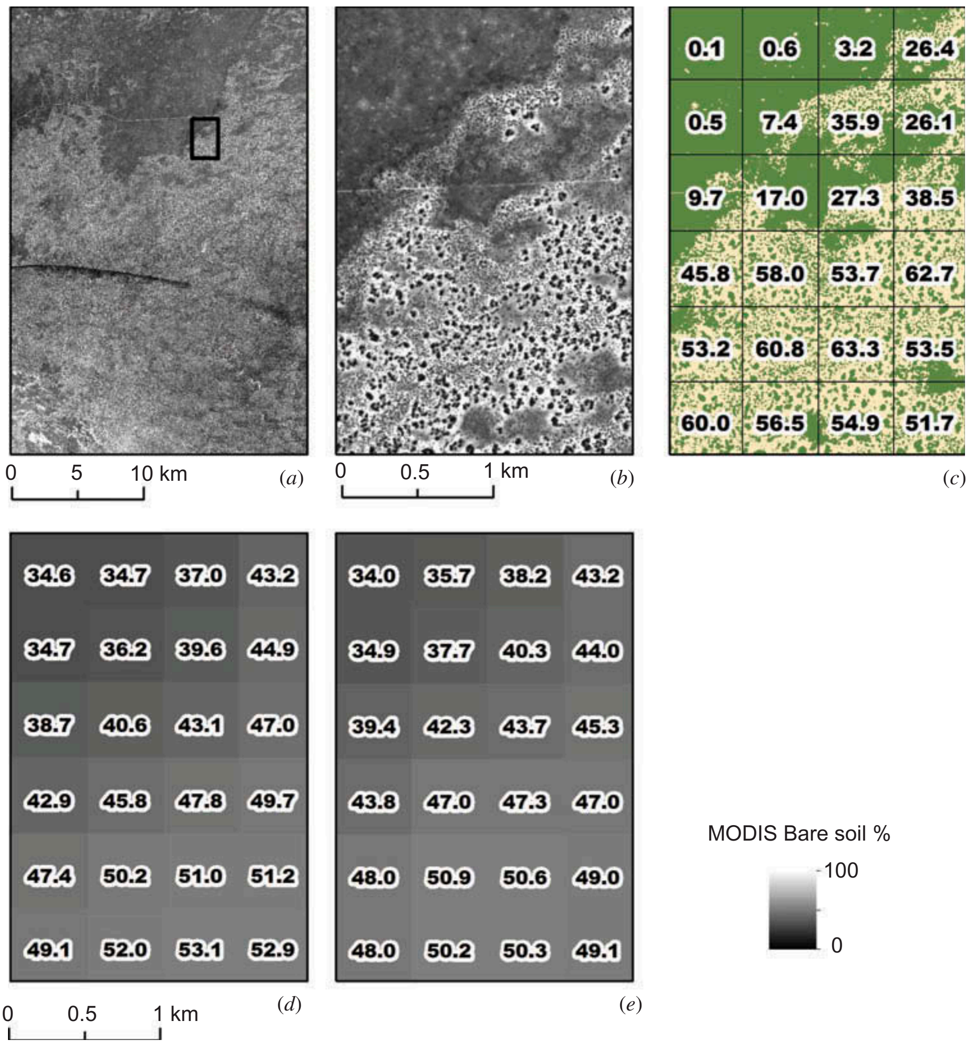


Figure 4. (*a*) ALOS PRISM sampling area 4230 at the southern edge of the Nullarbor Plain; subset outlined. (*b*) Enlarged subset showing east–west road and clearly visible tree crowns. (*c*) The subset classified, bare soil – yellow, cover – green, 500 m sampling grid and percentage bare soil per cell indicated. (*d*) Same subset in MODIS Fract-G 041 and (*e*) in MODIS Fract-G 049.

emubush, chenopod shrubland of bluebush, and low woodland of river redgum (Department of Environment 2011). The most outstanding features are the outcropping rock formations in the southern part of area 4140. The reflectance of these is lower than that of the surrounding grassy plains, which caused them to be classified as vegetation cover, in both the MODIS product and in the PRISM thresholding.

For the northernmost sampling area, 4130, there was no relationship between the MODIS Fract-G bare soil values and those determined in the ALOS PRISM imagery ($r$ = 0.04). The scene shows a eucalypt-lined dry creek, and several roads. In the enlargement of the image subset (Figures 5(*a*) and (*b*)) it is apparent that MODIS Fract-G has assigned areas of high soil exposure, for example southwest of the creek line, as

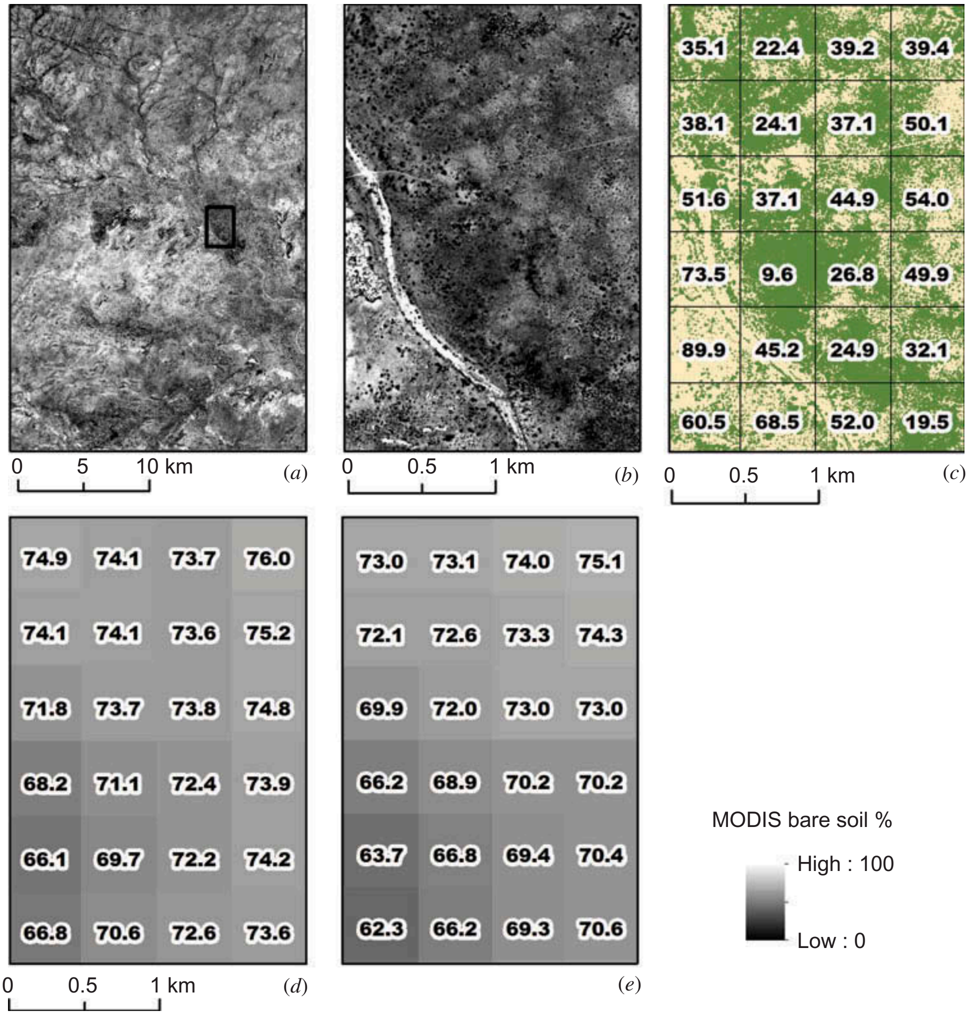


Figure 5. (*a*) ALOS PRISM sampling area 4130 in the northern pastoral region with subset outlined. (*b*) Enlargement of the subset showing an east–west road used to determine bare soil threshold and a dry creek bed, with tree crowns clearly visible. (*c*) ALOS PRISM enlargement classified: bare soil – yellow, cover – green; showing 500 m sampling grid and percentage bare soil per cell. (*d*) The subset in MODIS Fract-G 041 and (*e*) in MODIS Fract-G 049. Note that ALOS PRISM and MODIS Fract-G show a contradictory pattern in this subset.

high cover (Figures 5(*d*) and (*e*)), though it is clearly of low cover in the ALOS panchromatic image (Figure 5(*b*)).

MODIS Fract-G is reported to show good correlation with fire scars (Guerschman et al. 2009). This is visually supported in our analysis. Fires across the sand dunes east of Maralinga in early February 2007 left a large fire scar, visible in sampling area 4205 (Figure 6). The enlarged subset shows a strong relationship between MODIS Fract-G 049 and ALOS PRISM. However, away from the fire scar, MODIS Fract-G does not well represent the on-ground reality revealed in the ALOS PRISM imagery. The coefficient for the correlation between the MODIS Fract-G 049 and ALOS PRISM soil fractions for the entire 4205 sampling area is 0.26 (RMSE = 31.82) (Table 3).

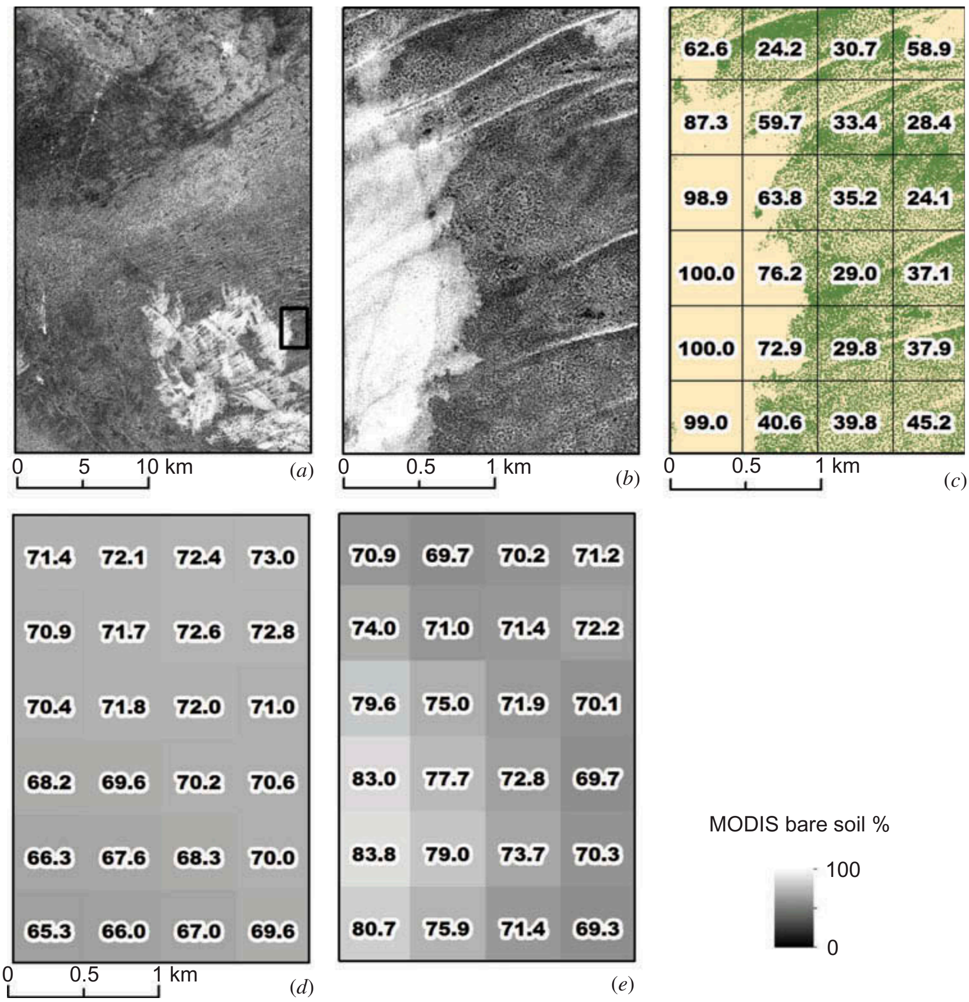


Figure 6. (*a*) ALOS PRISM sampling area 4205 in sand dunes east of Maralinga showing a fire scar in the south-east of the image and a subset outlined at the fire scar edge. (*b*) Enlarged ALOS PRISM subset, with bare soil visible in the fire scar and on the crests of longitudinal dunes. (*c*) The ALOS PRISM subset classified, bare soil – yellow, cover – green; showing 500 m sampling grid and percentage bare soil per cell. (*d*) The subset in MODIS Fract-G 041 revealing no fire scar. (*e*) The subset in MODIS Fract-G 049 revealing a fire scar pattern corresponding to the ALOS PRISM pattern in Figure 6(*b*).

It is interesting to note that as vegetation cover increases, MODIS Fract-G performance shows a slight improvement (Figure 7).

## 4. Discussion

MODIS Fract-G was initially developed for the Australian northern savanna region to provide a high temporal sub-pixel product that separates NPV, PV, and BS. It is proposed to be used across the Australian continent for land cover monitoring. Validation across a wider range of environments is therefore essential. Validation of remotely sensed

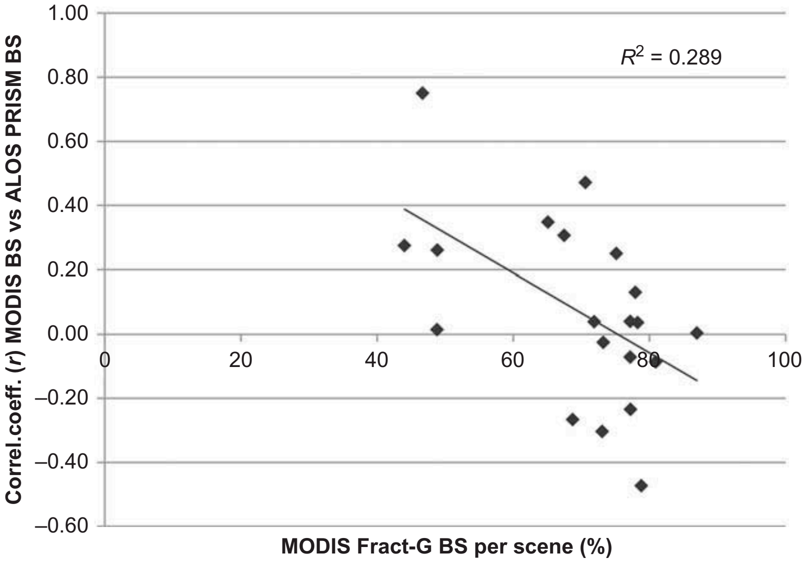


Figure 7. Correlation between MODIS Fract-G and ALOS PRISM bare soil is slightly better in areas with less bare soil.

environmental measures is usually approached through field data collection. Field validation of MODIS Fract-G is in progress but no evaluation had taken place for the extensive area of interest in South Australia.

This study used high-spatial resolution ALOS panchromatic imagery to evaluate the MODIS bare soil fractional cover estimates, thereby overcoming some of the challenges of field validation such as extrapolation uncertainties, difficulties of site access, and high expense and time demands. Although not validated by *in situ* cover data, the bare soil fraction estimates in the ALOS PRISM imagery are based on the well-recorded phenomenon that the visible-near infrared albedo in arid environments is strongly correlated with relative soil exposure – both photosynthesizing and non-photosynthesizing vegetation darken the bright reflectance of these soils. In this study the reflectance values of unpaved minor roads were used to set thresholds, and classify and calculate bare soil percentages, in 500 × 500 m cells, over large areas of the landscape.

Evaluation of MODIS Fract-G using high-spatial resolution ALOS PRISM imagery revealed that MODIS Fract-G apparently does not give a good representation of the bare soil fraction across the South Australian arid zone. Only minimal correlation was found between MODIS Fract-G bare soil and the bare soil distribution revealed in ALOS PRISM imagery. The high RMSE appears to suggest that the ALOS PRISM records greater variability in the landscape than that detected by MODIS Fract-G. It appears that the MODIS NDVI–CAI (proxy) unmixing scheme that was developed for the tropical savanna does not perform well in the arid region of South Australia.

Some of this lack of correlation may be explained by the lower than expected internal consistency within the MODIS Fract-G time series. The expectation of very high correlation between two sequential images is based on the fact that they represent composite values that overlap by eight days. In this arid landscape with predominantly perennial vegetation, under prolonged dry weather conditions very little change occurs over eight days, and providing no fires occur, bare soil values can be expected to remain constant over such a short time period. Contrary to expectation, the sequential MODIS Fract-G images did not correlate well with one another (Table 3). Two of the sampling areas that showed greatest MODIS Fract-G internal consistency, 4230 and 4140, were the same ones that showed strongest correlation between MODIS Fract-G and PRISM bare soil. This appears to indicate that some of the lack of correlation can be attributed to the internal noise, likely inherent in the original MODIS NBAR data and propagated into the MODIS Fract-G.

This can, however, only partly explain the wider lack of correlation. The greater lack of correlation between MODIS Fract-G and PRISM bare soil fractions might be explained by the fact that in an arid sparsely vegetated landscape, under dry conditions, the MODIS data have very low spectral dimensionality, particularly in the NDVI/CAI data space. During dry periods, when there is little photosynthetic vegetation, the data are in effect two- rather than three-dimensional (Graetz and Gentle 1982). However, within the two-dimensional data space there is a significant variation in soil albedo or colour, which was evident in the need to set unique threshold values for each scene. One bare soil spectrum, as used in the unmixing scheme to produce MODIS Fract-G, does therefore not represent the landscape very well (Graetz 1987; Pickup, Chewings, and Nelson 1993). MODIS Fract-G may in effect be responding to the differences in soil colour rather than to those between soil and cover.

The low spectral dimensionality may offer some explanation why scene 4230, located near the shores of the Great Australian Bight, showed the highest correlation between the MODIS and PRISM bare soil fractions. A study on vegetation dynamics of the arid zone (Lawley, Lewis, and Ostendorf 2011) showed that NDVI response in the coastal AWNRM region was stronger than for inland regions over a 25-year period. Cooler moist sea air supports vegetation growth, in this instance coastal mallee, which leads to elevated NDVI levels, even during generally dry periods. Consequently MODIS Fract-G, which is partly based on NDVI, is better able to define the fractions. This is further supported by our finding that a greater amount of vegetation cover appears linked to a somewhat improved performance of MODIS Fract-G.

Higher NDVI, however, does not explain the next strongest correlation ($r$ = 0.47) between the MODIS Fract-G and PRISM bare soil fractions. This is in sampling area 4140, which is located far inland (Figure 1). A possible explanation of why MODIS Fract-G better correlates with the PRISM bare soil here is that the southern part of this scene contains considerable areas of rocky hills and outcrops. This manifests in large areas of strongly defined contrast within the landscape. MODIS Fract-G may reveal this greater contrast in background colour, even though it fails to show the finer contrast between bare soil and cover apparent in the ALOS PRISM imagery. The rocky outcrops are classed as cover rather than bare soil, in both the MODIS Fract-G and PRISM estimates, undoubtedly due to the rocks being much darker than the surrounding dry bright soils.

The scene used to illustrate the method, sampling area 4165 (Figure 3), is located in a relatively uniform region of parallel dunes in the Great Victoria Desert. MODIS Fract-G does not record any of the bare soil patterns revealed in the PRISM bare soil analysis for this scene ($r$ = –0.07) and there are no large, strongly contrasting landscape components within this scene. The remaining sampling areas across the AWNRM region showed very low or no correlation or even low negative correlation between MODIS Fract-G and PRISM bare soil.

## 5. Conclusion

This study used 2.5 m-ground resolution ALOS PRISM imagery to evaluate the bare soil fraction of the 500 m-ground resolution MODIS Fract-G cover product. Accuracy assessment of fractional cover data is essential prior to use, but remoteness or lack of access may make field data collection impractical, too costly, or impossible. High-spatial resolution satellite imagery is especially useful as field data substitute in these situations, as it provides extensive coverage of even areas where access is difficult at relatively low expense.

Evaluating the MODIS Fract-G bare soil component using such high-resolution data showed that the distribution of bare soil fractions across the landscape as indicated by MODIS Fract-G bears little resemblance to that shown in the ALOS PRISM classified images, which suggests that MODIS Fract-G in its current form cannot yet be relied upon for monitoring purposes over the arid sparsely vegetated landscapes of South Australia.

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