# A novel algorithm for estimating photosynthetic vegetation, non-photosynthetic vegetation and bare soil fractions using Landsat and MODIS data



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## Highlights

- Fractions of photosynthetic vegetation (PV), non-photosynthetic vegetation (NPV) and bare soil (BS) are estimated from Landsat and MODIS data
- Model performance is best with Landsat data (RMSE= 0.112, 0.162 & 0.130),



- similar between MODIS 16-Day Nadir BRDF-Adjusted surface Reflectance (MCD43A4) and MODIS 8-day surface reflectance (MOD09A1) (RMSE= 0.128, **0.18** & **0.164**) (Figures 4 and 5)
- Model performance degrades as landscape heterogeneity increases (Table 1)
- Model performance is not greatly affected by soil colour or moisture (Table 1)
- A combined Landsat/MODIS product for fractional cover monitoring is proposed

mean=0.23 median=0.1

### **Field Measurements**



Figure 1: Summary of field observations of vegetation fractional cover. Part (a) shows the spatial distribution of field observations. Dot colours show observed fractional cover values in RGB as indicated in the legend (triangle). In sites with multiple observations the most recent is shown; (b) number of field observations per year; and (c) distribution during the year (x-axis numbers represent months (1=Jan, 2=Feb, ...)).



Figure 3: Characterisation of site spatial heterogeneity as measured by Landsat reflectance. The histogram (a) shows the distribution of the Log<sub>10</sub> of the Euclidean Distance (ED) across the 1171 observations. The Landsat images are examples of sites with different ED, increasing from (b) to (g) (the image size is 500x500 pixels or ~225 km<sup>2</sup>). In each image the 3x3 and 17x17 pixel windows are shown in black and red, respectively. The black areas (stripping effects due to ETM+ SLC-off) were ignored in the calculations. The inset plots show the mean reflectance for the two windows, also in black and red, respectively.

MOD09A1 (bottom row). The black line corresponds to the 1:1 agreement and n= 1171 in all cases.





Figure 2: Characterisation of field measurements of vegetation fractional cover: (a) ternary diagram showing the distribution of PV, NPV and BS fractions across the field observations. Dot colours show observed fractional cover values in RGB as indicated in the legend (triangle). Histograms showing the distribution of (b) PV, (c) NPV and (d) BS. In each histogram, the mean, median and standard deviation (std) of the three fractions are shown.

Methods

- Used 1171 observations (from 913 sites) (Figs 1 and 2)
- Obtained Landsat (TM and ETM+), MCD43A4 and MOD09A1 surface reflectance. Aggregated Landsat to coarser resolutions (Figs 3-6)
- Quantified spatial heterogeneity as  $ED=SQRT(\Sigma(L_{3x3}-L_{17x17}))$  (Fig 3)
- Obtained soil colour from Viscarra-Rossel et al (2010), soil moisture from Advanced SCATerometer (ASCAT, passive microwave) and modelled (AWRA-L v3.0)
- Derived endmembers through inverting the field observations using a least





Figure 5: Summary metrics for the spectral unmixing using alternative reflectance sources. (a) Pearson's correlation coefficient and (b) root mean square error. L3x3 to L42x42 correspond to the Landsat reflectance aggregated to alternative window sizes, MCD43A4 and MOD09A1 correspond to the two MODIS products tested

<u>Table 1</u>: Factors affecting model performance. The table shows the Pearson correlation coefficient (r) and the p-value of the linear regression model fitted to the data. The models fitted were: y= a+bx where x was the residual of the fitted model for each fraction (with the exception of site heterogeneity (\*) where x was the absolute value of the model residual).

	Reflectance source	n	PV		NPV		BS	
			r	p-value	r	p-value	r	p-valu
Site heterogeneity *	L <sub>3x3</sub>	- 1170	0.001	0.986	0.085	0.003	0.119	<0.00
	L <sub>17x17</sub>		0.053	0.069	0.152	<0.001	0.204	<0.00
	MCD43A4		0.077	0.008	0.149	<0.001	0.211	<0.00
	MOD09A1		0.080	0.006	0.173	<0.001	0.232	<0.00
Soil brightness – all sites	L <sub>3x3</sub>	- 1154	-0.003	0.931	0.095	0.001	-0.034	0.243
	L <sub>17x17</sub>		-0.031	0.293	0.109	<0.001	-0.033	0.262
	MCD43A4		-0.049	0.098	0.130	<0.001	-0.040	0.170
	MOD09A1		-0.048	0.105	0.113	<0.001	-0.025	0.40
Soil brightness - BS>50%	L <sub>3x3</sub>	272	-0.113	0.062	-0.045	0.460	0.147	0.01
	L <sub>17x17</sub>		-0.208	0.001	-0.071	0.243	0.230	<0.00
	MCD43A4		-0.327	<0.001	-0.144	0.017	0.350	<0.00
	MOD09A1		-0.291	<0.001	-0.164	0.007	0.360	<0.00
Soil Moisture - ASCAT - all sites	L <sub>3x3</sub>	- 421	0.125	0.010	0.023	0.633	-0.076	0.11
	L <sub>17x17</sub>		0.102	0.037	0.050	0.310	-0.085	0.08
	MCD43A4		0.064	0.188	-0.007	0.880	-0.003	0.94
	MOD09A1		0.053	0.281	0.001	0.983	-0.006	0.89
Soil Moisture - ASCAT - BS>50%	L <sub>3x3</sub>	93	0.255	0.014	-0.115	0.274	-0.039	0.70
	L <sub>17x17</sub>		0.281	0.006	-0.054	0.609	-0.130	0.21
	MCD43A4		0.230	0.026	0.131	0.211	-0.272	0.00
	MOD09A1		0.239	0.021	0.094	0.371	-0.239	0.02
Soil Moisture - AWRA-L - all sites	L <sub>3x3</sub>	961	-0.061	0.057	0.122	<0.001	-0.064	0.04
	L <sub>17x17</sub>		-0.015	0.639	0.120	<0.001	-0.102	0.00
	MCD43A4		0.006	0.857	0.038	0.238	-0.027	0.40
	MOD09A1		-0.009	0.783	0.056	0.083	-0.032	0.31
Soil Moisture - AWRA-L - BS>50%	L <sub>3x3</sub>	212	0.012	0.861	0.102	0.138	-0.125	0.07
	L <sub>17x17</sub>		0.125	0.070	0.159	0.021	-0.242	<0.00
	MCD43A4		0.322	<0.001	0.134	0.052	-0.294	<0.00

square estimator. Log transforms and band interaction terms added to account for non-linearities in the spectral mixing. A cross-validation step was included to select the optimal number of singular values to avoid over-fitting

- Applied linear unmixing using non-negative least squares, with a sum-to-one and non-negative fractions constraints
- For each reflectance source we investigated if the residuals were correlated with site heterogeneity, soil colour and soil moisture

Figure 6: Comparison between the unmixing results using Landsat  $(L_{3x3})$  and MODIS (MCD43A4) imagery for the same six example areas shown in Figure 5. The scatterplots show the relationship between Landsat and MCD43A4 estimates for PV (green), NPV (red and BS (blue); the text in the top left of each scatterplot indicates the geographic location of the scene centre and the date of the fiel observation. The maps under the plots show the spatial patterns of the fractional cover estimates from Landsat (left), the same aggregated and reprojected to MODIS resolution (centre) and from MCD43A4 (right) for 225 km<sup>2</sup> centred around the site. In the images PV, NPV and BS fractions are shown in Green, Red and Blue respectively as shown in the triangular legend. The black pixels in the TAS018 and NSW052 sites correspond to SLC-off areas and were ignored in the comparisons.

#### FOR FURTHER INFORMATION

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