Use of TOA satellite imagery for mapping vegetation fractional cover

Summary

The presented methodology has been used for large-area assessment of fractional cover (Fcover) in Victoria. It has been applied to 3 rapideye images (product 3B: e Ortho product) with an extension of 25kmx25km each.

Fractional cover was predicted using ensemble regression models through random forest technique. Random forest was trained using Fcover data extracted from LiDAR acquired over three 5kmx5km study sites as ground truth. Rapideye level 3A imagery was used in the form of top-of-atmosphere (TOA) reflectance. Results show LiDAR derived fractional cover was estimated over the three study sites yielding an r2=0.67 (p-value: < 2.2e-16).

Finally the Rapideye-derived Fcover layer was used to extract landscape Fcover features. Isodata unsupervised classification was applied considering only features greater than 62.5 ha as a minimum management area unit.

Study sites

Three 5 km2 sites located in Victoria, Australia were selected for this project. The sites were chosen as being undisturbed ecosystems representative of major Victorian ecosystem types. The first site (36.74S, 144.96E) is located in central Victoria and comprises Box Iron Bark forest dominated by red iron bark (Eucalyptus tricarpa), red stringybark (Eucalyptus macrorhyncha), red box (Eucalyptus polyanthemos), long leaf box (Eucalyptus goniocalyx) and grey box (Eucalyptus microcarpa). The second site (37.69S, 145.68E) is a Wet Sclerophyll forest representative of the plateaux and slopes of the upper watershed areas south of the Great Dividing Range. Species composition is characterised by a mature open forest of mountain ash (Eucalyptus regnans), Shining Gum (Eucalyptus nitens) and Alpine Ash (Eucalyptus delegatensis), vegetation is much denser and predominantly consists of two or more canopy layers. The third study site (37.48S, 148.33E) is a Mixed-Species Dry Sclerophyll forest located in east Victoria. The vegetation of this region is dominated by Shrubby Dry Forest and Damp Forest on the upland slopes; Wet Forest ecosystems which are restricted to the higher altitudes; and Grassy Woodland, Grassy Dry Forest and Valley Grassy Forest ecosystems are associated with major river valleys.

Airborne and satellite image data

Small-footprint ALS was acquired over each 25 km^2 study site (Table 1). The Riegl LMS-Q560 laser scanner digitised the backscattered energy in real-time and post-processing with Riegl RiAnalyze® (version 4.1.2) identified discrete peaks (“returns”) in the backscattered signal using a Gaussian Pulse Estimation (GPE) technique (Riegl, 2006). Flight line overlap was removed using Airborne Research Australia’s RASP software (Lieff, 2009) where for each 2 x 2 m area the returns with the scan angle closest to nadir were retained. Remaining returns were classified into either ground or non-ground, then using ground returns only, a triangulated irregular network (TIN) was computed and height relative to ground for all returns was calculated from the TIN. Return classification and height calculations were computed using LAStools (Isenburg, 2012). Point data was stored in the American Society of Photogrammetry and Remote Sensing (ASPRS) las 1.2 binary data format (ASPRS, 2008).

Table 1. Flight and sensor specifications for the ALS acquisition.

Specifications	
Capture specifications	
Date	15/4 - 18/4/2012
Flying height	<600 m agl
Pulse density (overlap removed)	10 pulses m^{-2}
Swath overlap	50%
Absolute vertical accuracy	±20 cm
Absolute horizontal accuracy	±30 cm
Mean footprint diameter	30 cm
Instrument specifications	
Instrument	Riegl LMS-Q560 laser scanner (Horn, Austria)
Operating wavelength	1550 nm
Beam divergence	0.5 mrad
Max off-nadir scan angle	±22.5°
Outgoing pulse rate	240 kHz

Rapideye 3B product data was used to upscale Fcover derived from LiDAR over the 5km by 5km study sites to the landscape scale. Table 2 presents the product attribute description. The imagery was collected on the Rushworth forest and Wattscreek sites on the 17^{th} and 18^{th} of April 2012 respectively. Imagery over ZigZag Creek was collected on the 21^{st} of May 2012. For the three sites, the cloud coverage percentage was 0. Rapideye 3b product imagery was radiometrically corrected and converted into TOA reflectance using the Exo-Atmospheric Irradiance values. The full procedure was done under the recommendation of the provider and is fully described in the Annex 1 of this document.

Table 2. Rapideye Ortho-take level 3B product description

PRODUCT ATTRIBUTE	DESCRIPTION
Product Components and Format	RapidEye Ortho Take image product consists of: - Image File – GeoTIFF file. - Metadata File – XML format metadata file. - Browse Image File – GeoTIFF format - Unusable Data Mask (UDM) file – GeoTIFF format
Tile ground extension	25km by 25km
Product Orientation	Map North up
Pixel spacing	5m
Bit Depth	16-bit unsigned integers.
Product size	Variable number of pixels (less than 11980 per line) and up to a maximum of 60000 lines.
Geometric corrections	Sensor-related effects are corrected using sensor telemetry and a sensor model, bands are co-registered, and spacecraft-related effects are corrected using attitude telemetry and best available ephemeris data. Orthorectified using GCPs and fine DEMs.
Horizontal Datum	WGS84
Map Projection	Universal Transverse Mercator (UTM)
Resampling Kernel	Cubic Convolution (default), MTF, or Nearest Neighbor

The input data needed to obtained TOA reflectance was illumination geometry and the data collection day to calculate the corresponding distance to the sun (see table in Annex 2). All this data is provided in the metadata XML file. No atmospheric correction was conducted, in this way no extra data other than the image metadata provided by the manufacturer is needed. TOA reflectance imagery was used under the hypothesis that differences in the atmospheric density will be reflected in Band 1 (470 nm). All images were acquired within 1 month under clear sky conditions. The sun elevation difference during image acquisition was 10 degrees, keeping the effects of the bidirectional reflectance distribution function (BRDF) at a minimum.

The imagery was resampled to 25m pixel size as the normal monitoring area unit for forest management. The spatial resampling allowed the estimation of Fcover at the stand scale.

Fractional cover estimated from LiDAR imagery

Gap probability was determined using the method of (Armston et al., 2013). Here a robust estimate of return intensity is derived by weighting individual returns by the *Number of Returns* (*NoR*) metadata value recorded for a single outgoing pulse (Armston et al., 2013; Lovell et al., 2003). By utilising *NoR,* a new dataset is created where each return is weighted as a proportion of the total outgoing pulse (e.g. 1 / *NoR*). Although this is a simplification, for example ignoring the differing reflective properties of ground and vegetation and partial backscatter due to surface orientation (Ni-Meister et al., 2001), it is considered a more robust estimate of total backscattered radiation than frequency or return intensity based interpretation (Armston et al., 2013). Using the weighted dataset, P_{gap} can be estimated with;

$$P_{gap}(z) = 1 - \frac{\{Tz_j | z_j > z\}}{T}$$

where *T* is the sum of 1 / *NoR* and Tz_j is the sum of 1 / *NoR* above height *z*. Here z was set at 1 m.

(script to be added at the back or we can have it separate and link it in the text)

Random forest ensemble regression model

Being a decision tree predictive a model that uses a set of binary rules applied to calculate a target value, Random Forests grows many regression trees to derive a variable from an input dataset. To make a new prediction from an input vector, it puts the input vector down each of the trees in the forest. The prediction for the new data point is the averaged response of all trees.

Pros: Input noise reduction and has been successfully applied in previous studies

Cons: Regression can't predict beyond range in the training data. In regression extreme values are often not predicted accurately – underestimate highs and overestimate lows

The rapideye TOA reflectance spectra and the Fcover corresponding to 3000 points randomly located were used to train a random forest regression model. The information extracted for another 1500 points was used as validation. All rapideye bands were used as input in the model as being related to vegetation greenness and volume (green, red, red edge and near-infrared bands) and to the air mass in the atmosphere (blue band); being critical as the imagery was not atmospherically corrected. It is suggested the results would not be repeated for imagery collected at other times of the year as errors from the atmospheric differences and BRDF effects would be more severe.

Automatic landscape feature extraction

Isodata classification (Ball and Hall, 1965) was used as segmentation method due to its simplicity and low demand of input data.

Annex 1: Rapideye conversion to TOA reflectance

It has been done using the formula provided by Rapideye documentation:

To convert the Digital Number (DN) of a pixel to TOA radiance it is necessary to multiply the DN value by the radiometric scale factor, as follows:

RAD(i) = DN(i) * radiometricScaleFactor(i)

The radiometric factors for each individual band is 99999776482582e-3

To convert from radiance values to TOA reflectance we use:

RFLi= RADi * (Pi*Sun_distance^2) / (EAIi * cos(Sun_zenith))

Where:

i: Number of the spectral band
REF: reflectance value
RAD: Radiance value
Sun_distance: Earth-Sun Distance at the day of acquisition in Astronomical Units
EAI: Exo-Atmospheric Irradiance
Sun_zenith is given in degrees

The imagery was collected the 17th of April 2012 corresponding to doy 108 (2012 leap year), therefore the sun distance is 1.00409

EAIi provided by Rapideye are:

Band1= 1997.8
Band2= 1863.5
Band3= 1560.4
Band4= 1395.0
Band5= 1124.4

Sun zenith = 90 - sun_elevation = 90-40.6476 = 49.3524 deg

Extra data:

Acquisition time: 17/04/2012 at 01:17:16.231791 UT equivalent to 11:17:16.231791 AEST

Annex 2: Sun distance in astronomical units as function of the day of the year

Day of the year equivalence table:

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
1	1	32	60	91	121	152	182	213	244	274	305	335	1
2	2	33	61	92	122	153	183	214	245	275	306	336	2
3	3	34	62	93	123	154	184	215	246	276	307	337	3
4	4	35	63	94	124	155	185	216	247	277	308	338	4
5	5	36	64	95	125	156	186	217	248	278	309	339	5
6	6	37	65	96	126	157	187	218	249	279	310	340	6
7	7	38	66	97	127	158	188	219	250	280	311	341	7
8	8	39	67	98	128	159	189	220	251	281	312	342	8
9	9	40	68	99	129	160	190	221	252	282	313	343	9
10	10	41	69	100	130	161	191	222	253	283	314	344	10
11	11	42	70	101	131	162	192	223	254	284	315	345	11
12	12	43	71	102	132	163	193	224	255	285	316	346	12
13	13	44	72	103	133	164	194	225	256	286	317	347	13
14	14	45	73	104	134	165	195	226	257	287	318	348	14
15	15	46	74	105	135	166	196	227	258	288	319	349	15
16	16	47	75	106	136	167	197	228	259	289	320	350	16
17	17	48	76	107	137	168	198	229	260	290	321	351	17
18	18	49	77	108	138	169	199	230	261	291	322	352	18
19	19	50	78	109	139	170	200	231	262	292	323	353	19
20	20	51	79	110	140	171	201	232	263	293	324	354	20
21	21	52	80	111	141	172	202	233	264	294	325	355	21
22	22	53	81	112	142	173	203	234	265	295	326	356	22
23	23	54	82	113	143	174	204	235	266	296	327	357	23
24	24	55	83	114	144	175	205	236	267	297	328	358	24
25	25	56	84	115	145	176	206	237	268	298	329	359	25
26	26	57	85	116	146	177	207	238	269	299	330	360	26
27	27	58	86	117	147	178	208	239	270	300	331	361	27
28	28	59	87	118	148	179	209	240	271	301	332	362	28
29	29	60	88	119	149	180	210	241	272	302	333	363	29
30	30		89	120	150	181	211	242	273	303	334	364	30
31	31		90		151		212	243		304		365	31
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	

Sun distance (d) in astronomical units for Day of the Year (DOY).

DOY	d	DOY	d	DOY	d	DOY	d	DOY	d	DOY	d
1	0.98331	62	0.99133	123	1.00806	184	1.0167	245	1.00898	306	0.99228
2	0.9833	63	0.99158	124	1.00831	185	1.0167	246	1.00874	307	0.99202
3	0.9833	64	0.99183	125	1.00856	186	1.0167	247	1.0085	308	0.99177
4	0.9833	65	0.99208	126	1.0088	187	1.0167	248	1.00825	309	0.99152
5	0.9833	66	0.99234	127	1.00904	188	1.01669	249	1.008	310	0.99127
6	0.98332	67	0.9926	128	1.00928	189	1.01668	250	1.00775	311	0.99102
7	0.98333	68	0.99286	129	1.00952	190	1.01666	251	1.0075	312	0.99078
8	0.98335	69	0.99312	130	1.00975	191	1.01664	252	1.00724	313	0.99054
9	0.98338	70	0.99339	131	1.00998	192	1.01661	253	1.00698	314	0.9903
10	0.98341	71	0.99365	132	1.0102	193	1.01658	254	1.00672	315	0.99007
11	0.98345	72	0.99392	133	1.01043	194	1.01655	255	1.00646	316	0.98983
12	0.98349	73	0.99419	134	1.01065	195	1.0165	256	1.0062	317	0.98961
13	0.98354	74	0.99446	135	1.01087	196	1.01646	257	1.00593	318	0.98938
14	0.98359	75	0.99474	136	1.01108	197	1.01641	258	1.00566	319	0.98916
15	0.98365	76	0.99501	137	1.01129	198	1.01635	259	1.00539	320	0.98894
16	0.98371	77	0.99529	138	1.0115	199	1.01629	260	1.00512	321	0.98872
17	0.98378	78	0.99556	139	1.0117	200	1.01623	261	1.00485	322	0.98851
18	0.98385	79	0.99584	140	1.01191	201	1.01616	262	1.00457	323	0.9883
19	0.98393	80	0.99612	141	1.0121	202	1.01609	263	1.0043	324	0.98809
20	0.98401	81	0.9964	142	1.0123	203	1.01601	264	1.00402	325	0.98789
21	0.9841	82	0.99669	143	1.01249	204	1.01592	265	1.00374	326	0.98769
22	0.98419	83	0.99697	144	1.01267	205	1.01584	266	1.00346	327	0.9875
23	0.98428	84	0.99725	145	1.01286	206	1.01575	267	1.00318	328	0.98731
24	0.98439	85	0.99754	146	1.01304	207	1.01565	268	1.0029	329	0.98712
25	0.98449	86	0.99782	147	1.01321	208	1.01555	269	1.00262	330	0.98694
26	0.9846	87	0.99811	148	1.01338	209	1.01544	270	1.00234	331	0.98676
27	0.98472	88	0.9984	149	1.01355	210	1.01533	271	1.00205	332	0.98658
28	0.98484	89	0.99868	150	1.01371	211	1.01522	272	1.00177	333	0.98641
29	0.98496	90	0.99897	151	1.01387	212	1.0151	273	1.00148	334	0.98624
30	0.98509	91	0.99926	152	1.01403	213	1.01497	274	1.00119	335	0.98608
31	0.98523	92	0.99954	153	1.01418	214	1.01485	275	1.00091	336	0.98592
32	0.98536	93	0.99983	154	1.01433	215	1.01471	276	1.00062	337	0.98577
33	0.98551	94	1.00012	155	1.01447	216	1.01458	277	1.00033	338	0.98562
34	0.98565	95	1.00041	156	1.01461	217	1.01444	278	1.00005	339	0.98547
35	0.9858	96	1.00069	157	1.01475	218	1.01429	279	0.99976	340	0.98533
36	0.98596	97	1.00098	158	1.01488	219	1.01414	280	0.99947	341	0.98519
37	0.98612	98	1.00127	159	1.015	220	1.01399	281	0.99918	342	0.98506
38	0.98628	99	1.00155	160	1.01513	221	1.01383	282	0.9989	343	0.98493
39	0.98645	100	1.00184	161	1.01524	222	1.01367	283	0.99861	344	0.98481
40	0.98662	101	1.00212	162	1.01536	223	1.01351	284	0.99832	345	0.98469
41	0.9868	102	1.0024	163	1.01547	224	1.01334	285	0.99804	346	0.98457
42	0.98698	103	1.00269	164	1.01557	225	1.01317	286	0.99775	347	0.98446

43	0.98717	104	1.00297	165	1.01567	226	1.01299	287	0.99747	348	0.98436
44	0.98735	105	1.00325	166	1.01577	227	1.01281	288	0.99718	349	0.98426
45	0.98755	106	1.00353	167	1.01586	228	1.01263	289	0.9969	350	0.98416
46	0.98774	107	1.00381	168	1.01595	229	1.01244	290	0.99662	351	0.98407
47	0.98794	108	1.00409	169	1.01603	230	1.01225	291	0.99634	352	0.98399
48	0.98814	109	1.00437	170	1.0161	231	1.01205	292	0.99605	353	0.98391
49	0.98835	110	1.00464	171	1.01618	232	1.01186	293	0.99577	354	0.98383
50	0.98856	111	1.00492	172	1.01625	233	1.01165	294	0.9955	355	0.98376
51	0.98877	112	1.00519	173	1.01631	234	1.01145	295	0.99522	356	0.9837
52	0.98899	113	1.00546	174	1.01637	235	1.01124	296	0.99494	357	0.98363
53	0.98921	114	1.00573	175	1.01642	236	1.01103	297	0.99467	358	0.98358
54	0.98944	115	1.006	176	1.01647	237	1.01081	298	0.9944	359	0.98353
55	0.98966	116	1.00626	177	1.01652	238	1.0106	299	0.99412	360	0.98348
56	0.98989	117	1.00653	178	1.01656	239	1.01037	300	0.99385	361	0.98344
57	0.99012	118	1.00679	179	1.01659	240	1.01015	301	0.99359	362	0.9834
58	0.99036	119	1.00705	180	1.01662	241	1.00992	302	0.99332	363	0.98337
59	0.9906	120	1.00731	181	1.01665	242	1.00969	303	0.99306	364	0.98335
60	0.99084	121	1.00756	182	1.01667	243	1.00946	304	0.99279	365	0.98333
61	0.99108	122	1.00781	183	1.01668	244	1.00922	305	0.99253	366	0.98331