A multi-stage database of field measurements and synoptic remotely sensed data to support model validation and testing in Earth observation

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Abstract

This paper presents a novel database of ground and remotely sensed data from the UK which is uniquely suited to scaling-up multispectral measurements from a single plot to the scale of satellite sensor observations. Multiple aircraft and satellite sensors were involved, and most of the data were acquired on a single day in June 2006, providing a synoptic view which at its largest extent covered most of southern England and Wales. Three airborne imaging spectrometers were involved (Specim AISA Eagle, Itres CASI-2 & -3) and three satellite sensors (UK-DMC, PROBA/CHRIS and SPOT HRG), complemented with airborne LiDAR, multispectral survey cameras and ground measurements (land cover, LAI, reflectance factors, atmospheric measurements). In this paper the NCAVEO Field Campaign (NFC) database is described and an example of its use to produce a high spatial resolution leaf area index map for the validation of medium resolution products (MODIS, VEGETATION, MERIS) is presented.

Keywords: field experiment, scaling-up, validation, NCAVEO, VALERI.

1. Introduction

One of the key tenets of remote sensing is that data may be ‘scaled-up’ from individual plots to a region, and ultimately to the whole globe. Relatively few synoptic, multi-stage datasets exist to test this assumption, especially from temperate and humid-tropical latitudes where cloud cover is a problem. The datasets that do exist in the public domain are mostly from particular vegetation types, such as grassland (Hall et al., 1992), boreal forest (Gamon et al. 2004), and desert shrubs (Privette et al., 2000), or cover small areas around flux towers (e.g. the BigFoot project, Running et al. 1999). In this paper we present a database acquired from a typical European landscape that is a spatially-complex mixture of small fields, river floodplain, areas of woodland, suburban and urban areas. The database is uniquely suited to studying the issues involved in scaling remotely sensed multispectral data from field measurements to the scale of satellite observations.

2. Description of the study area

An area 9km x 6km south-east of Andover, Hampshire [51°12' N, 1°29' W], was selected as the focus of the field campaign (area ‘B’ in Figure 1). The highest part of the study

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area is in the south (120 metres above sea level), from where the terrain slopes down to the valley of the River Test, around 45 metres above sea level. Soils are mainly well-drained on the higher areas of chalk downland, contrasting with the poorly-drained alluvial soils and patches of river gravel on the terraces and floodplain of the present river. The land cover comprises agricultural fields, an area of mixed woodland (conifer and broadleaf) and managed grassland of several types. Traditionally, the better drained areas of the River Test floodplain were managed as water meadows and flooded in the spring for sheep grazing, whereas the wetter areas were used for cattle grazing. The result has been a mosaic of species-rich unimproved grassland and ecologically important fen meadows as well as grass-dominated species-poor communities. The main agricultural crops at the time of data acquisition were barley, wheat, oats and oilseed rape. The area was chosen because of the range of land cover types present, and because it contained the Chilbolton Facility for Atmospheric and Radio Research (CFARR) which has a suite of meteorological instruments, including one of the UK AERONET sites (http://aeronet.gsfc.nasa.gov/).

[Figure 1 goes here]

3. The NCAVEO Field Campaign database

The database resulted from a field campaign organised and conducted in 2006 by members of a knowledge exchange partnership, the Network for Calibration and Validation in Earth Observation (NCAVEO), which comprises 26 partners, drawn from academia, government and the commercial sector in the UK (www.ncaveo.ac.uk). The database is 150GB in size and comprises over 20 data sets with associated metadata. The remotely sensed data sets are listed in Table 1 and the ground data acquired in support of the field campaign are described below.

[Table 1 goes here]

The majority of the NCAVEO Field Campaign (NFC) data sets were acquired on a single day in June 2006. Within a few hours on that day, two satellites and two aircraft collected a range of remotely sensed data, including hyperspectral, multi-angle and LiDAR datasets. The main specifications of the airborne imaging spectrometers used are shown in Table 2. Additional medium resolution data acquired by MODIS, VEGETATION and MERIS are available from the same day, providing the link between the data sets collected specifically for the field campaign and those routinely acquired from space. At the same time as the remotely sensed data were being acquired, teams on the ground measured the hemispherical-conical reflectance factor (HCRF) of a range of ground surfaces including an asphalt car park (10 m x 20 m), an area of concrete (40 m x 40 m) and three fabric sheets (each 6 m x 6 m). Three different spectroradiometers were used for these measurements: a dual-beam SpectraVista GER1500™ (asphalt), a SpectraVista GER3700™ (concrete) and an ASD FieldSpec Pro™ (fabric). The data were converted to HCRF using white Spectralon reference panels traceable to the UK National Physical Laboratory.

[Table 2 goes here]

Prior to the experiment, 28 Elementary Sampling Units (ESU) were established in order to represent the range of canopy type and conditions over the whole site. Each ESU corresponds to a 60 to 600 m² area depending on the instruments used and canopy height. The Delta-T SunScan™, LAI2000 and hemispherical photography from a digital camera were used to measure LAI. Garrigues et al. (2008) showed fair agreement in LAI estimates from these instruments for well developed canopies when the spatial sampling is large enough. Between 13 (hemispherical photos), 30 (SunScan) and 48 (LAI2000) individual measurements were made and then averaged from each ESU. Spectral reflectance data (HCRF) were also collected from each of the ESU using the same instruments used to measure the calibration targets.

A nested land cover survey was conducted around the time of the field campaign. Complete field-level data were acquired from the area covered by the airborne imaging spectrometers and sampled data were acquired over the more extensive area shown as area ‘A’ in Figure 1 as part of a pilot study for UK Land Cover Map 2007 (Smith et al. 2007). In addition, a river habitat survey was conducted comprising measurement of water depth, streamflow and substrate type at 15 cross-sections on the River Test within the study area.

Details of the processing of specific data sets are included in the metadata provided with each, an example of which is provided in Figure 2. The aerial remotely sensed data were geometrically corrected using data from attitude and location sensors on-board the aircraft, and overlain on Ordnance Survey vector data to check the accuracy of the correction. Ground control points were used to correct the satellite sensor data and details of the rms error are provided in the metadata. Standardisation of approach and on-going stewardship of the database were ensured by developing a Data Management Plan (DMP) in conjunction with the NERC Earth Observation Data Centre (NEODC). Key principles of the DMP were (a) use of commonly accepted ‘open’ data formats (e.g. ASCII, flat file binary, PDF); (b) the use of documented file structures for data sets (e.g. HDF, NASA Ames (Gaines and Hipskind, 1998)); (c) the requirement that each data set has an associated metadata document that has been checked by an independent person; (d) recognition that the intellectual rights to each data set belong to the person or organisation which collected it, and (e) an embargo period of 12 months following the initial release of the database, during which time only those involved in the NFC would be allowed access.

[Figure 2 in here]

4. An example of the use of the database: Generation of high resolution biophysical products for validation purposes

Global maps of leaf area index and fractional vegetation cover are routinely produced using data from sensors such as MODIS and VEGETATION (Myneni et al. 2007; Baret et al. 2007), however, validation of these products is difficult without corresponding high spatial resolution biophysical maps to quantify their accuracy as proposed by CEOS/LPV (Morisette et al., 2006). The VALERI project[2] attempts to contribute to this issue by generating high resolution biophysical products from a combination of high resolution EO data and ground measurements.

The SPOT image in the NFC database was acquired on 10th June 2006 by HRG1 on SPOT5, one week before the main field measurements were made. It was atmospherically corrected using a radiative transfer model, based on aerosol and water vapour measurements from the Chilbolton AERONET site and ozone data from the TOMS satellite sensor. The VALERI methodology involves establishing the transfer function between the biophysical variable of interest such as LAI and the top-of-canopy (TOC) reflectance. Given sufficient ESUs this is generally done using multiple robust regression between ESU reflectance (or infra-red/red ratio) and the biophysical variable of interest. In the present example this was done using the 'robustfit' function from the Matlab statistics toolbox which uses an iteratively re-weighted least squares algorithm, with the weights at each iteration computed by applying the bisquare function to the residuals from the previous iteration. The best combination identified was:
LAI=5.3361 + 8.4408(XS1) - 47.4188(XS2) + 0.3204(XS3) - 21.4674(XS4) + 163.4993(RN)
Three errors were computed: classical Root Mean Square Error (RMSE=0.62), weighted RMSE (using the weights attributed to each ESU: RMSE=0.57) and cross-validation RMSE (leave-one-out method: RMSE=0.83). More details are available in Rossello (2009).

Figure 3 presents the biophysical variable maps obtained with the best transfer functions described above. Although the algorithm has estimated values of LAI for all the pixels in the image, we should be wary about assuming that the accuracy of this product is equally high at all locations. The ESUs measured on the ground were mostly agricultural fields and forest, so there were no measurements from semi-natural grassland and fallow fields. Figures 3 represents this uncertainty by colour-coding pixels according to whether they are within the convex hull formed by the ground data reflectance measurements. Those pixels in red are where the transfer function has had to extrapolate beyond the bounds of the ground data, and therefore are less reliable.

Figure 4 presents the results of the analysis and shows good consistency between MODIS (Yang et al., 2006) and CYCLOPES (Baret et al., 2007) LAI products and the aggregated LAI value derived from up-scaling the ground measurements with the high spatial resolution SPOT image. In contrast, the GLOBCARBON LAI product appears to significantly underestimate the actual LAI value under these conditions. Other studies that have used the NFC data in global validation exercises include Garrigues et al. (2008a) and Camacho et al. (2010).

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[2] http://w3.avignon.inra.fr/valeri/

5. Conclusion

High quality databases comprising contemporaneous georeferenced remotely sensed data from different platforms and sensors are rare, especially from areas in Europe. Rarer still are those that have associated ground data. However, such data are vital for the development and testing of models and for education and training in Earth observation. Further information on the NCAVEO Field Campaign is provided on the NCAVEO website at www.ncaveo.ac.uk/2006_field_experiment/ and the data themselves are freely available from the NERC EO Data Centre (www.neodc.rl.ac.uk).

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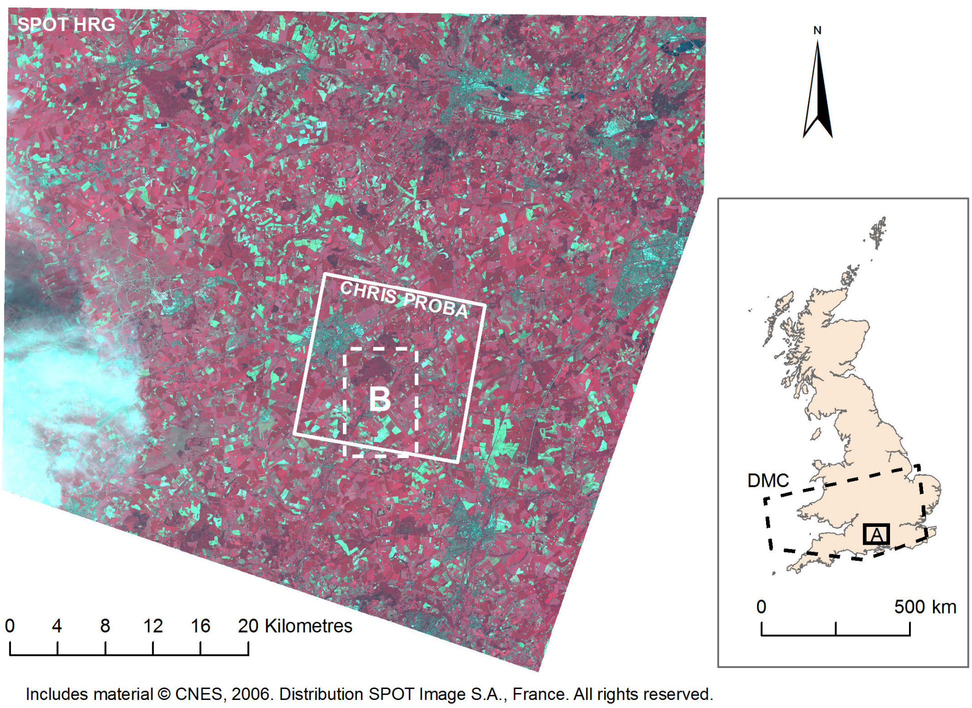
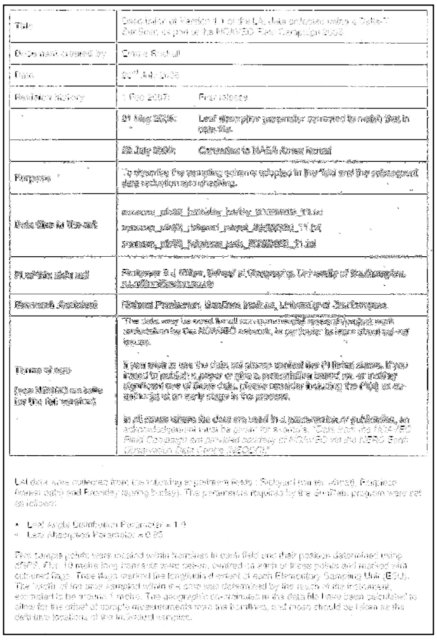


Figure 1. The area covered by the NFC database. 'DMC' shows the extent of the DMC image acquired on 17th June; area 'A' shows the extent of the sampled land cover which corresponds to the extent of the SPOT HRG image acquired on 10th June (main figure). Within the SPOT image, the extent of the CHRIS PROBA image acquired on 17th June is shown, and area 'B' shows the extent of the aircraft data and ground data acquired on 17th June.



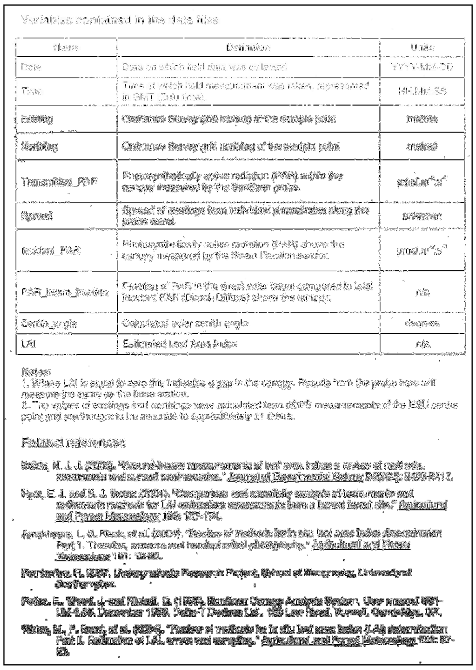


Figure 2. Example of the metadata associated with one of the ground data sets (LAI). In order to save space, the figure above is greatly reduced in size, and readers may wish to download a full version from: http://www.ncaveo.ac.uk/2006_field_experiment/metadata/ncaveo_sunscan_metadata_11.pdf

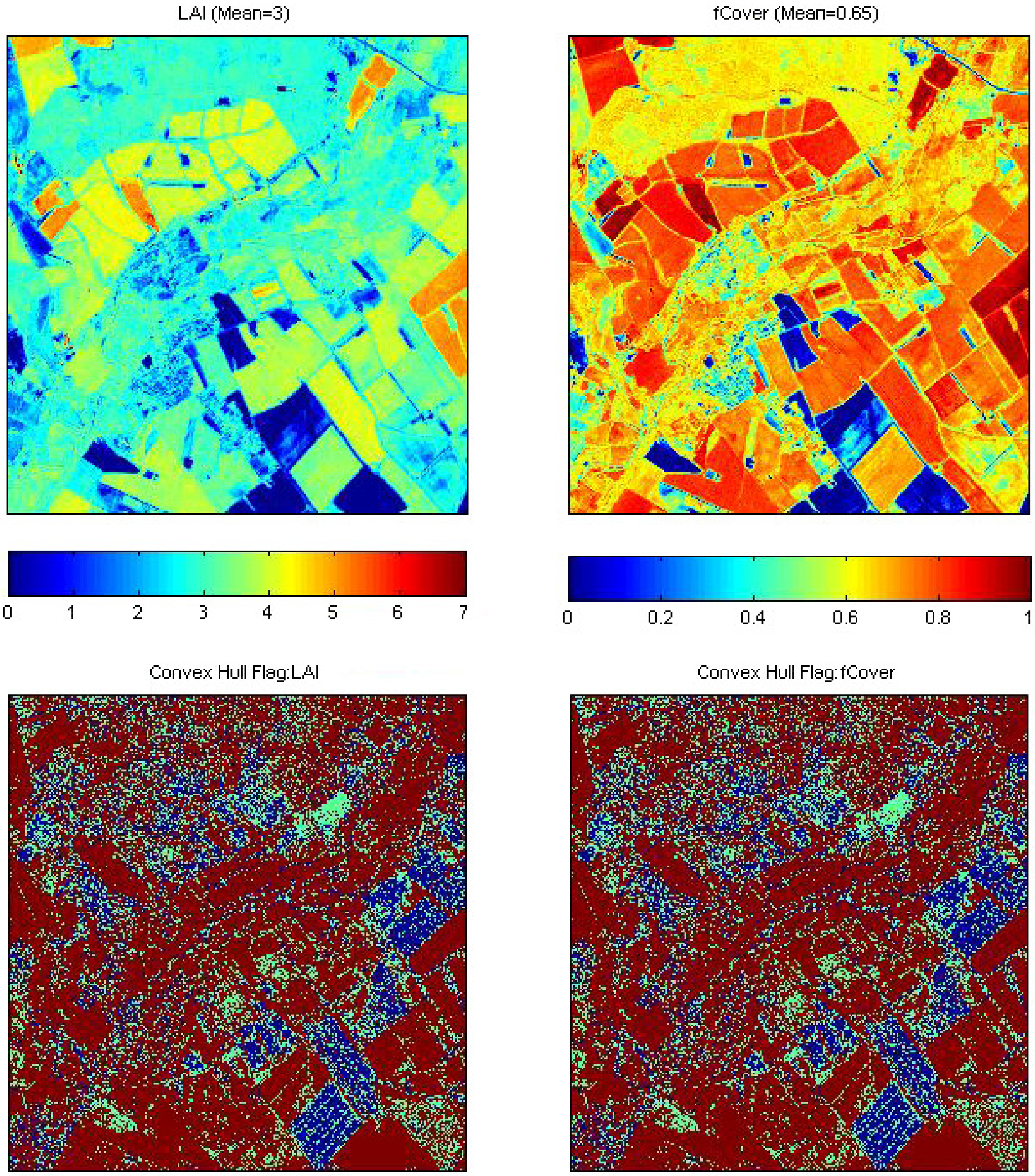


Figure 3. High resolution biophysical variable maps derived for the NFC test site: the upper images show LAI (left) and fCover (right), while those below represent the pixels classified according to whether the transfer function was within the bounds of the ground data (blue and cyan) or whether it was extrapolating (red).

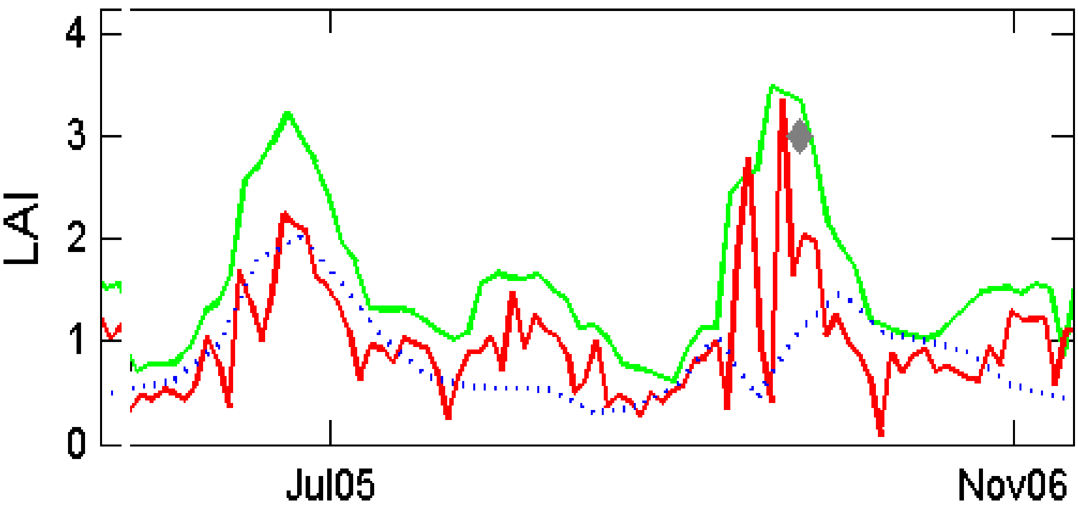


Figure 4. Dynamics of MODIS (red), CYCLOPES (green) and GLOBCARBON (dotted blue) LAI products for the Chilbolton site. The gray diamond represents the LAI value derived from aggregating the high spatial resolution LAI map generated using the ground measurements and the SPOT high resolution image.

Table 1. Remotely sensed data sets contained in the NFC database

Date	Platform	Bands	GRE		Sensor
09/06/2006	A	4	0.6	VNIR	Integraph Z/I Imaging DMC
10/06/2006	S	4	10/20	VNIR/SWIR	SPOT-5, HRG
13/06/2006	S	3	32	VNIR	Nigeria-Sat
17/06/2006	S	62	34	VNIR	PROBA/CHRIS (multiangle)
	S	3	32	VNIR	UK-DMC
	A	32	1	VNIR	Itres CASI-3
	A	15	2.5	VNIR	Itres CASI-2
	A	244	1	VNIR	Specim Aisa Eagle
	A	3	1	RGB	Rollei AIC Modular LS Camera
	A	1	1	1064 nm	Optech ALTM 2033™ LiDAR
14/07/2006	S	3	32	VNIR	Al-Sat

Notes:

1. Dates expressed as DD/MM/YYYY
2. Platform codes: A=aircraft, S=satellite
3. GRE= Size of nominal ground resolution element (m)
4. VNIR = visible and near infra-red, SWIR = short-wave infra-red

Table 2. Main specifications of the three airborne imaging spectrometers from which data were acquired on 17th June 2006

	CASI-2	**CASI-3**	**AISA Eagle**
Spectral range (nm)	451-941	400-994	398-974
Number of bands	15	32	244
Bandwidth (FWHM) (nm)	10.4 to 4.9	6.6 to 47.0	2.2 to 2.4
Quantisation (bits)	12	12	12
Nominal ground resolution at nadir (m)	2	1	1
Angular field-of-view (deg. full swath)	54.4	39.0	37.7
Pixels per line	512	1499	969
Flying height (above mean ground level) (m)	1620	1900	1620
Heading of main flightlines (deg.)	148/328	180	148/328
Heading of ‘east-west’ flightline (deg.)	61	90	61
Solar zenith angle [start] (deg.)	32.3	38.5	32.3
Solar zenith angle [end] (deg.)	27.7	29.3	27.7
Solar azimuth angle [start] (deg.)	140.9	122.7	140.9
Solar azimuth angle [end] (deg.)	177.4	156.2	177.4