INTERCALIBRATION OF VEGETATION INDICES – AN UPDATE

Michael D. Steven[a*], Timothy J. Malthus[b] and Frédéric Baret[c]

[a] School of Geography, University of Nottingham, Nottingham NG7 2RD, UK. - Michael.Steven@nottingham.ac.uk
[b] School of GeoSciences, University of Edinburgh, Kings Buildings, West Mains Road, Edinburgh EH9 3JW, UK.- tjm@geo.ed.ac.uk
[c] INRA-CSE, Agroparc, 84914 Avignon Cedex 09, France. - baret@avignon.inra.fr

KEY WORDS: Vegetation index; sensor systems; spectroradiometric measurements; validation, NDVI, SAVI, OSAVI

ABSTRACT:

In 2003 we addressed the issue of intercalibration of vegetation indices from different satellite-based optical sensor systems with differing spectral response functions in the visible and near-infrared bands (Steven *et al*., 2003). We used a database of spectroradiometric measurements made over a range of canopy densities, soils and foliage colours to simulate vegetation indices (NDVI, SAVI and OSAVI) to produce a table of intercalibration factors for the specific spectral response functions for 15 satellite instruments. We found that the indices are not identical, but are linearly related, allowing conversion from one system to another to a precision of 1–2%. Our results allow vegetation index data from different systems to be combined reliably. The present study extends the intercalibration of vegetation indices to include systems launched since our previous paper. We propose a standard pair of bands for the definition of vegetation indices and suggest that users apply our conversion coefficients to adjust vegetation index measurements to this standard. The margin of error in applying a two step conversion via the standard is at most 1% compared with a direct conversion from one system to the other. Independent validations of our conversion coefficients from a number of studies in the literature are discussed.

RÉSUMÉ:

Nous avons proposé en 2003 des relations statistiques permettant de passer de valeurs d'indice de végétation d'un capteur donné, à celles d'un autre capteur ayant une réponse spectrale différente dans les bandes rouge et infra-rouge (Steven *et al*., 2003). Une base de données expérimentale de réflectance spectrale couvrant une gamme de densité, de sols, et de couleur de feuillage avait permis de simuler les indices de végétation (NDVI, SAVI, OSAVI) pour une quinzaine de capteurs couramment utilisés. Les résultats montraient des différences marquées entre capteurs pour un même indice, mais qu'ils étaient toujours reliés de manière très forte et linéaire. Il est donc possible de passer d'un capteur à un autre avec une très bonne précision (1-2%). L'étude présente étend les résultats précédents aux nouveaux systèmes lancés ou qui vont être lancés dans un futur proche. Nous proposons un couple de bandes standard pour la définition des indices de végétation, et suggérons aux utilisateurs d'appliquer nos coefficients de conversion pour obtenir un indice de végétation 'standard'. Les incertitudes induites par le passage à l'indice de végétation 'standard' pour obtenir les valeurs de l'indice de végétation d'un autre capteur sont inférieures à 1% en comparaison d'une conversion directe. Les coefficients de conversion proposés ici sont validés et discutés à partir de différentes études publiées.

1. INTRODUCTION

1.1 Vegetation indices

Vegetation indices, based on the contrast between reflectance in the visible and near-infrared bands, have been a standard tool of earth observation since the 1970s. They have been applied in a variety of ways as measures of the vigour and productivity of vegetation; and at all scales, from continental scale vegetation dynamics, (e.g. Townshend and Justice, 1986) to regional crop predictions (de Koeijer *et al*., 2000) and pixel-scale application in precision agriculture (Steven and Millar, 1997).

A persistent issue in vegetation monitoring is the acquisition of sufficient data to capture the dynamics of plant growth. Plant growth requires water, usually supplied by rainfall, so the more productive vegetated regions are frequently cloudy (Heller, 1961). The data acquisition problem has broadly been resolved in two ways: at higher resolutions by the development of systems with pointable cameras that can target particular sites several times within the satellite repeat cycle; and at lower resolutions by data compositing over periods of 10 days or more. These solutions introduce their own problems. In particular, both pointing and compositing tend to increase the range of viewing angles, and to a lesser extent solar angles, used in the vegetation index product. Corrections can be made for these effects using a model of the bidirectional reflectance distribution function (BRDF), but this requires *a priori* knowledge of the vegetation type (Steven, 1998; Bacour, Bréon, and Maignan, 2006).

1.2 Standardisation

A complementary approach is to combine data from more than one system, sometimes referred to as the use of a virtual constellation (CEOS, 2006). Key to this approach is the adoption of a set of operating standards for the systems to be combined. Increasingly, there is a focus on ensuring the long-term continuity of vegetation observations, particularly at the larger scales, to establish a basis for monitoring the effects of climate change. There is also considerable interest in back-calibrating data from earlier systems, as near as possible to

* Corresponding author

current standards, to establish the long-term baseline. Precise calibration of instruments is required and attention to variations in BRDF associated with different orbital characteristics (Teillet, Markham and Irish, 2006; Röder, Kuemmerle and Hill 2005; Martinez-Beltrán *et al*., 2003).

However, as noted in our earlier paper (Steven *et al*., 2003) there is no accepted standard for vegetation indices. Even when instruments are precisely calibrated and all the proper corrections are applied for BRDF and atmospheric effects, indices from the various measurement systems differ systematically due to differences in the position, width and shape of the wavebands used (Gallo and Daughtry, 1987; Guyot and Gu, 1994). Steven *et al*. (2003) used a database of high resolution spectra of vegetation canopies to simulate the particular near-infrared and visible band responses and thence the vegetation index as measured by different orbiting systems. Differences between NDVIs on the same target could be as high as 14%, but the indices recorded by different observation systems were highly correlated so that different systems could be intercalibrated to a degree of precision of about ±1%. In the present paper we extend the intercalibration of vegetation indices forwards to include orbiting sensor systems launched since our previous report; and backwards to include historical variations in the NOAA AVHRR system. In addition, to simplify the issue of standardisation, we propose a standard pair of bands as the reference for all vegetation indices and provide conversion coefficients for operational systems (Table 1).

2. METHODOLOGY

2.1 Spectral response functions

Our solution to the differences between sensors is to simulate near-infrared and red measurements by the range of instruments available using the spectral response functions of each detector. The spectral response functions of 15 systems were reported in Steven *et al*. (2003). In the present study we extend the analysis to a total of 41 systems including some variants where more than one band combination can be used in the same system, and provide separate AVHRR simulations for NOAA6 to NOAA18 inclusive. Where possible the spectral response functions were found in the literature; others were obtained from the web or by personal communication. The spectral responses were digitised every 1nm to match the spectral data. The operators of the OrbView-2 and OrbView-3 systems were unwilling to release data on the spectral response functions of their instruments, so we tested two alternative models: a box function across the nominal wavelength range and a Gaussian fitted so that the nominal waveband limits were the half-power points. The wavebands for Venµs, which are relatively narrow but not as yet precisely defined, were similarly modelled with a Gaussian on the basis of the developer's advice.

2.2 Canopy database

The simulations were performed on a database of calibrated spectral reflectance measurements of plant canopies in the field made with a GER IRIS Mk1V spectroradiometer. The database consists of 166 measured reflectance spectra of crops of sugar beet and maize in the UK and France in 1989/90. The spectra were recorded in 975 channels spanning the 350–2500 nm range and were resampled to 1nm. Experimental treatments on the crops were designed to provide contrasting canopy structures from the different crop types and by thinning treatments, contrasting canopy greenness by treatments of disease or dilute herbicide to induce chlorosis in selected canopies, and a wide range of cover densities and backgrounds including black cloth, white cloth and various soils. The database thus provides a very wide range of canopy conditions, although as noted by Steven *et al*. (2003) it does not include the effects of senescent plant material.

2.2 Spectral band simulations

Spectral band responses were simulated by convolving the spectral top-of canopy radiance data with the spectral response function and normalising to reflectance with the corresponding convolved data for the reference panel, adjusted for its true reflectance. The simulated band reflectances were then applied to compute vegetation indices. Simulations were performed for NDVI, SAVI and OSAVI. Vegetation indices from the different simulated systems were then compared. In the 2003 study we compared all possible pairs of systems. With the larger number of systems considered here, this would be prohibitive. Instead, we relate indices from different systems to a standard vegatation index based on narrow bands at 670 and 815nm. Vegetation indices based on these wavelengths are close to the optimum; only one of the operational indices studied has a greater dynamic range.

3. RESULTS

3.1 Comparison of simulated vegetation indices

The simulations for NDVI, SAVI and OSAVI show that vegetation indices from different detector systems are not identical but are very highly correlated (minimum $r^2 = 0.984$). Plots of selected systems against the standard are shown in Figures 1 and 2, these examples representing the minimum and maximum slopes of the systems considered. In all cases the correlations are strong enough to allow precise linear conversion from one system to another.

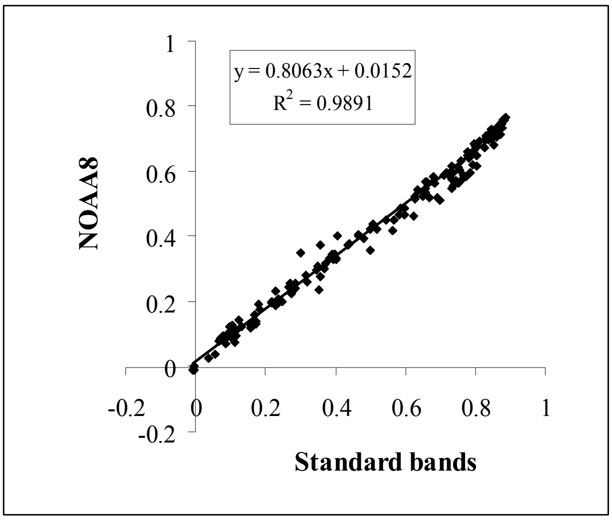

Figure 1. Regression of NDVI based on NOAA8 bands against the standard bands.

Table 1 presents the conversion coefficients to and from the standard pair of bands adopted in this study. Linear regressions for SAVI, OSAVI and NDVI differ in slope and intercept by no more than about 0.001 and 0.1 respectively. As these differences are considerably less than typical errors of measurement, a single conversion table is adequate for the range of vegetation index formulations considered. It is likely, although untested, that the same conversion factors will apply to most other formulations of ratio-type vegetation indices in common use.

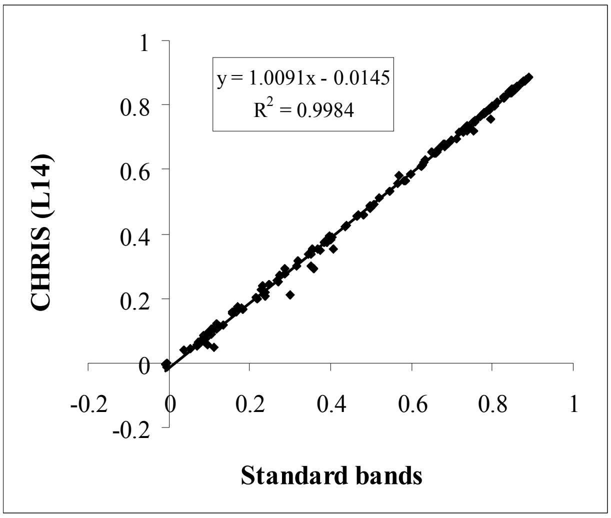

Figure 2. Regression of NDVI based on the CHRIS near-infrared (L14) and red bands against the standard bands.

	A		B	
	Sensor vs Standard		Standard vs Sensor	
Satellite sensor	**Intercept**	**Slope**	**Intercept**	**Slope**
ALI	-0.005	0.965	0.006	1.034
ASTER, using band 3B	-0.001	0.933	0.003	1.068
ASTER, using band 3N	0.000	0.933	0.002	1.068
ATSR2/ AATSR	0.008	0.968	-0.006	1.030
CHRIS, using band L14	-0.015	1.009	0.016	0.989
CHRIS, using band L15	0.005	0.991	-0.004	1.007
DMC	0.006	0.954	-0.005	1.046
Formosat	0.002	0.936	0.000	1.065
Ikonos	-0.010	0.870	0.015	1.144
IRS	0.005	0.950	-0.004	1.050
Kompsat	0.004	0.942	-0.003	1.058
Landsat 5 TM	0.005	0.938	-0.003	1.063
Landsat 7 ETM+	0.003	0.957	-0.002	1.041
Landsat MSS	0.029	0.883	-0.024	1.115
MERIS	0.008	0.983	-0.008	1.016
MISR	0.005	0.985	-0.005	1.014
	A		B	
MODIS	0.017	0.935	-0.015	1.065
NOAA10	0.003	0.854	0.001	1.160
NOAA11	0.015	0.831	-0.011	1.188
NOAA12	0.015	0.844	-0.012	1.173
NOAA13	0.017	0.835	-0.014	1.184
NOAA14	0.016	0.837	-0.013	1.180
NOAA15	0.016	0.902	-0.014	1.100
NOAA16	0.017	0.897	-0.015	1.107
NOAA17	0.016	0.904	-0.014	1.098
NOAA18	0.017	0.905	-0.014	1.097
NOAA6	0.021	0.850	-0.018	1.163
NOAA7	0.015	0.857	-0.012	1.155
NOAA8	0.015	0.807	-0.012	1.226
NOAA9	0.015	0.839	-0.012	1.179
OrbView-2, using block fcn	0.005	0.989	-0.004	1.009
OrbView-2, using Gaussian	0.005	0.982	-0.005	1.016
OrbView-3, using block fcn	0.002	0.937	0.000	1.063
OrbView-3, using Gaussian	0.002	0.857	0.001	1.159
POLDER	0.005	0.985	-0.005	1.014
QuickBird	0.000	0.909	0.002	1.096
Seawifs	0.005	0.982	-0.004	1.016
Severi MSG	0.012	0.926	-0.010	1.076
Spot2 Hrv2	0.012	0.921	-0.011	1.081
Spot4 Hrv2	0.010	0.917	-0.008	1.085
SPOT5	0.010	0.928	-0.008	1.073
Venus, using band B10 with Gaussian	-0.012	0.984	0.013	1.015
Venus, using band B11 with Gaussian	0.007	0.967	-0.006	1.032

Table 1. Conversion coefficients for vegetation indices for the different systems considered.

To convert a vegetation index from an operational system VI_{op} to the standard, VI_{std}, equation 1 is applied, using the slope and intercept values from column B. To convert from the standard to the operational system, equation 2 is applied, using the slope and intercept values from column A.

$$VI_{std} = VI_{op} \times [slope]_B + [intercept]_B \quad (1)$$

$$VI_{op} = VI_{std} \times [slope]_A + [intercept]_A \quad (2)$$

Spectral response data for the simulations were acquired from published sources or by direct communication from instrument manufacturers; where these data were not forthcoming, we have modelled the sensor firstly using a block function and secondly by fitting a Gaussian to the nominal bandwidth. For OrbView-2 both methods give comparable results so that adjustment to the standard can be made to better than 1% precision. For OrbView-3 however, the difference is about 8%; this uncertainty indicates that this system is unsuitable for applications requiring intercalibration with others.

Although we recommend that all vegetation indices should be converted to the standard bands, it is possible to convert from one operational system to another using Table 1 to convert first to the standard as an intermediate stage and then from the standard to the second system. On examples tested, the error in this two-stage process, as compared with direct conversion between the systems, was up to 0.01 in slope and 0.007 in intercept.

3.2 Validation

In our earlier study, we reported on a small number of direct comparisons of near-simultaneous vegetation index measurements by different sensors (Steven *et al*., 2003) which broadly supported the correction coefficients established in that study. A number of more recent studies provide further supporting evidence, either by direct comparisons of image data or different forms of simulation.

Martínez-Beltrán *et al*. (2003) compared ETM+, TM, LISS and AVHRR data on selected sites in south eastern Spain. Their study was mainly concerned with the effects of spatial data aggregation on the comparisons and atmospheric effects were not considered. Their best results were with high levels of aggregation. Compared with our study, they found similar linear relationships but with substantially greater slopes of the regression for ETM+ regressed on TM or LISS and a smaller slope for TM regressed on AVHRR. When they made comparisons between ETM+ and AVHRR on different dates, the slopes differed by 0.03.

Gallo *et al*. (2005) compared NDVI values for MODIS and AVHRR over the United States for identical 16 day compositing periods. Although the compositing process can introduce a systematic upward bias in NDVI (Goward *et al*., 1993), this would probably be similar for both systems. Gallo *et al*. found linear relationships between NDVI values from different sensors. Their regression slopes differ from ours by no more than 0.02 indicating good agreement within the limits of the data. They found a similar degree of variation when the same systems were compared over different time periods.

Fensholt, Sandholt, and Stisen (2006) compared MERIS, MODIS and VEGETATION products on grass savannah in Senegal using wide angle *in situ* measurements with band radiometers designed to approximate the relevant bands. They report generally good agreement with Steven *et al*. (2003) but with higher MERIS sensitivity to vegetation than predicted by our results. However, the accuracy of their comparisons depends on the degree to which the *in situ* sensor bands match those of the satellite instruments. In addition, wide angle measurements would exaggerate vegetation indices, particularly in the middle of the range, as they noted in their study. It is possible to make a systematic correction for the wide angle effect (Steven, 2004). However, given the degree of overlap of the spectral bands, the angular response effect is likely to be very similar for the different systems compared.

Miura, Huete and Yoshioka (2006) compared NDVI values for a number of systems on Hyperion hyperspectral image data over tropical forest and savannah in Brazil. They applied a similar approach to our own, combining the atmospherically corrected data with spectral response functions to simulate surface measured radiance in various bands. Although relationships between simulated radiances in paired bands were found to be land cover dependent, the relationships for NDVI were independent of land cover. However, they were non-linear, requiring a quadratic function to provide an adequate conversion between systems.

Van Leeuwen *et al*. (2006) simulated NDVI from AVHRR, MODIS and VIIRS using the SAIL model with a wide range of LAI. The model was parameterised with inputs from spectral libraries of vegetation, soil and snow data. Their result for NOAA16 versus MODIS is within 0.01 of values predicted from Table 1, but their prediction for NOAA14 has a slope 0.03 higher.

4. CONCLUSIONS AND DISCUSSION

It is now widely recognised that vegetation indices from different systems cannot be regarded as directly equivalent, being dependent on the particular band responses of the instruments concerned. The magnitude of the correction required is significant: considering just the slopes in Table 1, the values of the correction required to match our standard bands range from –1% (CHRIS using the L14 infrared band) to +23% (NOAA8 AVHRR). The present paper and a few other studies have found that vegetation indices can be linearly intercalibrated to a degree of precision of about ±2%. However, the study by Miura, Huete and Yoshioka (2006), in which a quadratic correction was required, may indicate that these relations are not quite universal. Further investigation would help to resolve these differences. Nevertheless, the intercalibration coefficients presented in Table 1 allow progress to be made in standardising systems, but with caution, for as Miura, Huete and Yoshioka point out, observations with different spectral bands are inherently different and may introduce bias into downstream products.

A number of the studies, cited above or in Steven *et al*. (2003), have attempted intercalibration by direct comparison of vegetation indices from different systems. In addition to the spectral band effects discussed here, these comparisons of necessity include errors associated with instrument calibrations and atmospheric effects as well as bidirectional effects associated with time differences between data capture by the systems compared. In addition, direct comparisons are usually confined to two or three individual systems. Similarly, studies by Röder, Kuemmerle and Hill (2005), Turner *et al*. (2006) and Zhao *et al*. (2005) have applied the direct approach to address the intercomparison of various downstream vegetation products. While these studies are important in validating such products, direct intercomparisons do not of themselves indicate the sources of errors that arise, which must ultimately be traced through the various components of the algorithms applied. Conversely, there are advantages in developing the intercalibration of systems by a component-wise approach, treating calibration, bidirectional, atmospheric and spectral band effects separately. In the present study, simultaneous measurements by a single instrument were used to simulate the different sensors on a common set of observations. Our approach has the advantage over direct studies of being relatively free of calibration errors; such calibration errors as exist are associated with the spectral flatness of the reference panel used in the field and are expected to be very small. Moreover, our approach is able to deal with the complete range of sensors on a common basis, including sensors on systems that no longer exist or that are still in development.

Standardisation of vegetation indices and related earth observation products is important to ensure long-term data continuity as well as in addressing shorter-term monitoring issues that are not adequately provided for by single observation systems. Our results, taken together with advances in instrument calibration, characterisation of angular responses and correction of atmospheric effects indicate that standardisation is now possible for most systems, within margins of error that are reasonable for a wide range of applications. To account for differences in spectral band responses, we propose here the adoption of a pair of standard reference bands at 670 and 815nm. To standardise for bidirectional effects it is also necessary to adopt standard solar and viewing angles. Bacour, Bréon and Maignan (2006) proposed standardising on viewing at nadir with a solar zenith angle of 40°. Conveniently, these angles correspond approximately to the average measurement conditions that apply to the canopy spectral database used in the present study; the solar angle proposed is also a reasonable mid-value for summer viewing conditions at mid latitudes. A more intractable problem may be the adoption of a standard form of the vegetation index. While NDVI is one of the simplest and most widely used indices, it has well documented problems particularly with variation in soil background. Some of these problems could be resolved with little additional complexity by adoption of one of the SAVI family of indices (Huete, 1988; Rondeaux, Steven and Baret, 1996). The conversion factors in Table 1 are valid, to the precision given, for the full range of the SAVI family as well as for NDVI.

References.

Bacour, C. Bréon, F.M. and Maignan, F., 2006. Normalization of the directional effects in NOAA–AVHRR reflectance measurements for an improved monitoring of vegetation cycles. *Remote Sensing of Environment*, 102**,** pp. 402–413.

CEOS (2006) The CEOS Virtual Constellation Concept V0.4, Committee on Earth Observation Satellites http://stratus.ssec.wisc.edu/cryos/docs/CEOS_constellations.doc (accessed 31 Mar. 2007).

de Koeijer, K.J., Steven, M.D., Colls, J.J. and Williams, J., 2000. Integration of earth observation data with a crop model for yield forecasting. *Aspects of Applied Biology*, 60, pp. 91–98.

Fensholt, R., Sandholt, I. and Stisen, S., 2006. Evaluating MODIS, MERIS, and VEGETATION vegetation indices using in situ measurements in a semiarid environment *IEEE Transactions on Geoscience and Remote Sensing*, 44, pp. 1774–1786.

Gallo, K.P. and Daughtry, C.S.T., 1987. Differences in vegetation indices for simulated Landsat-5 MSS and TM, NOAA-9 AVHRR and SPOT-1 sensor systems. *Remote Sensing of Environment*, 23, pp. 439–452.

Gallo, K., Ji, L., Reed, B., Eidenshink J. and Dwyer, J., 2005. Multi-platform comparisons of MODIS and AVHRR normalized difference vegetation index data. *Remote Sensing of Environment*, 99, pp. 221–231.

Goward, S.N., Dye, D.G., Turner, S., Yang, J., 1993. Objective assessment of the NOAA global vegetation index data product. *International Journal of Remote Sensing*, 14, pp. 3365–3394.

Guyot, G. and Gu, X.F., 1994. Effect of radiometric corrections on NDVI- determined from SPOT HRV and Landsat TM data. *Remote Sensing of Environment*, 49, pp. 169–180.

Heller, J. (1961). *Catch 22***.** Simon and Schuster, New York.

Huete, A.R., 1988. A soil adjusted vegetation index (SAVI). *International Journal of remote Sensing*, 9, pp. 295–309.

Martínez-Beltrán, C., Calera Belmonte, A. and Jochum A., 2003. Inter-satellite cross-calibration: Integration of reflectance and NDVI from different satellites by means of a linear model. In Owe, M., d'Urso, G., Moreno, J.F. and Calera, A. (Eds) *Remote Sensing for Agriculture, Ecosystems and Hydrology*, *SPIE*, 5232, pp. 128–139.

Miura, T., Huete, A., and Yoshioka, H., 2006. An empirical investigation of cross-sensor relationships of NDVI and red/near-infrared reflectance using EO-1 Hyperion data. *Remote Sensing of Environment*, 100, pp. 223–236.

Röder, A., Kuemmerle, T. and Hill, J., 2005. Extension of retrospective datasets using multiple sensors. An approach to radiometric intercalibration of Landsat TM and MSS data. *Remote Sensing of Environment* 95, pp. 195–210.

Rondeaux, G., Steven, M.D. and Baret, F., 1996. Optimization of Soil Adjusted Vegetation Indices. *Remote Sensing of Environment*, 55, pp. 95–107.

Steven, M.D., 1998. The sensitivity of the OSAVI vegetation index to observational parameters. *Remote Sensing of Environment*, 63, pp. 49–60.

Steven, M.D., 2004. Correcting the effects of field of view and varying illumination in spectral measurements of crops. *Precision Agriculture*, 5, pp. 51–68.

Steven, M.D., Malthus, T.J., Baret, F., Xu, H. and Chopping, M., 2003. Intercalibration of vegetation indices from different sensor systems. *Remote Sensing of Environment*, 88**,** pp. 412–422.

Steven, M.D and Millar, C., 1997. Satellite Monitoring for Precision Farm Decision Support. In Stafford J.V. (Ed.) "*Precision Agriculture*" *Proceedings 1st European Conference on Precision Agriculture*, Warwick, 8-10 September 1997, Bios Scientific Publishers, Oxford. pp 697–704.

Teillet, P.M., Markham, B.L. and Irish, R.R., 2006. Landsat cross-calibration based on near simultaneous imaging of common ground targets. *Remote Sensing of Environment*, 102, pp. 264–270.

Townshend, J.R.G. and Justice, C.O., 1986. Analysis of the dynamics of African vegetation using the normalized difference vegetation index. *International Journal of Remote Sensing*, 7**,** pp. 1435－1446.

Turner, D.P., Ritt, W.D., Cohen, W.B., Gower, S.T., Running S.W., Zhao M., Costa M.H., Kirschbaum A.A, Ham J.M., Saleska, S.R. and Ahl, D.E., 2006. Evaluation of MODIS NPP and GPP products across multiple biomes. *Remote Sensing of Environment*, 102, pp. 282–292.

Van Leeuwen, W.J.D., Orr, B.J., Marsh, S.E. and Herrmann, S.M., 2006. Multi-sensor NDVI data continuity: Uncertainties and implications for vegetation monitoring applications. *Remote Sensing of Environment*, 100, pp. 67–81.

Zhao, M., Heinsch, F.A., Nemani, R.R. and Running, S.W., 2005. Improvements of the MODIS terrestrial gross and net primary production global data set. *Remote Sensing of Environment*, 95, pp. 164–176.

Acknowledgements

The authors acknowledge financial assistance at various stages of this work from NERC, AFRC, SBREC and INRA. We are particularly indebted to numerous colleagues who assisted with fieldwork in the UK and France and to the NERC Equipment Pool for Field Spectroscopy who provide instrumentation and much valued advice.