The Application of Kernel—driven BRDF Models and AVHRR Data to Monitoring Land Surface Dynamics in the Sahel

P. Lewis, E. Vives Ruiz de Lope
(*Remote Sensing Unit, Dept. Geography, University College London 26 Bedford Way, London WC1H 0AP, United Kingdom*)

Abstract The Ambrals BRDF model which will be used to process the BRDF/Albedo product from data from the forthcoming EOS MODIS and MISR instruments is used to model directional reflectance data of the Sahel from AVHRR data. The model proves to be capable of describing the observed data well. Issues related to kernel selection and information content of the derived model parameters are addressed.

Key words BRDF, HAPEX sahel, AVHRR

1 INTRODUCTION

When making use of data from wide field of view sensors such as AVHRR or the forthcoming EOS MODIS instrument[1] one must be aware of the impact of directional reflectance effects on the methods traditionally used to derive information on land surface dynamics such as temporal profiles of Vegetation Indices. Leroy[2] reviews several techniques for AVHRR data compositing that attempts to correct for, among others, such directional reflectance effects. An alternative to seeing these effects as a problem is to explore the additional information on land surface dynamics that might be gathered from a useful parameterization of the BRDF, since the magnitude and shape of the BRDF are affected by such factors as vegetation cover, soil reflectance, leaf optical properties and vegetation structure. It is not clear that most of the wide range of mathematical models of the BRDF which have been developed are appropriate to the task of modelling directional reflectance from moderate spatial resolution instruments, as most have been developed and tested using simulation or field-based studies; at such a resolution (1.1km at nadir for AVHRR LAC data) heterogeneity issues become important, and since the majority of physical parameters used in BRDF modelling do not scale linearly, models which assume surface homogeneity cannot be directly used to derive reliable estimates of surface biophysical properties. Roujean *et al.*[3] propose a solution to this in which a linear superposition of kernels is used to model BRDF, where each kernel is a function of viewing and illumination angles only. Leroy and Roujean[4] used one manifestation of these kernels to apply a correction for view and sun angle variations in AVHRR data. Such kernels can be derived from physical principles[3,5] but involve considerable approximations which must be linked in an empirical fashion. The model parameters thus become weighting terms associated with, for example, an isotropic component, volumetric scattering, and scene—shadowing components in the heterogeneous land cover within a pixel. Kernel-based models of this type have a wide range of advantages which are discussed by Roujean *et al.*[3], Lewis[6] and Wanner *et al.*[7]. In the work presented in this paper, the range of kernels developed for the Ambrals model to be used in the EOS MODIS BRDF/Albedo product[8] are used to model BRDF effects. This model uses a range of kernels which make different assumptions about the nature of the surface (optically-thin, optically-thick etc.). The model then makes some choice as to which model is appropriate to a particular circumstance. At present, this choice is made on the basis of the best-fitting model over all wavebands, but the factors influencing this choice are one of the issues investigated in this paper.

2 DATA

The data used in this study are AVHRR LAC data of a 512×512 pixel area of Niger in the Sahel for the months of May to October 1992 during the HAPEX Sahel field campaign[9]. The main land cover types in the region are: millet crop; fallow areas, and Guiera Senegalensis, a woody bush that grows on the fallow savannah. The landscape is generally very heterogeneous, meaning that it is difficult to identify 'pure' pixels of any of these cover types at AVHRR resolution. In this study, the nominal geographical coordinates of components of the various 'super-sites' of the HAPEX Sahel campaign (Fig. 1) were used to locate pixels which might be considered as being representative of the different cover types. The AVHRR data from NOAA-11 and-12 were processed by the HAPEX Sahel Information System (HSIS). HSIS level-1 reflectance data were used in this study, corresponding to at-ground reflectance in AVHRR channels 1 and 2 (visible and near infrared). The area covered by the data is between 0° and 5° East and 11° and 16° North. The geometric and atmospheric corrections were performed by the HSIS Science team. Cloud screening was performed using the CLAVR algorithm[10,11] developed for AVHRR GAC data. A small percentage of residual clouds were filtered out as they appeared as strong outliers in the BRDF analysis. The average number of cloud-free samples over the whole of the image obtained on a 29-day moving window varied from 9 in May to 21 in October.

3 MODEL SELECTION

Nine areas in the HAPEX supersites representing the dominant cover types of the region, and indicated by crosses in Fig. 1, were selected for testing goodness of fit of the model (kernels) to the data. Four kernel combinations within Ambrals were used in the model inversion; combinations of the isotropic kernel and RossThin or RossThick and LiSparse or LiDense. These kernels are described in more detail in Wanner *et al.*[5]. If the model inversion provides model parameters which are negative, a constraint should be applied to make the value of that parameter zero[6], in which case, the set of kernels used is reduced from a combination of three terms to one of two. Table 1 shows a representative example of the error term (Root Mean Square Error, RMSE) for cover types in the Central East and Central West areas. Kernel combinations which give the lowest RMSE are marked with *. Other kernel combinations which have a RMSE within 5% of this are marked with -. Combinations of Ross Thick and both LiSparse and LiDense

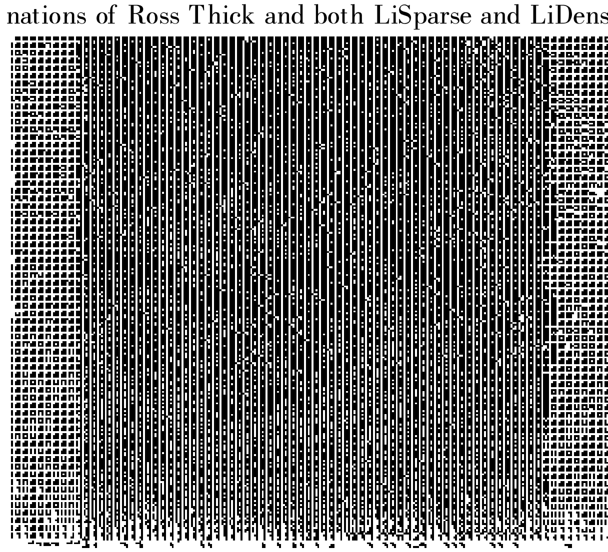

Fig. 1 View angle-corrected avhrr channel 1 reflectance data for May 1992 showing HAPEX Sahel sites. Data are scaled from 0.1 to 0.4 reflectance

gave typically negative parameters for all cases, and so are not shown. Most of the time, the three kernel combinations are reduced to an isotropic term and one of the other kernels due to the non-negativity constraint, and so all combinations of two kernels are shown in the table. The results indicate that: (i) the lowest RMSE is small (a few percent) in the months of May to July, but increases to up to 7% from August to October; (ii) the inversions generally yielded only two model parameters; (iii) a preference is noted for the Ross kernels (volume scattering); (iv) as it is often the case that the RMSE for different kernel combinations are very similar, it would be useful to take into account additional information in selecting the 'best' set of kernels for a particular month. Temporal consistency of low RMSE may be one option for this last point; the millet RMSE shown in Table 1, for example could be consistently-modelled with the isotropic and RossThin or RossThick kernels without too much loss of accuracy in the model fit. There seems little justification for selecting the three-kernel RossThin-LiSparse kernels over the Ross kernels for the case of millet in June, even though the RMSE of the former is slightly smaller. Even though the criterion of lowest-RMSE kernel selection would appear to need some strengthening with additional information, it is interesting to note that spatial analyses of model selection tend to produce interesting clusters which are currently being investigated for their relationship to land cover.

Table 1 RMSE of model Fits for cover types at central sites for kemel combinations

RMSE%	TIGER BUSH(CW)AVHRR Band 1					
	RossThin	TossThick	LiSparse	LiDense	RossThin-LiSparse	RossThin-LiDense
May	1.9*	2.1	2.6	1.9●	2.0	2.0
June	1.7*	1.8	3.7	2.1	1.8	4.4
July	3.6*	4.0	-	-	-	-
August	6.7*	6.8●	-	7.0	-	-
September	5.8*	-	-	-	-	-
October	6.8*	6.9●	-	-	-	-

RMSE%	FALLOW(CW)AVHRR Band 1					
	RossThin	TossThick	LiSparse	LiDense	RossThin-LiSparse	RossThin-LiDense
May	1.7	1.5*	2.0	1.6●	1.8	1.7
June	1.5*	1.7	3.3	2.0	-	1.6
July	3.3*	3.5	-	3.7	-	-
August	3.0*	4.6	-	8.0	-	-
September	5.0*	5.1●	-	5.3	-	-
October	10.1	2.9*	-	-	-	-

RMSE%	MILLET(CE)AVHRR Band 1					
	RossThin	TossThick	LiSparse	LiDense	RossThin-LiSparse	RossThin-LiDense
May	1.8	1.7*	2.5	1.8●	2.0	2.0
June	1.8	1.8●	3.5	2.0	1.7*	1.9
July	2.6●	2.7*	-	2.8●	-	-
August	7.0*	7.5	9.0	8.2	-	-
September	5.2*	5.3	-	5.6	-	-
October	6.4*	6.6	-	-	-	-

4 INTERPOLATION AND EXTRAPOLATION

The derivation of a set of model parameters, and, in the case of Ambrals, kernel selection, is of course based on some limited sample set of observed reflectances. One can distinguish a number of different types of products that one may wishto directly derive from such data[7]: namely, interpolated and extrapolated quantities. As the range of view angles in a set of AVHRR observations is generally larger than the range of sun angles, interpolated quantities in this context refer to some normalization of the view angle effects to some nadir-equivalent at the average solar zenith angle. Both normalized bidirectional reflectance and normalized directional-hemispherical reflectance (for the average solar zenith angle) might be considered. Extrapolated quantities in this respect refer to, for example, a normalized bidirectional reflectance for nadir viewing and illumination angles, directional-hemispherical reflectance for nadir illumination, or bihemispherical reflectance.

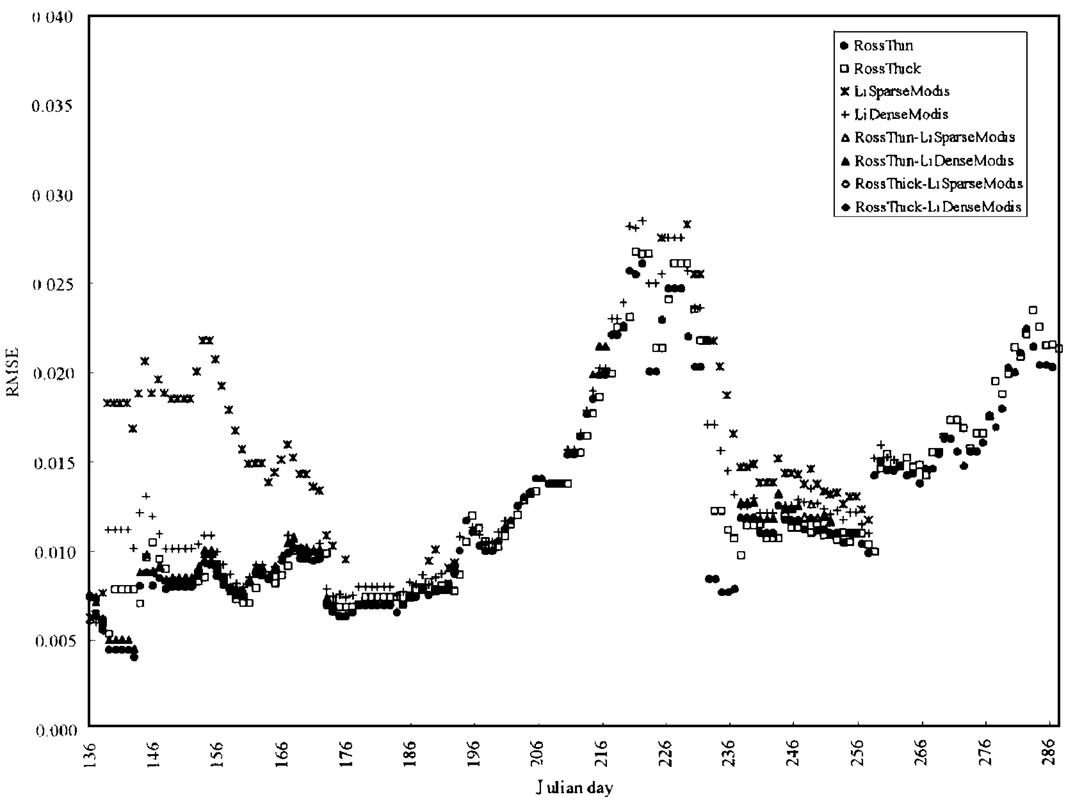

Fig. 2 (a) RMSE

The theory of linear models[7] tells us that interpolated quantities are more stable (reliable) estimates than extrapolated quantities and allows us to put error bars on these various terms. This theory is based on the assumption that the model (in this case, each particular set of kernels) under investigation is able to adequately describe the measurements and that the uncertainty comes from both the lack of fit (RMSE) and the angular sampling scheme. Results from experimentation with the AVHRR data set described above indicate that interpolated quantities also tend to be not critically dependent on kernel selection, but extrapolated quantities can be very sensitive to this. This is demonstrated in Fig. 2. Fig. 2(a) shows a temporal profile of the RMSE of the Central East Millet site with a window of 29 days and a 1-day step between samples. The symbols indicate the RMSE of the valid (non-negative) kernel selections. It is perhaps clearer from this figure , even more so than in Table 1, that the difference in RMSE is often very small between different models. A major point to note however is that, again, generally only two—kernel combinations are valid, and that only the isotropic and either of the Ross kernels are valid for the complete time period considered. Fig. 2(b) shows the normalized reflectance (bidirectional reflectance at the average solar zenith angle for nadir viewing) for AVHRR band 1 for these different (valid) kernels. There is clearly not a huge difference in this quantity among the various kernel combinations that might have been selected. Fig. 2(c) shows the isotropic parameter, which is equivalent to the nadir bidirectional reflectance for nadir illumination, and, as such is an extrapolated quantity. There is a lot more variation in this term than the interpolated quantity depending on which kernels are selected. The same result is found for other extrapolated quantities, with bihemispherical reflectance, for example, varying by as much as 24% depending on the kernels selected. This result is hardly surprising given the different 'shape' of the various kernels[5] but reinforces the point that 'correct' model selection is generally critical for extrapolated quantities but less so for interpolated ones. This finding is likely to apply to whatever model of BRDF one were to use: for example, if there is too much noise or insufficient angular sampling to parameterize the rate of increase (or even decrease) in bihemispherical reflectance with solar zenith angle, then one is unlikely to be able to accurately derive bihemispherical reflectance.

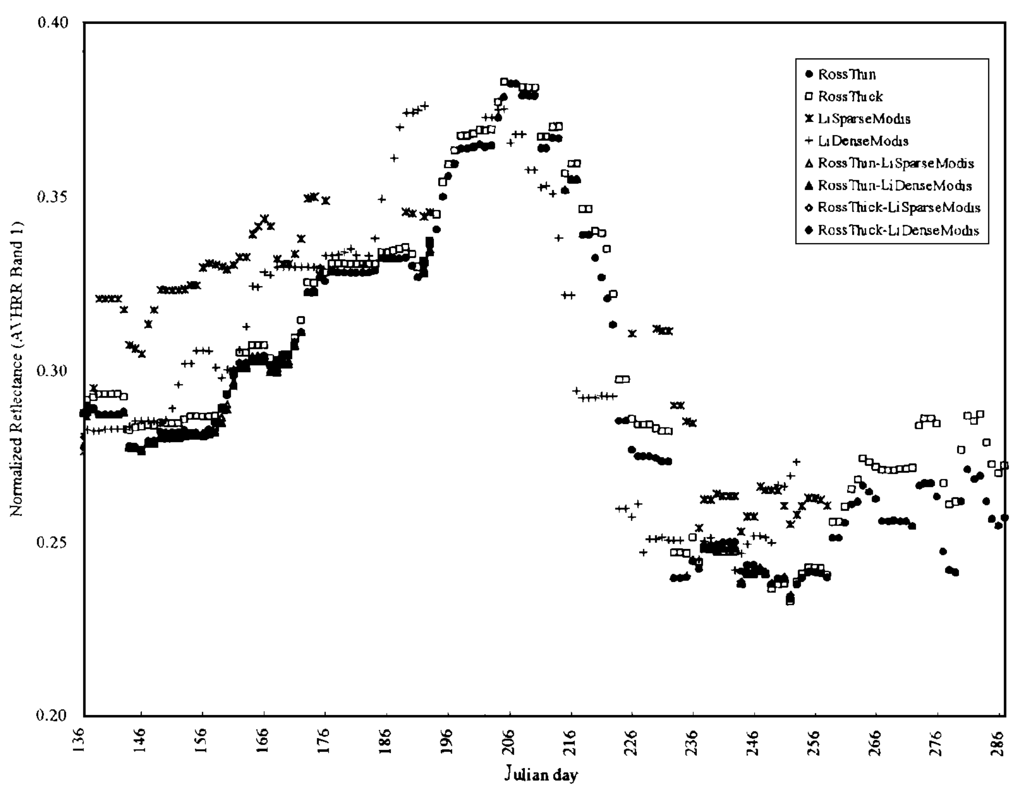

Fig. 2　(b) Normalized bidirectional reflectance

5　MONITORING LAND SURFACE DYNAMICS

Whilst the results above indicate that care must be taken in kernel selection, they also show that the Ambrals model is generally able to model the observed reflectance data to a high degree of accuracy. Further work is continuing with examinations of the behavior of model parameters over time, such as that shown in Fig. 3. An investigation of the information content of these temporal profiles looking at the eigenvectors of the temporal data for specific locations indicates that the information contained in the trajectory of the

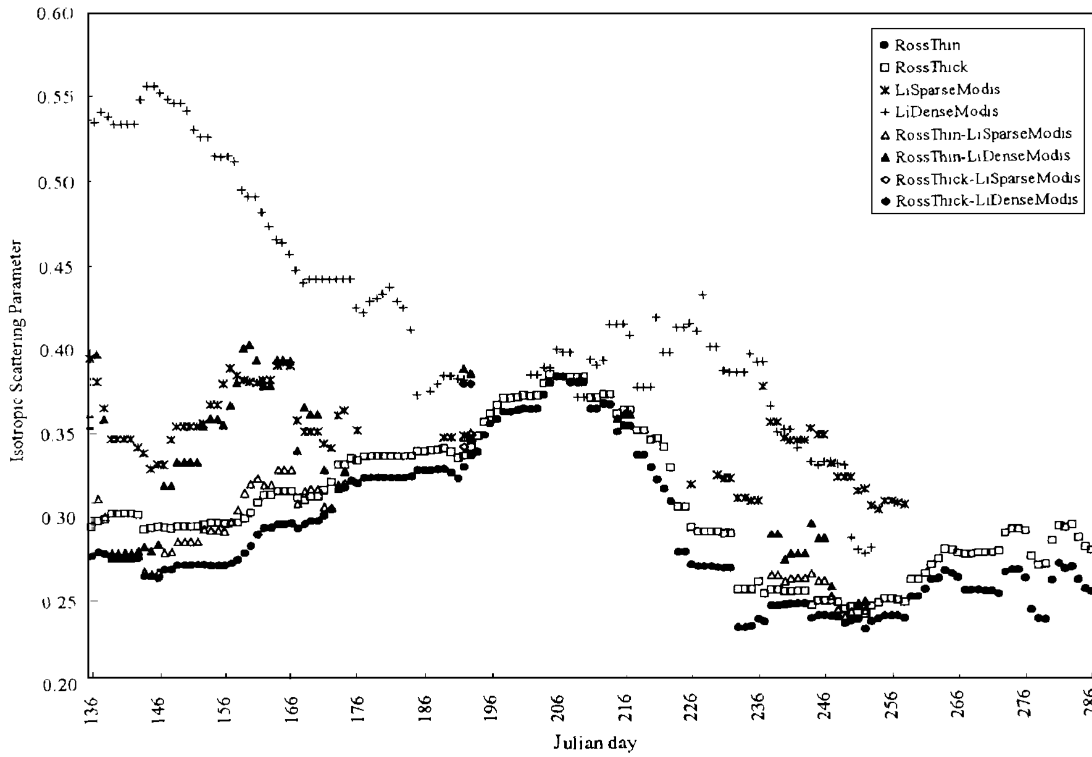

Fig. 2 (c) Isotropic parameter temporal profiles for central east supersite millet

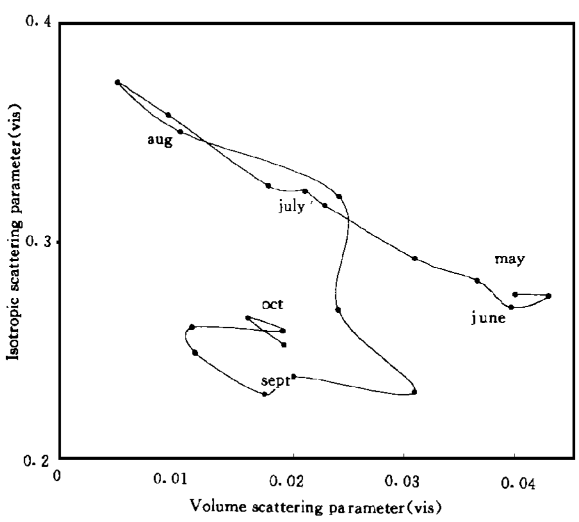

Fig. 3 Temporal trajectory of isotropic parameter and volume-scattering parameter for AVHRR channel 1 for central east supersite millet

BRDF 'shape' parameters, such as the RossThin term, is distinct from that contained within the Isotropic term. We also note similar 'shapes' for trajectories of nominally the same cover type, although that particular part of the analysis is at present rather uncertain due to the very mixed nature of the cover types at this spatial resolution. Further work is required in examining the nature of this potential information content and how it might be used in monitoring land surface dynamics.

6 CONCLUSION

(i) The Ambrals model appears to work well in describing the observed BRDFs.

(ii) Extrapolated quantities such as bihemispherical reflectance and nadir reflectance at nadir illumination are less stable than interpolated quantities such as nadir reflectance at the average solar zenith of the observations and more critically dependent on the set of kernels selected.

(iii) Initial investigations of temporal profiles of model parameters indicate that there is additional information to that contained in normalized reflectance data alone.

(iv) Spatial patterns of model selection may be related to different land cover type, but this requires further investigation.

ACKNOWLEDGEMENTS

This work is funded by the EU as part of an HCM project, 'Monitoring Land Surface Parameters and Processes in Africa North of the Equator'. Travel and conference funds to attend this meeting have been provided by NASA under NAS—31369. The authors would like to thank all of those involved with the HAPEX Sahel project, especially HSIS, for providing data for this study, as well as collegues involved in the NASA MODIS BRDF/Albedo product and the POLDER BRDF product for many fruitful discussions. The data processing for this project was performed on equipment provided by the ULIRS.

REFERENCES

[1] Running, S. W., Justice, C. O., Salomonson, V., Hall, D., Barker, J., Kauffman, Y. J., Strahler, A. H., Huete, A. R., Muller, J—P., Vanderbilt, V., Wan, Z. M., Teillet, P., Carnegie, D. Terrestrial remote sensing science and algorithms planned for EOS/MODIS. *Int. J. Remote Sens.*, 1994, **15**: 3587—3620.

[2] Leroy, M. Compositing reflectances measured from space for vegetation monitoring. Proc. 6th Int. Symp. Phys. Meas. and Sig. in Remote Sens., Val d'Isere, France, 1994, 21—32.

[3] Roujean, J—L., Latoy, M., Deschamps, P. Y. A bidirectional reflectance model of the Earth's surface for the corrections of remote sensing dsta. *J. Geophys. Res.*, 1992, **97**: 20,455—20,468.

[4] Leroy, M., J—L. Roujean. Sun and view angle corrections on reflectances derived from NOAA/AVHRR data. *IEEE Trans. geosci. Remote Sens.*, 1994, **32**: 684—697.

[5] Wanner, W., Li, X., Strahler, A. H. On the derivation of kernels for kernel—driven models of bidirectional reflectance. *J. Geophys. Res.*, 1995, **100**: 21,077—21,090.

[6] Lewis, P. The utility of linear kernel—driven models in global BRDF and Albedo studies. Proc IGARSS'95, Firenze, It, 1995.

[7] Wanner, W., Lewis, P., Roujean, J—L. The influence of directional sampling on bidirectional reflectance and albedo retrieval using kernel—driven models, Proc. IGARSS'96, 1996, 1,408—1,410.

[8] Strahler A. H., Barnsley, M. J., d'Entremont, R., Hu, B., Lewis, P., Li, X., Muller, J—P., Schaaf, C., Wanner, W., Zhang, B. MODIS BRDF/Albedo product: algorithm theoretical basis document. NASA EOS — MODIS doc and update V. 3.2, 1995.

[9] Prince, S. D., Kerr, Y. H., Goutrobe, J. P., Lebel, T., Tinga, A., Bessemoulin, P., Brouer, J., Dolman., A. J., Engman, E. T., Gash, J. H., Hoepffner, M., Kabat, P., Monteny, B., Said, F., Sellers, P., Wallace, J. Geographical, biological and remote sensing aspects of the Hydrologic Atmospheric Pilot Experimental in the Sahel (HAPEX—Sahel). *Remote Sens. Environ.*, 1995, **51**: 215—234.

[10] Stowe, L., McClain, R., Carey, R, Pellegrino, G., Gutman, G., Davis, P., Long, C., Hart, S. Global distribution of cloud cover derived from NOAA/AVHRR operational satellite data. *Adv. Space. Res.*, 1991, **11**: 51—54.

[11] Stowe, L., Davis, P., McClain, R. Evaluating the CLAVR (Clouds from AVHRR) phase I: cloud cover experimental product, *Adv. Space. Res.*, 1995, **16**: 21—24.

AUTHOR

Philip Lewis, born in 1964, received B. A. in 1987, MSc Remote Sensing in 1988, PhD Remote Sensing in London, UK, 1996 repsectively. His research fields are BRDF modelling, modelling and measurement of vegetation structure. He has around 30 conference and journal papers.

应用核驱动BRDF 模型与 AVHRR 数据监测撒哈拉土壤表面动态变化

P. Lewis, E. Vives Ruiz de Lope

(*Remote Sensing Unit, Dept. Geography, University College London 26 Bedford Way, London WC1H 0AP, United Kingdom*)

摘　要　将要用来处理来自即将开始运行的 EOS MODIS 和 MISR 仪器的 BRDF/反照率乘积的反照率反演程序包中的 BRDF 模型在该文中被用来对来自 AVHRR 数据的 SAHEL 地区的方向反射数据进行建模。模型被证明能够很好地描述观测到的数据。同时也讨论了核的选择和导出模型的参数所含的信息内容等问题。

关键词　BRDF，HAPEX sahel，AVHRR