1997

Spectral Information Content of the Boreal Forest

Elizabeth A. Walter-Shea
University of Nebraska - Lincoln, ewalter-shea1@unl.edu

Walter-Shea, Elizabeth A., "Spectral Information Content of the Boreal Forest" (1997). *Papers in Natural Resources*. 1178.
https://digitalcommons.unl.edu/natrespapers/1178

PROCEEDINGS OF THE SEVENTH INTERNATIONAL SYMPOSIUM ON
PHYSICAL MEASUREMENTS AND SIGNATURES IN REMOTE SENSING
COURCHEVEL/FRANCE/7-11 APRIL 1997

Physical Measurements and Signatures in Remote Sensing

Editors
GERARD GUYOT
INRA, Unité de Bioclimatologie, Avignon, France
THIERRY PHULPIN
Centre National d'Etudes Spatiales, Toulouse, France

OFFPRINT / TIRE-A-PART

A.A. BALKEMA / ROTTERDAM / BROOKFIELD / 1997

Physical Measurements and Signatures in Remote Sensing, Guyot & Phulpin (eds)
© 1997 Balkema, Rotterdam, ISBN 90 5410 917 3

Spectral information content of the Boreal Forest

C.L.Walthall – *United States Department of Agriculture, USA*
S.E.Loechel, K.F. Huemmrich & E. Brown de Colstoun – *University of Maryland, Md., USA*
J.Chen – *Canadian Center for Remote Sensing, Ottawa, Ont., Canada*
B.L.Markham – *NASA, Goddard Space Flight Center, Greenbelt, Md., USA*
J. Miller – *Department of Physics and Astronomy, York University, Canada*
E.A.Walter-Shea – *Dept. of Agricultural Meteorology and Climatology, University of Nebraska, Nebr., USA*

ABSTRACT: A major question concerning remote sensing of natural resources in boreal forest regions is the nature of the relationships between spectral reflectance and biophysical information. Regression and model-based analyses were explored to address this question using multispectral data collected from a helicopter platform during the 1994 BOReal Ecosystem and Atmosphere Study (BOREAS) in northern Canada with coincident surface-based biophysical data of boreal forest sites . Potentially useful, simple linear relationships appear to exist between spectral reflectances (primarily visible-red) and biophysical parameters of Aspen; relationships in coniferous canopies (such as Spruce and Pine) are more heavily influenced by their structure and understory, and therefore lack such easily-exploitable correlations. A modified version of the SAIL model incorporating geometric effects of discontinuous canopies, GeoSAIL, was used to assess the role of stand-level structure on reflectance. The structure of the specific tree canopies, significant amounts of shadow, and spectral characteristics of the understory were shown to influence the measured reflectances by varying amounts depending on the canopy. The results of these analyses support stratification of the boreal landscape by cover/species type or some other aggregation prior to retrieval of biophysical parameters as a probable first step in remote sensing of this landscape.

1. INTRODUCTION

A major question concerning remote sensing of boreal forest regions is the nature of the relationships between spectral reflectance and biophysical information. The use of remotely sensed observations for applications beyond assessments of landcover have relied on assumptions concerning the correlations between spectral reflectance data and/or vegetation indices (VI) and vegetation parameters such as leaf area index (LAI) and fraction of absorbed photosynthetically active radiation (f_{APAR}). Regression analysis and model-based analysis using a hybrid vegetation canopy reflectance model, GeoSAIL, were explored to address these assumptions using multispectral data collected from a helicopter platform during the 1994 BOReal Ecosystem and Atmosphere Study (BOREAS) in northern Canada with coincident surface-based biophysical data of boreal forest sites (Sellers et al., 1994). The regression analysis was conducted to address the assumptions of near linearity between spectral reflectance and canopy density. The model analysis was conducted to assess the influence of the heterogeneity of the forest canopy structure and illumination conditions on spectral reflectance.

2. METHODS

Spectral data were collected using an eight channel Modular Multiband Radiometer (MMR) incorporated into the NASA Goddard Space Flight Center/Wallops Flight Facility helicopter-based optical remote sensing system (Walthall et al., 1996). Only the MMR3-visible-red (0.63-0.68 μm) and MMR4-near infrared (NIR) (0.75-0.88 μm) data were used in the analysis. The data were collected from an altitude of 300 m using a 15 degree field-of-view lens while the helicopter hovered over the study sites, yielding an instantaneous field of view of approximately 23 m.

Recorded voltages were converted to at-sensor absolute radiances using procedures described in Markham et al. (1988). The at-sensor absolute radiances were converted to at-surface reflectance factors using Version 3.2 of the Second Simulation of the Satellite Signal in the Solar Spectrum (6S) (Vermote et al., in press) using aerosol optical depths derived from surface-based sun photometer measurements (Markham et al., in press) as inputs. The simple ratio (SR) and normalized difference vegetation index (NDVI) were calculated from reflectances as (MMR4/MMR3) and as (MMR4-MMR3)/ (MMR4+MMR3), respectively.

The analysis data sets were restricted to those for "Tower Sites" as these were the focus of detailed, repeated measurements during BOREAS. These sites consisted of Aspen (*Populus tremuloides*), Jack Pine (*Pinus banksiana*), and Black Spruce (*Picea mariana*) (Sellers et al., 1994). Supplemental data sets that were used in this analysis included measurements of leaf area index (LAI) and canopy architecture parameters, needle and twig optical properties, and understory reflectances. Only LAI was included in the linear regression analysis (N=37), while all of the supplemental data sets were necessary in the model-based analysis (N=25). The simple linear regression analyses was performed on all available tower site data; the GeoSAIL analysis was performed only on those sites where understory data were available. The preliminary processing performed on these data sets is described below.

Measurements of LAI are documented in Chen (in press) and Chen and Cihlar (1995, 1996) using procedures based on measurements of gap fractions and gap size distributions in canopies. Effects of foliage clumping and the fraction of green foliage were also quantified in LAI by means of destructive sampling performed at each site.

Both canopy (needle and twig) and understory reflectances were collected using a Spectron Engineering SE-590 visible-near infrared spectroradiometer; the methods used are described in Middleton et al. (1996) and White et al. (1995), respectively. Needle and twig optical properties were obtained using the methods of Daughtry et al. (1989) and an average value was assumed for each species. Understory reflectances were calculated directly from the digital counts by ratioing target counts with irradiance measurement counts from a reference panel. An observation of each site was made during each intensive field campaign (IFC). Since the SE-590 measures radiance from 0.4 to 1.1 μm (Markham et al., 1995), understory and canopy measurements were integrated to the bandwidths of MMR3 and MMR4.

Table 1: Regression Analysis of VIs and Canopy LAI by Species. Tower Sites Only

Predictor Variables						
N	SR (r^2, slope, offset)			NDVI (r^2, slope, offset)		
	All					
37	0.003	0.27	5.8	0.11	0.04	0.58
	Aspen					
6	0.58	17.0	-24.0	0.46	0.14	0.53
	Pine					
21	0.46	1.45	1.1	0.42	0.1	0.42
	Spruce					
10	0.14	-0.8	9.5	0.14	-0.03	0.85

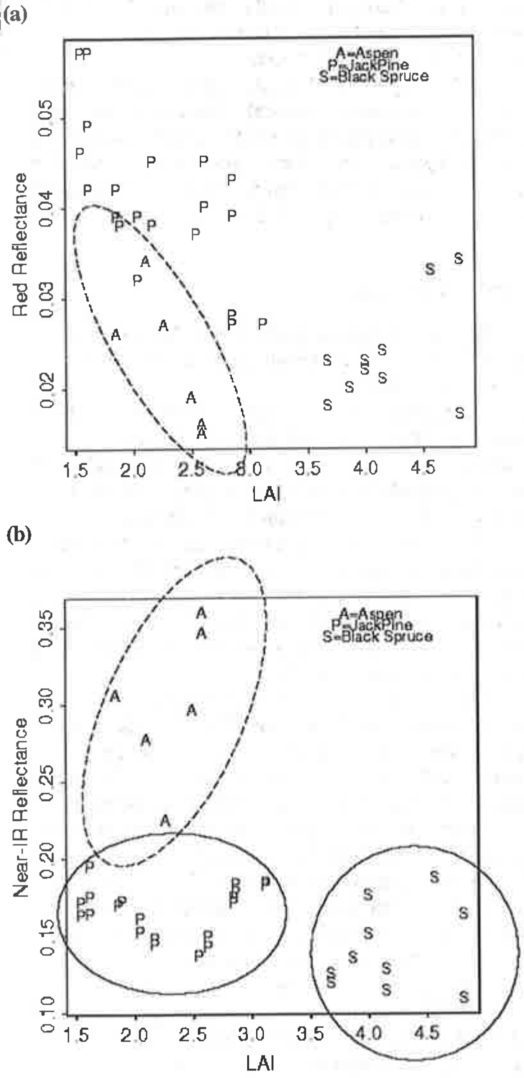
Table 2: Regression Analysis of Reflectances and Canopy LAI by Species: Tower Sites Only

Predictor Variables						
N	MMR3 (r^2, slope, offset)			MMR4 (r^2, slope, offset)		
	All					
37	0.38	-0.01	0.05	0.10	-0.02	0.24
	Aspen					
6	0.62	-0.02	0.07	0.21	0.08	0.13
	Pine					
21	0.50	-0.01	0.07	0.00	0.00	0.16
	Spruce					
10	0.24	0.01	0.00	0.06	0.02	0.08

3. REGRESSION ANALYSIS

Results of the linear regression analyses of LAI (X) to VIs and reflectances (Y) show the amount of variability in canopy reflectance explained by changes in LAI (Tables 1 and 2). For the data set as a whole, r^2 values in the VI regressions were low, ranging from 0.003 for the SR and 0.11 for the NDVI to 0.38 for MMR3 and 0.10 for MMR4.

When stratified by species, the better performance of simple linear relationships in the reflectance regressions at the Aspen sites and poor performance at the conifer sites, especially in the Black Spruce, can be seen (Figures 1 a and b). The Aspen LAI showed a negative relationship with the MMR3 and a positive relationship with the MMR4 data, which maximizes the utility of the vegetation indices, with r^2 values of 0.62 and 0.21, respectively. The Jack Pine sites performed reasonably well in the relationship of LAI to MMR3 ($r^2=0.50$ with a negative slope), although the relationship of LAI to MMR4 ($r^2=0.0$) showed substantial scatter. Thus, we observed a decline in the predictive ability of the SR and NDVI in spite of an increase in the number of observations in the regression relative to the Aspen. The linear relationships performed poorly at the Black Spruce sites as well. The scatter for the MMR3 and MMR4 plots with LAI is sufficient to mask any obvious trend in the relationship. Similar confusion is shown in the vegetation indices, with a reduction of Black Spruce sites to r^2 values of 0.14 for both SR and NDVI. We conclude that little of the variation in reflectance over the Black Spruce can be explained by LAI variations alone. These trends in the tower site data were supported in the results of an analysis of the data over all sites (tower and auxiliary sites) given in Loechel et al. (in press).



Figures 1 a and b: LAI vs. Helicopter-Measured Canopy Reflectances in the red **(a)** and NIR **(b)** at Aspen (A), Spruce (S), and Pine (P) sites.

4. GEOSAIL MODEL ANALYSIS

Given the poor performance of LAI relationships in explaining the variability of the conifer stand reflectances, a hybrid scene radiation model was used to assess the contribution of other stand variables. A modified version of the SAIL (Verhoef, 1984) model incorporating geometric effects of discontinuous canopies, GeoSAIL, has proved to be a useful tool for assessing the sources of variability in forest stand reflectance (Huemmrich, 1995). GeoSAIL uses the turbid media radiative transfer solution of the SAIL model coupled with the geometric model of Jasinski (1990) to simulate reflectance from discontinuous canopies. Endmember reflectance of the scene components (sunlit crown, sunlit background and shaded background), are calculated. Full scene reflectance is then calculated using a weighted sum of these components depending on the percent cover of the stand. Inputs to the model include measurements of optical properties of the understory and canopy (twigs and needles), LAI, leaf angle distribution, percent cover, percent green-to-total foliage area, and view and solar geometry. A cylindrical tree shape was assumed at all sites. Spherical and planophile leaf angle distributions were assumed for needles and branches, respectively (Huemmrich, 1995). Only conifer stand data where understory reflectances were available were addressed with this analysis.

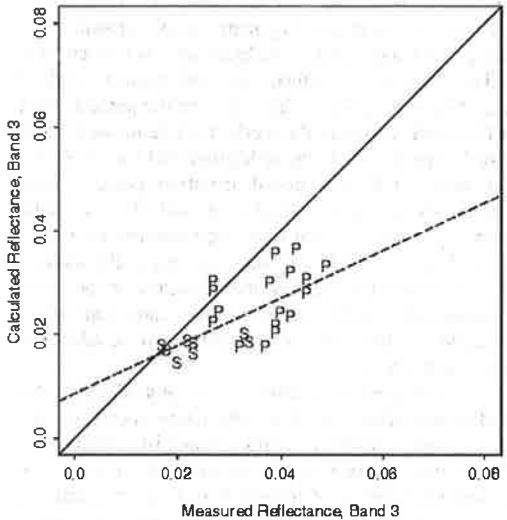
The GeoSAIL simulations are plotted against the MMR3 and MMR4 spectral reflectances measured with the helicopter system (Figures 2 a and b). Above each plot are two regression equations which describe: (1) the plotted relationship of measured (X) vs. modeled (Y) reflectance in the given band, and (2) the regression of LAI (X) vs. reflectance (Y) of the same data (N=25). In each band, the relationship between modeled and measured reflectances fell near the 1:1 line. The relationship of simulated and measured red reflectances showed greater scatter and a trend away from the 1:1 line at higher values. For MMR3 reflectance, the percentage of variation explained by the GeoSAIL model ($r^2=0.43$) is less than that explained by the LAI-Regression model ($r^2=0.51$). Almost none of the variation in reflectance was explained by LAI alone ($r^2=0.05$) in the MMR4 conifer regression model. Variation explained in that data set increased with the inclusion of understory, canopy closure, shadow and background reflectance, and view and illumination geometry, as indicated by the relation between measured and GeoSAIL modeled reflectances ($r^2=0.42$).

5. DISCUSSION

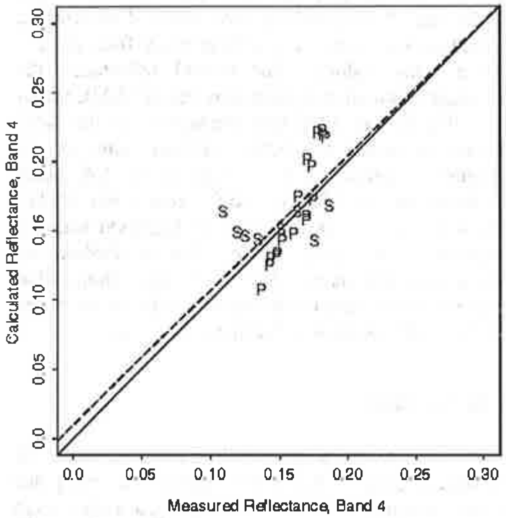
The Aspen sites exhibit traditional trends of spectral reflectance relationships with LAI probably due to the correlation of LAI with percent cover often present in deciduous canopies. Some effects of Aspen scene structural influence on reflectance are evidenced by the low r^2 values indicating that LAI alone does not explain the NIR reflectance.

The conifer site red and NIR reflectances appear to be heavily influenced by factors other than LAI, which may be attributed to the "clumped" nature of conifers decoupling LAI from percent cover. Thus, in conifers, percent cover, background reflectance, and shadow (determined by illumination and viewing geometry) make important contributions to scene

(a) MMR3-red regression results:
Modeled vs. Measured: Y=0.46X + 0.01; r^2=0.43
Measured vs. LAI: Y=-0.01X + 0.05; r^2=0.51



(b) MMR4-NIR regression results:
Modeled vs. Measured: Y=0.97X + 0.01; r^2=0.42
Measured vs. LAI: Y=-0.01X + 0.17; r^2=0.05



Figures 2 a and b: Measured (X) vs. Modeled (Y) Canopy Reflectances in the red **(a)** and NIR **(b)** at Spruce (S) and Pine (P) sites.

heterogeneity. The increasing departure of GeoSAIL simulations from the MMR3 measurements at higher values suggests that the absorption-dominated endmembers of the scenes (shadow and hence associated geometries of tree shape), and the amount of background reflectance present may be under represented and are in need of examination. The high degree of correlation between the GeoSAIL simulations and the MMR4 measurements emphasizes the importance of structure and multiple scatter in the scene.

A study by Hall et al. (1995) used this same model to decompose spectral reflectance data into endmembers of sunlit crown, shadowed background, and sunlit background and found a promising relationship between shadow and LAI that was better than the sunlit endmember relationship with LAI.

6. CONCLUSIONS

1. Simple relationships appear to exist between spectral reflectances and LAI of Aspen: negative with visible-red and positive with NIR.
2. Reflectance from coniferous canopies, such as Spruce and Pine, are more heavily influenced by their structure and understory, and lack the traditional easily-exploitable correlations of Aspen. Specifically, a positive NIR-LAI relationship is not apparent.
3. The heterogeneity of the structure of the specific tree canopies, significant amounts of shadow, and spectral characteristics of the understory were shown to influence the measured reflectances in the NIR. However, some variability in the NIR is still found and the red trend varies from the 1:1 line.
4. The comparison of simulations with the measurements shows that a model such as GeoSAIL is appropriate to describe the reflectance of the scene. Further refinements to the inputs and the model assumptions, such as the more accurate representation of tree shape and mutual shadowing effects among trees, would most likely improve the results.
5. Reliable retrieval of conifer LAI will have to rely on something other than a linear LAI-NDVI relationship, as LAI alone is insufficient in accounting for a majority of the variability in canopy reflectance.
6. Stratification of the boreal landscape by cover/species type or some other aggregation prior to retrieval of biophysical parameters as a probable first step in remote sensing of this landscape.

Acknowledgments. The authors gratefully acknowledge the contributions of all of the BOREAS field staff, including those working on BORIS. Specifically, we thank the helicopter crew and technical support involved in surface biophysical and radiometric measurements. The funding for this research was provided by NASA Grant #NAG52308. Manufacturer names are given for information purposes only and do not imply endorsement.

7. REFERENCES

J.M. Chen and J. Cihlar, "Retrieving leaf area index of boreal conifer forests using Landsat TM images." Remote Sens. Environ., vol. 55, pp. 153-162, 1996.

J.M. Chen and J. Cihlar, "Quantifying the effect of canopy architecture on optical measurements of leaf area index of plant canopies using two gap size analysis methods." IEEE Trans. Geosci. Remote Sens., vol. 33, pp. 777-787, 1995.

J.M. Chen, Rich, P.M., Gower, T.S., Norman, J.M., and Plummer, S., "Leaf area index of boreal forests: theory, techniques, and measurements," J. Geophys. Res., in press, 1997.

C.S.T. Daughtry, L.L. Biehl and K.J. Ranson. A new technique to measure the spectral properties of conifer needles. Remote Sens. Environ. 27:81-91, 1989.

F.G. Hall, Shimabukuro, Y.E., and Huemmrich, K.F., "Remote sensing of forest biophysical structure using mixture decomposition and geometric reflectance models", Ecological Applications, 5(4), 993-1013, 1995.

K.F. Huemmrich, "An analysis of remote sensing of the fraction of absorbed photosynthetically active radiation in forest canopies," University of Maryland, College Park, Ph.D. Dissertation, 207 pp, 1995.

M.F. Jasinski, "Functional relation among subpixel canopy cover, ground shadow, and illuminated ground at large sampling scales," Society of Photo Optical Instrumentation Engineers, 1990.

S. Loechel, C.L. Walthall, E. Brown de Colstoun, J. Chen, B. Markham, "Spectral reflectance from a helicopter platform at BOREAS," J. Geophys. Res., in press, 1997.

B.L. Markham, R.N. Halthore, J.S. Schafer, and B.N. Holben, "Atmospheric aerosol and water vapor characteristics over north central Canada during BOREAS," J. Geophys. Res., in press, 1997.

B.L. Markham, F. M. Wood Jr., and S.P. Ahmad, Radiometric calibration of the reflective bands of NS001-thematic mapper simulator (TMS) and modular multispectral radiometers (MMR) in Recent Advances in Sensors, Radiometry, and Data Processing for Remote Sensing, Proc. SPIE, 24, pp. 96-108, 1988.

E.M. Middleton, Chan, S.S., Mesarch, M.A., and Walter-Shea, E.A., "A revised methodology for spectral optical properties of conifer needles," International Geosciences and Remote Sensing Symposium (IGARSS) Spring 1996, Lincoln, Nebraska, 1005-1009, 1996.

P.J. Sellers, F.G. Hall, M. Apps, D. Baldocchi, J. Cihlar, J. Den Hartog et al., BOREAS Experiment Plan (Version 3.0), NASA/GSFC, Greenbelt, Md. 20771, May 1994, pp 358 plus Appendices.

W. Verhoef, "Light scattering by leaf layers with application to canopy reflectance modeling: The SAIL model," Remote Sens. Environ., 16: 125-141, 1984.

E. Vermote, D. Tanre, J. Deuz, M. Herman, and J. Morcrette, "Second simulation of the satellite signal in the solar spectrum: an overview," IEEE Trans. Geosci. Remote Sens., in press, 1997.

C. Walthall, D.L. Williams, B. Markham, J. Kalshoven, R. Nelson, "Development and present configuration of the NASA GSFC/WFF helicopter-based remote sensing system," International Geosciences and Remote Sensing Symposium (IGARSS) Spring 1996, Lincoln, Nebraska.

H.P. White, J.R. Miller, J. Chen, D.R. Peddle, "Seasonal change in mean understorey reflectance for BOREAS sites: Preliminary results," Proceedings of the 17th Canadian Remote Sensing Symposium, Saskatoon, June 1995.

FROM THE SAME PUBLISHER:

Gudmandsen, Preben (ed.) 90 5410 933 5
Future trends in remote sensing – *Proceedings of the 17th EARSeL symposium, Lyngby, 17-19 June 1997*
1998, 25 cm, c.460 pp., Hfl.205 / $105.00 / £68
Other themes covered are: Land applications, ice, water, ocean and coastal management and more technical papers on methods, models and system aspects and a section on data fusion, which is at leading edge of current research.

Scanvic, Jean-Yves 90 5410 725 1
Aerospatial remote sensing in geology
1997, 24 cm, 280 pp., Hfl.180 / $95.00 / £60 (No rights India)
Translation of 'Télédétection aérospatiale et informations géologiques', updated for the English edition in 1995. This book explains how the human eye and brain can extract and use remotely sensed data in the fields of applied geology & mineral exploration, using numerous operational and research-oriented examples combining the technics of digital processing and specialised interpretation.

Spiteri, A. (ed.) 90 5410 855 X
Remote sensing '96 – Integrated applications for risk assessment and disaster prevention for the Mediterranean – *Proceedings of the 16th EARSeL symposium, Malta, 20-23 May 1996*
1997, 25 cm, 380 pp., Hfl.195 / $120.00 / £65 (No rights India)
The topics covered dealt with environmental change; Desertification; Rainfall; Drought and floods; Erosion & geomorphological hazards; Land degradation & marine pollution; Further presentations dealt with practical applications of remote sensing and Geographic Information Systems for Environmental Mapping and Risk Assessment.

Parlow, E. (ed.) 90 5410 598 4
Progress in environmental remote sensing research and applications – *Proceedings of the 15th EARSeL symposium, Basel, Switzerland, 4-6 September 1995*
1996, 25 cm, 496 pp., Hfl.240 / $120.00 / £80 (No rights India)
Themes: Land applications and environmental monitoring; Data calibration, preprocessing and validation; Atmosphere, hydrology & global change; Marine & inland waters; & Snow & ice. The symposium was followed by a specialist workshop on 'Satellite meteorology and hydrology' with papers and papers on themes of: Transpiration, & energy balance, atmospheric gases and aerosols.

Askne, Jan (ed.) 90 5410 524 0
Sensors and environmental applications of remote sensing – *Proceedings of the 14th EARSeL symposium, Göteborg, 6-8.06.1994*
1995, 25 cm, 500 pp., Hfl.260 / $130.00 / £87
Research covering the analysis of data from the most advanced systems, including visible and infrared optical sensors and both passive and active microwave sensors, demonstrating their contribution to our understanding of dynamic environmental processes.

Winkler, Peter (ed.) 90 5410 311 6
Remote sensing for monitoring the changing environment of Europe – *Proceedings of the 12th EARSeL symposium, Eger, Hungary, 8-11 September 1992*
1993, 25 cm, 318 pp., Hfl.220 / $110.00 / £73
Earth observation from aircraft and satellites, has a key role to play in helping scientists to understand processes on a regional and global scale in all areas of the natural environment. Visible and infrared imaging systems and now, with data flowing from ERS-1, microwave, both passive and active, are of particular importance for the study of land surface processes. Environment; Forestry and agriculture; Methodology; Cartography.

Kozlov, N.P. (Technical editor) 90 6191 137 0
Earth's nature from space – *A study of the natural resources of the earth using satellite data*
(Russian translations series 89)
1991, 24 cm, 287 pp., Hfl.210 / $105.00 / £70 (No rights India)
Satellite designers deal with the special features of satellites for remote sensing. Engineers explain spacecraft sensors, while mathematicians & special programmers discuss the problems of processing remote sensing data. Application of remote sensing to the national economy & environmental protection. An outstanding feature of the book are the original images from Russian Meteor satellites.

Kuznetsov, O.L. & E.M.Simkin 90 5410 221 7
Transformation and interaction of geophysical fields in the lithosphere
(Russian translations series, 106)
1994, 24 cm, 278 pp., Hfl.150 / $75.00 / £50 (No rights India)
Translation of *Preobrazovanie i vzaomodeistvie geofizicheskikh polei v litosfere*, Moscow, 1990. Energy sources of geophysical fields & processes & their distribution in the lithosphere are examined based on remote sensing, surface & subsurface observations; Theoretical basis of interaction & transformation of geophysical fields; Effect of geophysical fields on filtrational transport in rocks; Examples of interaction & transformation of geophysical fields.

Singh, R.B. (ed.) 90 5410 704 9
Global environmental change - *Remote sensing and GIS perspectives / Selected papers of – the International Geographical Union-Seminar on monitoring geosystems-perspectives for the 21st century*
1995, 25 cm, 320 pp., Hfl.190 / $95.00 / £63 (No rights India)
Role of geographical monitoring and forecasting in ecosystem modelling and management; Human response to environmental degradation in endangered areas; Remote sensing based ecosystems dynamic model; Issues in environmental mangement for sustainable development in Nigeria; Coastal land use change and the resulting impact on environment; Land use change, diversification of agriculture and agroforestry in Northwest India; etc.

All books available from your bookseller or directly from the publisher:
A.A. Balkema Publishers, P.O. Box 1675, NL-3000 BR Rotterdam, Netherlands (Fax: +31-10-413-5947)
For USA & Canada: A.A. Balkema Publishers, Old Post Rd, Brookfield, VT 05036-9704 (Fax: 802-276-3837)