SCIENCE DU SOL - 1992 - Vol. 30, 3 169-184,

Description of land surfaces, reflectance measurements and modelling for correlation with remote sensing data

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SUMMARY

The physiognomy of two land surfaces of two different soils in Tunisia is described. Reflectance measurements were done on the different components of the land surface.

The surface components were mathematically defined enabling computerized modelling. A geometric model was developed, called GEOREM, which calculates the shadow configuration of the different components at various solar positions.

The summation of the percentages of surface components directly illuminated by solar irradiance or in shadow and of shadow projected on other components all multiplied by the reflectance of those components (: 100) finally produces the total land surface reflectance.

While the two surfaces were identical according to their planetary reflectance based on TM data at two acquisition dates, it appeared to be possible to discriminate these surfaces with the approach adopted in GEOREM.

KEY WORDS : Tunisia - soil roughness - microrelief - modelling - reflectance - remote sensing.

DESCRIPTION DE SURFACES DE SOLS, DE MESURES DE REFLECTANCE ET DE MODÉLISATION EN VUE D'UNE CORRÉLATION AVEC DES DONNÉES DE TÉLÉDÉTECTION

Afin d'obtenir des corrélations entre les données au sol et des mesures par télédétection, on a étudié deux surfaces de sols en Tunisie, qui diffèrent par la nature du sol, le relief et la végétation. Des mesures de réflectance (coefficient de réflexion) ont été effectuées sur les différents composants de la surface des sols.

Les composants des surfaces ont été mathématiquement définis, permettant une modélisation par ordinateur. Un modèle géométrique (GEOREM) a été développé afin de calculer la configuration d'ombres des différents composants pour plusieurs positions solaires.

La sommation des pourcentages des composants de surface directement éclairés par rayonnement solaire ou situés à l'ombre, et des pourcentages de l'ombre projetés sur les autres composants et multipliés par la réflectance de ces derniers (: 100) donne finalement la réflectance totale de la surface de sol. Bien que les deux surfaces soient iden-

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tiques au niveau de leur réflectance planétaire obtenue avec des données TM (Thematic Mapper) à deux dates d'acquisition différentes, la distinction entre ces surfaces s'avère possible en appliquant la méthode adoptée dans le modèle GEOREM.

MOTS-CLÉS : *Tunisie - rugosité du sol - microrelief - modélisation - réflectance - télédétection.*

INTRODUCTION

The soil surface forms the interface between soil and atmosphere. As such, it plays an important part in hydrology and vegetation development (ESCADAFAL, 1989). In remote sensing, it can be studied directly in case of bare soil, but often it is partly visible or even invisible due to coverage by vegetation or superficial water, or it is absent where rock exposure occurs. Therefore in remote sensing studies, another concept should be applied, this being the land surface, which covers the whole assembly of soil, rock, vegetation and superficial water.

The properties of the land surface, or the actual state of the surface, determine the interaction with the incident electromagnetic radiation. For example, grey tones on panchromatic aerial photographs are the result of interaction with solar irradiance in a selected range e.g. 0.48-0.72 µm. Modern remote sensing systems are able to collect multispectral data, which can be used for characterization and identification of land surfaces. One of those systems is the Thematic Mapper or TM operating in the Landsat satellites 4 and 5. It has a ground resolution cell of 30 x 30 m in the visible and near infrared bands (TM bands 1-2-3-4-5 and 7), and 120 x 120 m in the thermal infrared band (TM band 6). For the informative potential of the different bands, the reader is referred to U.S. Geological Survey (1982) and to MULDERS (1986 and 1987).

The present text focuses on the description of the land surface and the problems connected with the translation reflectance measurements at land components to reflectance values of surfaces large enough to characterize the TM ground resolution cell. For this, surfaces of 100 x 100 m are generally studied.

In this research, visible and near infrared reflectance is studied, including bands 2, 3 and 4, which are positioned in the same zone as that of the spectroradiometer used for measurement of field reflectance.

Reflectance values are the result of measurements of momentary interactions of solar irradiance with the land surface. Such values obtained in different bands may be used to construct spectral curves which provide for spectral signatures of surfaces at acquisition time.

If the bands used for field reflectance measurements are comparable with those of the satellite system, the results can be used for calibrating the latter. Repeated measurements on reflectance at specific time and date can be used to obtain average data on overall land reflectance for correlation with remote sensing data. However, the following problems exist :

1) how many measurements in time and space are needed to obtain an average value, which is representative for the land surface as a whole (?) ;

2) how to estimate the land reflectance at other time and date in a cost-effective way (?).

For this, another way of estimation of representative reflectance values for a land surface can be followed involving the measurement of reflectance of the different land components and subsequent use of models to estimate overall land (surface) reflectance.

Most models on reflectance are directed towards vegetation. They require a large number of input parameters such as transmittance of single leafs, soil reflectance, Leaf Area Index (LAI), leaf angle distribution and average canopy leaf angle (BUNNIK, 1978 ; DEN DULK, 1989) or are based on estimation of LAI from reflectance values (CLEVERS, 1986).

A first attempt on theoretic reflection modelling of soil surface properties was done by VAN DEN BERGH and BOUMAN (1986).

Other researchers attempted to model the geometry of the soil surface to evaluate the effect of different solar altitudes. The soil was considered to be composed of spheres (CIERNIEWSKI, 1987 and 1989), cylinders (DEN DULK, 1989), or cubes (ESCADAFAL, 1989).

In considering these different models, the following conclusions were drawn :

– it is most practical to model vegetation canopies broadly, that is in contour forms, such as paraboloids ; the influence of leaf condition and orientation can best be evaluated by measurements on reflectance (in the terrain) at different solar altitudes ;

– reflection modelling of the intrinsic soil surface is worth-wile, but again measurements on reflectance at different solar altitudes should be carried out to provide for data which are enable to evaluate its influence ;

– geometrical models are needed for the different surface features, considering various shapes which can be mathematically formulated.

A model is introduced, which uses approximated shapes of blocks, ripples and paraboloids in their mathematical formulations to characterize the land surface. Applications are given for land surfaces in Tunisia. First, we present a summary on the parameters important in interaction of solar radiation with objects at the land surface.

I. PARAMETERS IMPORTANT FOR THE INTERACTION PROCESS

The solar irradiance reaches the earth surface after its path through the atmosphere and consequently is altered by interaction with its constituents. It interacts with the objects at the land surface through the processes : specular and diffuse reflection (scaterring), absorption, transmission and emission.

One of the first parameters to be considered in interaction is the solar altitude specific for place and time of observation.

The measurable influence of direct solar radiation is clearly present in the roughness as apparent in micro- (< 1 m) and mesorelief (> 1 m) of the soil surface and in rock and vegetation components, all producing shadow. The radiance reflected from these shaded parts of the terrain is composed of diffuse radiance, which originates from skylight and scattered radiance from the surface itself.

The intrinsic soil surface is characterized by among others : soil texture, mineralogy, organic matter and soil moisture. The soil texture characterization defines all elements smaller than 2 mm to belong to the intrinsic soil surface. This is for convenience ; the dominant reflection of the intrinsic soil surface is regarded to be diffuse and composed of external and multiple internal reflections (VAN DEN BERGH *et al.*, 1986).

For rocks and vegetation, there is not such a size limit. Leafs, or canopies as a whole, are considered to be intrinsic. Rock surfaces are regarded as mineral assemblages where each mineral shows its specific contribution to the overall reflected radiance which may show specular components.

Apart from the relation between wavelength of the radiation and roughness as defined by Raylegh's criterion, the intrinsic surface determines the spectral properties evident in absorption features of spectral curves covering a range of wavelengths (MULDERS, 1987).

Different intrinsic surfaces may have different spectral signatures.

II. DESCRIPTION OF THE LAND SURFACE

The conventional method of description of the land surface is presented in the "Guidelines for Soil Description" (FAO, 1990). For convenience, most aspects are presented in classes which often cover large ranges e.g. slope class 09 (slopes between 30 and 60%) and surface coarse fragments class M (coverage between 15 and 40% of the land surface). These classes are too extensive for our purpose. If data on description of the land surface are used as input to models which evaluate surface roughness, they have to be given in real, more explicit figures. Furthermore, detailed information is needed on the configuration (shape, dimensions and distance) of micro- and mesorelief features as well as on vegetation, which is not provided for by the "Guidelines" mentioned above. In fact, the physiognomy or morphographic appearance of the land surface as a whole has to be described to obtain data of the field of interaction.

POUGET and MULDERS (1988) have presented a description method and a form which aims at a quantitative description of land surface features. Much emphasis is put upon the description of the land surface by ESCADAFAL (1989). This author used besides systematic description and granulometry, micromorphological analysis to increase the knowledge on soil surface properties. Furthermore, rain simulation was applied to study the dynamics of the surface with regard to rain impact.

In the present study, sites for land surface description and reflectance measurements were selected, using spectral homogeneity visible on combinations of TM bands (including Principal Components) as a guide. Fieldwork and aerial photo-interpretation are means to decide if the homogeneity is due to regular repetition of complex assemblages of terrain features or due to repetition of relatively simple assemblages of terrain features.

After the acquisition of quantitative data on configuration of terrain features, sites for reflectance (% reflected radiance/solar irradiance) measurements, which cover the total variation in terrain features, have to be selected and geometrical modelling is applied to obtain insight in the amount of surface exposed to direct solar irradiance as it is dependent on surface roughness, surface exposition and solar altitude.

III. REFLECTANCE MEASUREMENTS ON TWO SELECTED LAND SURFACES

The Seftimi area was selected as study area. It is located at the border of Chott el Fedjaj near Kebili in Tunisia (coordinates 8.77° E, 33.6° N). The two surfaces selected for testing, a stony surface and a dune area, show great difference in features causing surface roughness (Figures 1 and 2).

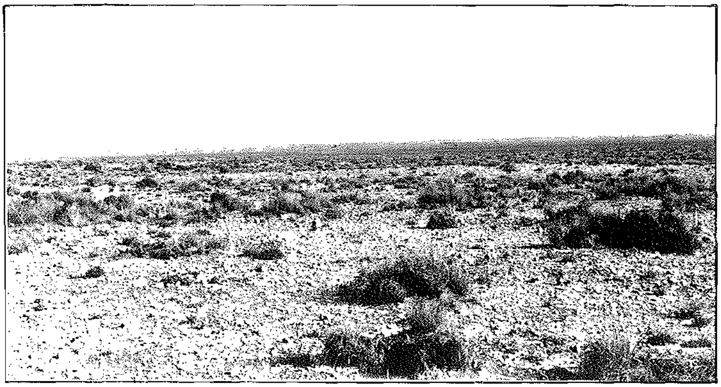

Figure 1 : Stony surface with low dunes partly covered by vegetation ; Glacis of Seftimi (G surface).
Surface caillouteuse avec des dunes basses, couvertes de végétation ; glacis de piémont de Seftimi (surface G).

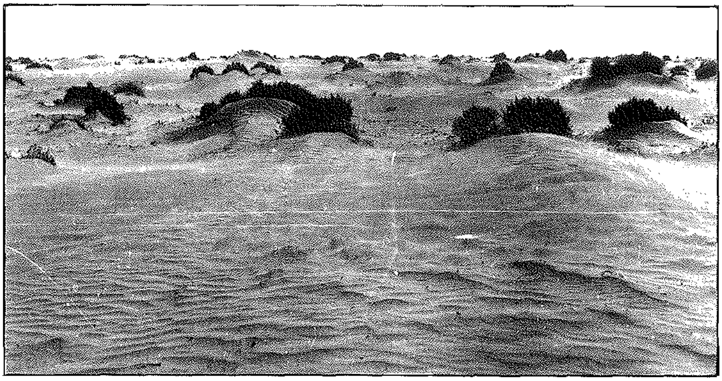

Figure 2 : Dune area with sand ripples and high and low dunes partly covered by vegetation ; Seftimi (D surface).
Zone de dunes avec des rides éoliennes de sable et des dunes hautes et basses partiellement couvertes de végétation ; Seftimi (surface D).

The surfaces are described in Table I by their mesorelief (surface D), microrelief and vegetation (surfaces G and D). The relief is described by length (L), breadth (B) and height (H) of shapes as well as their coverage percentage. Vegetation is considered in the same way but in addition the transparence percentages (as results of visual estimates) are given. Surface G represents the stony surface with low dunes (Fig. 1). Surface D describes the surface with high and low dunes and ripples (Fig. 2).

Table I : Description of selected dry land surfaces in the Seftimi area (Tunisia).

Description de surfaces de sols arides sélectionnées dans la zone de Seftimi (Tunisie).

Code	abiotic surface roughness								vegetation		
	mesorelief H > 1 m				microrelief H < 1 m				type and nr	L - B - H in cm	% /tr
	type	L - B - H in m	pref. orient /slope	%	type and nr	L - B - H in cm or texture	pref. orient /slope	%			
G					dunes 1	250 - 160 - 70	80	0.2	shrub	30 - 20 - 20	30 /50
					2	150 - 150 - 40	106	1.7	2	10 - 8 10	60 /20
					3	120 - 120 - 20	106	2.5	3	8 - 8 -8	40 /40
					4	200 - 90 - 20	76	1	grass 4	60 - 60 - 60	75 /5
					5	35 - 30 5	non	5	shrub 5	8 - 8 - 8	40 /5
					stony 6	20 - 13 15	non	5			
					7	12 - 6 - 2	non	22			
					8	0.4 it - 0.4	non	5			
					9	silt loam		57.6			
D	dunes	15 - 10 - 3.2	170/35 NW - 15 SE	30	dunes 1	60 - 40 - 10	336	0.5	shrub grass 1	60 - 40 - 30	30 /30
					ripple 2	61 - 23 - 2	272/ 39 - 5	30			
					3	32 - 12 - 1.1	272/ 31 - 6	69.5			
		10 - 5 2.1	360/35 NW - 15 SE	10	dunes 4	100 - 50 20	336	10	grass 4.1	100 - 50 - 30	30 /30
									shrub 4.2	100 - 50 - 25	20 /20
					ripple 5	61 - 23 - 2	272/ 39 - 6	20			
					6	32 - 12 - 1.2	272/ 35 - 7	70			
	depr.	30 - 20 - 0	270	60	dunes 7	130 - 70 - 30	336	7	shrub 7.1	70 - 30 - 19	20 /40
									grass 7.2	100 - 10 - 36	10 /40
					8	40 - 20 - 10	336	15	salicornia	10 - 4 - 5	3 /60
									debris	10 - 0.4 - 5	4
					ripple 9	32 - 12 - 1.5	336/ 37 - 9	77			
					crust 10	sand		1			

Reflectance measurements were done systematically on the different land components, or parts of it :

– D, part of land component exposed to direct solar irradiance + skylight (white in Fig. 3) ;

– S, part of land component exposed to skylight and scattered radiance from adjacent surface components (shadow, black in Fig. 3) ;

– P, shadow projection of components on components of the same class or on components of lower classes (grey in Fig. 3).

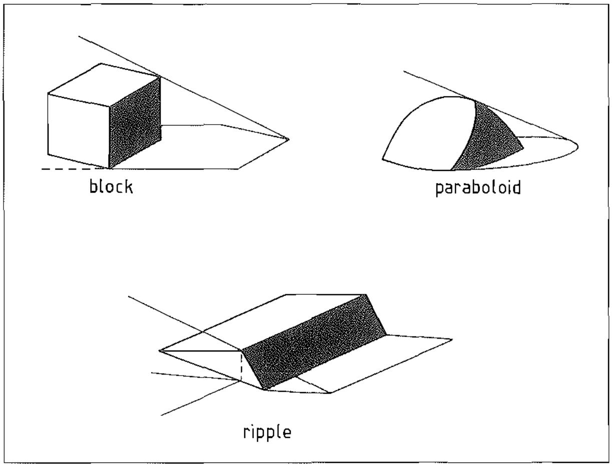

Figure 3 :

The three shapes which form the basis for GEOREM with D (white), S (black) and P (grey).

Les trois formes de base du modèle GEOREM avec D (en blanc), S (en noir) et P (en gris).

In this research, a hand-held Exotech spectroradiometer (model SN 3415) was used, which is capable to measure in the Landsat MSS bands 0.5-0.6 µm (channel 1 = green), 0.6-0.7 µm (channel 2 = red), 0.7-0.8 µm (channel 3 = NIR) and 0.8-1.1 µm (channel 4 = NIR). For measurement of solar irradiance a diffusor cap was used ; the field of measurement from h = 1.7 m equals at specific diaphragms 10.2 x 10.2 cm or 44.6 cm x 44,6 cm. The reflectance is measured as the ratio between the reflected radiance (from

Explanation Table I : L = length, B = breadth and H = height ; preferred orientation in degrees clockwise from West (W = 0 degrees, N = 90 degrees, etc.) ; % = percentage of surface ; tr = transparency for G at 16:00 hrs 22-04-86 and for D at 09:25 hrs 01-05-86 and 15:00 hrs 22-04-86 (times 2 and 3 in Table V) ; orientation and slopes in degrees ; shrub 1 is expressed in % coverage of micro-relief unit 1, etc. ; G1-5 coverage 10.4%, vegetation coverage 47% with transparency of 17%.

Code	Physiographic unit	Soil type **	Soil texture	Surface Colour	Surface type
G	glacis (slope NE 2.3 degrees)	Typic and Petrogypsic Gypsiorthids	silt loam	10YR8/4	stony rough with small dunes and scarce vegetation
D	dunes	Typic Torripsamments	sand	10YR7/4	moderately rough with scarce vegetation

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** acc. Soil Survey Staff : 1975 (Soil Taxonomy).

below) and the solar irradiance (from above) multiplied by 100. The accuracy of measurement of field reflectance was in the order of 10%.

Table II : Zenith and azimuth in degrees for times of field measurements and satellite overpass.
Le zénith et l'azimut en degrés au moment des mesures de terrain et du passage du satellite.

time nr.	date	time	solar angle (degrees)		angle corrected for slope	
			zenith	azimuth	zenith	azimuth
1	29-01-83	10 : 32-GW	59.73	234.84	60.15	236.13
2	22-04-86	15 : 00-LT	41.55	338.44	43.67	337.53
3	22-04-86	16 : 00-LT	53.57	349.90	55.47	349.03
4	25-04-86	09 : 45-LT	41.23	200.05		
5	25-04-86	11 : 10-LT	26.30	226.58		
6	01-05-86	09 : 25-LT	43.96	193.85	42.80	196.05
7	01-05-86	10 : 36-LT	30.28	211.26		
8	18-05-86	10 : 32-GW	28.05	203.00		

Explanation : * slope G surface = NE 2.3 degrees ; GW = Greenwich time ; LT = local time ; zenith angle measured from nadir.

Table III : Field reflectance measurements.
Valeur de la réflectance mesurée sur le terrain.

Unit codes	time nr.	4	(…1)		5	(…8)	
	channel	1	2	4	1	2	4
G 1 - 5 veg		12	15	24	11	18	25
G 1 - 5 soil		27	37	39	27	36	38
G 6 - 7		22	28	36	27	33	40
G 8 - 9		19	28	34	24	33	34
	time nr.	6	(…1)		7	(...8)	
	channel	1	2	4	1	2	4
D 1.1		9	9	23	9	9	23
D 2		27	36	37	27	36	38
D 3		28	36	36	28	36	36
D 4.1		13	16	21	13	16	21
D 4.2		18	27	46	16	22	39
D 5		27	36	37	27	36	37
D 6		27	36	38	27	36	38
D 7.1 + 7.2		26	35	42	26	33	40
D 7.8		16	30	36	15	20	34
D 8.1 + 8.2		12	12	32	11	15	30
D 9 - 10		27	38	45	27	37	43
experimental shadow factors		0.18	0.17	0.14	0.18	0.17	0.14

Notes Table III : unit codes used as codes and numbers in Table II ; time nrs. of Table V ; channel 1 = 0.5 - 0.6 µm, channel 2 = 0,6 - 0.7 µm, channel 4= 0.8 - 1.1 µm. The experimental shadow factors are average values of a number of spectral reflectance measurements of shadows of different components.

The field reflectance measurements should be done at the times of satellite overpass (times 1 and 8 in Table II) or have to be near to solar zenith and azimuth at satellite overpass (e.g. times 4 and 6 for time 1, and times 5 and 7 for time 8) to enable comparison of reflectance values. The field reflectance values of the channels 1, 2 and 4 of the Exotech spectroradiometer are given in Table III as average values (of 5 measurements) for the different complexes of surface features described in Table I.

IV. MODELLING OF LAND REFLECTANCE

A GEOmetric REflection Model or GEOREM was developed which at present considers the following shapes :

- blocks e.g. soil aggregates ;
- ripples e.g. windripples, longitudinal dunes, ploughed ridges ;
- paraboloids (unbounded axis points vertically downwards) e.g. scrub and low dunes with vegetation.

Software was formulated, which uses Monte Carlo methods (COOPER and SMITH, 1985 ; LI and STRAHLER, 1985 ; ROSS and MARSHAK, 1990) with fixed series of at random chosen figures for location of objects. The order, in which objects are simulated, is taken from high to low position above a reference surface. The programme performs calculation of the three basic units per form : D, S and P (see text on reflectance measurements).

Figure 3 illustrates the system ; the input parameters of the object shapes are presented in Table IV. After the land surface is generated, a geometrical algorithm taking into account the simulated position of the sun and height value per pixel, is applied to calculate D, S and P.

The step following on the calculation of the surfaces D, S and P in GEOREM is to fit reflectance data measured from a vertical position at components of the land surface into the overall land reflectance ρ(tot) as it can be estimated by remote sensing from nadir position. In this approach, the overall land reflectance is considered to be a summation of the field reflectance of the different components, as follows :

$\rho(tot) = \Sigma\, \rho D + \rho' S + \rho' P$

where D, S and P are the surface fractions calculated for a group of simulated land components by GEOREM,

ρD = "real" field reflectance (ρ) of the illuminated part of the components

or

(reflected radiance of D/direct solar irradiance + skylight) x 100

ρ'S, ρ'P = "reduced" field reflectance (ρ) of S and P as it can be calculated from :

(reflected radiance of S or P/direct solar irradiance + skylight) x 100.

V. RESULTS

The imaging capability of GEOREM is demonstrated in Figures 4 and 5 (relief units in Table I ; time nrs in Table II). Figure 4 presents paraboloids of differents sizes and orientation. Figure 5 illustrates shadow configuration of random blocks covering locally blocks of same or other size.

Figure 4 :

GEOREM image of relief units G 1-5 at time nr. 1 covering an area of 14.4 m x 14.4 m.

Image GEOREM des éléments de relief G 1-5 au temps n° 1, recouvrant une parcelle de 14,4 m sur 14,4 m.

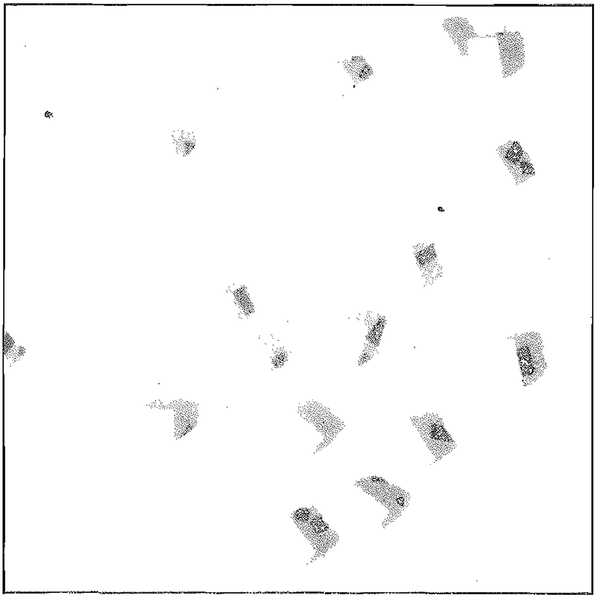

Figure 5 :

GEOREM image of relief units G 6-7 at time nr. 2 covering an area of 2.9 m x 2.9 m.

Image GEOREM des éléments de relief G 6-7 au temps n° 2, recouvrant une parcelle de 2,9 m sur 2,9 m.

Before operation of GEOREM, the basic parameters for imaging of features as well as the output wanted for shadow configuration were determined. The programme has to be used for as many components as possible in order to include mutual influence of components (the shadow of one component may cover other components). Since maximum iteration for Monte Carlo try outs is currently set equal to 1 000 and due to the limited output resolution (number of pixels), there is a maximum coverage of objects, which in practice is equal to a figure between 50% and 60% of the surface.

Another limitation with respect to shadow computation is the fact that the shadow section will be rejected if it is smaller than one pixel.

Therefore, the minimum ground cell dimensions of the square pixels were estimated. The smallest acceptable pixel dimension should be at least 0.1 of the minimum size (B in Table I) of the objects to be described. The resulting dimensions for the ground resolution cells described by the pixels and for the corresponding ground scenes are given in Table V. In case of surface G, we are dealing with a sloping surface with many components. Surface D on the contrary is characterized by three surfaces at different levels (resp. 3.2 m, 2.1 m and 0 m), which influence each other with their shadow configuration. However, the microrelief units of each of these surfaces are supposed to have no influence on units of the same order in other surfaces.

Table IV : GEOREM : input of shape parameters.
GEOREM : données d'entrée du modèle (paramètres de formes).

Shape	parameters
Block	L = length (m) B = breadth (m) H = height (m) p = azimuth angle long axis
Ripple	L = length (m) H = height (m) α = steep slope angle of ripple surface with horizontal plane β = item but gentle slope R = azimuth angle long axis
Paraboloid	a = 1/2. long axis (m) b = 1/2. short axis (m) c = height (m) p = azimuth angle of long axis of the elliptic section
Remarks. The paraboloid is given by its x and y coordinates and the height (z) per pixel : $z = c - \alpha x^2 - \beta y^2$, where $\alpha = c/a^2$; $\beta = c/b^2$. The angle of the incident direct solar irradiance with the horizontal is a common input parameter.	

The output wanted for shadow configuration is determined by the times of field measurement and satellite overpass : 29-01-83/10:32 and 18-05-85/10:32 (Greenwich Mean Time). For unit G, the solar angle of incidence was corrected in programme execution for the slope of surface (Table II).

The results of GEOREM for the different combinations of surface components are presented in Table VI. Percentages of the surfaces projected on a horizontal reference plane and of the total surfaces of D, S and P of the different components (grouped in complexes) are given. The total surface percentage involves a calculation of the total area of the surface, which is exposed to incident radiation. The calculation of the percentage D, S and P of groups with relatively low height (e.g. G 6-7 and D 3) has to take into account the P values of the groups with higher height (resp. G 1-5 and D 1-2).

Table V : Dimensions of pixels on the ground and total surfaces described for micro- and meso-relief units of G and D.

Les dimensions des pixels points sur la surface des sols et les surfaces entières décrites pour les éléments, en micro et mésorelief de G et D.

Relief units	One side of square	
	grc* (cm)	gs* (m)
G 1 - 5	3	14.4
G 6 - 7	0.6	2.88
G 8	0.04	0.192
Dmeso	50	240
D 1 - 2	2.3	11.04
D 3	1.2	5.76
D 4 - 5	2.3	11.04
D 6	1.2	5.76
D 7 - 8	2	9.6
D 9	1.2	5.76

*grc = square ground resolution cell (area on the ground), which pixel describes.
*gs = ground scene, the total surface of terrain, which 480 x 480 pixels describe.

Reflectance values were calculated as aided by these results and the field reflectance measurements (Table III). As an example, the formulae used for calculation of the components G 1-7 are given below :

G 1-5 10^{-4} [(V . Dt 1-5 . ρG1-5 veg) + (100-V) . (Dt 1-5 .
ρG1-5 soil) + (100-T) . f . St1-5 . ρG1-5 soil] +

G 6-7 10^{-4} [(100 - Pp'1-5) . (Dt 6-7 + f . St6-7) . (ρG6-7)] +

P 1-7* 10^{-2} [(Pp'1-5 . (G6-7/100 - G1-5) . f . ρG6-7) + (Pp'1-5 .
(G8-9/100 - G1-5) . f . ρG8-9) + (Pt6-7 . f . ρG8-9)]

where * = projected shadow, corrected for surface area projected shadow of higher components ;

V = vegetation coverage, T = transparency of vegetation ;

Dt and Dp', St and Sp', Pt and Pp' = total and projected surface of D, S and P (like V and T in % of surface) ;

f = experimental shadow factors (Table III) ;

ρD, ρS, ρP = reflectance (%) of D, S or P.

The ultimate results per combination of components and for total (land reflectance) values are given in Table VII. Differences were found in total reflectance values for G and D surfaces between January and May (resp. times 1 and 8). The G surface had by far the greatest difference between these two acquisitions, having in May its highest reflectance.

Such a difference was not found in remotely sensed reflectance values, which were related to the intensity at the top of the atmosphere (Table VIII) ; the socalled planetary

Table VI : Results of GEOREM at times 1 and 8.
Résultats de GEOREM aux temps 1 et 8.

Relief units	Shape	D, S or P	Projected		Total	
			time 1	time 8	time 1	time 8
G 1-5	parab	D	11.50	12.22	12.77	13.73
		S	0.72	0.0	0.97	0.0
		P	0.27	0.0	0.26	0.0
G 6-7	block	D	26.44	27.50	28.46	33.94
		S	1.20	0.14	16.82	11.34
		P	17.67	4.64	13.36	3.51
G 8	block	D	5.14	5.14	10.43	11.20
		S	0.0	0.0	8.69	7.92
		P	10.19	2.77	8.69	2.36
Dmeso	parab	D	31.29	39.37	34.50	44.39
		S	8.08	0.0	9.89	0.0
		P	4.06	0.0	3.69	0.0
D 1-2	parab	D	0.55	0.63	0.62	0.72
		S	0.08	0.0	0.10	0.0
		P	0.02	0.0	0.02	0.0
	ripple	D	30.78	30.55	31.04	30.81
		S	0.0	0.0	0.0	0.0
D 3	ripple	D	70.52	70.50	71.10	71.10
		S	0.0	0.0	0.0	0.0
D 4-5	parab	D	7.78	10.61	9.44	13.2
		S	2.75	0.0	3.79	0.0
		P	1.83	0.0	1.77	0.0
	ripple	D	20.23	20.26	19.90	19.90
		S	0.03	0.0	0.04	0.0
D 6	ripple	D	70.60	70.59	71.30	71.30
		S	0.0	0.0	0.0	0.0
D 7-8	parab	D	15.87	22.70	19.22	28.60
		S	6.80	0.0	9.42	0.0
		P	5.93	0.0	5.44	0.0
D 9	ripple	D	79.60	79.60	79.30	81.30
		S	0.0	0.0	1.26	0.0
		P	2.54	0.0	2.48	0.0

Explanation :
parab = paraboloid ; times 1 and 8 of Table II ;
D = parts of land components exposed to direct solar irradiance + skylight (% of surface) ;
S = parts of land components exposed to skylight and scattered radiance from adjacent surface components (shadows in % of surface) ;
P = shadow, projections of components on surface components of same or other classes (% of surface).

reflectance according to EPEMA (1990). The planetary reflectance values showed hardly any difference for TM bands 2 and 3 between acquisitions in January and May. The effect of shadow configuration (strongest in January at low solar altitude) is not expressed in these values.

Both methods indicate the increase in reflectance from green over red to near infrared for the two surfaces at two acquisition times.

Table VII : Calculation of reflectance based on field reflectance data and GEOREM results.

Le calcul de la réflectance d'après les données de la réflectance de terrain et les résultats du GEOREM.

Unit codes	Channel 1 (%) time 1	Channel 1 (%) time 8	Channel 2 (%) time 1	Channel 2 (%) time 8	Channel 4 (%) time 1	Channel 4 (%) time 8
G 1-5	2.6	2.7	3.5	3.8	4.2	4.4
G 6-7	6.9	9.7	8.7	11.8	11.1	14.2
G 8	2.1	3.4	3.1	4.1	3.6	4.1
GP 1-7	0.5	0.2	0.6	0.2	0.7	0.2
G 9	5.4	11.4	8.0	15.7	9.7	16.2
Total G	17.5	27.4	23.9	35.6	29.3	39.1
D 1-2	2.2	2.8	2.9	3.8	3.0	3.9
D 3	5.2	6.6	6.6	8.5	6.6	8.5
D 4-5	0.6	0.8	0.8	1.0	0.9	1.1
D 6	1.6	2.1	2.2	2.8	2.3	3.0
DStmeso	0.5	0.0	0.7	0.0	0.5	0.0
DPtmeso	0.2	0.0	0.2	0.0	0.2	0.0
D 7-8	2.5	3.2	4.2	4.1	5.1	6.2
D 9-10	10.9	13.3	15.4	18.2	18.2	21.2
Total D	23.7	28.8	33.0	38.4	36.8	43.9

Note : unit codes correspond with Table I ; time nrs according Table II ; channels according Table III.

Table VIII : Reflectance values of TM bands 2, 3 and 4, as related to the intensity at the top of the atmosphere.

Valeurs de réflectance des bandes TM 2,3 et 4 rapportées à l'intensité en haut de l'atmosphère.

TM bands	Reflectance (%)			
	unit G		unit D	
	1*	8*	1*	8*
2	28	26	29	28
3	34	35	38	37
4	45	49	48	52

1* and 8* = acquisition in January 1983 (1*) and May 1985 (8*).

VI. DISCUSSION AND CONCLUSIONS

The results obtained by GEOREM proved surfaces, which were more or less identical according their planetary reflectance, to be different at the acquisition time with lowest solar zenith. At the acquisition time with high solar zenith, they were nearly identical.

With GEOREM, it is possible to evaluate the effects of different surface components. In case of surface G, the difference was largely due to the high contribution of shadow by the blocks G 6-8 at low solar zenith.

Geometric modelling enables to calculate the effect of surface roughness in relation to solar zenith and azimuth and as such may play its part in calculating reference data at other solar positions. The results may be used for calculation of total land surface reflectance at specific times as aided by field reflectance measurements and consequently for calibration of remotely sensed data.

The ultimate results may through detection of surface properties enable the discrimination of soils in arid areas with relatively high bare soil coverage. In this case, discrimination was possible between Gypsiorthids and (gypsiferous) Torripsamments (see addition to Table I).

Imperfections in landsurface description, such as transparency of vegetation, and imperfections in reflectance data, such as the contribution to total reflectance of shaded components, can be solved. It is furthermore without doubt that in this approach, spectroradiometers with high spatial resolution are preferred above those with low spatial resolution.

The formulae on calculation of reflectances are given as examples on methodology. Il is possible to develop software for these calculations. GEOREM has to be completed with a mathematical approach, which enables to model trees. Crowns of trees can be modelled by defining shapes at a certain height (the stem) above reference level (or height above pixel level).

Most of the time needed for application of GEOREM is paid to fieldwork. Description of one site, including measurements on reflectance, takes about half a day for two trained persons. Data input of GEOREM and computation requires about 5 minutes with a 486/50 MHz computer and about 10 minutes with a 386/20 MHz computer.

If one considers another view angle than nadir, as SPOT is able to do, it is possible with GIS (Geographic Information Systems) to superpose a GEOREM image with object and shadow configuration at particular solar position with another GEOREM image, which shows the surface of components visible to the remote sensing system with oblique view. However, both images have to be corrected for oblique viewing.

The amount of D, S and P visible to the central part of the oblique view angle than can be estimated. The second image of the surface generated by GEOREM is identical to the first one of that surface since GEOREM uses fixed series of random distributions.

Reçu pour publication : Janvier 1992
Accepté pour publication : Octobre 1992

ACKNOWLEDGEMENTS : Colleagues of the ITC (International Institute for Aerospace Survey and Earth Sciences, Enschede, The Netherlands) have been so kind to make available the Exotech radiometer after bad luck with our own spectrometer during field work. Data have been used of the reports of Bart Krol (1988) and Rob Hootsmans, Kees Schotten and Marlies Verspui (1989). Thanks are due to Mr. B.R. Damste (formerly employed by Department of Mathematical Sciences of the Wageningen Agricultural University) for his contribution to the mathematical definition of objects and to Dr. H. Cruys for French translation.

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