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# Model for inferring soil surface roughness from soil directional reflectance data

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ABSTRACT: A simple geometrical model was used as a computer tool to infer soil surface geometry from soil bidirectional reflectance data. The model simulates rough soil surfaces as equal-sized spheroids regularly spaced on a flat horizontal surface. The geometrical structure is illuminated by the direct solar beams and diffuse skylight. The normalised soil bidirectional reflectance (NR) data collected along the solar principal plane are the basic input into the model. The NR is defined as the proportion of the total radiance measured from an off-nadir direction to the radiance measured from the nadir direction The shape of the spheroids, the distance between them, and the skylight condition parameter are output data of the model.

## 1 INTRODUCTION

Soil surfaces show variation in their brightness due to the direction of irradiation and the direction from which reflectance is observed. Irregularities of the soil surface, i.e., soil aggregates, clods and soil micro-relief configuration, make it impossible to illuminate the whole surface directly. They produce shadows on soil surface fragments. The energy leaving them is many times lower than the energy reflected from sunlit soil fragments. In the absence of strong specular behaviour, soil surfaces seem to be brighter from a direction which displays a lower proportion of shaded fragments (Cierniewski, 1987, 1989; Graetz and Gentle, 1982; Huete, 1987; Pech *et al.*, 1986; Ransen *et al.*, 1985).

This explanation of the bidirectional character of soil surface reflectance was used to work out geometrical models describing soil directional reflectance. The model of Norman *et al.* (1985) describes rough soil surfaces with aggregates and clods on the surfaces as cuboids situated on a horizontal plane. The Monte Carlo soil surface reflectance model, developed by Cooper and Smith (1985), simulates soil surface irregularities by two micro-relief forms whose height varies periodically according to a cosine function in one or two directions for 'row' and 'clump' soils, respectively. The models of Cierniewski (1987, 1989) and Irons *et al.* (1992) describe the soil surface as made of uniform opaque spheres, or spheroids (Cierniewski and Verbrugghe 1994, 1997; Cierniewski *et al.*, 1996) regularly spaced on a horizontal surface.

The assumption that the bidirectional character of soil surface reflectance in principle depends on the incident angle of the direct solar beam on a rough soil surface and its shadowing was used to work out a new simple geometrical model. It works as a computer tool to infer soil surface geometry from soil directional reflectance data.

## 2 THE MODEL

The model simulates rough bare soil surfaces as equal-sized spheroids of given horizontal (a) and vertical (b) radii lying on a flat horizontal surface. They are regularly spaced at a distance (d). The geometrical structure is illuminated by the direct solar beam at a zenith angle ($\theta_s$) and diffuse skylight (Fig. 1).

In the first step the model, using trigonometrical equations, calculates the area of illuminated and shaded fragments of the simulated soil surface, visible at a given view zenith angle ($\theta_v$) of the sensor.

In the second step the model calculates the electromagnetic energy coming to an individual facet of directly illuminated fragments of the geometrical structure, using the factor ($E_{il}$) defined as:

$$E_{il} = \cos\gamma + f\,\delta/180° \qquad (1)$$

where $\gamma$ = the angle between the normal to a given illuminated facet and the direct solar beam; $\delta$ = the angle describing the reduction of diffuse skylight energy reaching the facet, caused by the adjoining spheroids; and f = the diffuse skylight factor (Fig. 1, 2).

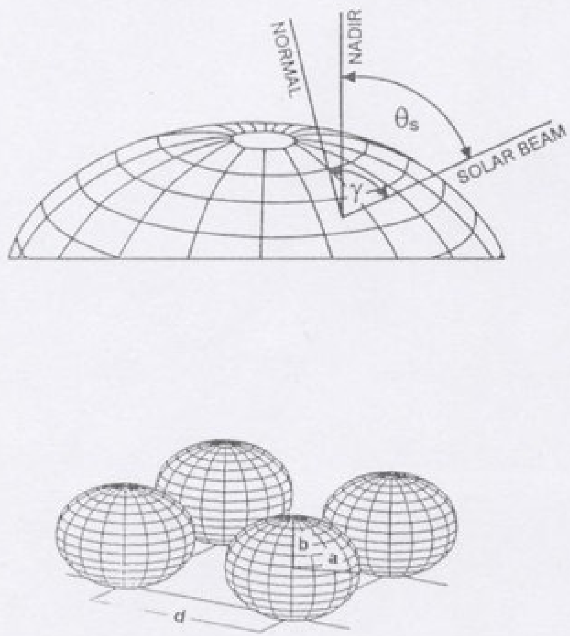



Figure 1. Geometry of the simulated soil surface, where a and b are the horizontal and the vertical radii of the spheroids, d is the distance between their centres, $\gamma$ is the zenith incidence angle of the solar beam on a facet, and $\theta_s$ is the solar zenith angle.

The second component of the Eq.1 also describes the energy reaching shaded fragments ($E_{sh}$) of the structure:

$$E_{sh} = f\,\delta/180° \qquad (2)$$

The model assumes that the energy reflected from a soil surface is directly proportional to the energy coming to it. The total radiance of the analysed soil surface ($Lt_{\theta v}$) visible to the sensor at the given angle $\theta_v$ can be formulated as:

$$Lt_{\theta v} = \sum_{i=1}^{j} (E_{il,\,si}\,\beta_{il,\,si}/\alpha + E_{sh,\,si}\,\beta_{sh,\,si}/\alpha + E_{il,\,gi}\,\beta_{il,\,gi}/\alpha + E_{sh,\,gi}\,\beta_{sh,\,gi}/\alpha) \qquad (3)$$

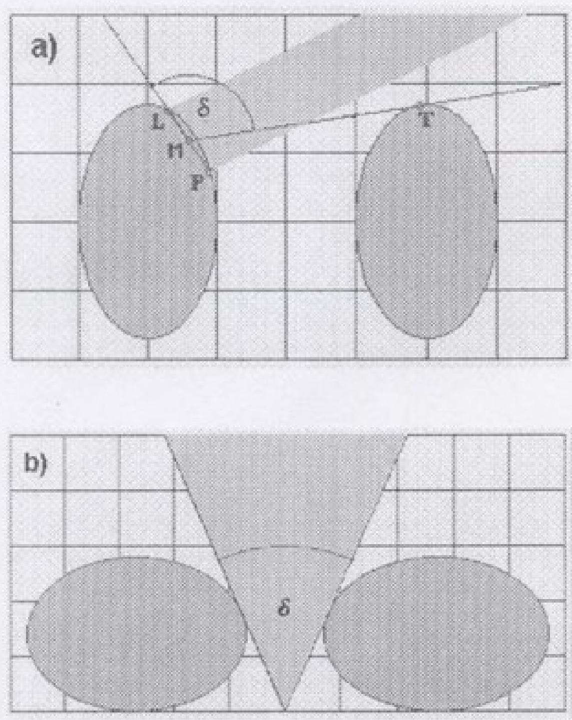



Figure 2. Angle ($\delta$) describing the reduction of diffuse skylight reachnig the facet: a) on the spheroid (L, P lay on the arc, M is the middle point between L and P, and T is the point of tangency); b) on the ground.

where i = the i[th] facet of the geometrical structure; $\beta$ = the angle at which the facet, either directly illuminated (il) or shaded (sh), is viewed by the radiometer; $\alpha$ = the radiometer's field of view; and subscripts 's' and 'g' refer to spheroids and the ground between the spheroids, respectively.

The model calculates the radiance for the profile going through the centre of the spheroids, and then for several following profiles parallel to the first one, taking into account the cosine variation of the azimuth position of a spheroid facet. The total radiance is computed as an average of all the profiles. The reflectance of the simulated surface, visible at a given $\theta_v$ angle, is finally expressed by the normalised reflectance (NR), defined as the proportion of the total radiance ($Lt_{\theta v}$) measured from an off-nadir direction to the radiance measured from the nadir direction. The model predicts the NR of a horizontal soil surface along the solar principal plane.

The discussed model uses the iteration procedure in the following way. The input data are normalised soil directional reflectance (NR) values measured along the solar principal plane. They are given as

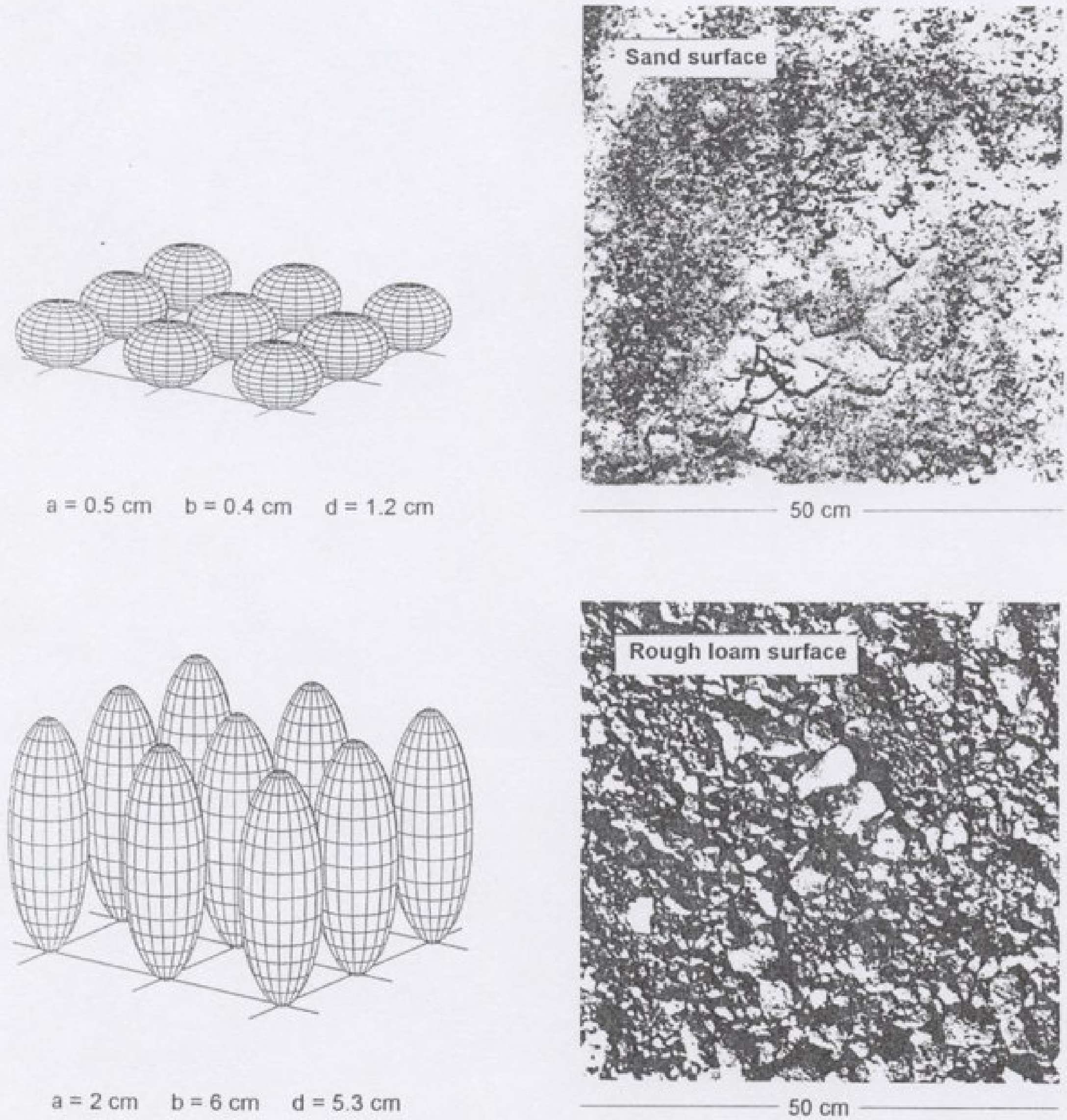
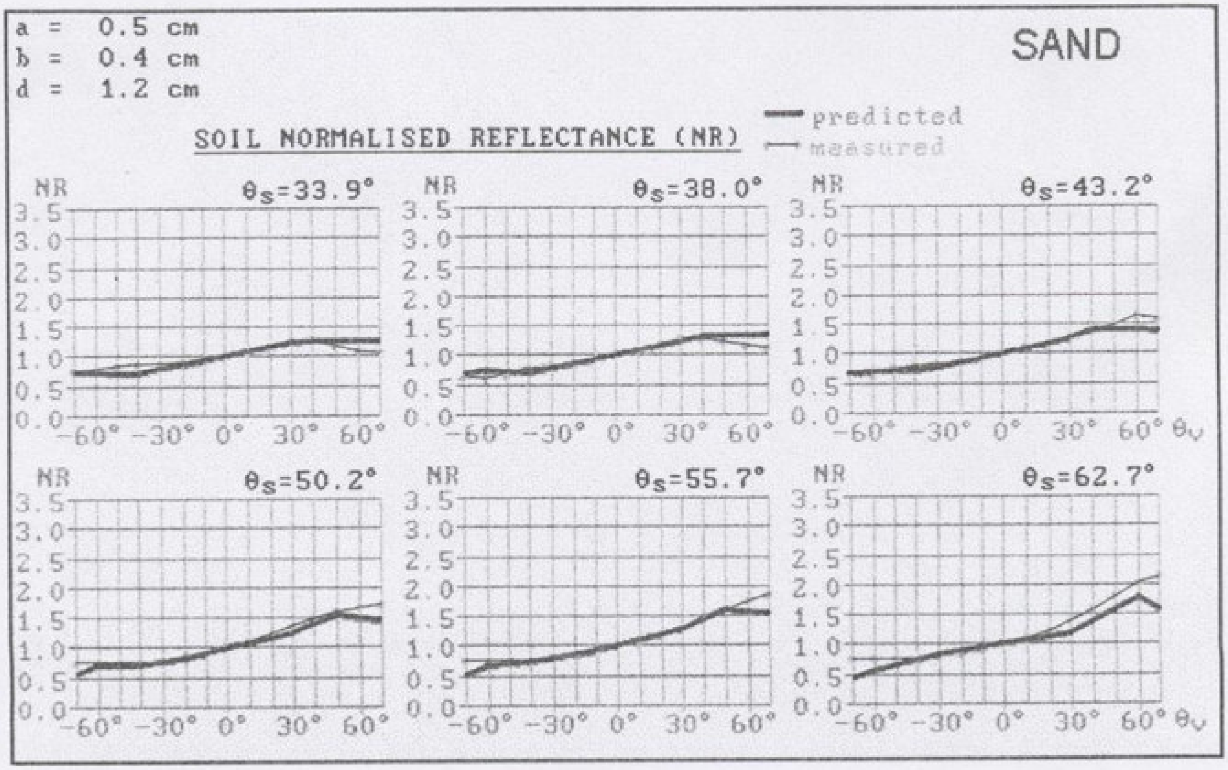



Figure 3. Ground photographs of the discussed soils and their synthetic surfaces.

sequences of triples $\theta_s$, $\theta_v$, and NR. The iteration procedure starts with the initial values of geometrical parameters of the simulated soil surface: the horizontal (a) and vertical (b) radii of the spheroids, the distance between their centres (d), and the diffuse skylight factor (f), describing the proportion of skylight energy to the direct beam energy coming perpendicularly to the soil surface. These values are supplied by the user. He also defines their increments and the final values. The procedure generates the soil normalised reflectance (NR) and compares it with the measured data, using the mean deviation error. Finally, the best fitted parameters a, b, d, and f are chosen.

## 3 OBSERVED DATA

The usefulness of the model for inferring soil surface roughness was tested using directional reflectance data of sandy and loamy surfaces of different roughness states. They were measured in outdoor conditions by a five channel field luminancemeter CIMEL 313-21 working in the optical domain: 450 nm, 550 nm, 650 nm, 850 nm, and 1650 nm. The radiation data were collected along the solar principal plane in 15 directions at 10° increments from 70° of the view zenith angle towards the Sun, through the nadir, to 70° away from the Sun.



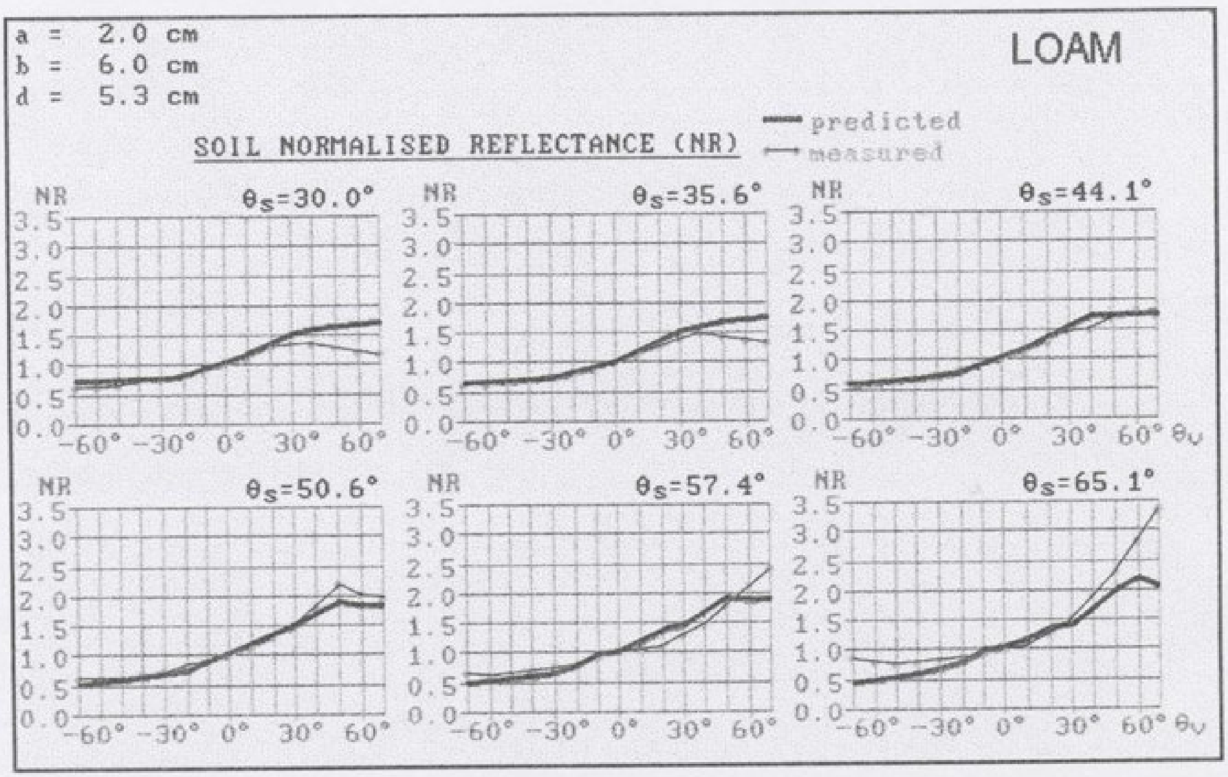




Figure 4. Normalised reflectance (NR), measured and predicted, for smooth sand and rough loam.

## 4 RESULTS

Two characteristic of soil surfaces, one rough and the other smooth, are presented here (Fig. 3). Their texture is described in Table 1.

Table 1. Textures of soil materials.

| Material | Content in % of | | |
|---|---|---|---|
| | sand | silt | clay |
| Loam | 46 | 45 | 9 |
| Sand | 91 | 9 | 0 |

The model generated their normalised reflectance (NR), assuming that the skylight factor (f) is 0.1, the height of the radiometer equals 2 m., and the radiometer field of view ($\alpha$) is 10°.

Generally, the higher the roughness of a soil surface, the higher the variation of the NR in the function of the view zenith angle ($\theta_v$). The peak of backscattering radiation becomes more pronounced as the solar zenith angle ($\theta_s$) increases (Fig. 4).

Vertically elongated spheroids and flatted ones are output data of the discussed model for rough and smooth soil surfaces, respectively. Soil surfaces like pebbles, sand, and loamy sand, containing simple dense particles with rounded edges, can be described satisfactorily by their actual geometry. The great elongation of the spheroids simulating the rough loam surfaces is forced by a secondary porous structure of the loam aggregate (Cierniewski *et al.*, 1996).

## 5 CONCLUSIONS

The initial results of the soil bidirectional reflectance model application of the facet illumination by for inferring soil surface roughness show that it predicts soil surface geometry quite correctly for relatively smooth soil surfaces with the least complicated surface geometry. For extremely rough soil surfaces, of a more complicated geometry with irregular secondary porous aggregates, the model correctly predicts their geometry using vertically elongated spheroids in the limited range of the solar zenith angle, between 40° and 60° (Fig. 4).

Capabilities of inferring soil surface geometry for local to regional scales from soil directional reflectance data will be enhanced by satellite sensors enabling multi-directional viewing, like the Multi-Angle Imaging Spectroradiometer (MISR) complementing the US Moderate Resolution Imaging Spectrometer (MODIS) on the EOS platform and the French Polarization and Directionality of the Earth's Reflectance (POLDER) instrument due for launching on the Japanese ADEOS.

## AKNOWLEDGES

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## REFERENCES

Cierniewski, J. 1987. A model for soil surface roughness influence on the spectral response of bare soils in the visible and near-infrared range. *Remote Sensing of Environment.* 123: 97-115.

Cierniewski, J. 1989. The influence of the viewing geometry of bare rough soil surfaces on their spectral response in the visible and near-infrared range, *Remote Sensing of Environment.* 127: 135-142.

Cierniewski, J. & Verbrugghe, M. 1994. A geometrical model of soil bidirectional reflectance in the visible and near-infrared range. *Proceedings of 6th International Symposium on Physical Measurements and Signatures in Remote Sensing, January 17-2, 1994, Val d'Isér. France*: 635-642.

Cierniewski, J., Baret, F., Verbrugghe, M., Hanocq, J.F., & Jacquemoud, S. 1996. Geometrical modelling of soil bidirectional reflectance incorporating specular effects. *International Journal of Remote Sensing.* 17: 3691-3704.

Cierniewski J. & Verbrugghe, M. 1997. Influence of soil surface roughness on soil bidirectional reflectance. *International Journal of Remote Sensing.* 18: 1277-1288.

Cooper, K.D. & Smith, J.A. 1985. A Monte Carlo reflectance model for soil surfaces with three-dimensional structure. *IEEE Transations on Geoscienc and Remote Sensing.* 1GE-23: 668-673.

Graetz, R. D. & Gentle, M. R. 1982. A study of the relationship between reflectance characteristics in the Landsat wavebands and the composition and structure of an Australian semi-arid rangeland. *Photogrametric Enineering and Remote Sensing.* 148: 1721-1736.

Huete, A. R. 1987. Soil and Sun angle interactions on partial canopy spectra. *International Journal of Remote Sensing*. 18: 1307-1317.

Irons, J. R., Campbell, G. S., Norman, J. M., Graham, D. W. & Kovalick, W. M. 1992. Prediction and measurement of soil bidirectional reflectance. *IEEE Transations on Geoscience and Remote Sensin*. 30, 2: 249-260.

Norman, J. M., Welles, J. M. & Walter, E. A. 1985. Contrast among bidirectional reflectance of leaves, canopies, and soils. *IEEE Transations on Geoscience and Remote Sensing*. 1GE-23: 659-667.

Pech, R. P., Graetz, R. R. & Davis, A. W. 1986. Reflectance modelling and the derivation of vegetation indices for an Australian semi-arid shrubland. *International Journal of Remote Sensing*. 17: 389-403.

Ranson, K. J., Biehl, L. L., & Bauer, M. E. 1985. Variation in spectral response of soybeans with respect to illumination, view and canopy geometry. *International Journal of Remote Sensing*. 16: 1827-1842.