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Inversion of the Hapke model with diurnal multispectral reflectance data for assessing soil surface roughness

Jesús Rodríguez González, Pablo J. Zarco-Tejada, and José Alfonso Gómez
Institute for Sustainable Agriculture (IAS), Consejo Superior de Investigaciones Científicas (CSIC), Cordoba, Spain (jrodriguez@ias.csic.es)

Soil surface roughness (SSR) affects a variety of surface processes on bare terrestrial surfaces and soils under agricultural use, such as water and wind erosion. Therefore, erosion models like the RUSLE, WEPP, Kineros or STREAM include quantitative measures of soil surface roughness as input parameters. Generally, non-contact methods are preferred to measure SSR, such as using laser profiling instruments or scanners, digital close range stereo-photogrammetry and terrestrial laser scanning or LIDAR systems. However, the area that can be reasonably covered by these methods is usually well below several square meters, and they lack the potential to assess SSR over lager areas at the plot or field scales.

Numerous investigations on soil reflectance in the optical wavelength region showed that the observed bidirectional soil reflectance anisotropy is caused by shadow casting and mutual shadowing between soil particles and soil aggregates, facets or clods and topographic features – in other words soil roughness. Hapke's semi-physical BRDF model (Hapke, 1993), a standard BRDF model for Planetary Remote Sensing applications, accounts for the influence of SSR through a shadowing function and its roughness parameter θ. The application of the full model, i.e. including its shadowing function, has been suggested only recently to assess surface roughness of terrestrial desert surfaces (Wu et al., 2009). The roughness parameter θ as a quantitative descriptor of physical SSR of terrestrial soils has the potential to map SSR on a pixel-by-pixel basis at suitable spatial scales.

We report here on the results obtained for the inversion of the full Hapke model under simplified conditions using diurnal reflectance data gathered over an experimental field (100x40m). The relationship between the model's roughness parameter θ obtained through inversion and different quantitative roughness indices extracted from field measured digital elevation models (DEMs) was then studied using simple linear correlation and regression analysis.

Different roughness levels were obtained applying five conventional tillage methods on different subplots of the experimental field. A laser-scanning instrument was used to obtain three representative digital elevation models (DEMs) for each treatment with a grid resolution of 7.2x7.2mm over an area of 0.9x0.9m. Four main roughness indices (standard deviation, the tortuosity indices T_A and T_B, mean surface slope) were calculated for each DEM as quantitative descriptors of SSR. For each DEM location, reflectance data at wavelengths 550, 670 and 800nm at four times of the day were extracted from very high spatial resolution reflectance imagery (12.5cm). The imagery was acquired with the narrow-band multispectral ADC sensor (Tetracam Inc., USA) onboard an unmanned aerial vehicle (UAV) platform and then corrected to at-ground reflectance after geometric, radiometric sensor calibration, and atmospheric correction.

The inversion of the Hapke model was validated with a RMSE of 0.03 in reflectance units. The comparison between the model's roughness parameter θ and the physical roughness indices showed determination coefficients (r^2) above 0.70. These results indicate that the suggested approach using the Hapke model could be useful for providing a quantitative measure of SSR at very high spatial resolutions, providing SSR maps by physical model inversion.

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