SATELLITE OBSERVATION OF BARE SOILS FOR THEIR AVERAGE DIURNAL ALBEDO APPROXIMATION

Jerzy Cierniewski
Department of Soil Science and Remote Sensing of Soils, Institute of Physical Geography and Environmental Planning, Adam Mickiewicz University, 61-680 Poznań, Poland

Keywords: Soil, Roughness, Albedo, Satellite Orbit.

Abstract: This study explores the diurnal variation in broadband blue-sky albedo (α) of soils with respect to their roughness. Uncultivated soils and cultivated ones, after ploughing, harrowing and rolling were studied in Israel and Poland. The relation between α of the surfaces and the solar zenith angle allowed to predict the diurnal α variation of the surfaces located at a given latitude at any date, and calculate the optimal time T_O related to their average diurnal albedo $\overline{\alpha}$ observation. This procedure was used to assess the usefulness of satellites on the sun-synchronous orbits for approximation of $\overline{\alpha}$ for the moderately rough bare soil surfaces, located between the latitude angles of 75° S to 75° N, within an error lower than ±2%. It was found that the satellites on the orbits crossing the Equator at 10:30, such as the MODIS, and like the SPOT and IRS IC, are not very useful for that, while the NOAA-15 on the orbit crossing the Equator at 7:30 is much more useful. The best dates for the collection of data with this satellite are 16 April and 28 August, while the worst date is June 22.

1 INTRODUCTION

The Earth's surface shows variation in its reflected radiation due to the direction of irradiating solar energy and the direction along which the reflected energy is viewed by ground, air-born and satellite sensors. The reason for this variation is the irregularities of the surface, which produce shadow areas, where the solar beams do not directly reach all surface areas. The radiation leaving shaded areas is many orders-of-magnitude smaller than radiation reflected from sunlit fragments. Reflectance of the Earth's surface is usually highest from the direction which gives the lowest proportion of shaded fragments. For example, bare soils with irregularities caused by the soil texture, aggregates and micro-relief configuration usually display a backscattering reflectance peak towards the Sun, and decreasing reflectance in the direction away from the peak (Milton and Webb, 1987; Cierniewski *et al*., 2004). Desert surfaces can have both a backscattering and forward-scattering character (Shohsany, 1993). They display maximum reflectance in the extreme forwardscatter direction near horizon if they are relatively smooth with a strong specular behaviour (Coulson, 1966).

The bidirectional reflectance is defined as the fraction of incident radiation that is reflected from a surface along a given direction. Its value corresponds to the precisely specific direction of the surface illumination. Another physical quantity describing a reflectance of a surface is the albedo. It integrates the surface reflectance over all view angles and is defined as the fraction of the incident solar short-wave radiation (0.3-3µm) that is reflected from a surface. The upwelling and downwelling radiations are integrated over the whole hemisphere (Schaepman-Strub *et al*., 2006). Martonchik *et al*. (2000) recommend using the terms *broadband albedo* or the *narrowband (spectral) albedo* if the albedo characterizes the entire solar short-wave spectrum or only a part of it, respectively. The *blue-sky albedo* describes the albedo measured under field conditions, where a surface is illuminated by both direct solar irradiance and diffuse irradiance, scattered by the atmosphere (Baret *et al*., 2005). In many parts of the Earth, the reflectance of the land surface changes seasonally. However, annual variation of albedo is usually smaller than its daily variation. The albedo, characterizing the intrinsic properties of a surface, such as the surface bidirectional reflectance, varies with solar zenith

Cierniewski J..
SATELLITE OBSERVATION OF BARE SOILS FOR THEIR AVERAGE DIURNAL ALBEDO APPROXIMATION.
DOI: 10.5220/0003903902290234
In *Proceedings of the 1st International Conference on Sensor Networks* (SENSORNETS-2012), pages 229-234
ISBN: 978-989-8565-01-3

angle (Liang *et al*. 1999). Kondratyev (1969) mentioned that, during the morning when the sun elevation increased from 10° to 60°, the albedo of dry rocky and loamy soil surfaces decreased from 0.22 to 0.14 and from 0.34 to 0.21, respectively. Pinty *et al*. (1989), Eckardt (1991), Lewis and Barnsley (1994), Matthias *et al*. (2000) and Wang *et al*. (2005) confirmed that the albedo of cultivated and uncultivated desert surfaces varied significantly at relatively high solar zenith angles.

Satellite radiometers are not able to measure directly the broadband blue sky Earth's surface albedo. The anisotropic, non-Lambertian distribution of the reradiation of soil and other Earth's surfaces must be inferred through a series of manipulations of the raw remote sensing reflectance data (Maurer, 2002). Only the data representing cloud-free pixels are analyzed. Since the satellite instruments measure the radiance at the top of the atmosphere, and we intend to estimate the albedo of the Earth's surface, a correction is required in order to account for the effect of the intervening atmosphere. Because most satellites collect the Earth's surface data only at one or a few directions inside their small field-of-view, these data are recomputed with consideration of the bidirectional reflectance of Earth objects. Lastly, since satellites measure the Earth's radiation in a number of separate narrowband channels, an extrapolation of the narrowband albedo values to their broadband values is necessary.

The broadband albedo is used for modelling environmental biophysical processes associated with the energy transfer between soil, vegetation and atmosphere, as well as for studying climate changes at regional and global scales. Because the processes are analyzed in the diurnal cycle, as well as over wider time ranges, such as monthly, seasonal and year-long, the average diurnal surface albedo seems to be a helpful basis for the modelling. Sellers *et al*. (1995) determined the accuracy requirement of albedo for the global models as ±2%. It seems that more attention should be focused on the time of the satellite data acquisition because: i) the albedo clearly vary during the day, ii) its value is required with such a small error, and iii) the algorithms used to convert the reflectance of a surface to its albedo, relying on a semi-empirical approach (Olsen *et al.*, 2003, Zhou *et al*., 2003,Tsvetsinskaya et al., 2006), are aimed at an effective elimination of the influence of the non-equal distributed radiation from the surface during a satellite passing.

This paper shows how the albedo of bare soil varies as the solar zenith angle function depending on their roughness. Examples of the broadband blue-sky soil albedo sets were used, measured from the ground level from midday to sunset. These relations allowed to predict the albedo variation of bare soil surfaces located at a chosen latitude during any day of the year. The paper shows in which local solar time the albedo of the moderately rough soil surfaces located between the latitude angles of 75° in the Northern and Southern Hemispheres represents its diurnal averaged value within an error lower than ±2%. We consider how it is possible to observe a soil surface from satellites on sun-synchronous orbits in the optimal time close to the moment when its albedo reaches the average diurnal value with that low error. The usefulness of a satellite placed on the orbit close to that being optimal, as well as satellites which most often have been used to the albedo approximation, is analyzed here.

2 METHODS

The paper reports the relation between the broadband blue-sky albedo α of soil surfaces in Israeli Negev desert near Sede Boker (30° 51'26"N, 34°47'09"E) and the solar zenith angle θ_s**.** There, it was possible to collect the data relating to the soils developed from a loessial substrate with an extremely high diversity of their roughness, including extremely smooth uncultivated soil surfaces, as well as moderate and very rough cultivated surfaces after shallow and deep ploughing, respectively (Fig. 1). These studies have been continued in Poland on soil surfaces in the western part of Poland near Poznań (52°34'57"N, 16°38'49.23"E; 52°28'48"N, 16°49'49.36"E). These include cultivated soils (*Luvisols* according the World Reference Base for Soil Resources), developed from sands and sandy loams. Figure 1 shows three examples of such soils that were shaped by ploughing, harrowing and rolling, respectively.

The α values of all surfaces were measured by an albedometers LP PYRA 06 in a spectral range of 0.335–2,200 μm using data loggers. Shape of the surfaces was controlled by a 3D laser scanner Konica-Minolta VIVID-910. The texture and the organic carbon content of the soil surface material was controlled in the laboratory using a hydrometer and Walkley Black's method, respectively (Sparks *et al*., 1996).

3 RESULTS AND DISCUSSION

This paper focuses on the most important results

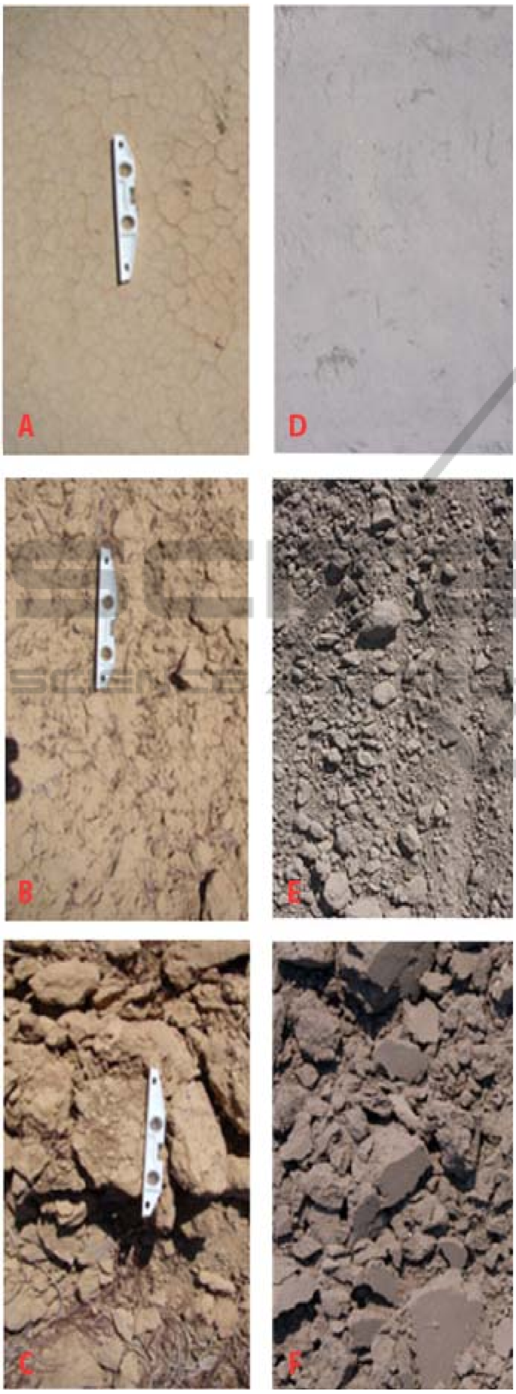

Figure 1: Soil surfaces tested in Israel (A-C) and Poland (D-F).

obtained during tests carried out in Israel and Poland.

The measurements of the albedo were carried out in Israel on August 2008, and those in Poland from May to September, 2011, under clear sky conditions from solar local noon to sunset.

The relation between α and θ_s, derived from the studies in Israel (Cierniewski *et al.*, 2012) and Poland clearly shows that α of a bare soil strongly depends on its surface roughness (Fig. 2). The curves for the smooth surfaces (the uncultivated surface and the cultivated ones after rolling) are consistently higher than those of the very rough surfaces (deeply ploughed). The curves related to the extremely rough surfaces do not rise at θ_s angles lower than 80°, while for the extremely smooth ones they increase throughout the analyzed θ_s range, rising strongly at θ_s higher than 75°. The shape of the curves clearly affects the θ_s value at which the α reaches its average value.

The above relations, expressed by curvilinear functions, were used to compute instantaneous values of α for surfaces of a given roughness, located at a chosen latitude during any day of the year. They were also used to find the optimal time T_O relating to their average diurnal albedo $\overline{\alpha}$ observation. The T_O value was defined as the local solar time when the α value, acquired by an instantaneous observations best represents the $\overline{\alpha}$ value for an given day (from almost sunrise to sunset, i. e., when the θ_s does not exceed 85°).

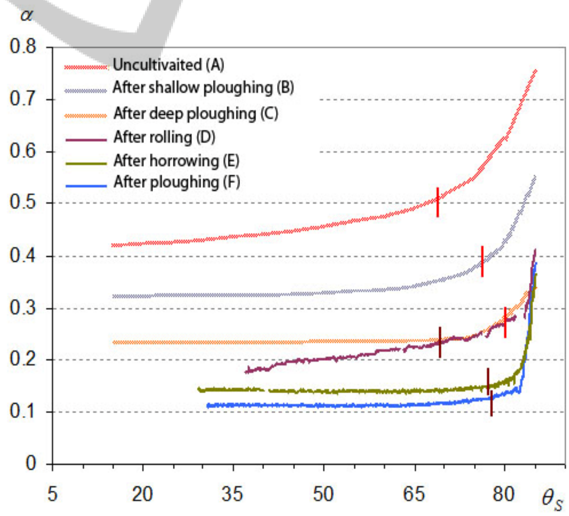

Figure 2: Variation of the broadband blue-sky albedo (α) of the studied surfaces as a function of the solar zenith angle θ_s. Vertical red lines mark θ_s values that relate to the average diurnal albedo $\overline{\alpha}$ of the surfaces.

The semi-diurnal distributions of α and $\overline{\alpha}$ of the moderately rough soil surface (such as that tested in Israel) are presented in Figure 3. The panels represent selected days in the Northern hemisphere (NH) to: the astronomical spring (21 March) and autumn (23 September) equinoxes and the

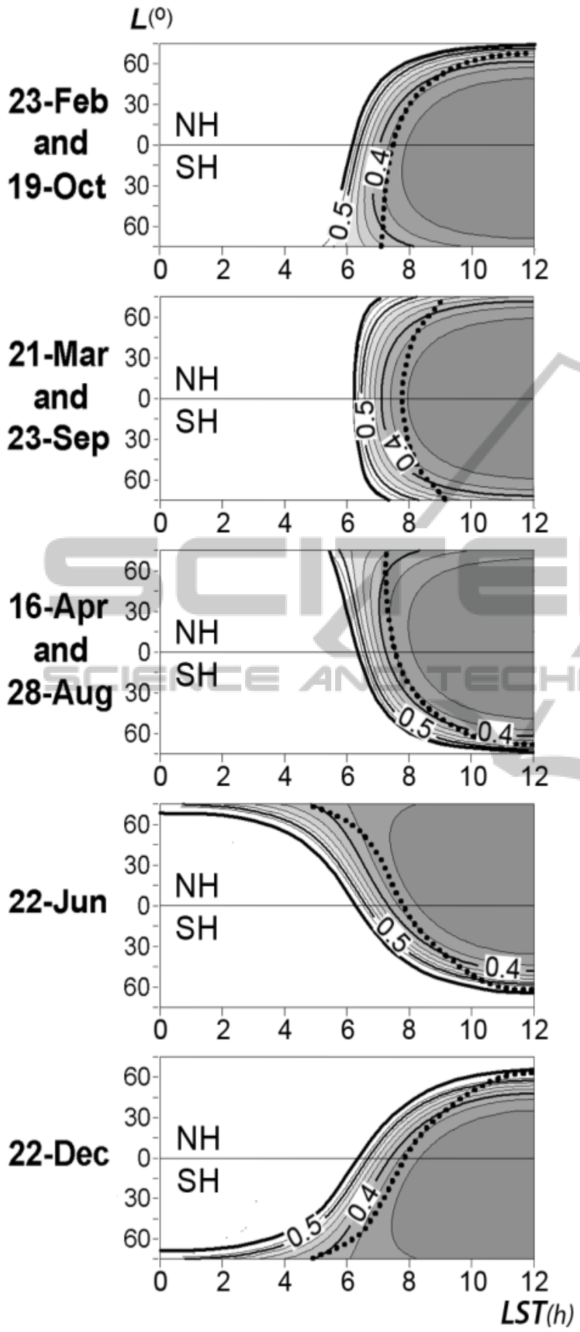

Figure 3: Morning semi-diurnal distributions of the broadband blue-sky albedo α for the moderately rough soil surfaces in the latitude (*L)* and local solar time (*LST*) functions for the chosen dates. The bold isoline on the left-hand side of the graphs shows extreme values of α for the solar zenith angle θ_S = 85°, and bold dotted line - the average diurnal $\overline{\alpha}$ value for a given *L*. NH and SH represent the Northern and Southern Hemispheres, respectively.

beginning of the astronomical summer (22 June) and winter (22 December), and additionally other days that have a different pattern than mentioned above (23 February, 16 April, 28 August and 19 October). Each panel show contour lines (emphasized with shading) of the α values as a function of the local solar time and the latitude. The bold dotted line shows the $\overline{\alpha}$ values for a given latitude (Cierniewski and Gdala, 2010).

Figure 4 gives the opportunity to observe the moderately rough soil surfaces (as representing the most common cultivated bare areas) at the time close to the moment when their albedo viewed from satellites on sun-synchronous orbits reaches the average diurnal value with error lower than ±2%.

The following dates are chosen: 21 March, 16 April, 7 May and 22 June, using the examples of the satellite NOAA-15 and MODIS, crossing the Equator at 7:30 and 10:30 morning, respectively. The orbit of the NOAA-15, as one of the few civilian remote sensing satellites with the descending node at so early local solar time, allows to obtain these rough soil albedo data with the acceptable error in limited ranges of the latitude. The ranges are described by intersection points of the two kinds of lines, describing limits of the acceptable error ±2% of the data and the time of the satellite passage. These latitude ranges are: 30°N-50°S for 21 March, 75°N-15°S for 16 April, 60°N-5°S for 7 May and 25°N-5°S for 22 June. The widest range, larger than 90°, was found for the 16 April (and correspondingly for 28 August) and the narrowest one, 30°, for June 22.

The data obtained from the MODIS (like the SPOT and the IRS IC), which have been often used for the albedo approximation, can be much less useful for this purpose. As Figure 4 shows, one can obtain sufficiently precise results only in the very narrow ranges of the latitude, not wider than 5°, and moreover in the very high latitudes positions, higher than 65°S for 16 April, 60°S for 7 May and 50°S for 22 June.

4 CONCLUDING REMARKS

The broadband blue-sky albedo α variation of a bare soil as a function of the solar zenith angle θ_s clearly depends on the soil surface roughness. The curves describing this relation for the extremely rough surfaces almost do not rise at θ_s angles lower than 80°, while the curves for the extremely smooth surfaces increase throughout the analyzed θ_s ranges, rising strongly at θ_s higher than 75°. The shape of the curves clearly affects the θ_s value at which

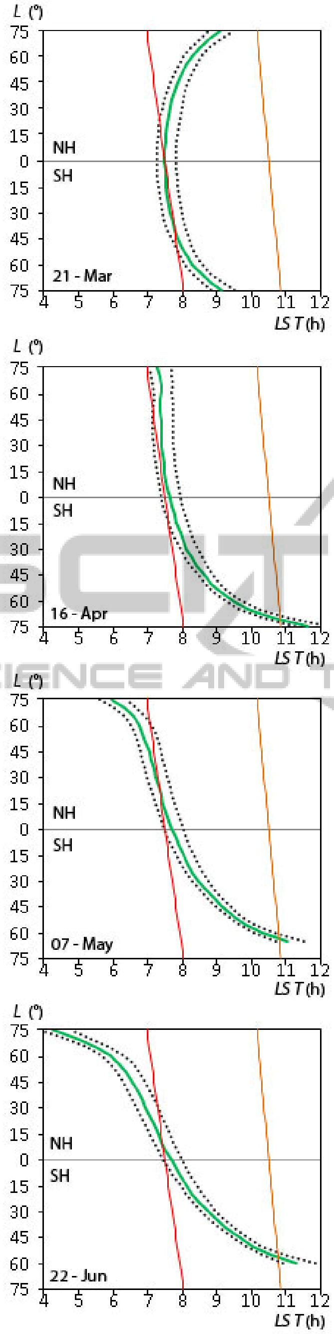

Figure 4: Time in the hour scale of local solar time (*LST*), when the average diurnal albedo of the moderately rough soil $\overline{\alpha}$ (green line), predicted for the chosen dates varying with the latitude (*L*), is available to be approximated with the error lower than ±2% (dotted lines). The red and orange lines depict the time the NOAA-15 and MODIS passage. NH and SH represent the Northern and Southern Hemispheres, respectively.

instantaneous α reaches its average value. The relations between α and θ_s, expressed by curvilinear functions, allow to predict the α variation of bare soils located at a given latitude at any date, and calculate the optimal time T_O relating to their average diurnal albedo $\overline{\alpha}$ observation.

Such a procedure allowed to asses the usefulness of satellites on the sun-synchronous orbits for approximation the $\overline{\alpha}$ of the most common cultivated bare soil areas within an error lower than ±2%. The moderately rough soil surfaces, located between the latitude angles of 75° in the Northern and Southern Hemispheres were chosen for this assessment. It was found that the satellites on the orbits crossing the Equator at 10:30, such as the MODIS, and like the SPOT and IRS IC, are not very useful for that, while the NOAA-15 on the orbit crossing the Equator at 7:30 is much more useful. Tho first group of the satellites is only useful for the surfaces located in very high latitudes and not for all dates. The latter satellite is useful within wide latitude ranges in lower latitudes. The best dates for the collection of data with this satellite are 16 April and 28 August, while the worst date is June 22.

Approximation of the Earth's surface albedo via satellite data, collected closely to the time T_O when the soil surfaces reaches $\overline{\alpha}$ value, will probably result in a significantly reduced error in the calculation of the albedo. The semi-empirical approach, used to convert the soil reflectance to its albedo, would be simpler. It would be only limited to correction of the reflectance distribution relative to a specific direction of a satellite viewing.

ACKNOWLEDGEMENTS

This work was supported by the Polish Ministry of Science and Higher Education carried out under the Project NN306600040. The author wishes to thank Prof. Bajorski for the language revision of the manuscript, as well as Dr. Cezary Kaźmierowski, Dr. Sławomir Królewicz, Dr. Jan Piekarczyk, Krzysztof Kuśnierek, MSc, and Michał Rymaniak, MSc for their help in the measurements and preparation of the figures.

REFERENCES

Baret, F., Schaaf, C., Morisette, J. and Privette, J. (2005). Report on the Second International Workshop on Albedo Product Validation. *The Earth Observer*, 17, 13–17.

Cierniewski, J., Gdala, T. and Karnieli, A. (2004). A hemispherical-directional reflectance model as a tool for understanding image distinctions between cultivated and uncultivated bare surfaces. *Remote Sensing of Environment*, 90, 505–523.

Cierniewski, J. and Gdala T. (2010). Calculating the optimal time when albedo approximates its daily average: an example using soil surfaces with various roughnesses at different latitudes. *International Journal of Remote Sensing*, 31, 2697-2708.

Cierniewski, J., Karnieli, A., Kuśnierek, K. and Herrmann, I. (2012) Approximation the average daily surface albedo with respect to soil roughness and latitude. *International Journal of Remote Sensing* (accepted for publication).

Coulson, K. L. (1966). Effect of reflection properties of natural surfaces in aerial reconnaissance. *Applied Optics,* 5, 905-917.

Eckardt, M. (1991). Albedo changes and satellite observations of the Earth. In *Climate and Global change – Proceedings of the European School of Climatology and Natural Hazards Course, held in Arles/Rhone, France, from 4 to 12 April 1990*. Brussels, Lxemburg: ECSC-EEC-EAEC, 123-137.

Kondratyev, K. Y. (1969). *Radiacjonnyje Charakteristiki Atmosfery i Zemnoy Poverkhnosti*. Leningrad: Gidrometeorologicheskoye Izdatelstvo.

Lewis, P. and Barnsley, M. J. (1994). Influence of the sky radiance distribution on various formulations of the Earth surface albedo. In *Proceedings Mesures Physiques et Signatures en Teledetection, Val d'Isere, France, 17–21 January, 1994,* 707–716.

Liang G, S., Strahler, A. H. and Walthall, C. (1999). Retrieval of land surface albedo from satellite observations: a simulation study. *Journal of Applied Meteorology*, 38, 712–725.

Martonchik, J. V., Brugge, C. J. and Strahler, A. (2000). A review of reflectance nomenclature used in remote sensing. *Remote Sensing of Environment*, 19, 9–20.

Matthias, A. D., Fimbres, A., Sano, E. E., Post, D. F., Aciolly, L., Batchily, A, K., and Ferreira, L. G. (2000). Surface roughness effects on soil albedo, *Soil Science Society of America Journal*, 64: 1035-1041.

Maurer J. (2002). *Retrieval of surface albedo from space*. Retrived from: http://www2.hawaii.edu/~jmaurer/.

Milton, E. J. and Webb, J. P. (1987). Ground radiometry and airborne multispectral survey of bare soils. *International Journal of Remote Sensing*, 18, 3-14.

Olsen K. W., Bonan, G. B., Schaaf, C., Gao, F., Jin, Y. and Strahler, A. (2003). Assessment of global climate model land surface albedo using MODIS data. *Geophysical Research Letters*, 30, 1443, doi: 10.1029/ 2002GL016749.

Pinty, B., Verstratte, M. M. and Dickinson, R. E. (1989). A physical model for predicting bidirectional reflectance over bare soil. *Remote Sensing of Environment*, 27, 273–288.

Schaepman-Strub, G., Schaepman, M. E., Painter, T. H., Dangel, S. and Martonchik, J. V. (2006). Reflectance quantities in optical remote sensing – definitions and case studies. *Remote Sensing of Environment*, 45, 15–27.

Shoshany, M. (1993). Roughness-reflectance relationship of bare desert terrain; An empirical study. *Remote Sensing of Environment*, 103, 27–42.

Sellers, P. J., Meeson, B. W., Hall, F. G., Asrar, G., Murphy, R. E., Schiffer, R. A., Bretherton, F. P., Dickinson, R. E., Ellingson, R. G., Field, C. B., Hummerich, K. F., Justice, C. O., Melack, J. M., Roulet, N. T., Schimel, D. S. and Try, P. D. (1995). Remote Sensing of the land-surface for studies of global change: models-algorithms-experiments. *Remote Sensing of Environment,* 51, 3-26.

Sparks, D. L., Page, A. L., Helmke, P. A., Loeppert, R. H., Soltanpour, P. N., Tabatabai, M. A., Johnston, C. T. and Summer, M. E. (1996). *Methods of Soil Analysis. Part 3.* Madison: Soil Science Society of America and American Society of Agronomy.

Tsvetsinskaya, E. A., Schaaf, C.B., Gao, F., Strahler, A. H. and Dickinson, R. E. (2006). Spatial and temporal variability in moderate resolution imaging spectroradiometer derived surface albedo over global arid regions. *Journal of Geophysical Research*, 111, D20106, doi:10.1029/2005JD006772.

Wang, Z., Barlage, M. and Zeng, X. (2005). The solar zenith angle dependence of desert albedo. *Geophysical Research Letters*, 32, doi: 10.1029/2004GL021835.

Zhou, L., Dickinson, R. E., Tian, Y., Zeng, X., Dai, Y., Yang, Z.-L., Schaaf, C. B., Gao, F., Jin, Y., Strahler, A., Myeneni, R. B., Yin, H., Wu, W. and Shaikh, M. (2003). Comparison of seasonal and spatial variations of albedos from Moderate-Resolution Imaging Spectroradiometer (MODIS) and Common Land Model. *Journal of Geophysical Research*, 108, 15-1-15-20.