Characteristic spectral reflectance of a semi-arid environment

R. T. PINKER
Department of Meteorology, University of Maryland, College Park, MD 20742, U.S.A.

and A. KARNIELI
The Remote Sensing Laboratory, J. Blaustein Institute for Desert Research, Ben Gurion University of the Negev, Sede Boker Campus 84993, Israel

(Received 17 March 1994; in final form 17 November 1994)

Abstract. Comprehensive information on the spectral reflectivity of several desert habitats and of dominant desert vegetation are presented. No previous high resolution spectral reflectance measurements were made in this semi-arid Sahara-Arabian phytogeographic zone. Due to the relative homogeneity of the region, in terms of terrain type and comprehensive sampling, the local scale surface albedo was estimated to be about 30–33 per cent. It was also possible to revisit the currently accepted hypothesis on the observed contrasts in surface reflectivity between protected and overgrazed areas. It seems that anthropogenic activities, which prevent the accumulation of crust or destroy an existing crust, rather than the overgrazing mechanism itself, are the main reasons for the sharp contrast between the protected and overgrazed surfaces.

1. Introduction
1.1. Background

The intensity of surface/atmosphere interactions is determined by the surface energy budget. A key parameter in the formulation of this budget is the surface albedo which regulates the amount of shortwave radiation absorbed by the surface. Effects of changes in surface albedo on large scale climate have been previously investigated (Dickinson 1983, Rowntree 1991, Henderson-Sellers and Brown 1992). On a regional scale, Otterman et al. (1990) speculated that an increase of early rains in southern Israel is attributable to intensification of the dynamical processes of convection and advection, resulting from plant induced enhancement of the daytime sensible heat flux from the dry surface. This enhancement results both from reduced surface albedo and reduced soil heat flux. For the formulation of the net shortwave radiation balance, information on the total albedo is required; for monitoring vegetation development, information on the spectral reflectance of the surface is sufficient. To be useful in climate research, information is needed on a global scale. Many attempts have been made to do so from satellite observations (Pinker 1985, Pinty and Ramond 1987, Gutman 1988, Barker and Davis 1989, Saunders 1990, Arino et al. 1991, Nacke 1991). It was also demonstrated that satellite observations are sufficiently sensitive to monitor longer term climate change (Courel et al. 1984). Yet, information on surface albedos from satellites is not readily available. Satellites measure only the Earth-Atmosphere reflectance in narrow spectral intervals, and
narrow solid angles, at selected solar zenith angles. To derive surface albedo, one has first to compute the total reflected planetary flux, integrated over the entire spectrum and over all the viewing angles. A transformation from the top of the atmosphere to the surface is also necessary.

Depending on the approach used to transform top of the atmosphere parameters to their corresponding values at the surface, a priori knowledge of the surface spectral reflectivity or the total surface albedo is needed. As such, there is a need for different types of surface reflectance observations. Information on the composition of the atmospheric constituents should be always used.

1.2. Past observations of surface reflectance

Early observations were made with inverted pyranometers, sensitive in the 0.3-2.8 μm spectral interval; they represent spectrally integrated albedos. Extensive summaries on such observations can be found in Kondratyev et al. (1982), Rosenberg et al. (1983), and Iqbal (1983). Some measurements of this type have been made from aircraft (Kung et al. 1964) and more recently, from tall towers (Dutton 1990). While such information is useful for local shortwave energy balance studies, it is not representative of larger scales. Moreover, to enable to discriminate between different crop species, there is a need for information on spectral reflectance (Pinter et al. 1990). For validating satellite observations of surface reflectivity or for assessing satellite capabilities to monitor changes in surface reflectivity, there is a need for observations taken at the ground in similar spectral intervals and similar viewing angles, and if possible, of similar aerial extent as the satellite is viewing (Holben and Kimes 1986). To respond to such needs, Bowker et al. (1985) present a collection of uniformly digitized spectral reflectances of natural targets. The data were taken from literature and include laboratory, field and aircraft measurements, obtained with different instruments, measurement techniques, viewing angles, and ambient conditions. Their data base includes 156 reflectance curves. Similarities were found among reflectances from many of the targets. Subsequently, they grouped the data into the following characteristic types: vegetation; soils; rocks and minerals; water; snow; and clouds. More recently, spectral measurements were reported by Satterwhite and Henley (1990) and by Grove et al. (1992).

Information is also needed to characterize the bidirectional properties of the surface (e.g., Kimes 1983, Kimes et al. 1985, Deering et al. 1990). The anisotropic patterns of the surface are very complex and are affected by soil type, roughness, solar zenith angle and vegetation structure. Technically, it is difficult to make such measurements in all the viewing directions. Most of the available observations extend to 45° only. For instance, Qi and Huete (1993) collected ground and air-based data sets of high spectral resolution during the Monsoon '90 experiment in south eastern Arizona during a dry and a wet season (Kustas et al. 1991). They measured bidirectional reflectance factors with a spectroradiometer up to 40° off-nadir over a semi-desert grassland. They found that view angle influences and spectral signature contrasts were greatest at the larger solar zenith angles, consistent with the proposed model of desert scrub shadowing effects of Ottermann and Tucker (1985). Similarly, sun angle influences were more apparent at the larger view zenith angles. Differences between vegetation types were also larger at larger solar zenith angles. Similar measurements at discrete spectral intervals were made from aircraft by Kriebel (1978) and from helicopters by Williams et al. (1984), Purgold et al. (1993), and Whitlock et al. (1987). In order to derive the albedo from such
Characteristic spectral reflectance of a semi-arid environment

measurements, one would need observations in numberous viewing angles, for a wide range of solar zenith angles. Such measurements are difficult to make at an accuracy which would enable to distinguish between instrumental error, terrain differences, and bi-directional effects.

Several attempts have been made to derive information on the bi-directional properties of the Earth-Atmosphere system from satellite observations. The most comprehensive data sets are those derived from the Nimbus-7 observations (Jacobowitz et al. 1984, Taylor and Stowe 1984), augmented with observations from geostationary satellites (Suttles et al. 1988). The higher resolution scanners like the multi-spectral scanner (MSS) and the thematic mapper (TM) onboard the Landsat satellites, observe the Earth at near-nadir. The SPOT-HRV as well as the new sensors to be launched on the Earth Observing System (EOS) platforms such as the MODIS (Moderate Resolution Imaging Spectrometer) (Salomonson et al. 1989), HIRIS (High Resolution Imaging Spectrometer) (Goetz and Herring 1989), MISR (Multi-angle Imaging Spectral Radiometer) (Diner et al. 1989), will have capabilities for off-nadir observations. As yet, derivation of representative bidirectional models from ground observations, relevant for modelling at satellite scale, is not feasible.

1.3. Inherent issues

An unresolved issue in the process of constructing surface albedo or reflectance models representative of large scales, is the problem of spatial averaging. Very little is known to what extent surface characteristics documented at one scale, could be transformed to another scale. For instance, as reported in Pinter et al. (1990), surface small scale structures which dictate the local scale observed bi-directional properties, may become of secondary importance on larger scales because the small scale structures average out. Similar findings were reported by Pinker and Stowe (1990) based on satellite observations and model simulations. Experience has also shown that differences due to sampling for each surface type, could be large enough to mask differences due to angular effects.

These issues are of primary concern in studies where information on the average surface properties is required for simulations at regional scale. Adopting a ‘local’ surface model, even if very ‘accurate’ for one particular location, might not represent conditions over an area seen by a satellite. The objective of this study was to obtain information on the spectral reflectivity of typical soil and vegetation types of a climatically important semi-arid region, and to integrate this information for modelling at satellite scales and for validation of satellite based estimates of surface albedos. In what follows, the rationale for the study will be presented.

1.4. Rationale

Very little is known on spectral reflectance characteristics of semi-arid regions in the Saharo-Arabian phytogeographic zone. In previous studies attempts have been made to estimate the surface reflectance from various satellites (e.g., Otterman and Fraser 1976, Otterman and Tucker 1985) and to speculate about the implications of land use on the surface albedo. In an early study Otterman (1974) reported on the impact of overgrazing and other anthropogenic pressures on the surface albedo in the arid region of Sinai-Negev demarcation line and in the Sahel (Otterman et al. 1975) and concluded that semi-dormant desert fringe plants strongly reduce the albedo of sandy terrain. Based on observations made with Landsat satellites and transformations from top of the atmosphere to the surface, under the assumption
that the surface is Lambertian, Otterman (1983) points out that since the contrast between an overgrazed area and a protected area is about the same in all the spectral bands of the Landsat MSS (0.5-0.6; 0.6-0.7; 0.7-0.8; 0.8-1.1 μm), the plant cover on the vegetated/protected side does not exhibit the high infrared-to-red reflectance ratio common to green vegetation of non-arid regions.

The present study was aimed at obtaining a comprehensive data base on spectral reflectance of several habitats in the Northern Negev desert; synthesizing this information for use in investigations at larger scales; and for correct interpretation of surface properties from satellite observations. Specifically, we wanted to document the variability within several typical land types; the dependence on solar zenith angle of each surface type; and the characteristic spectral reflectance of desert plants. No previous high resolution spectral reflectance measurements were made in this region. The site will be described in § 2; instrument specifications will be presented in § 3; the methodology used to obtain the observations will be described in § 4; results will be presented in § 5; discussion will be given in § 6; and a summary will be presented in § 7.

2. The site

The area where the observations were taken is located in a desert climatic transition zone in the Northern Negev, Israel. Annual precipitation is about 100 mm, mean annual temperature is 10°C and average daily relative humidity is about 54 per cent. The main pedological/lithological units of the region which represent also the main plant habitats are: (a) sand dunes and sand fields which originate from the sands of the Mediterranean shores; (b) sedimentary (carbonatic) rocky terrain which forms the hills and ridges composed of Eocene and in a lesser degree of Cenomanian, Turonian and Senonian limestone, chalk and dolomite; (c) loessial plains, originally imported into the region by winds and dust; and (d) gravel and loessial wadi beds (Evenari et al. 1971). Most of the observations were made at or within 40 km of the J. Blaustein Institute for Desert Research, Ben-Gurion University, Israel, located at 30°51'N; 34°47'E in the Negev Highlands.

The Negev is located on the northern border of the planetary desert belt, and can be considered as a continuation of the Egyptian desert, which is part of the Sahara. It is located in a region where desert encroachment is of concern. It was previously shown (Joseph and Ganor 1986) that this relatively small area is the centre of 'aridity boundary' migration, as defined by various aridity indices. It is also in the vicinity of the Israeli-Egyptian political border which is crossing sand dunes and sand fields of the same lithologic unit. The border line is visualized as a sharp contrast between the higher reflectance on the Egyptian (Sinai) side, and the lower reflectance on the Israeli (Negev) side. This contrast has been discussed in various papers for the last twenty years (Otterman 1974, 1977, 1981, Otterman et al. 1974; Otterman and Fraser 1976, Allison et al. 1978, Danin et al. 1989, Danin 1991). The relatively higher reflectance on the Egyptian side has been interpreted as being caused by severe anthropogenic impact of the Sinai Bedouin tribes, in particular by overgrazing, as well as by gathering of plants for firewood. The adjacent Negev, on the other hand, has been under strict conservation policy. Therefore, it would be important to monitor the conditions in this region, and methods of remote sensing are of interest. Development of remote sensing methods and their validation requires a priori knowledge of existing conditions at the ground. The locations we have selected are well suited for such an endeavour because of the relative homogeneity in
terms of terrain type; this should allow to characterize the average conditions at the
ground by selective sampling. Moreover, observations of aerosol optical depth are
being made at Sede Boker since 1986; and measurements of dust deposition and
surface radiation components have been made for over ten years. Such combined
information could facilitate interpretations of satellite observations.

The reflectance measurements to be described here were made during 4-10 May
1990 and 26-29 March 1991. During the 1991 observational period, all the
measurements were made under completely clear sky conditions. Average rainfall in
Sede Boker for March is 13 mm and for May it is 1 mm. During March 1991 Sede
Boker received 61 mm while the nearby Shivta received only 49 mm. During May
1990, neither location had any rainfall.

3. Instrument specifications

We used the Spectron Engineering SE-590 Spectroradiometer (Williams et al.
1984), which can operate on a small 12-volt battery. It has an optical scan head
sensitive in the VIS/IR range between 0.4-1.1 μm, and a controller unit. The optical
scan head contains a 256 element linear photodiode array sensor. A diffraction
grating is used as a dispersive element, and each element of the array simultaneously
integrates a separate wavelength. The nominal spectral resolution is 2.34 nm. The
total observing time for one spectrum scan is of the order of few seconds.

We mounted the spectrometer on a tripod for firm hold during the measure­
ments. To avoid the need for calibration of the scanning device, a barium sulfate
(BaSO₄) panel was used as a reference standard for reflection. The BaSO₄ panel is
known to exhibit bi-directional properties which should be known for optimal data
reduction. Jackson et al. (1992) studied the bi-directional properties of 11 moulded
halon and 16 BaSO₄ reference reflectance panels. They found that the halon panels
differed both in their directional/hemispherical and directional/directional reflec­
tances but the differences were small so that general calibration coefficient could be
developed for the molded halon panels.

The directional/directional reflectances of the 16 BaSO₄ panels varied among
panels so it was not feasible to develop a single calibration equations. They conclude
that the non-Lambertian properties of the BaSO₄ panels are dependent upon the
method of applying the barium sulphate coating. Among the 16 panels, differences
in surface roughness were clearly visible. The degree of surface roughness is a
primary determinant of non-Lambertian properties. Since the bi-directional proper­
ties of the particular BaSO₄ panel used were not evaluated, no correction factors
were applied in the current case.

4. Observational procedures

About 200 spectral reflectance measurements over approximately 25 different
surface types were collected. The sites were characteristic of semi-arid regions and of
dominant desert vegetation. Most observations were made at nadir; some were
obtained at an angle of 45° perpendicular to the principal plane. When measure­
ments are made at nadir, there is a problem of shading by the instrument, as
discussed by Coulson and Reynolds (1971). After preliminary analysis, the ‘best’
cases were selected, namely, cases where exact location of the observation was well
documented and when the sky was cloud free. During a few observations there was
partial cloud cover. Cases when cloud cover was rapidly changing during scene and
reference panel observations, were not used. Large differences in cloud cover or
partial cover of the Sun during such measurements would introduce error in the derived reflectance. The observational strategy was to collect a range of reflectance values representative of different surface types and vegetation, typical of the region; to document solar zenith angle dependence, when feasible; to experiment with measurements from higher platforms, such as a car top and a tower; and to obtain information on the effect of vegetation on the surface reflectance.

The following environments of different surface types and plant habitats were sampled:

1. Loessial plain environment (e.g., Sede Zin) which at the sampling time was partially cultivated. Some portion of the area was yellow wheat field and another portion was ploughed field. The natural part of the plain was covered either by loess, annuals or gravel. An attempt was made to sample each different soil type several times a day, to enable to characterize the solar zenith angle dependence. Not all the angles are represented in the observations due to cloudiness.

2. Sand dunes and sand field environments were sampled at several sites along the Israeli-Egyptian border (e.g., Be'er Malaga; Har Keren; Nizana; Shivta). At each site the dunes were sampled both in crests and troughs. The dune crests consists of active sand while the interdune area is covered with biogenic crust which consists of 20-40 per cent fine soil particles (clay and silt) and cyanobacteria. Vegetation cover in this area was found to be 20-30 per cent (D. Lavee, private communication).

3. Wadi bed environments (e.g., Wadi Avdat) consist of alternating gravel and loess patches. The wadis in the region are flooded once or twice a year. On the bare surface one can find irregularly spread individual plants.

4. Rocky terrain environment (e.g., Sede Boker West) consists of Upper Turonian limestone with 5-10 per cent vegetation cover.

5. The Shivta tower site is a heterogeneous site. The 90 m meteorological tower (table 1) allows observations to be obtained from different heights and in different directions around the tower. As such, these observations provide better spatially representative data.

At each of the above locations spectral in situ measurements were taken to characterize typical surface substrate, as well as typical perennial plants. The plant

<table>
<thead>
<tr>
<th>Platform No.</th>
<th>dH (m)</th>
<th>H (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>11</td>
<td>6.6</td>
<td>87.2</td>
</tr>
<tr>
<td>10</td>
<td>9.8</td>
<td>80.6</td>
</tr>
<tr>
<td>9</td>
<td>10.7</td>
<td>70.8</td>
</tr>
<tr>
<td>8</td>
<td>6.9</td>
<td>60.1</td>
</tr>
<tr>
<td>7</td>
<td>8.4</td>
<td>53.2</td>
</tr>
<tr>
<td>6</td>
<td>6.9</td>
<td>44.8</td>
</tr>
<tr>
<td>5</td>
<td>8.4</td>
<td>37.9</td>
</tr>
<tr>
<td>4</td>
<td>6.9</td>
<td>29.5</td>
</tr>
<tr>
<td>3</td>
<td>6.9</td>
<td>22.6</td>
</tr>
<tr>
<td>2</td>
<td>8.4</td>
<td>15.7</td>
</tr>
<tr>
<td>1</td>
<td>7.3</td>
<td>7.3</td>
</tr>
</tbody>
</table>
spectral reflectances will be accounted for in the spatial average at each site and also presented independently. Some plant spectral measurements were made after removing the leaves from the plant and placing them on a rotating table, so that several samples could be obtained and averaged. Measurements were also made from elevated platforms such as a car top looking at an enclosure where the environment was undisturbed, and from a tower.

5. Results

In figure 1 we present six characteristic spectra (figure 1(a)) taken at the loessial plain site and selected photographs of these sites (figure 1(b)). The bare soil (No. 1) has the highest reflectance followed by gravel (No. 6), sparsely grassy loess (No. 2), ploughed field (No. 3), annuals (No. 5), and the wheat field (No. 4). Note that the spectral dependence of all the sub-targets is similar in characteristics to the bare loessial soil but of lower value. The yellow wheat field resembles reflectance characteristics of vegetation in the NIR, but is missing the vegetation signature in the visible. We averaged all six measurements and compared them with the reflectance as measured from the car top. As evident from figure 2, the agreement is very close. This would indicate that sampling of characteristic sites could provide a measure of average reflectance, and that aircraft observation could be useful.

Similar measurements were performed at times corresponding to the following solar zenith angles: 16.97°; 25.33°; 31.44°; 34.66°; and 65.62°. Not all sites were sampled at each of these additional times. In particular, no additional measurements were taken from the car top or for the wheat field. We averaged all the available measurements at each time interval, and plotted the results as a function of solar zenith angle, corresponding to the middle of the observational time interval (figure 3). The solar zenith angle dependence is typical for natural surface types as observed with inverted pyranometers, and reported in numerous publications (e.g., Rosenberg et al. 1983). It is of interest to note that when the solar zenith angle dependence was plotted for each individual site, the patterns differed from site to site and displayed an irregular behaviour.

In figure 4, spectral reflectance measurements for characteristic surface elements of a sand dune are presented. Typical dune plants are: Artemisia monosperma, Retama raetam, Lycium schweinfurthii, and Stipagrostis scoparia (# 1–4 respectively); # 5 cyanobacteria crust in interdune areas; # 6 sand dune. The cyanobacteria crust spectra which consists mostly of Microcoleus vaginatus accompanied with Scytonema, Schizothrix, Calothrix, Chroococcidiopsis, Nostoc, and Phormidium (Danin et al. 1989, Danin 1991) is lower than the sand dune spectra. Of interest is the large difference in reflectance between the soil and the crust spectra which are much higher than the vegetation. It can be concluded that the dune vegetation signal is masked by the soil signal both because of the relative sparseness of vegetation and because of the lower reflectance.

In figure 5 results are presented for the wadi bed site (Avdat Farm). These measurements were made at nadir and each represents the average of about four samples. The samples displayed very little scatter. The curves represent the typical ground cover: (cobblestone (○) discuss (□) crust (○), gravel (x), as well as typical vegetation species: Atriplex halimus (+) and Verbascum fruticulosum (△). It can be seen that the vegetation reflectance is relatively low. Also, note the slight dip around 680 nm in the loessial biogenic crust spectra, due to photosynthetic activity of the cyanobacteria. Similar relationships are presented for the rocky terrain environ-
ment (figure 6). Here the typical substrate is Upper Turonian limestone (◯) and the typical vegetation is *Zygophyllum dumosum* (□), *Artemisia herba-alba* (◇), and *Erodium hirulit* (✗).

Figure 7(a) represents average observations made from a 90 m meteorological tower, at ten different heights, ranging from 15 to 87 m, and at three directions: west (◯), north (□), and east (◇). Selected views from the tower as well as examples of typical dunes and dune plants, are shown in figure 7(b). The southward observations were focused on dense vegetation over loessial soil and to a lesser extent, to exposed Eoceneian chalks. The northward observations were pointed to sand dunes with sparse vegetation. It can be seen that the eastward sand dune has the higher reflectance followed by the northward and the westward reflectance. All have a dip of different intensity in the red region due to vegetation photosynthetic activity, depending on vegetation density. Also note the water absorption regions around 0.82 and 0.95 μm in eastward spectra. Tower observations allow to integrate over large areas and to obtain a more representative sample. These darkens the scene. This last point is illustrated by comparing the all-direction average from the tower to a point observation at the ground, as illustrated in figure 7(a).

In figure 8 an attempt has been made to obtain a representative weighted average value for the different environments presented in the previous figures. The weighting procedure is based on a 30 to 70 per cent ratio between vegetation and their substrates (soil, sand or rocks). As evident, there is a wide range of observed reflectivities ranging from below 30 per cent in the NIR to over 50 per cent. Again,

Figure 1. (a) Spectral reflectance observed at 45°, perpendicular to the principal plane, for six characteristic surface types of a loessial plain (Sede Zin), 3 May 1990, 9.44–10.42 am. Due to high spectral density of the observations, only every fifth data point was plotted (one sample at every 10 nm). In computations, all data points were used. (b) Scenes from the loessial plain (Sede Zin): 1. bare dry sand with crust; 2. gravel; 3. sparsely grassy loess; 4. annuals (old alfalfa).
Figure 2. Comparison between spectral reflectance as observed over an enclosure from a car top and the average reflectance in figure 1.

Figure 3. Solar zenith angle dependence of the average reflectance for all six surface types of figure 1.
Figure 4. Spectral reflectance for characteristic sand dune (Be'er Malaga) taken on 27 March 1991 around 10:10 am, 45° to principal plane: #1: Artemisia monosperma delile; #2: Lycium schweinfurthii; #3: Retama raetam; #4: Stipagrostis scoparia; #5: cyanobacteria crust; #6: sand dune.

Figure 5. Spectral reflectance for characteristic surface types at a wadi bed (Avdat Farm), taken on 28 March 1991, around 3.40 pm at nadir: ○ cobble stone; □ discus; ◦ crust; × gravel; + Atriplex h.; Δ Verbascaum f.; spectra for Atriplex halimus were taken on 26 March 1991 around 3.40 pm. Each curve represents an average of about four samples.
Figure 6. Spectral reflectance for characteristic surface types of a rocky terrain (Sede Boker West), taken on 3 May 1990. ○ limestone; □ Zygophyllum dumosum; ◊ Artemisia herba-alba; × Erodium hirtum.

Figure 7. (a) Average spectral reflectance observations taken from several platforms of the 90m Shivta Tower. 28 March 1991, 10:56 a.m.-1:30 p.m., sampling in each of the following three directions: ○ west; □ north; ◊ east; x average; + observation taken at the ground (sand dune). (b) View from the Shivta Tower: 1. to the east; 2. to the north. Scenes from sand dunes: 3. dunes around Be'erotaim; 4. sand dune typical plant (Artemisia monosperma).
Characteristic spectral reflectance of a semi-arid environment
Figure 8. Average values for each desert habitat. The average value for each location was obtained as explained in text.

Figure 9. Average characteristic spectra of common vegetation types for the region: Lycium schweinfurthii, Artemisia monosperma, Retama raetam, Stipa scoparia, Verbascum fruticulosum, Atriplex halimus, Zygophyllum dumosum, Artemisia herba-alba, Erodium hirtum, Erodium glaucophyllum.
the observations from the tower, averaged in all three directions are somewhere in the middle, since the reflectivities are integrated over various environments. In figure 9 characteristic values for typical desert vegetation found at the different environments are presented. Each vegetation type has been sampled several times. In figure 10 a local average value was derived, based on observations at all the locations of figure 8 and an average of all the plants of figure 9. Since the vegetation is changing seasonally, several possible weights were assigned to the vegetation, from 10 to 40 per cent. This selection range of weights is based on results obtained from sampling of vegetation cover at 500 locations in the Northern Negev (A. Danin, private communication). The average cover of ephemeral vegetation was found to be about 13 per cent and that of perennial vegetation about 11 per cent. The combined average value is about 23 per cent. It was also found that 85 per cent of the sampled locations were with vegetation cover under 40 per cent.

For modelling at satellite scales, there is a need for information which is spectrally integrated in intervals which are commonly used in such studies. We used the following spectral intervals for integration: (0.37-0.40), (0.40-0.50), (0.50-0.60), (0.60-0.70), and (0.70-1.1 μm). The integration was performed as follows:

$$R_{\Delta} = \sum_{i=1}^{n} R_i \Delta S_i / \sum_{i=1}^{n} \Delta S_i$$

where the reflectance reported at wavelength $i$ is multiplied by the energy in the solar spectrum ($\Delta S_i$) in a 0.01 μm interval around $i$, using data from Labs and Neckel (1984). The products are summed in the spectral intervals of interest and divided by the total solar energy in that interval. Spectrally integrated values of some typical bright surface types as observed at a wadi bed (figure 5) are presented in figure 11. The integration was subsequently extended to 4.0 μm under the assumption that the reflectance observed at 1.1 μm remains the same up to 4.0 μm. This is based on data presented in Bowker et al. (1985) where measurements up to 2.5 μm are available. The spectrally integrated value, as given in table 2 is about 33.5 per cent. Realistically, this would be an overestimate since the reflectance above 1.1 μm could decrease. A similar integration was performed for characteristic vegetation spectra (figure 12). Here too, the integration was extended to 4.0 μm under the assumption that the reflectance beyond 1.1 μm is equal to 20 per cent of what was measured at 1.1 μm. This assumption is also based on data presented in Bowker et al. (1985). Numerical values of this integration are presented in table 3, the average value is about 20 per cent. Figure 13 is similar to figure 12 for average spectra as presented in figure 11.

Numerical values are presented in table 4. The effect of the different assumed densities of vegetation on the reduction of albedo ranged from 28.0 to 31 per cent.

6. Discussion

The effects of landscape changes on climate have been recognized. In particular, investigated were: anthropogenic impacts on arid regions which could have caused significant surface albedo increase; limitation of grazing and the resulting increase in vegetation cover over high albedo soil (Otterman 1977). Otterman (1974) observed the contrast at the Sinai/Negev boundary in the first Landsat image of the area taken in 1972 and pointed out that semi-dormant desert fringe plants strongly reduced the albedo of sandy terrain. The contrast reported on in that study was
Figure 10. Average for all habitats; average for all plants; and local average obtained by weighting the vegetation increasingly from 10 to 40 per cent, as could be the case during a seasonal cycle.

Figure 11. Spectrally integrated values for some typical surface types as observed at a wadi bed (see figure 5). Numerical values are presented in table 2.
Table 2. Average, spectrally integrated surface albedos for surface types presented in figure 11. The spectral intervals of integration are as specified.

<table>
<thead>
<tr>
<th>Wavelength (nm)</th>
<th>Cobblestone</th>
<th>Discus</th>
<th>Crust</th>
<th>Gravel</th>
<th>Average</th>
<th>G</th>
</tr>
</thead>
<tbody>
<tr>
<td>370·00</td>
<td>17.755</td>
<td>8.2784</td>
<td>15.734</td>
<td>15.944</td>
<td>14.427</td>
<td>33.493</td>
</tr>
<tr>
<td>400·00</td>
<td>17.755</td>
<td>8.2784</td>
<td>15.734</td>
<td>15.944</td>
<td>14.427</td>
<td>33.493</td>
</tr>
<tr>
<td>400·00</td>
<td>21.758</td>
<td>10.577</td>
<td>19.844</td>
<td>19.544</td>
<td>17.930</td>
<td>33.493</td>
</tr>
<tr>
<td>400·00</td>
<td>21.758</td>
<td>10.577</td>
<td>19.844</td>
<td>19.544</td>
<td>17.930</td>
<td>33.493</td>
</tr>
<tr>
<td>500·00</td>
<td>29.822</td>
<td>16.954</td>
<td>30.583</td>
<td>27.972</td>
<td>26.333</td>
<td>33.493</td>
</tr>
<tr>
<td>600·00</td>
<td>29.822</td>
<td>16.954</td>
<td>30.583</td>
<td>27.972</td>
<td>26.333</td>
<td>33.493</td>
</tr>
<tr>
<td>600·00</td>
<td>36.437</td>
<td>23.675</td>
<td>38.296</td>
<td>35.632</td>
<td>33.510</td>
<td>33.493</td>
</tr>
<tr>
<td>700·00</td>
<td>36.437</td>
<td>23.675</td>
<td>38.296</td>
<td>35.632</td>
<td>33.510</td>
<td>33.493</td>
</tr>
<tr>
<td>700·00</td>
<td>42.665</td>
<td>29.142</td>
<td>51.200</td>
<td>41.158</td>
<td>41.041</td>
<td>33.493</td>
</tr>
<tr>
<td>1050·0</td>
<td>42.665</td>
<td>29.142</td>
<td>51.200</td>
<td>41.158</td>
<td>41.041</td>
<td>33.493</td>
</tr>
<tr>
<td>1050·0</td>
<td>41.896</td>
<td>26.703</td>
<td>46.833</td>
<td>40.575</td>
<td>39.002</td>
<td>33.493</td>
</tr>
<tr>
<td>4000·0</td>
<td>41.896</td>
<td>26.703</td>
<td>46.833</td>
<td>40.575</td>
<td>39.002</td>
<td>33.493</td>
</tr>
</tbody>
</table>

Figure 12. Similar to figure 11 for an average desert vegetation. Numerical values are presented in table 3.

about the same in all spectral bands of the MSS, which included two visible (0.5-0.7 $\mu$m) and two NIR (0.7-1.1 $\mu$m) bands. It was claimed that the plant cover on the vegetated side of the Negev does not exhibit characteristics common to green vegetation of non-arid regions. It was further stated that green plants would have produced a Sinai/Negev contrast ratio much higher in the visible bands and in particular in the MSS red band from 0.6 to 0.7 $\mu$m, where plant chlorophyll strongly
R. T. Pinker and A. Karnieli

Table 3. Same as Table 2 for vegetation types presented in figure 12.

<table>
<thead>
<tr>
<th>Wavelength (nm)</th>
<th>Average</th>
<th>G</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>370.00</td>
<td>5.17</td>
</tr>
<tr>
<td>1</td>
<td>400.00</td>
<td>5.17</td>
</tr>
<tr>
<td>2</td>
<td>400.00</td>
<td>6.62</td>
</tr>
<tr>
<td>3</td>
<td>500.00</td>
<td>6.62</td>
</tr>
<tr>
<td>4</td>
<td>500.00</td>
<td>10.36</td>
</tr>
<tr>
<td>5</td>
<td>600.00</td>
<td>10.36</td>
</tr>
<tr>
<td>6</td>
<td>600.00</td>
<td>11.49</td>
</tr>
<tr>
<td>7</td>
<td>700.00</td>
<td>11.49</td>
</tr>
<tr>
<td>8</td>
<td>700.00</td>
<td>31.94</td>
</tr>
<tr>
<td>9</td>
<td>1050.00</td>
<td>31.94</td>
</tr>
<tr>
<td>10</td>
<td>1050.00</td>
<td>25.82</td>
</tr>
<tr>
<td>11</td>
<td>4000.00</td>
<td>25.83</td>
</tr>
</tbody>
</table>

Figure 13. Similar to figure 12, for local averages as presented in figure 10. Numerical values are presented in Table 4.

absorbs. The contrast therefore was attributed to the dark plant debris littering the surface and to shadowing effects. Otterman and Fraser (1976) estimated an effective average surface albedo for all wavelengths based on Landsat observations, to be between 0.47-0.52 for Sinai, which is higher than reported in previous investigations. For instance, Kondratyev et al. (1974) reported surface albedos of 0.28-0.32 for the Arabian peninsula and of 0.21-0.30 for the Sahara. Kung et al. (1964) reported results from aircraft measurements over the Sonora Desert of 0.22, over Yuma California of 0.27-0.28, and over a desert near Las Vegas of 0.24-0.27. Budyko (1974) recommends a single value of 0.28 for deserts.
Table 4. Same as table 2 for a combination of land and vegetation as presented in figure 13.

<table>
<thead>
<tr>
<th>Wavelength (nm)</th>
<th>1</th>
<th>1-avg</th>
<th>2</th>
<th>2-avg</th>
<th>3</th>
<th>3-avg</th>
<th>4</th>
<th>4-avg</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>370.00</td>
<td>8·91</td>
<td>27·57</td>
<td>9·53</td>
<td>28·75</td>
<td>10·15</td>
<td>29·93</td>
<td>10·77</td>
</tr>
<tr>
<td>1</td>
<td>400.00</td>
<td>8·91</td>
<td>9·53</td>
<td>10·15</td>
<td>10·77</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>400.00</td>
<td>11·15</td>
<td>11·90</td>
<td>12·66</td>
<td>13·41</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>500.00</td>
<td>11·15</td>
<td>11·90</td>
<td>12·66</td>
<td>13·41</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>500.00</td>
<td>17·84</td>
<td>19·09</td>
<td>20·33</td>
<td>21·58</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>600.00</td>
<td>17·84</td>
<td>19·09</td>
<td>20·33</td>
<td>21·58</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>600.00</td>
<td>23·50</td>
<td>25·51</td>
<td>27·51</td>
<td>29·51</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>700.00</td>
<td>23·50</td>
<td>25·51</td>
<td>27·51</td>
<td>29·51</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>700.00</td>
<td>38·15</td>
<td>39·19</td>
<td>40·22</td>
<td>41·26</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>1050.00</td>
<td>38·15</td>
<td>39·19</td>
<td>40·22</td>
<td>41·26</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>1050.00</td>
<td>32·89</td>
<td>34·07</td>
<td>35·25</td>
<td>36·43</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>4000.00</td>
<td>32·89</td>
<td>27·57</td>
<td>34·07</td>
<td>28·75</td>
<td>35·25</td>
<td>29·93</td>
<td>36·43</td>
</tr>
</tbody>
</table>

The results from our study yield an average surface albedo for the dominant soil types of about 33·5 per cent; and an average of 20·0 per cent for the dominant vegetation types. The effect of vegetation was found not to reduce the surface albedo significantly. If the vegetation comprises only 10 per cent of the surface, the reduction would be to an average value of 30·0 per cent. It was already noted by Hutchinson (1982) that it is difficult to extract vegetation signal from satellites when the vegetation cover is less than 30 per cent. Tueller (1987) pointed out that there seems to be a vegetation threshold at 25 to 35 per cent below which the soil is the principal contributor to the overall spectral response of the terrain. In our case, the vegetation is also sparse, and as such, the soil background is the major contributor to the observed reflectance.

We have also found that the spectral reflectance signature of the desert plants is similar to the signature of 'green' vegetation, and that for some plants, the NIR reflectance can be as high as 70 per cent while most of the observed values were much lower; the lowest values observed were about 20 per cent. Furthermore, field surveys which have been conducted in the area (Abramsky 1989) report that the vegetation cover is less than 14 per cent (10·5 per cent annual vegetation and 2·8 per cent perennial vegetation cover). This amount is obviously smaller than the 30 per cent threshold specified earlier for detecting vegetation by satellite methods.

It can be concluded that the dune vegetation signal is masked by the soil signal both because of the relative sparseness of vegetation and its lower spectral signature.

If we contrast field measurements of spectral reflectance of sand dunes and cyanobacteria crust it can be seen that the typical sand dunes have lower spectral reflectance than the crust. The cyanobacteria crust spectra is lower than the sand dune spectra, except below 0·55 μm. It can be therefore further concluded that the contrast between the Sinai and the Negev has been caused by the different distribution of active sand and crust. As suggested by Tsoar (1990) and Danin (1991), the following mechanism is plausible. In the absence of human activities or overgrazing in the Negev region, air borne silt and clay, originating from adjacent deserts have been deposited and trapped by the vegetation and accumulated mainly in the interdune areas (Yaalon and Ganor 1973, Yaalon and Dan 1974). Once the fine material of the top layer exceeds 1·5-2%, cyanobacteria communities may be
established (Danin 1978). Their extent increases with time, causing aggregation of finer grain soil particles, which cover larger areas than the interdunes themselves. Consequently, most of the area may be overlaid with cyanobacteria crust and the active dunes turn into stable sand fields. On the Egyptian side, the anthropogenic disturbances prevent the crust from becoming established. Since the cyanobacteria has a lower reflectance than the pure sand, the entire area of the Negev appears darker than the adjacent area in the Sinai. It is suggested, therefore, that anthropogenic activities which prevent accumulation of crust or destroy an existing crust, rather than the overgrazing mechanism itself, are the main reason for the sharp contrast between the Sinai and the Negev (Karnieli and Tsoar 1994).

7. Summary

Most previous surface spectral reflectance measurements made for remote sensing applications, were designed to match various satellite sensors such as the MSS or TM of the Landsat, and particular viewing angles. The objective of this study was to obtain information on high resolution spectral reflectivity of typical soils and vegetation in a climatically important arid region; and to generalize these observations, for use in developing spectral reflectance models at larger spatial scales. Preliminary tests have shown that in the selected study area sampling differences exceeded angular differences. Therefore, the emphasis was placed on obtaining spectra from a large number of surface types and it was assumed that the angular dependence averages out in these samples, or, is of secondary importance.

The data collected were aggregated into models of spectral reflectance of land and desert vegetation and subsequently, the effect of vegetation on the surface reflectance albedo was estimated. It was found that an average value of a Lambertian surface albedo in the solar spectrum was in the range of 38.0-31.0 per cent.

The upper limit values of 31.0 per cent were characteristic of the soils; inclusion of vegetation at various levels of density tended to reduce the albedo, but not significantly. The need for 'ground truth' on surface albedo for validating remotely sensed estimates has been recognized. As yet, little was done to obtain such information at larger scales. In this study, an attempt has been made to generalize in situ observations of a large number of samples to obtain reflectance models which could be used for simulations at satellite scales.

Acknowledgments

The work of R. T. P. is supported by grants NAG5-914 from the National Aeronautics and Space Administration, Earth Science and Space Administration, Earth Science and Applications, Climate Research Program and grant NA16RCO113-01 from NOAA/Climate and Global Change Program. We wish to thank the granting agencies, Drs J. Otterman, and S. Goward for helpful comments, T. Mulhern for assistance with the Spectron Engineering SE-590 Spectroradiometer, Dr M. V. Chien and Ch.-Ch. Chang for their assistance with data processing.

References


Characteristic spectral reflectance of a semi-arid environment


