

Locating potential vicarious calibration sites for high-spectral resolution sensors in the Israeli Negev Desert by GIS analysis

U. Gilead & A. Karnieli

*The Remote Sensing Laboratory, Jacob Blaustein Institute for Desert Research,
Ben Gurion University of the Negev, Israel*

ABSTRACT: Deserts, and especially dry playas, are preferable regions for implementing reflectance-based vicarious calibration of multi- and hyper-spectral sensors. This research attempted to locate potential vicarious calibration sites for small footprint sensors by using GIS techniques, i.e. analyzing spatially mapped, satellite, and tabular data, with respect to certain criteria (such as spectral reflection, temporal stability, size, elevation). This methodology was applied to the Negev Desert in Israel and resulted with 8 sites that were selected for further *in situ* characterization and measurements for validation. Results of one validation campaign are presented. The GIS analysis has proven to be a useful tool for saving time and efforts by searching through vast and remote regions.

1 INTRODUCTION

Optimal operation of any air or spaceborne multispectral imaging system for remote sensing applications depends on accurate calibration of the system. Different methods and approaches are commonly used for calibration, namely preflight, onboard, and vicarious techniques. Regardless of the quality of the preflight calibration, once launched, any spaceborne sensor is susceptible to significant changes in its performance (Teillet et al. 2001). Consequently, in order to ensure the best performance of the system, all the above-mentioned complementary methods should be used independently to determine if systematic errors exist in one or more techniques and, if possible, to identify, examine, remove, or account for them in the calibration results.

Several approaches are usually used for vicarious calibration. These are the radiance-, irradiance-, and reflectance-based approaches. The latter involves extensive ground truth measurements of the surface spectral reflectance and the atmosphere during satellite overflight. After applying a radiative transfer code, it is possible to compare the sensor's top-of-atmosphere (TOA) measurements with those conducted independently *in situ*. This absolute calibration method produces a new set of radiometric coefficients that can be used instead of those derived during the preflight process (Thome 2001).

Deserts, and especially dry playas, are preferable regions for implementing vicarious calibration.

Well-used and documented sites are the White Sands National Monument, Railroad Valley Playa, Lunar Lake, and Roach Lake Playa, all in the southwestern part of the United States (Thome 2001), and Lake Frome in South Australia (Barry 2001). In order to minimize calibration uncertainties, Scott et al. (1996) and Thome (2001) listed crucial conditions for selecting vicarious calibration sites. Such sites should be characterized by:

1. High reflectivity values that reduce the impact of errors in determining the radiance due to atmospheric scattering. A site reflectance greater than 0.3 ensures that the radiance of the direct solar irradiance from the surface is the dominant contributor to the at-sensor radiance.
2. High spatial uniformity, relative to the pixel size, over a large area that minimizes the effects of scaling the reflectance data to the size of the entire test site.
3. Nearly lambertian surface to decrease uncertainties due to changing solar and view geometry. These are flat sites and thus reduce bidirectional reflectance factor (BRF) effects and eliminate shadow problems.
4. Spectral uniformity over as wide a spectral region as possible. This simplifies band integrations and decreases the effects of spectral mismatch between the ground-based measurements and the sensor.
5. High probability of cloud-free days.
6. Location in remote areas, far from anthropogenic (urban and industrial) aerosols.

7. Extremely low precipitation providing minimum change in soil moisture.
8. Lack of vegetation so the seasonal dynamics is minimal.
9. Location far from the sea in order to minimize the influence of atmospheric water vapor.
10. High accessibility to the organization that performs the *in situ* measurements.

Scott et al. (1996) describe a search algorithm that was used to identify suitable sites for vicarious calibration based on Landsat-MSS imagery covering a vast portion of the southwest USA drylands (including southern California, Arizona, southern Nevada, and southern Utah). This search program mainly focused on locating areas that have large spatial extent, spatial uniformity, and high surface reflectance. The search algorithm identified many promising sites, however only two of them (Railroad Valley Playa and Lunar Lake) were selected for further ground investigation.

The State of Israel, which has already manufactured, launched, and operated several earth observation satellites (the EROS and Ofek series) (Steinberg 2001), is seeking independent calibration sites for such small footprint sensors. The current research explores the Israeli Negev desert by Geographic Information System (GIS) technology to locate and characterize potential sites that may be used for vicarious calibration.

2 MATERIALS AND METHODS

2.1 GIS data

The search for potential calibration sites was conducted in accordance with the criteria described above. That is, the site should be characterized by high spectral reflectance, high elevation, high-spatial uniformity, minimal slope, spectral uniformity, minimal seasonal changes, and be readily accessible to the organization that will perform the calibration. The site should also be large enough relative to the pixel size of the sensor (Clark et al. 2002).

Locating potential sites was performed, for the most part, by GIS techniques, i.e. analyzing spatial mapped data and satellite imagery, along with tabular data. This facilitated the location procedure by eliminating areas that were not suitable, leaving only a small number of appropriate ones. The idea behind this methodology is to save time and effort by searching through a vast and remote region while checking a number of critical variables such as spectral reflection, temporal stability, size, and elevation. Nevertheless, one should keep in mind that as promising as the results may be, there is still a need to perform *in situ* examinations in order to verify the results and appraise the site's suitability.

The general concept underlying the search for sites was to join information from relevant GIS layers,

one polygonal layer with an inclusive attribute table. The variables attributed to each polygon are key parameters considered necessary to characterize calibration sites. Building such a layer enables finding ideal sites by selecting polygons that have specific parameters.

2.2 Study site – the Negev Desert

The study area is comprised of the southern part of Israel in the Negev Desert. The eastern (Jordan) and western (Egypt) borders of this area were delineated according to political considerations. The northern border of the Negev is considered to be the 200 mm isohyetal line, thought to be the beginning of the dryland (Stern et al. 1986). The overall size of the study area is 10,000 km².

Summer in the Negev is characterized by hot (mean annual temperatures of 25 degrees C), dry (relative humidity ranges from 20 to 50 percent), and clear days with little day-to-day variations. Rain falls almost exclusively in the cool (9 degrees C) winter. Mean annual rainfall decreases gradually from 200 mm at the northern boundary to about 25 mm at the southern edge. The number of rainfall days per annum varies between 40 in the north to 5 in the south. Since the Negev has a relatively small size, the spatial changes in solar radiation are minor. The horizontal global total radiation is generally around 2000 kWh/m²/year. The highest radiation is in June (220-250 kWh/m²/year) and the lowest in December (90-115 kWh/m²/year) (Faiman et al. 2003). The main soils found in the Negev are coarse desert alluvium, calcareous serozems, sands, and bare rocks. Perennial vegetation is sparse (less than 20 percent) in the northern Negev, and concentrated only along the ephemeral streams in the southern part (Danin 1983). Annual phenology is limited to the spring months (Karnieli 2003).

For this report, the Negev can be divided into 3 different zones that vary mainly in topography, mineral composition, precipitation, and radiation levels:

1. Northwestern Negev. Average elevation ~150 m, precipitation 100-200 mm per year, 20-25 percent cloud cover per year, annual horizontal global total radiation ~1900 kWh/m²/year. The area is comprised of sandy regosol, sand dunes, and arid brown soils.
2. Eastern Negev along the Rift Valley. Elevation ranges between -400 m to sea level (increase southwards), precipitation 25-100 mm per year (increase northwards), 15-20 percent cloud cover per year, annual horizontal global radiation changes with elevation, between 1900-2100 kWh/m²/year. The area is comprised of reg soils and coarse desert alluvium.
3. The central Negev highlands – average elevation 500 m, precipitation ranges from 0 to 100 mm per year, 15 - 20 percent cloud cover per year,

Annual horizontal global radiation ~2100 kWh/m²/year. The area is comprised of calcareous serozems (higher areas), bare rock, desert lithosols, reg soils, and coarse desert alluvium.

2.3 Building the GIS

The first step in constructing the GIS was to gather input layers that include relevant data. All components of the GIS are described in Table 1 and illustrated in Figure 1.

The digital elevation model (DEM) of the Negev is based on the Geographical Society of Israel (GSI) Digital Terrain Model (Hall 1993). Forty sheets, each consisting of a matrix of 801 × 801 pixels, were mosaicsed. The spatial resolution of the DEM is 25 m while the height resolution is 10 cm. The DEM was used for slope retrieval, after being converted to slope map (Fig. 2a). Later on, since the site should be as flat as possible, all areas with slope higher than 0 degrees were excluded. The final product was a binary raster map where 1 = 0 degrees slope and 0 = no data. Afterwards, the raster map was converted to vector polygons. This enables building topology for the slope 0 degrees areas - i.e. size, perimeter and xy coordinates for each polygon. An attempt to include more areas, by including all pixels with value of slope = 1 degree, presented similar results with no significant increase in polygon size.

A major advantage of converting raster to vector is the better handling of excess polygons. This occurs since

each pixel with 0 degree slope can become a polygon. In the current research, more than 87,000 polygons were created for a size smaller than 10,000 km². When not clustered, these polygons are useless since they do not qualify as potential sites due to their small size. One of the advantages of working in vector format is the possibility of assigning each aggregation of pixels (now polygon) an area dimension, whereas in raster format this operation is difficult since pixels maintain the value of each single

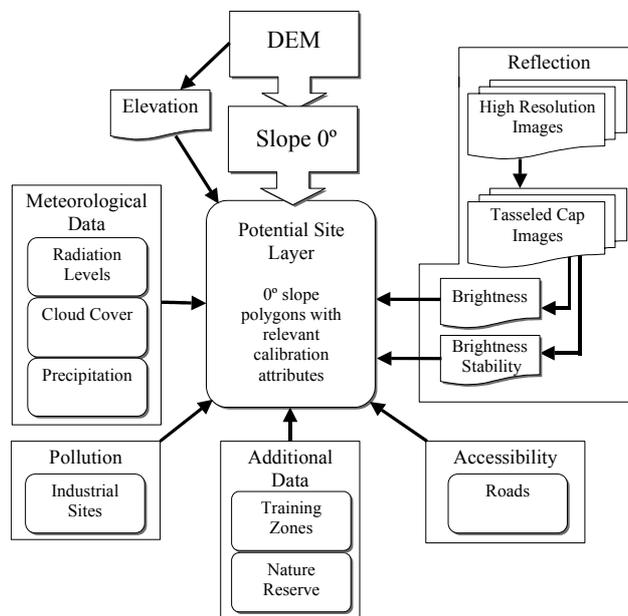


Figure 1. Input layers of the GIS (graphic scheme).

Table 1. Input layers of the GIS.

Input	Details	Data use
DEM	25 m spatial resolution 10 cm height resolution Raster	Obtain elevation and slope
Landsat-TM and ETM+ images	Frame 174-39 (South Israel) Dates of acquisition: 18 Jan. 1987; 14 Aug. 1987; 29 Mar. 1995; 21 Sep. 1995; 6 Apr. 1998; 7 Aug. 1999; 10 Oct. 1999; 30 Jan. 2000; 21 May 2000; 27 July 2001 30 m spatial resolution	Tasseled cap index was preformed in order to obtain brightness values (represent high reflection)
Precipitation	Annual mean precipitation in Israel Polygonal vector layer 100 mm isohyets	Predicting precipitation amounts at the selected site
Cloud Cover	Mean yearly cloud cover of the sky (percent)	Assess probability of clear days throughout the year
Radiation	Mean monthly radiation levels (kWh/m ² /year) Polygonal vector layer	Assess probability of clear days throughout the year
Air-polluting industry	Air pollution sources Polygon point layer	Knowledge of air polluting industries nearby sites
Roads	Main roads of Israel Line vector layer	Distance information and accessibility
Military training zone	Training zones of the Israeli Army Polygonal vector layer	Identify potential sites which are inside military training zones
Nature reserves	Nature reserves in Israel Polygonal vector layer	Additional information

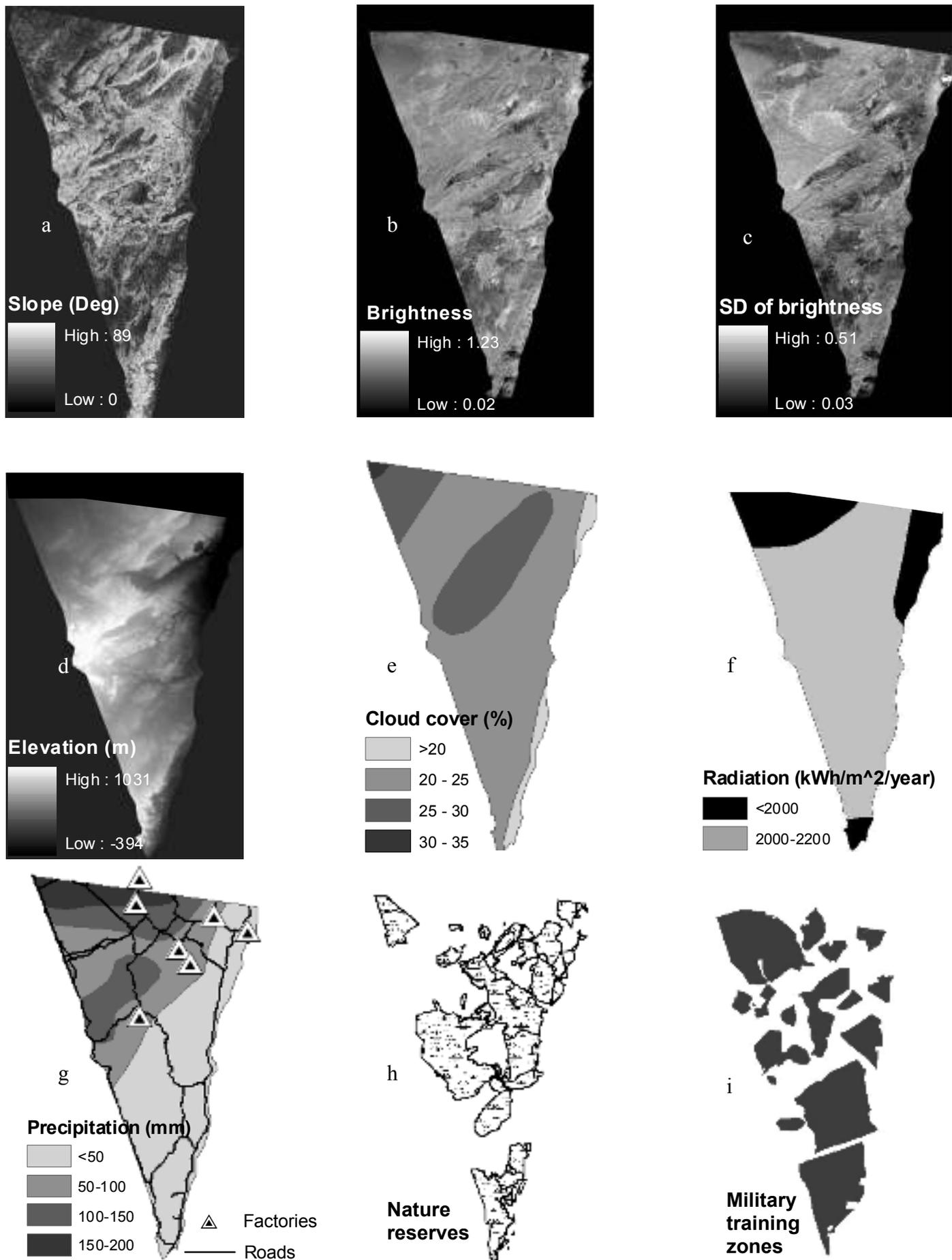


Figure 2. Input layers of the GIS. (a) slope; (b) brightness; (c) standard deviation (SD) of brightness; (d) DEM – elevation; (e) cloud cover; (f) radiation; (g) precipitation, roads and factories; (h) nature reserves; (i) military training zones.

pixel and do not aggregate to one object with area dimension. The conversion to vector therefore enables deletion of polygons under a specific size, resulting in a smaller file with relevant polygons that may be used as potential sites for vicarious calibration. Another advantage of working in vector is that it permits integration of polygons that are close to each other and could thus actually be considered as one large site. After deleting all polygons smaller than 1 km² (minimum size determined for potential calibration site) only 87 polygons remained, creating a reduced polygonal layer on which the rest of the analysis was performed. These polygons are referred to hereafter as 'potential sites layer' or PSL.

The next step was associating the PSL polygons with Tasseled Cap brightness values in order to locate sites with high soil reflectance. The Tasseled Cap transformation (Crist 1984) is a vegetation index used to disaggregate the amount of soil brightness, vegetation, and moisture content in individual pixels. The transformation was performed on 5 Landsat TM and 4 Landsat ETM+ images using the appropriate Tasseled Cap coefficients of each sensor (Huang et al. 2002). Later, all images were overlaid and a mean value of each pixel was calculated to produce one brightness image (Fig. 2b). Since the 9 Landsat images were acquired at different months of the year, it was possible to assess the temporal brightness dynamics due to seasonal changes of vegetation and/or wetness. This was performed by calculating the standard deviation from the mean brightness value. As seen in Fig. 2c, the lower the standard deviation, the higher the stability of the site. A DEM was used to create a mean topographical elevation attribute for each PSL polygon (Fig. 2d).

Spatial distribution of meteorological data, such as cloud cover (Stern et al. 1986), radiation (Faiman et al. 2003), and precipitation (Survey of Israel 1995), were extracted from different maps. Industrial air-polluting facilities were mapped as points, and roads as vector lines (Figs 2e, f, g). Polygonal vector layers of military training zones and nature reserves were obtained and intersected with the PSL, in order to gain additional information involving potential restrictions for each potential site (Figs 2h, i). Finally, the accessibility of each site was calculated using a line-vector layer of roads. The 'distance' attribute was calculated from the remote sensing laboratory at Sede Boker to the centroid of each potential site. The final product is an inclusive attribute table that enabled selecting, by means of a query with desired parameters as input, optimal sites out of the 87 sites that initially composed the PSL.

3 RESULTS

The final step, after completing the construction of the GIS, was to locate potential sites for vicarious calibration

in the Negev, by performing a query with desired parameters on the PSL layer. Doing so revealed, as expected, that no site has ideal characteristics that meet all the attribute requirements. Consequently, the chosen sites are a function of the flexibility of the stipulations set in the query. The area with the highest brightness values (>1.0) is the Eastern Negev along the Rift Valley, which is rich in bright surface minerals. The downside of this area is the low elevation, between 0 to -380 m. Furthermore, the 'Dead Sea Works' industry, located near the Dead Sea, produce air pollution that might affect the visibility and atmospheric conditions in this region. In terms of elevation, the best potential sites are at the western parts of the study area, where the highest points reach elevations of over 1000 m. However, these potential sites are characterized by relatively low brightness (0.85-0.95). Radiation and precipitation do not change dramatically over the entire study area due to its relatively small size. Similarly, the distance factor in the Negev is negligible, since every point can be reached in less than a 3-hour drive from any other point. In some regions, such as along the Rift Valley, one principle wind direction (north to south) is dominant throughout the entire year. In other regions, industrial air pollution should be dealt with individually in each case since the wind regime changes temporarily. A site within a distance of 2 km from a polluting factory can have aerosol-free air in a certain month at certain hours, while at different times the situation may be reversed.

To reduce the number of potential sites, a brightness threshold was set at 0.95. This resulted in 8 potential sites rather than 87. These 8 selected sites should be carefully examined by remote sensing methods and by *in situ* measurements as well. Although the PSL and its attributes may be comprehensive, there are other factors that may prevent the potential site from being used as a vicarious calibration site, e.g. sparse vegetation, surface roughness. Examination by spectroscopic methods can spot unknown parameters of the site, e.g. soil mineralogy with pronounced absorption features. Therefore, ground verification is an essential condition to complete the GIS study.

Of the final 8 sites the most appropriate one appears to be site no. 5, with a size of almost 6 km², elevation of 370 m, and high brightness values of 0.96. It also has low cloud cover and high radiation levels. The disadvantage of this site is that it is located in a military training zone, which may restrict access and mobility. Site no. 2 also is inside a military training zone. Sites nos. 7 and 8 have high brightness values and are located outside military training zones. Their setbacks are low elevation (-220 m and -261 m, respectively) and relative proximity to the Dead Sea Works industry (3.84 km and 13.94 km, respectively).

Some regions were disqualified due to unsuitable conditions. The Northwestern Negev, with relatively

low brightness values (0.5-0.75) and medium elevation (~200m), is an example of such an area. Furthermore, precipitation levels are higher in the Northwestern Negev than in other regions and radiation is lower. All of these conditions led to the removal of this region from the potential site list.

4 AMIAZ PLAIN - CHARACTERISTICS

Within the framework of the GIS validation efforts, each of the selected sites was visited in order to verify and characterize its suitability for vicarious calibration. This section presents one example. Site no. 8, Amiaz Plain, is located at 31°4'41"N, 35°22'10"E. The total size of the plain, which is a part of the 'Judea Desert Nature Reserve', is about 6 km². About 1 km² has a 0 degree slope; the rest of the area has slopes ranging up to 10 degree. The elevation of the site ranges between -260 to -270 m below mean sea level (MSL), with mountain ridges on the western and eastern edges (-50, -180 m below MSL, respectively).

Climatically, the site is found in an extremely arid area. The mean annual rainfall is 47 mm, with large variations between years. 99 percent of the rainfall occurs between October and April. The probability for more than 50 mm/year is 45 percent. Cloud cover is about 27 percent from October to May and 4 percent from June to September. Horizontal global total energy ranges between 81 kWh/m² in December to 231 kWh/m² in June. The prevailing wind directions are south (December-February), north (March-May, October-November) and northwest (June-September) (Faiman et al. 2003). The site is located approximately 4 km northwest of the Dead Sea Works industry; therefore aerosol pollution should be taken into account, particularly during December-February. The site is within a one-hour drive from the remote sensing lab at



Figure 3: Bright surface consists of marls at Amiaz

Sede Boker. The plain's substrate consists of bright marls of the Lisan formation that contribute to its high surface brightness (fig. 3). Figure 4 presents the spectral reflectance of the site as measured by a portable analytical spectral device (ASD).

The graph depicts the relative advantage of this site – very high reflectance throughout the reflective range (350-2500 nm) with minimal fluctuations.

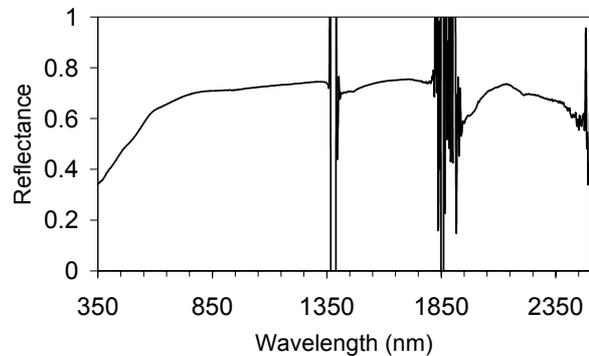


Figure 4. Spectral reflectance of Amiaz Plain.

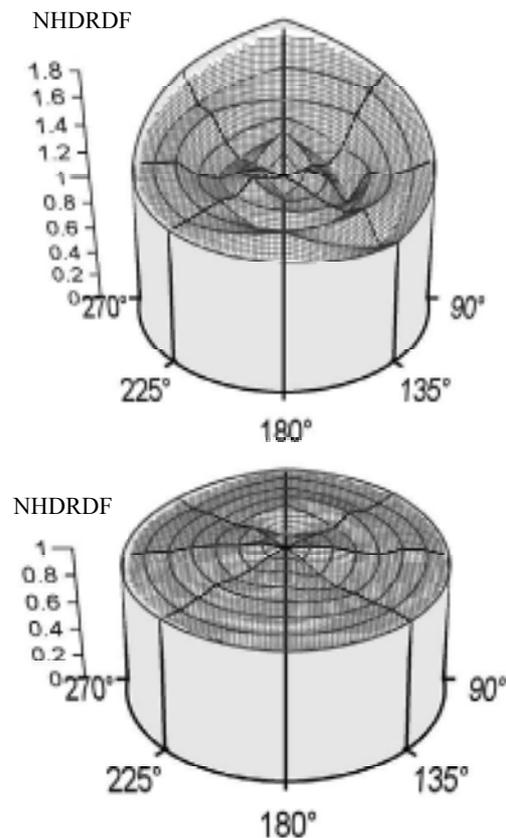


Figure 5. NHDRDF for a smooth surface at Amiaz plain for the 850 nm waveband and for solar zenith angle of 75 degrees (a) and 15 degrees (b). The basis of each diagram represents the view angle with respect to the solar principle plane.

The Normalized Hemisphere-Directional Reflectance Distribution Function (NHDRDF), of the surface is presented in Figures 5a, b. Measurements conducted by a CIMEL radiometer (Cierniewski, in press) reveal near-Lambertian characteristics of the surface.

5 CONCLUSIONS

The advantage in using GIS analysis for locating potential sites for vicarious calibration is the ability to search through large areas and identify suitable areas by intersecting various crucial parameters such as reflectance levels and elevation. Furthermore, the temporal dynamics of these variables can be checked over time using time series techniques. However, this GIS analysis is by no means a replacement for *in situ* measurements; validation of the suitability of sites is also essential. As extensive as the GIS characterization may be, one must keep in mind that it provides general results, which are dependent on the resolution used in the GIS, and may not provide micro-characterization of the site. A 25 m resolution DEM, as used in this research may not detect gullies, rough soils, and other types of micro-morphologies that can affect the distribution of incoming radiation. Such is also the case for other parameters, e.g. precipitation and radiation values, that should be extracted at site resolution and not by regional interpolation. The brightness values for each site are the average of all pixels within the site, and do not necessarily reflect a homogeneously bright site. Consequently, further research should be conducted in order to assess site reflectance homogeneity as suggested by Bannari et al. (2002).

Another reason for *in situ* validation is the potential lack of information concerning land use. While some land use maps are easily obtained and inserted in the GIS, it is hard to obtain all possibilities. Generally, the resolution of the GIS input is dependent on the spatial resolution of the sensor intended for calibration. For high spatial sensors, the higher the resolution used in the raster input, the better the results. However, it should be taken into consideration that the higher the ratio between the study area and the spatial resolution of input, the more computer power is needed for processing, especially when working in vectors. Altogether, the GIS analysis has proven to be a useful tool for saving time and efforts by searching through vast and remote regions.

ACKNOWLEDGEMENTS

The authors thank Prof. Jerzy Cierniewski, Adam Mickiewicz University in Poznan, Poland, for providing indispensable BRDF data and assistance in performing the field measurements.

REFERENCES

- Bannari, A., Omari, K., Teillet, P. & Fedosejev, G. 2002. Potential of Getis Statistic to characterize the spatial and temporal uniformity of test sites used for radiometric calibration of earth observation sensors. *International symposium on recent advances in quantitative remote sensing*, Valencia, Spain.
- Barry, P.S., Jarecke, P. & Pearlman, J. 2001. *Radiometric calibration of the Hyperion Instrument using ground truth at a site in Lake Frome, Australia*. TRW Redondo Beach, CA 5.
- Cierniewski, J., Gdala, T. & Karnieli, A. (in press). A Hemispherical-Directional Reflectance Model as a Tool for Understanding Image Distinctions Between Cultivated and Uncultivated Bare Surfaces. *Remote Sensing of Environment*.
- Clark, R.N., Swayze, G.A., Livo, K.E., Kokaly, R.F., King, T.V.V., Dalton, J.B., Vance, J.S., Rockwell, B.W., Hoefman, T. & McDougal, R.R. 2002. Surface reflectance calibration of terrestrial imaging spectroscopy data: a tutorial using AVIRIS. *US Geological Survey*: 33.
- Crist, E.P. & Cicone, R.C. 1984. A physically-based transformation of Thematic Mapper data - the TM Tasseled Cap. *IEEE Transactions on Geoscience and Remote Sensing* GE-22: 256-263.
- Danin, A. 1983. *Desert vegetation of Israel and Sinai*. Jerusalem, Cana.
- Faiman, D., Feuermann, D., Ibbston, P., Zemel, A., Ianetz, A., Liubansky, V. & Setter, I. 2003. *Data processing for the Negev radiation survey: ninth year*. The Jacob Blaustein Institute for Desert Research, Sede Boker.
- Guo, X., Price, K.P. & Stiles, J.M. 2000. Modeling Biophysical Factors for Grasslands Using Landsat TM Data in Eastern Kansas. *The Second International Conference on Geospatial Information in Agriculture and Forestry*, Lake Buena Vista, Florida.
- Hall, J.K. 1993. The GSI digital terrain model (DTM) project completed. *GSI Current Research* 8: 47-50.
- Huang, C., Wylie, B., Yang, L., Homer, C. & Zylstra, G. 2002. Derivation of a tasseled cap transformation based on Landsat 7 at-satellite reflectance. *International Journal of Remote Sensing* 23: 1741-1748.
- Survey of Israel 1995. *The new Atlas of Israel*. Tel Aviv: Survey of Israel Publications.
- Karnieli, A. 2003. Natural vegetation phenology assessment by ground spectral measurements in two semi-arid environments. *International Journal of Biometeorology* 47: 179-187.
- Scott, K.P., Thome, K.J. & Brownlee, M.R. 1996. Evaluation of the Railroad Valley playa for use in vicarious calibration. *Proc. SPIE Conference*, 2818: 158-166.
- Steinberg, G.M. 2001. Commercial observation satellites in the Middle East and the Persian Gulf. Commercial observation satellites. In Baker, J.C., O'Connell, K.M., Willimason, R.A. (eds.), *Commercial observation satellites*; Santa Monica: RAND.
- Stern, E., Gradus, Y., Meir, A., Krakover, S. & Tsoar, H. (eds.) 1986. *The Atlas of the Negev*. Be'er-Sheva: Keterpress enterprises.
- Teillet, P.M., Fedosejevs, G., Gauthier, R.T., O'Neill, N.T., Thome, K.J., Biggar, S.F., Ripley, H. & Meygret, A. 2001. A generalized approach to the vicarious calibration of multiple earth observation sensors using hyperspectral data. *Remote Sensing of Environment* 77: 304-327.
- Thome, K.J. 2001. Absolute radiometric calibration of Landsat 7 ETM+ using the reflectance based method. *Remote Sensing of Environment* 78: 27-38.