COMPARISON OF MULTISPECTRAL AIRBORNE SCANNER REFLECTANCE IMAGES WITH GROUND SURFACE REFLECTANCE MEASUREMENTS*

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ABSTRACT

Simultaneously with an airborne data taking campaign near the city of Nürnberg (FRG), performed with an imaging 11-channel scanner of type Daedalus AADS 1268, ground reference measurements of reflectance spectra were conducted with a spectrally high resolving spectroradiometer of type IRIS at selected test sites. Based on a method developed by Richter (1994) and Hepp (1994) reflectance images are calculated from the aerial raw data. Thus, physical quantities of the surfaces are generated, which are independent of illumination and registration conditions. The airborne scanner reflectance images are compared with ground reference reflectance measurements. The comparison yields deviations up to 35%. They can partially be explained by an inaccurate calibration of the airborne scanner. In addition, errors appear during calculation of the reflectances due to simplifying model assumptions and an inexact knowledge of the values of the model input parameters. It is shown that calibration of the airborne scanner data with the ground reference measurements improves the results, as compared to calibration based on laboratory testbench measurements.

1.0 INTRODUCTION

Change detection based on multitemporal image data sets enhances the potential of remote sensing in many areas of application. Ususally multitemporal data sets are taken under different illumination conditions and observation geometries. This introduces changes into the recorded radiances. In order to be independent of the conditions of the illumination and observation, generally a transformation of the measured multispectral $radiances$ into multispectral surface-*reflectances* $\rho(\lambda)$ is a prerequisite. If $E_S(\lambda)$ stands for the irradiance of illumination and $L_R(\lambda)$ symbolizes the spectral radiance of the light reflected by the surface, $\rho(\lambda)$ is defined as follows:

$$\rho(\lambda) \; = \; \pi \, \frac{L_R(\lambda)}{E_S(\lambda)} \quad .$$

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The determination of multispectral surface reflectances can be done in two ways. One is to calibrate the airborne multispectral scanner before and/or after a flight in abolute radiances with radiance normals, e.g. integrating spheres (Oertel, 1994) and then to invert a radiative transfer model (which calculates radiances from surface reflectances) for example by applying the *look-up-table* technique. For this study the SENSAT-4 algorithm by Richter (1994), which uses the look-up-table technique, was selected (see also Hepp (1994)). Thus, assumptions on the influence of the atmospheric, illumination, and observation conditions have to be made. The other approach is to measure the spectral reflectance at selected points on the ground while the overflight takes place and to calibrate the airborne measurements with these ground-reference reflectances. In this study, we compare the results of the both procedures with ground spectral reflectance measurements.

2.0 MEASUREMENTS

2.1 SITE AND DATA TAKING CONDITIONS

The overflight took place on 18. October 1994 from 11:00h to 12:15h a.m. local time near the city of Nürnberg, FRG (11°03' of longitude, 49°29' of latitude). Visibility was 30km at 12:00h, wind speed 4.6m/s from 125°, clouds were 2/8 cirrus at 8km, the pressure was 1023hPa and the relative humidity 53%. Ground reflectance reference measurements were done between 10:45h and 15:00h.

2.2 AIRBORNE MEASUREMENTS

The airborne measurements were performed with the multispectral scanner of type Daedalus AADS 1268. This instrument measures the radiance within 11 spectral channels. 10 of them are located in the range of the solar spectrum from 0.42μm to 1.05μm (Si-detectors) and from 1.55μm to 2.35μm (InSb-detectors) and one lies in the thermal infrared centered at 8.8μm (HgCdTe-detector). The instantaneous field of view is 2.5mrad yielding a ground resolution (extension of a pixel) of 0.75m, when a flight altitude of 300m is chosen. The swath of $\pm 43°$ is divided into 716 pixels, each of wich is recorded with 7Byte radiometric resolution in each channel. Roll compensation is done automatically up to 15° with a gyrometer. Operated by the Deutsche Forschungsanstalt für Luft- und Raumfahrt (DLR) the Daedalus scanner was installed in a DO 228 aircraft (also DLR), flying at 300m altitude.

2.3 GROUND REFLECTANCE MEASUREMENTS

Simultaneous to the overflight a total 24 ground reference measurements of the spectral reflectance were done at six selected locations of the experimental area in cooperation with DLR. Fig. 1 shows details of the images recorded from 300m altitude. The six spots of the ground reference measurements are indicated. Mainly surfaces with no vegetation (man made surfaces) were selected due to their higher spatial homogeneity. The samples were, in the order of the measurements:

1) New, unused concrete, at the Nürnberg airport (10:45-11:45h a.m.)
2) Asphalt at the Nürnberg airport (11:45h a.m.)
3) Red tennis court (12:54h a.m.)
4) Artificial lawn (01:15-01:45h p.m.)
5) Asphalt, industrial area (02:05h p.m.)
6) Natural lawn (02:37h p.m.)

Ground measurements of spectral reflectances were done with an IRIS Mark IV (GER, USA) spectroradiometer operated with nadir view. Fig. 2 shows the instrument at test site 1 (new, unused concrete). The simultaneous operation of two detectors inside the intrument, one measuring a reflectance standard, one measuring the sample (target), avoids the need of absolute radiance calibration: the absolute reflectances are obtained just by comparison of the two detector signals. During the field measurements a $BaSO_4$ reflectance standard was used for the IRIS measurements. Its reflectance was compared in the laboratory with a more stable spectralon panel before the measurements. The IRIS Mark IV covers a spectral range from 300 to 3000nm, which is divided into three subranges corresponding to three diffraction mirror gratings installed. Spectral resolution is 2, 4 and 6nm for the three subranges. In total the spectrum is recorded in 862 channels with $3 \cdot 10^6$ dynamic range. One reference and one target spectrum is recorded within 30s simultaneously.

Different sources of errors must be accounted for, if the total error of the absolute reflectance measurement is to be estimated. If a systematic error of 2.5% in each IRIS channel is assumed (value from DLR) and an uncertainty of the reflectances of the spectralon standard of 5% in the ranges 250-360nm and 740-2500nm and 0.5% for 360-740nm (values from LABSPHERE (USA)) is taken into account the resulting systematic error amounts to 5.6%, 2.6% and 8.4% in the ranges 250-360nm, 360-740nm abd 740-2500nm respectively. In addition, sun movement during the measurement series causes reflectances variations due to the bidirectional reflectance properties. While the sun elevation varies from 55° at the beginning (10:45h a.m.) to 61° (maximum) and to 51° at the end of the ground measurements, the azimuth angle varies from 138° to 241° during this time. (For spectral Bidirectional Reflectance Distribution Functions (BRDF) of artificial surfaces see Meister (1996)). The statistical error is heavily wavelength dependent: If 5 IRIS reflectance measurements are done without changing the arrangement, statistical analysis results in errors of the relative reflectances of 1% in the visible and up to 10% in the range up to 2500nm.

3.0 ANALYSIS AND RESULTS

The Daedalus based reflectances ρ_D are calculated in two steps. From the grey levels, the gain factor and a calibration in the laboratory with a Daedalus testbench, the Daedalus spectral radiances $L_R(\phi)$ are calculated for each pixel (with scan angle ϕ) and each channel. From the atmospheric and detection conditions, such as sun elevation, aerosol extinction coefficient, direction of flight, and from the scanner characteristics (spectral response function in each channel) radiances $L_S(\phi, \rho_D)$ as a function of ground reflectances ρ_D and scan angles ϕ are simulated with the SENSAT-4 algorithm (Richter (1994), Hepp (1994)) as if measured by the Daedalus scanner. SENSAT-4 is based on the LOWTRAN-7 atmospheric radiadive transfer code. The 'McClatchey Midlatitude Summer Standard Atmosphäre' (McClatchey, 1972) was chosen as the model of the atmospheric stratification. Also the adjacency effect, i.e. the mixing of light from adjacent pixels into a particular pixel, is corrected for. By comparing $L_R(\phi)$ and $L_S(\phi, \rho_D)$, while ϕ is known, ρ_D is determined using the look-up-table method and linear interpolation.

IRIS based spectral reflectances ρ_I are calculated by comparison of the grey levels resulting from simultaneous measurement of a $BaSO_4$ reference and of the target.

Two kinds of averaging where done to obtain comparable ρ_D and ρ_I values. a) In the homogeneous areas of the aerial images, where the ground measurements had been performed (see Fig. 1), spatial averaging of

ρ_D was done to decrease the statistical error before comparison with ρ_I. In each case, at least 20 adjacent image pixels were averaged surrounding the spots of the ground measurements. In each case, the standard deviation does not exceed 0.5% of relative reflectance. Spatial avaraging was also done for IRIS measurements where more than one ground measurement had been performed at one location (sometimes laterally displaced by a few 10cm). b) Since the IRIS spectral resolution of 4.3nm, defined here as the full-width-of-half-maximum of the He-Ne-Laser line at 632.5nm, is lower than the Daedalus spectral resolution (channel widths of 20 to 140nm in the solar spectrum up to 2.5μm), spectral averaging of the IRIS measurements is done before the comparison.

Fig. 3 shows ρ_D and ρ_I for the six targets of ground measurements. It can be seen that the Daedalus based spectra in the shortwave range ($\lambda \leq 1.5\mu$m) for five targets show too low reflectance values (deviations up to 35%), while in the longwave part ρ_D tends to be too high (up to 25%) compared to the IRIS ρ_I spectra. Since this is the case for nearly all targets (except for number 3), a systematic error is indicated. Regression of ρ_D against ρ_I results in nearly linear relationships with offsets very close to 0 (see Kollewe (1996)). Thus, by calculating an offset and a correction factor for each channel, an adjustment of ρ_D and ρ_I can be reached. However, due to two reasons only three ground target measurements are suitable for correction: Firstly, the Daedalus scanner has scan angles up to 43°, while the IRIS detectors are arranged to measure perpendicular to the surface (nadir). Secondly, in general IRIS and Daedalus measurements were not taken at exactly the same time, thus, the sun position is different for both measurements of one target. This means that both the direction of observation and illumination is different for determination of ρ_D and ρ_I, respectively. The roughness of targets 1 (unused conrete), 2 (asphalt) and 5 (asphalt) is comparatively small compared to the other targets, leading to spectral Bidirectional Reflectance Distribution Functions (BRDF) which are closer to the Lambert (isotropic) reflector and thus less sensitive to changing directions of illumination and observation. Measurements and simulations of spectral BRDF of artificial surfaces indicate, that roofing felt covered with coarse sand (roughness comparable to sand on tennis court), has a BRDF which is significant more sensitive to changing angles than concrete (Meister, 1996). For that reason these surfaces were selected to determine the offset and factor for correction of ρ_D. Tab. 1 lists the correction values, which were determined by linear regression of ρ_D versus ρ_I for targets 1,2 and 5 in each channel.

Tab. 1: Values for linear correction of ρ_D.

Channel	1	2	3	4	5	6	7	8	9	10
Offset	0.02	0.00	0.00	0.00	0.00	0.00	-0.01	0.00	-0.02	-0.02
Factor	1.09	0.95	0.90	0.93	0.88	0.83	0.79	0.74	1.18	1.07

In Fig. 4 the linear encorrected ρ_D values are compared to the ρ_I spectra. The agreement for the surfaces 1,2 and 3 is very good in each channel. As assumed before, the remaining deviations for surfaces 3,4 and 6 are with high probability due to angle dependences of the corresponding spectral BRDF, since these surfaces have a pronounced macroscopic roughness.

4.0 DISCUSSION AND CONCLUSION

We have retrieved spectral reflectances with airborne techniques and an inverted radiative transfer model at one hand and with ground spectral reflectance measurements at the other hand. The resulting reflectance spectra show significant deviations, which underlines the importance of adequate calibration capabilities. As the second source of errors the influence of angle dependent BRDF must be accounted for (Meister, 1996).

When observing deviations between ground and aerial determined spectral reflectances, one has to discuss, which ones are less susceptible to systematic errors. The following reasons lead to the conclusion, that the ground measurements are less biassed.

- The algorithm for calculating reflectances from grey levels of Daedalus signals has more single steps than the procedure for obtaining IRIS spectra, each of which presents an error source.
- The error resulting from the use of a radiative transfer model cannot be determined in an analytical way.
- Daedalus reflectance measurements from former years (1991, 1992) but the same locations show better agreements with 1994 ground measurements than with 1994 Daedalus airborne measurements (Kollewe, 1996).
- Retrieval of reflectances from scanner grey levels is a multistep procedure, wheras ground measurements of spectral reflectances are more direct; the reflectance standard is measured simultaneously with the target.

The linear regression of the Daedalus-IRIS reflectances with nearly vanishing offsets (see Tab.1) shows, that the simulation of the path radiance is correctly implemented in the SENSAT-4 code.

We conclude, that ground reference measurements are necessary to obtain spectral reflectances with 10% uncertainty or less from airborne scanners (Daedalus AADS 1268 - technology). In this case, homogeneous artificial surfaces should be chosen, with BRDF as close to that of a Lambert reflector as possible. However, the measurement of ground references can not be realized in each case (especially in the context of the Open-Skies Treaty, where data over foreign terrain are taken). So, more efforts have to be undertaken to improve the calibration procedures of airborne instruments. In addition, the magnitude of the influence of spectral BRDF has to be investigated in more detail and compared with the effect of calibration uncertainties.

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REFERENCES

Daedalus Enterprises, Inc.: *Technical Proposal DS-1269/DS-1861 Packages*, Michigan, USA, 1990.

P. Hausknecht,*Reflektionsspektroskopische Laboruntersuchungen an Mineralien und Gesteinen*, Diploma Thesis, DLR, Ludwig-Maximilians-University of Munich, FRG, 1994.

T. Hepp, *Erzeugung multispektraler Reflektanzbilder zur automatisierten Bildauswertung*, Diploma Thesis, CENSIS Report 10-94, University of Hamburg, FRG, 1994.

T. Kollewe, *Vergleich multispektraler Flugzeugscanneraufnahmen mit Reflektanzmessungen am Boden*, Diploma Thesis, CENSIS Report 17-96, University of Hamburg, FRG, 1996.

R.A. McClatchey, W. Fenn, J.E.A. Selby, F.E. Volz, J.S. Garing, *Optical Properties of the Atmosphere*, AFCRL Envirn. Res. Papers, **411**, 108pp, 1972.

G. Meister, *Messung der spektralen Reflektionsfunktion (BRDF) ausgewählter Oberflächen bei natürlicher Beleuchtung*, Diploma Thesis, CENSIS Report 18-96, University of Hamburg, FRG, 1996.

D. Oertel, ”The first stage of the digital airborne imaging spectrometer DAIS-7915 laboratory calibration at DRL Oberpfaffenhofen” in *Proceedings of the First International Airborne Remote Sensing Conference and Exhibition*, Strasbourg, Fance,p. II-214 - 224, 12.-15. September 1994.

R. Richter, *Model SENSAT-5, Sensor-Atmosphere-Target*, DLR - IB 552-01/94, DLR-Institut for Optoelektronics, Weßling/Munich, FRG, 1994

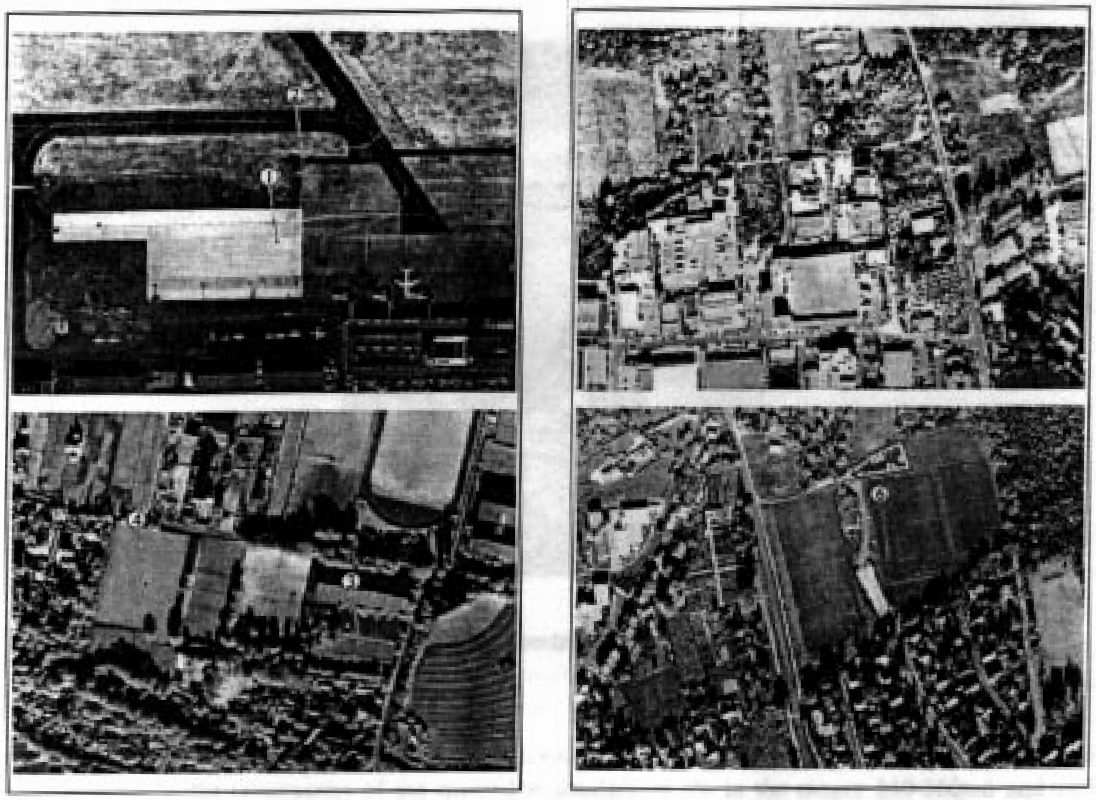

Fig. 1: Locations of the six ground spectral reflectance reference measurements.

Fig. 2: The IRIS spectroradiometer (DRL)

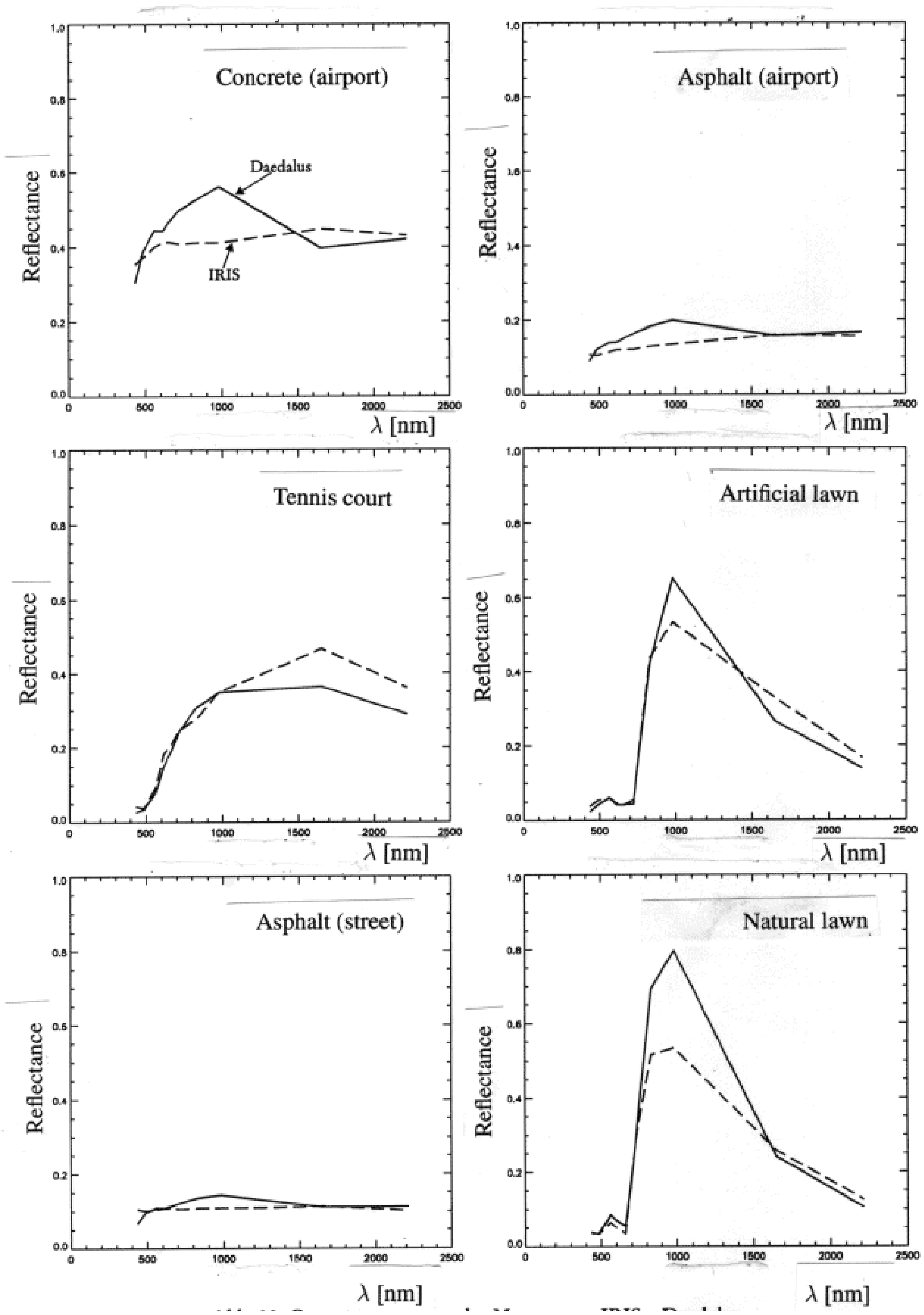

Fig. 3: Comparison of Daedalus based (solid line) and IRIS based (dashed line) spectral reflectances for six target areas.

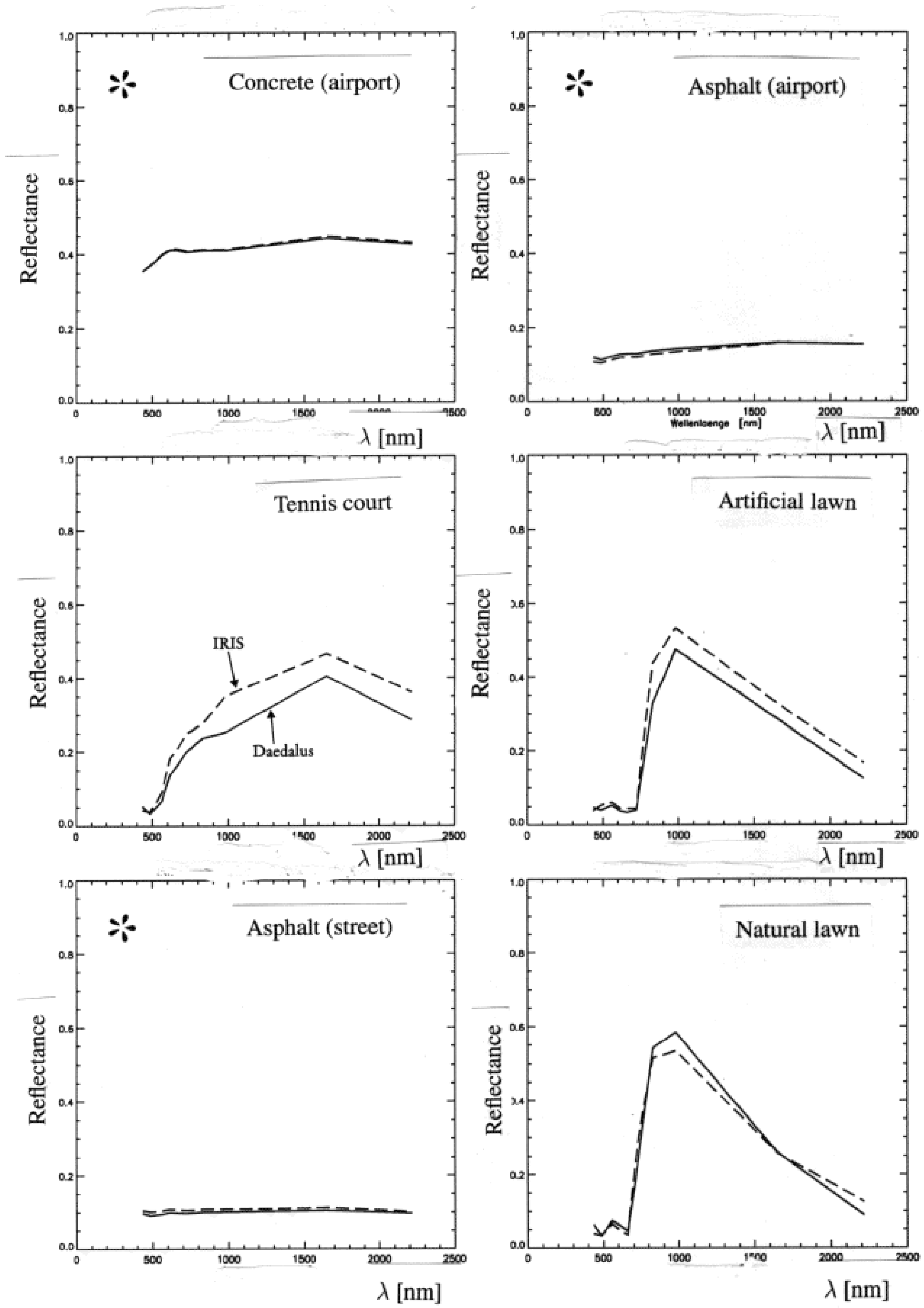

Fig. 4: Comparison of corrected Daedalus and initial IRIS based spectral reflectances from 1994. Adjustment factors derived from targets 1,2 and 5 were also used to correct the ρ_D spectra of targets 3,4 amd 6.