Large Scale Multispectral BRDF of an Urban Area

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ABSTRACT

This paper presents BRDF data of an urban area, assuming a pixel size of about 750 m × 750 m. It is derived from multispectral scanner data acquired over Nuremberg, Germany, with a small spatial resolution (pixelsize 2.1 m × 2.1 m) by averaging over several 1000 lines of scanned data. The data show a clear decrease of reflectance across nadir as distance from the retrosolar direction increases. This behaviour is created by the 3-D surface structure of an urban scene and the associated shadow casting.

INTRODUCTION

The 'Bidirectional Reflectance Distribution Function' BRDF was defined by [1] to describe the bidirectional reflectance of diffusely scattering, homogenous surfaces. Very often in remote sensing applications the surfaces are not homogenous. This is especially true for urban areas, that consist of a heterogenous mixture of houses, streets and vegetation. Furthermore the color of these components varies considerably. Measuring the BRDF of small homogenous urban surfaces is possible and has been done previously [2], [3]. But the heterogenity seems to make the definition of a universal BRDF for a pixelsize of 1 km of an urban area unrealistic. Although in principle it is possible to average over a very large area, the results can hardly be expected to be universal because an urban area will be heterogenous even on the large scale. E.g. usually the amount of vegetation present drops the closer you get to the urban center. Furthermore, structures like 'airports' or 'train stations' have dimensions in the kilometer range, and their BRDF is expected to be different from e.g. residential areas. However, large scale satellite data (e.g. from the MODIS sensor) needs to be corrected for BRDF effects [4]. In a first stage of the MODIS data processing, a 'Beta-BRDF' will be assumed for every pixel that doesn't allow a meaningful BRDF inversion. It will consecutively be replaced by a BRDF based on measurements. This paper presents data for such a 'Beta-BRDF' for urban areas.

DESCRIPTION OF THE DATASET

The data used was taken with an airborne line scanner, the DAEDALUS AADS 1268, at a flight height of 900 m, yielding a nadir pixel size of 2.1 m × 2.1 m. 10 spectral channels cover a wavelength range from 0.43 μm to 2.16 μm. The measured radiances were converted to reflectances R (after an atmospheric correction) by using ground reflectance measurements as reference [5]. The maximum scan angle is $42.9°$ with 716 pixels per scan line. The images were acquired in August 1997 over Nuremberg, Germany, see Fig. 1 for a sample. The investigated scene consists of residential, industrial and vegetated areas. Buildings usually have less than 5 stories, the vegetated areas are dominated by deciduous trees, but there is also a significant fraction of grass. The sun zenith angle is $40.1°$, the relative azimuth angle in backscatter direction is $25.6°$, in forward scattering direction $154.4°$. Care was taken to eliminate sensor characteristic angular effects [6].

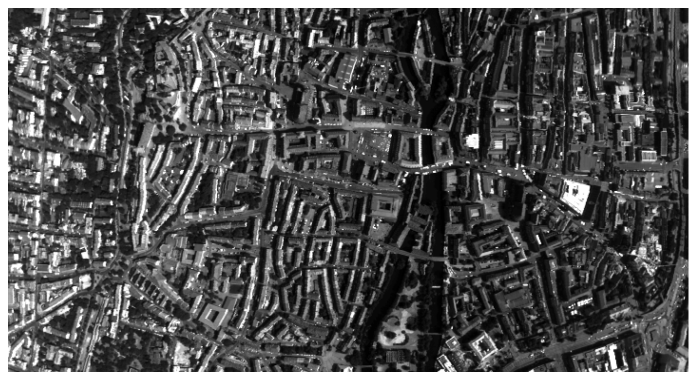

Fig. 1: Sample of the image data (about 10% of the subset 'densely populated area') at a wavelength of 0.66 μm, histogram equalized. Flight direction is from top to bottom, scanning direction from left to right. The sun illuminates the scene from the right. The area in backscatter direction (left) is brighter than the area in forward scatter direction (right).

METHODOLOGY

Two subsets from the available images were chosen. The first subset contains a densely populated urban area with a low fraction of vegetation, the second subset consists of a suburban area with a high fraction of vegetation. We projected the 716 pixels per line to a view zenith angle grid from $-40°$ to $+40°$ with an interval of $5°$, yielding 17 different view zenith angles. For each view angle, we averaged each subset over its scan lines (about 3000), yielding a 'rectangular pixel' of $(\frac{716}{17} \cdot 3000 \cdot 2.1\text{m}) \times 2.1\text{m}$. This size seems to be adequate to average over the heterogenity of this specific scene, the resulting BRDFs are quite smooth (Fig. 3). The basic assumption of our method is that the reflectance of a rectangular pixel is

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equivalent to the reflectance of a square pixel of the same area (in this case 750 m$\times 750$m, a common size for a satellite pixel), as long as the viewing angle is the same.

We also tried to use scanner data from a flight height of 300 m (the area available for averaging was about 10 times smaller for our 300 m data than for the 900 m data), but the resulting BRDF was not smooth, showing peaks and valleys due to the large heterogenity of the scene on this scale.

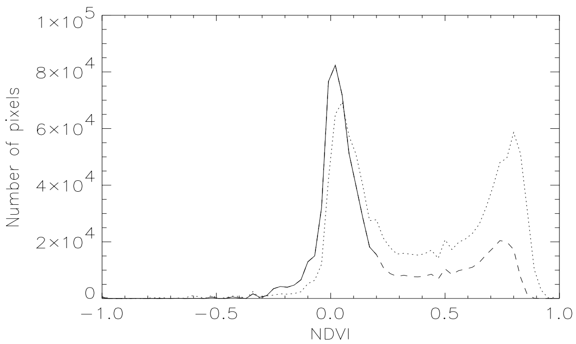

Fig. 2: NDVI histogram of the first subset (densely populated area) excluding vegetation (solid line), including vegetation (solid + dashed line) and of the second subset (suburban area, dotted line).

Fig. 2 shows the histograms of the NDVI of the subsets. NDVI is calculated as $(R_{(\lambda=0.83\mu m)} - R_{(\lambda=0.66\mu m)})/(R_{(\lambda=0.83\mu m)} + R_{(\lambda=0.66\mu m)})$. Two peaks can be recognized for each subset, one centered around 0.05 (resp. 0.1) corresponding to not vegetated areas, the other one has its maximum at about 0.8 corresponding to vegetation. This figure shows that our scene contains a considerable amount of vegetation. We chose to classify pixels with an NDVI greater than 0.2 as vegetation. Assuming this threshold, 35 % of the pixels in the densely populated area are vegetation and 60 % in the suburban area.

As for some applications it may be desirable to use the BRDF without the vegetation pixels, we also determined the BRDF based only on the non-vegetation pixels. E.g. it may be favorable to compute the NDVI of the satellite pixel and determine its BRDF by making a linear interpolation between the BRDFs presented in this study (the averaged NDVI of the densely populated area including vegetation is 0.22, excluding vegetation it is 0.03, and 0.40 for the suburban area).

RESULTS

The resulting BRF values (BRF = $\pi\cdot$BRDF) are plotted for the 10 spectral channels in Fig. 3. The BRDF of the densely populated area excluding vegetation is plotted as a solid line, including vegetation as a dashed line. The dotted line shows the BRDF including vegetation for the suburban area. Each plot shows a strong rise in the backscatter direction ('hotspot'). This can be explained by the declining amount of shadow present the closer the viewing direction gets to the illumination direction. For visible wavelengths, the absolute shape of all curves is very similar, increasing the amount of vegetation results in a negative offset, caused by the low reflectance of vegetation. In NIR, the absolute intensity of the hotspot increases when the amount of vegetation increases.

The relative rise of the BRDFs including vegetation is always stronger than for the BRDF of areas without vegetation (about 20 % on average). This can be seen from the plot of the ratio of the maximum to the minimum BRDF value in Fig. 3 called Anisotropy Index (ANIX) by [7]. The largest relative rise occurs at a wavelength of 0.83 μm. In previous studies ([8], [7]) the relative intensity of the hotspot of grass was found to be highest for visible wavelengths, for NIR the hotspot intensity decreases due to multiple scattering. This disagreement might be due to the fact that the hotspot caused by the urban vegetation is produced by large scale shadowing effects (e.g. trees casting shadows). In this case, multiple scattering will not be strong. The ANIX at $1.68\mu m$ is higher than at $2.16\mu m$ for all 3 curves. This behaviour is not correlated to the mean spectrum (solid line rises, dashed line constant, dotted line falls from $1.68\mu m$ to $2.16\mu m$). We believe that for a detailed explanation of the spectral BRDF behaviour the spectral contrasts of the image pixels need to be investigated.

The ANIX plot also demonstrates the intensity of the BRDF effect: for the densely populated area excluding vegetation (solid line), the ANIX is about 1.7, i.e. the radiance measured at a relative azimuth of $25.6°$ is 70 % higher than at a relative azimuth of $154.4°$ for view zenith angles of $40°$. For the subsets including vegetation, the ANIX has a value of about 2.0. We expect these values to rise even more if the measurements are done at relative azimuths of $0°$ resp. $180°$.

Fits (not shown) with a kernel model containing formulations for volume and geometric-optical scattering [4] show that the geometric-optical-kernel very clearly provides the dominant features of all of the BRDFs observed, also indicating the predominance of surface scattering from scattered vegetation over volumetric scattering even in a suburban scene.

In summary, we have outlined a method for deriving the BRDF of large scale urban areas from airborne multispectral scanner data. The resulting BRDF at pixel scales of e.g. 750 m x 750 m can be used for BRDF corrections of future Earth imaging multispectral satellite data.

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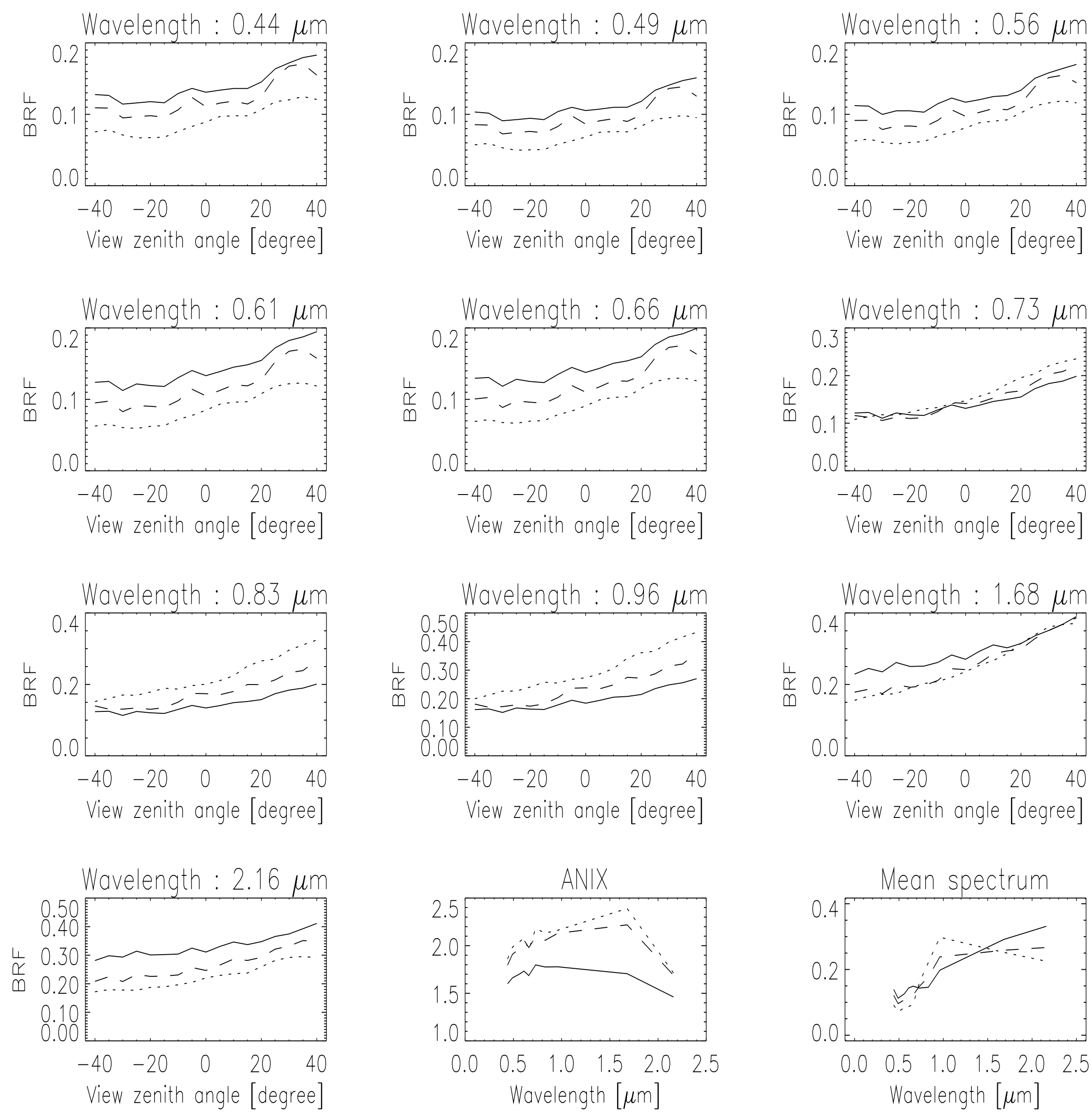

Fig. 3: Measured BRF values, ANIX and mean spectrum. The solid line is derived from the subset 'densely populated area' excluding vegetation, the dashed line including vegetation. The dotted line is derived from the subset 'suburban area'. Positive view zenith angles correspond to a relative azimuth of 25.6° (backscattering), negative view zenith angles to forward scattering (154.4°). Sun zenith angle is 40.1° from nadir. The first 10 plots show BRF's ($BRF = \pi \cdot BRDF$) for the respective wavelength given in the plot heading. ANIX is defined as maximum BRDF value divided by minimum BRDF value. 'Mean spectrum' is the average over all pixels.