BRDFS ACQUIRED BY DIRECTIONAL RADIATIVE MEASUREMENTS DURING EAGLE AND AGRISAR

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ABSTRACT

Radiation is the driving force for all processes and interactions between earth surface and atmosphere. The amount of measured radiation reflected by vegetation depends on its structure, the viewing angle and the solar angle. This angular dependence is usually expressed in the Bi-directional Reflectance Distribution Function (BRDF). This BRDF is not only different for different types of vegetation, but also different for different stages of the growth. The BRDF therefore has to be measured at ground level before any satellite imagery can be used the calculate surface-atmosphere interaction. The objective of this research is to acquire the BRDFs for agricultural crop types.

A goniometric system is used to acquire the BRDFs. This is a mechanical device capable of a complete hemispherical rotation. The radiative directional measurements are performed with different sensors that can be attached to this system. The BRDFs are calculated from the measured radiation.

In the periods 10 June - 18 June 2006 and 2 July - 10 July 2006 directional radiative measurements were performed at three sites: Speulderbos site, in the Netherlands, the Cabauw site, in the Netherlands, and an agricultural test site in Goermin, Germany. The measurements were performed over eight different crops: forest, grass, pine tree, corn, wheat, sugar beat and barley. The sensors covered the spectrum from the optical to the thermal domain. The measured radiance is used to calculate the BRDFs or directional thermal signature.

This contribution describes the measurements and calculation of the BRDFs of forest, grassland, young corn, mature corn, wheat, sugar beat and barley during the EAGLE2006 and AGRISAR 2006 fieldcampaigns. Optical BRDF have been acquired for all crops except barley. Thermal angular signatures are acquired for all the crops.

INTRODUCTION

The potential of operational calculation of the fluxes of energy, water and carbon dioxide is very high. The calculation of these fluxes is currently performed only during overpass of the satellites. In an operational scheme the time between overpasses will be modelled with a combination of micrometeorological models and radiative transfer models. In order to perform operational calculations the models should both be fast and accurate.

The land surface fluxes as well as the underlying processes cannot be directly measured from space, but can only be calculated using micrometeorological models, [1]. In the effort to obtain fluxes of energy, water and carbon dioxide radiative transfer models are of vital importance. The parameters that drive the micrometeorological models are obtained by inversely using radiative transfer models [2].

These radiative transfer models have grown from the simple optical models to more advanced models which incorporated the whole spectrum and enable multiple view-angles. The Suits model [3] was one of the first models to calculate bidirectional spectral reflectances. The extension of the Suits model to incorporate also more realistic leaf orientations resulted into the SAIL model [4]. This model has recently been extended to also include the thermal part of the spectrum [5]. Where the SAIL model still only incorporates 1 dimension, the DART model incorporates all three dimensions to simulate the radiative transfer [6].

To find the best model for the incorporation into an operational scheme, the two models should be compared with each other and with real data. A comparison of the two models with real data is troublesome due to lack of an appropriate dataset. Therefore optical and thermal measurements over different types (homogeneous and heterogeneous) of vegetation should be performed. The objective of this research is to measure optical BRDFs and thermal directional signatures.

METHODOLOGY

Setup

For the directional measurements two different setups were used: a goniometric setup and a tower setup. The best method for acquiring optical BRDFs and thermal directional signatures is to use a goniometric setup. However for high vegetation (forest), such a setup would be too large to operate and a tower setup has to be used. Both setups are explained in detail in the following paragraphs. A single measurement consists of 2 transects of each 11 angular positions each, the nadir angular position is recorded twice; therefore the total number of angular positions per measurement is 21.

Goniometric Setup

Goniometers are used extensively to perform multi directional measurements, as is illustrated by [7] and [8]. The goniometer, Fig.1 is a mechanical system consisting of two parts: a train that can move over a circular track and a system of arms that pivot over a central axis. The sensors are attached at the end of these arms. Together they enable complete hemispherical measurements of the same target area.

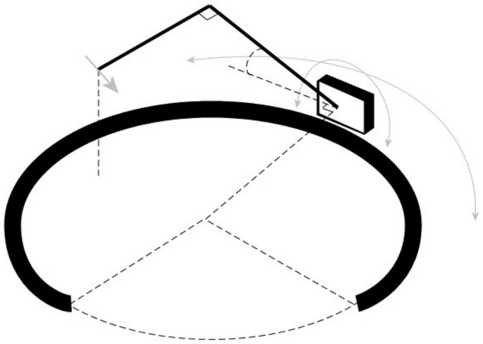

Figure 1: Schematic of Goniometric setup

Tower Setup

Goniometric measurements at forest height are impossible. The directional measurements of forest are therefore performed by pointing the sensor from the tower towards the forest. The sensor is attached to a frame with angular marks to control viewing angle.

Sensors

The directional measurements were performed using various sensors, spanning from the visible to the thermal part of the spectrum. These instruments are explained briefly in the paragraphs below.

VNIR measurements

The measurements in the wavelength range from 400 nm – 2500 nm were performed with an ASD Fieldspec Pro spectrometer [9] and a GER spectrometer [10]. BRDFs are calculated as the ratio of the target radiance for different angles with radiance reflected by a white (Lambertian) reflectance panel. Multiple spectral acquisitions were taken per angular position. By investigation of these acquisitions the most stable spectrum was selected. This acquisition was used for calculation of the BRDF.

The normalized reflectance ratio of the difference between the R_θ and R_{nadir} is used to illustrate the effects of the angular dependence more clearly, see (1).

$$Ratio = \frac{R_\theta - R_{nadir}}{R_\theta + R_{nadir}} \tag{1}$$

The maximum standard deviation of this ratio per view angle is calculated to have a single parameter describing the directionality of the vegetation. This standard deviation is calculated for three different parts of the spectrum: VIS (400 nm - 800 nm), NIR (800 nm - 1000 nm), MWIR (1500 nm - 1700 nm).

Thermal measurements

The measurements in the wavelength range from 8 µm – 12 µm were performed with an Irisys 1010 thermal imager [12] and an Everest 3000 radiometer [12]. Thermal BRDFs cannot be unique per time step, as in the thermal region the components of target are radiating themselves. The different components of the target (soil, leaves, sunlit shaded) will have different temperatures in the day, resulting in different thermal BRDFs.

Instead of a thermal BRDF only a thermal directional signature is created for every multiple times per day. The thermal directional signature is calculated by (2).

$$Signature = \max\left(\frac{\tilde{\dddot{T}}}{\overline{\dddot{T}}}\right) \quad \text{, with } \tilde{\dddot{T}} = std(\dddot{T}) \text{ and } \overline{\dddot{T}} = mean\left(\dddot{T}\right). \tag{2}$$

The definition of $\dddot{T}$ differs for measurements with an imager and measurements with a radiometer. For the Everest acquisitions $\dddot{T}$ is defined as the measured temperature. For imager measurements $\dddot{T}$ is defined as the average temperature of per single image, $\dddot{T} = mean\left(T_{ij}\right)$, and $\hat{T}$ as the standard deviation per single image, $\hat{T} = std\left(T_{ij}\right)$.

The extra information a thermal imager acquires can be used to separate the component temperatures. Before these temperatures can be extracted from the image an investigation has to be done in the potential of this retrieval.

A separation potential can be defined, using average temperature per single image and the standard deviation per single image. This potential is an indication of the temperature variation within a single image. If the temperature variation per pixel in the image is large there exist a potential to retrieve the individual temperatures of the different components (sunlit/shaded, leaf/soil). The component temperature separation parameter is calculated with (3).

$$\text{parameter} = \max\left(\frac{\hat{T}}{\overline{\dddot{T}}}\right) \tag{3}$$

STUDY AREA

The measurements are performed in three field sites, the Speulderbos forest site [12], the Cabauw agricultural site [13], and the agricultural site in Görmin. The coordinates of the test sites are given in Table 1. All the measurements were performed using the goniometric setup except for the forest measurements. The directional measurements over forest were taken from a 45m tower situated at the Speulderbos forest site. This tower is maintained by the RIVM. All of the vegetation had fully developed canopies except for the young corn. The young corn had a very low canopy density.

Table 1: Test sites

Campaign	Site	Vegetation	Height(m)	Coordinates
EAGLE	Speulderbos	Forest	35.00	52°15'08.1" N, 05°41'25.80" E
		pine tree	0.60	
	Cabauw	Tall grass	0.40	51°58'00.0" N, 04°54'00.00" E
		young corn	0.15	
AGRISAR	Görmin	Mature corn	0.30	53°59'41.7" N, 13°16'36.95" E
		Wheat	1.20	
		Sugar beat	0.30	
		Barley	1.20	

RESULTS

The measurements with the hyperspectral spectrometers were performed successfully over forest, tall grass, young and mature corn, wheat and sugar beat. The hyperspectral measurements over barley were not performed. All the measurements have been converted to BRDFs successfully. The BRDF of forest is shown Fig. 2A.

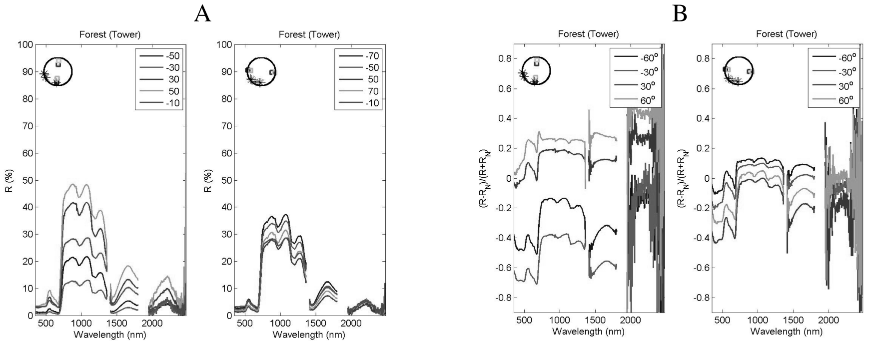

Figure 2: VNIR radiative directional measurement (one transect only) of forest. In figure A, the splice corrected reflections per angle are given. In figure B the corresponding normalized reflections ratio is shown.

All BRDFs were converted to normalized reflection ratios to investigate the directionality of the vegetation. The normalized reflection ratio of forest is shown in Fig.2B. The maximum standard deviation of the normalized reflection ratio is given in Table 2.

Table 2: Maximum standard deviation of this ratio per view angle.

Vegetation	max(STD) VIS	max(STD) NIR	max(STD) MWIR
Forest	9.18	10.79	14.53
Pine tree	9.17	09.22	09.54
Grass (tall)	20.98	09.76	16.56
Young Corn	13.63	12.29	11.58
Mature Corn	15.39	18.38	08.00
Wheat	25.59	7.54	17.28
Sugar beat	24.12	11.87	16.73

The measurements with the thermal instruments were carried out successfully over tall grass, young corn (Fig.3), wheat, sugar beat and barley. No thermal radiative measurements were performed over forest. The combination of a changing target area per view angle and the changing thermal signature per time would not produce repeatable results. No thermal radiative measurements with the Everest radiometer could be performed over mature corn, due to failure of the Everest Radiometer. The thermal directional signatures and the separation parameters of all the vegetation are given in Table 3.

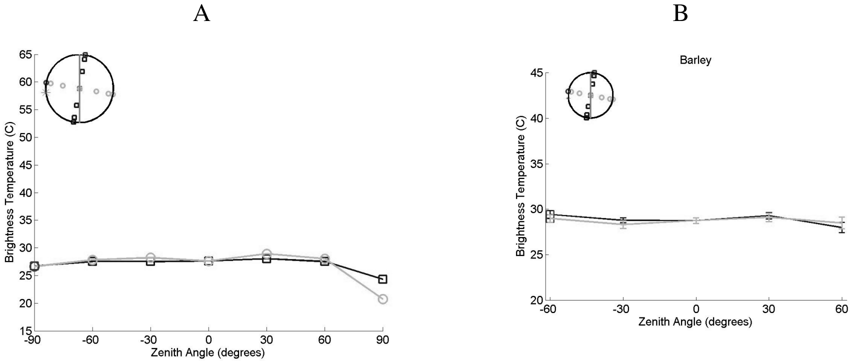

Figure 3: TIR radiative directional measurement (one transect only) for barley at 17:59 Local time, 06-07-2006. In figure A the Everest measurement is shown. In figure B the Irisys mean image temperature is shown; the error bars depict the standard deviation to the mean image temperature.

Table 3: Thermal directional signatures and component temperature separation parameter.

	Directional signatures		Separation parameter
Vegetation	Everest	Irisys	Irisys
Grass (tall)	97.0	48.7	04.17
Young Corn	179.0	69.6	09.30
Mature Corn	-	67.9	12.47
Wheat	116.6	56.4	02.29
Sugar beat	66.0	46.69	07.15
Barley	20.5	20.7	01.59

DISCUSSION AND CONCLUSIONS

Inspection of the maximum standard deviation of reflection ratio shows that tall grass and wheat display the largest directional behaviour in the VIS region, young and mature corn in the NIR region, and wheat and sugar beat in MWIR. The overall directionality in the VNIR part of the forest seems low. This is caused by the smoothing effect of the large FOV under low viewing angles.

Comparison between the directional signatures of the Everest measurements and the Irisys measurement show similar behaviour. With both instruments young corn and sugar beat show the largest directional behaviour. Also mature corn has a directional behaviour equal to the young corn in the measurements with the Irisys. The directionality of young corn is created because at low viewing angles the canopy of the corn is very dense, while at nadir the canopy of the corn is very thin.

Inspection of the Irisys separation parameter shows us similar results to the directional signatures of the Everest and the Irisys. The standard deviation of the temperatures per image is highest at sugar beat, young corn and mature corn. The directionality of these vegetations can therefore be used to separate the temperature of the different canopy components.

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