

A Measurement Concept for Hot-Spot BRDFs from Space

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Abstract Several concepts for canopy hot-spot measurements from space have been investigated. The most promising involves active illumination and bistatic detection that would allow hot-spot angular distribution (BRDF) measurements from space in a search-light mode. The concept includes a pointable illumination source, such as a laser operating at an atmospheric window wavelength, coupled with a number of high spatial-resolution detectors that are clustered around the illumination source in space, receiving photons nearly coaxial with the retro-reflection direction. Microwave control and command among the satellite cluster would allow orienting the direction of the laser beam as well as the focusing detectors simultaneously so that the coupled system can function like a search light with almost unlimited pointing capabilities. The concept is called the Hot-Spot Search-Light (HSSL) satellite. A nominal satellite altitude of 600 km will allow hot-spot BRDF measurements out to about 18 degrees phase angle. The distributed are taking radiometric measurements of the intensity wings of the hot-spot angular distribution without the need for complex imaging detectors. The system can be operated at night for increased signal-to-noise ratio. This way the hot-spot angular signatures can be quantified and parameterized in sufficient detail to extract the biophysical information content of plant architectures.

Key words Hot-Spot, Canopy BRDF, Plant architecture, Structural remote sensing signature, Satellite concept, Cluster

1 INTRODUCTION

All structured (three-dimensional) surfaces, such as a plant canopy, mountainous terrain, or a broken cloud scene, exhibit angular signature effects which may be described as a Bidirectional Reflectance Distribution Function (BRDF) in remote sensing. Vegetated surfaces are typical for such structured surfaces because plant architectures are three-dimensional in nature. An important component of every BRDF of a structured surface is its internal shadowing that depends on illumination and observation directions, and carries information on the internal structure (architecture) of the 3D surface. Within the last few years many theoretical and experimental analyses have been carried out establishing the value of BRDF data in identifying structural (architectural) characteristics of vegetation canopies^[1,2]. Measurements of BRDFs have been made in the laboratory with large goniometers, and from aircraft with imaging sensors, but not yet from satellites. Such measurements of angular signatures require observations from different view di-

rections. Airborne and satellite remote sensing systems that operate only at nadir, for example, are incapable of recording angular signatures. Some developmental instruments, such as ASAS and PARABOLA, and future EOS detectors, such as MISR, are capable of measuring angular signatures, or components of BRDFs.

2 THE CANOPY HOT-SPOT BRDF

A prominent component of every BRDF of a three-dimensional surface, such as a vegetation canopy, is the canopy hot-spot which is a directionally localized angular signature around the solar retro-reflection direction, and is an important special case of a BRDF. Fig. 1 shows two examples of hot-spot photographs taken from an airplane with standard panchromatic film in the visible. Additional such data are shown in [3]. Model calculations have demonstrated that leaf size and canopy height may be retrieved from the hot-spot angular distribution, in particular from its angular width, e.g. Qin *et al.* in Ref.^[1]. Fig. 2 shows the results from a simple ana-

lytical model^[3], where a cut through the calculated hot-spot BRDF is shown.

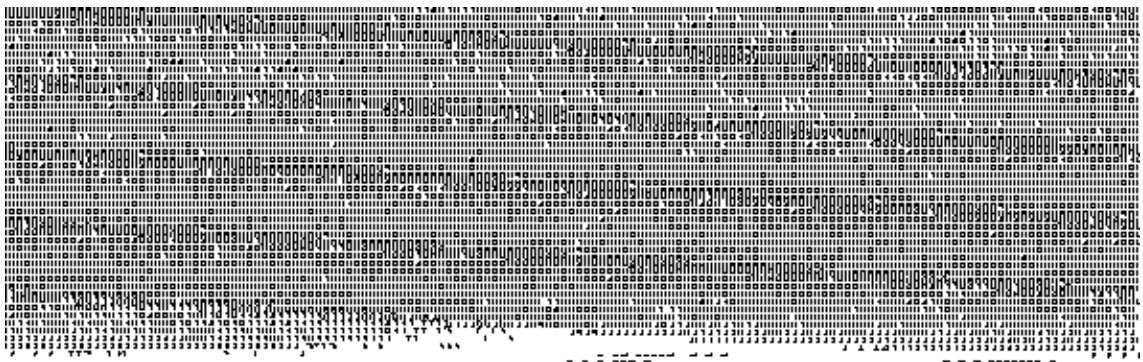


Fig. 1 Canopy hot-spot photographed from about 300 m altitude over coniferous forest (left) and grass land (right)

In Fig. 3 we reproduce an image of a more recent hot-spot data acquisition by an experimental NASA remote sensing instrument, the MODIS Airborne Simulator (MAS)^[4]. The image shows the

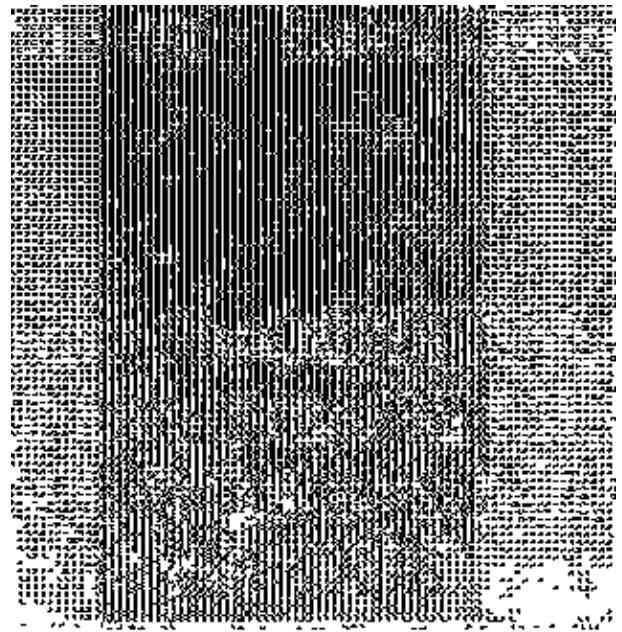


Fig. 3 Canopy Hot-Spot streak acquired by MODIS airborne simulator (MAS), see ref. 4

Analytic Model for HOT SPOT

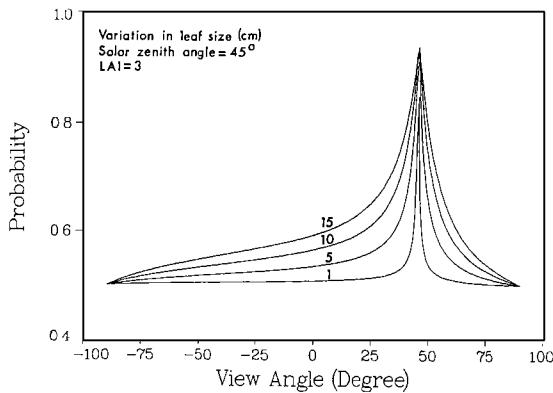


Fig. 2 Modelled HS-BRDF for circular leaves of diameters of 1, 5, 10, and 15 cm

area of the Great Dismal Swamp in Virginia near Norfolk which is primarily covered with deciduous trees and occasionally contains some open water surfaces. The flight-line of the airplane with the MAS detector is approximately along the vertical centerline of the image; to the right of the flight line and parallel to it the specular reflections from the open water surfaces

can be seen clearly, while symmetrical to it on the left half of the image, the canopy hot-spot streak can be

identified as a second vertical line. This bright retro-reflection streak is created when the instrument scans through the hot-spot direction and at the same time

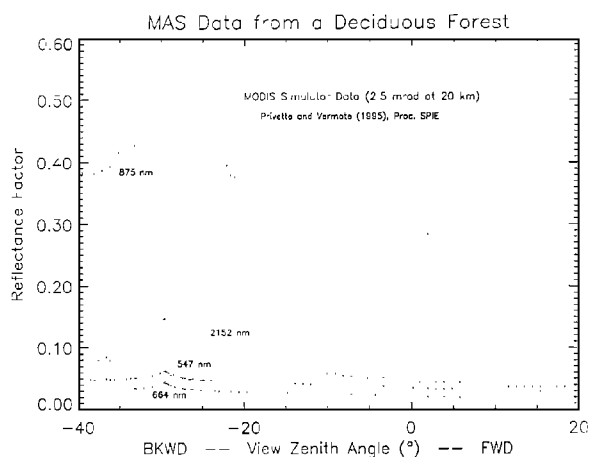


Fig. 4 MAS hot-spot BRDF data from 20 km over deciduous forest at 4 wavelengths in VIS and NIR

moves across the scene with the airplane, from the bottom to the top of the image. The actual MAS data, normalized as a reflectance factor, are shown for four wavelengths in Fig. 4 which exhibits the transect through the hot-spot BRDF very well^[5].

3 THE HOT-SPOT SEARCH-LIGHT (HSSL) SATELLITE CONCEPT

Taking hot-spot data from an aerial platform with an imaging detector is fairly simple as is demonstrated by the photographic images in Fig. 1 and the cross-track scanner data in Figs. 3 and 4, as long as the sensor direction can be controlled. Recently, large goniometers have been used at the Joint European Research Center in Ispra, Italy, and at the Changchun Institute of Optics and Fine Mechanics in China, to perform laboratory measurements of complete BRDF's of small patches of vegetation targets. In every case the almost unlimited pointing capabilities of these instruments and platforms have been exploited, which is not a given for today's space-based sensors. Two fundamentally possible conical scanning techniques that would allow hot spot

angular signature measurements have been described in [2] and [6]. In any case, however, the location of where the hot-spot will appear is always at the intersection of the sun/detector line with the earth surface as long as solar radiation is the only scene illumination. Replacing the solar illumination with an active and pointable illumination source allows us to present a new concept enabling space-borne measurements of hot-spot angular signatures/BRDFs.

Our new concept for canopy hot-spot BRDF measurements from space envisions active illumination and bistatic detection that would allow hot-spot angular distribution measurements from space in a search-light mode. The concept includes a pointable illumination source, such as a laser, coupled with a number of high spatial-resolution detectors that are clustered around the source receiving photons nearly coaxial with the retro-reflection direction, see Fig. 5. This measurement concept is an extension to the conical scan pattern described in [6] and will allow measurements of the intensity wings of the hot-spot angular distribution, especially its angular shape (circular or elongated) and width.

Several possible realizations of this distributed detector concept have been studied, including tethered receivers that rotate around the illumination source, cf. Gerstl in Ref. [1], which did not seem practically feasible. The most promising concept includes a single illumination source, i. e. a laser, together with a free-flying constellation of N detectors (N is 2 to 6) that are clustered around that source up to distances of approximately 10 to 200 km but fly on independent orbits very similar to that of the source, cf. Fig. 5. The laser emits a collimated beam whose direction can be pre-programmed, while the detectors are telescopes that collect photons reflected from the laser-illuminated surface area. The detectors are pointed at the same surface spot as the laser and the directions of illumination and detection are fully synchronized through a microwave command and control unit among the satellite cluster in space. The integrated system is expected to operate like a search-light, providing it with almost unlimited pointing capabilities. Typical configuration parameters of this Hot-Spot

Search-Light (HSSL) satellite system might be:

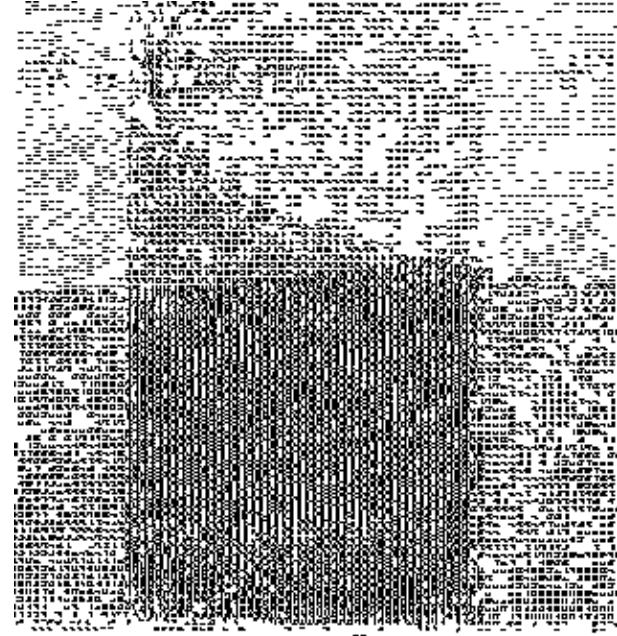


Fig. 5 The hot-spot search-light satellite concept. Free-fly-ing constellation of a laser source and a cluster of telescope detectors

HSSL Satellite Altitude:	600 km
Detector lateral distances from source laser:	10 to 200 km
Ground IFOV (Laser and Telescope footprints):	200 m
Angular range of measured Hot-Spot BRDF:	2 to 18 degrees

The illumination wavelength of the laser source has to be selected so as to minimize atmospheric interference, preferably within the atmospheric transmission windows in the near infrared, or the 8 to 14 micrometer IR region. Such selection will make night-time observations possible, which will increase the signal-to-noise ratio due to reduced or nearly eliminated solar background radiation. Operating the laser source in a pulsed mode will further increase the diagnostics capabilities of the HSSL satellite, e.g. to allow laser ranging and the determination of canopy height, and bring its power requirements into a range that has been demonstrated feasible in the laboratory^[7] and with recent NASA experiments using lasers

in space^[8]. Typical specifications for the laser source of the HSSL system that appear feasible are listed in Table 1.

Table 1 Typical specifications for HSSL satellite illumination source

Central pulsed solid-state laser in NIR or IR atmospheric window	
Illumination Type	= Nd:YAG Laser
Laser Energy	= 1.5 Joule
Wavelength	= 1.064 μ m
Beam Diameter	= 1 cm at waist
Divergence (IFOV)	= 3 to 5 times diffraction limit = 0.6 mrad
Pulse Length	= 17 ns
Lifetime	= 10^9 pulses
est. Total Mass	= 40 kg

The detector system of the HSSL satellite consisting of N identical receivers at lateral distances between 10 and 200 km from the central laser in space, must be able to focus on the instantaneous ground field-of-view ('foot print') that is illuminated by the laser source. This can be accomplished for each of the clustered detector satellites by a telescope with a photon detector at its focal point. It is not necessary that imaging detectors be employed because of their synchronized pointability. In addition, if an optical bandpass filter is employed that will only transmit the desired laser wavelength to the detector element in the telescope, its sensitivity can be greatly enhanced. Assuming a 600 km operational altitude for the HSSL detector cluster, it would require a telescope of 5 m focal length to achieve a 200 m diameter instantaneous field-of-view (IFOV) on the ground. This is possible with a Cassegrain design telescope that could weigh less than about 40 kg. Typical specifications for the clustered detectors of the HSSL system that appear feasible are listed in Table 2. Detailed engineering systems analyses and feasibility studies for all components of the HSSL satellite concept have yet to be

**Table 2 Typical specifications for
HSSL satellite detectors**

N identical detector satellites (N=2;6)	
Telescope with optical filter and photon detector (non-imaging)	
Receiver Type	= Cassegrain Tele.
Focal Length	= 5 m (f 6.5)
Aperture Diam.	= 70 cm
Angular pixel size	= 0.6 mrad
Ground IFOV	= 200 m at 600 km
Bandpass Filter	= 1 nm at 1.06 μ m
est. Total Mass	= 30 kg

4 CONCLUSIONS

BRDF measurements can provide information about vegetation surfaces, e. g. about their canopy architecture, which is not otherwise accessible by today's remote sensing methods. A new concept is presented that may allow BRDF measurements from a space-borne platform involving active laser illumination with bi-static observation, and would operate at night. Potentially most useful applications of the concept are to measure canopy hot-spot parameters from space. Hot-spot angular signatures are expected to be quantified and parameterized by the HSSL satellite in sufficient detail to extract the relevant information content on plant architectures and specific structural remote sensing signatures.

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Dr. Siegfried Gerstl is a long-term scientific staff member at the Los Alamos National Laboratory and a project leader for remote sensing science. Educated as a physicist, he holds a PH.D. from the University of Karlsruhe, Germany. He has published over 30 full-length scientific papers in refereed journals. His primary interests and expertise are in science and technology related to satellite remote sensing and analysis, with emphasis on modeling and data interpretation. Current fields of special interest are the theory and application of radiative transfer and radiosity methods, atmospheric corrections, angular and spectral signatures in active and passive remote sensing, and the development of new satellite and sensor concepts. Dr. Gerstl is an active scientific investigator in NASA's Earth Observing System (EOS) and a science team member of the Multi-angle Imaging Spectro-Radiometer (MISR) instrument to be launched with the first EOS-AM satellite platform in 1998.

从空间测量热点 BRDF 的构想

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摘要 我们已经研究了从空间测量冠层热点 BRDF 的几个构想, 其中最具前景的研究有主动光照和分置探测, 以上二法可以从空间用探照灯模式进行热点的角度分布测量。构想中包含了一个可定向的光照源, 如工作在大气窗波长的激光器, 和一些固定在光源周围的高空间分辨率的探测器, 用来接收几乎和原路反射方向同轴的光子。卫星微波控制和指令将允许激光定向和探测器聚焦, 使整个系统象一个具有近于无限定向能力的探照灯一样工作。我们称这种构想中的卫星为热点探照卫星 (HSSL)。卫星的标准高度为 600km, 这将可以测量热点 BRDF 达到 18 度的相位角。分布的探测器可测量热点角度分布的强度方面, 而无需复杂的成像探测器。为提高信噪比, 系统可在夜间工作。这样, 热点角度特征就能被量化和参数化得足够细, 也就可以提取植被结构和生物物理信息。

关键词 热点, 冠层 BRDF, 植物结构, 结构遥感特征, 卫星构想, 集群