# Assessment of Canopy Structure and Heterogeneity from Multi-angular CHRIS-PROBA Data

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**Abstract: The spaceborne ESA-mission CHRIS-PROBA (Compact High Resolution Imaging Spectrometer-Project for On-board Autonomy) provides hyperspectral and multi-angular data of selected terrestrial targets (Barnsley et al. 2004). For vegetated surfaces, the spectral information content of CHRIS data may yield the biochemical and biophysical properties of a vegetation canopy, while the directional component may deliever additional information on its canopy structure. Here, the multi-angular CHRIS observations are investigated and related to surface structure using the parametric Rahman-Pinty-Verstraete (RPV) model. RPV parameters, in particular the Minnaert function parameter *k*, are able to quantify the anisotropy of surface reflectance, which in turn is sensitive to the structure and heterogeneity of the observed surface. Thus to investigate the potential of multi-angular high spatial resolution data for delivering quantitative surface structure information the retrieved values of the k parameter are compared with proxies derived from detailed LIDAR observations describing the 3-D canopy structure of the target site.**

## 1. INTRODUCTION

The reflectance of a vegetation canopy is known to be primarily a function of the foliage optical properties, the canopy structure, the understory and soil background reflectance, the illumination conditions, and finally the viewing geometry. The CHRIS instrument observes the canopy reflected radiance in the spectral, directional and spatial dimensions, describing the canopy reflectance based on two independent but complementary information sources. Multi-angular observations of the reflectance anisotropy have been proven to be diagnostic for structural surface properties, which are helpful to complement the spectral measurements for a complete and robust characterization of a vegetation canopy. Particularly in the case of a coniferous forest the interaction of incident radiation with the canopy is dominated by the complex 3-D structure, which has a significant impact on the degree of anisotropy in the reflected radiation field. The parametric RPV model is able to decompose this reflectance anisotropy into an amplitude and a shape function (Rahman et al. 1993). Further, the Minnaert function parameter, *k*, as implemented in the RPV, is describing the degree of anisotropy has been shown to be related to canopy structure and subpixel heterogeneity. So called bell-shaped Bidirectional Reflectance Factors (BRF) pattern can be associated to heterogeneous canopies of medium density over a bright background. A bell-shaped BRF pattern is caused by the relative contribution of uncollided radiation from the bright background for close to nadir observations.

Conversely, homogeneous or closed vegetation canopies develop a bowl-shaped BRF pattern instead, provided the background brightness is sufficiently low (Pinty et al. 2002).

In this study we propose to assess the structure and heterogeneity of a coniferous canopy based on its degree of reflectance anisotropy as observed by the multi-angular imaging spectrometer CHRIS. The RPV model fitted to CHRIS data provides the variation of the Minnaert function parameter *k* over the observed coniferous canopy, which in turn are compared with independently derived proxies of the 3-D surface structure provided by LIDAR data.

## 2. DATA

The test site for this study is located in the eastern Ofenpass valley, which is part of the Swiss National Park (SNP) in South East Switzlerland. The Ofenpass represents an inner-alpine valley with an average altitude of about 1900 m a.s.l. The south-facing Ofenpass forests, where the observations have been made, are largely dominated by mountain pine species (*Pinus montana ssp. arborea*).

CHRIS data was acquired over the SNP on February 17 2004 (sun zenith: 59.7°, azimuth:165.4°) under cloud free conditions. The specific scene was recorded using the Chlorophyll mode 4 of CHRIS (Table 1). Due to operational constraints, only four (instead of five) view angles have been recorded. The CHRIS scene has subsequently been geometrically and radiometrically corrected following an approach dedicated for rugged, mountainous terrain (Kneubühler et al. 2005). The results of the preprocessing of the CHRIS data are geo-corrected Hemispherical-Directional-Reflectance-Factor (HDRF) data with a spatial resolution of 18 meters.

In October 2002 an airborne LIDAR survey of the test site was carried out. The LIDAR (of type FALCON) is a small-footprint push-broom laser altimeter operated by TopoSys, and provides both, a first and last reflection measurement of the laser signal (first/last pulse) in a high point density. The segmentation of the single LIDAR returns into tree crowns allowed for the retrieval of the geometric properties of single trees, such as tree position, height, crown radius and crown length (Morsdorf et al. 2004). The such derived tree heights and positions were used to calculate a parameter set characterizing the spatial and vertical canopy structure (Widlowski et al. 2004). The vertical dimension of the canopy structure is described by the 'mean effective scene height' – the mean height of all trees within the respective IFOV of the CHRIS data, weighted using the fractional cover of each pixel. For the characterization of the horizontal dimension, the ratio

between the stem density and the nearest-tree-distance within the considered IFOV was used.

| Spatial Sampling | Image area | View zenith[1] | View azimuth[2] | Spectral bands | Spectral range |
|---|---|---|---|---|---|
| 17 m @ 556 km altitude | 13 x 13 km (744x748 pixels) | 48.4°, 27.3°, 6.6°, 32.6° | 8.9°, 3.4°, 223.7°, 201.9° | 18 bands with 6-10 nm width | 489 – 792 nm |

[1]nominal 5 view angles @ 55°, 36°, 0°, -36°, -55°; [2] azimuth is defined by the plane target-to-sensor

## 3. QUANTIFICATION OF THE HDRF ANISOTROPY

The Rahman-Pinty-Verstraete (RPV) parametric model (Rahman et al. 1993) simulates the anisotropy of the surface reflectance as a function of four parameters. The RPV parameters are decomposing the anisotropy into an amplitude component ($r0$), a symmetric ($k$) and an asymmetric shape function ($Q$), as well as a hotspot descriptor ($rh$).

During initial testing the inversion of the RPV model was performed by fitting the HDRF provided by CHRIS to the RPV model BRF simulations (Gobron and Lajas 2002) The red spectral band (631 nm) was chosen as spectral input. The RPV parameter set(s) that best explained the analysed HDRF represented the inversion solution along with an uncertainty of the retrieval performance. Although the hot spot descriptor $rh$ of the RPV model may bias these results, it was assumed that the bright snow background – which enhances $r0$ and thus also $rh$.⁻ will reduce this effect. Of particular interest here is the modified Minnaert function parameter, $k$, which quantifies the overall shape of the surface BRF. Based on the $k$ values the anisotropy of the observed reflectance pattern can be classified into a bell- ($k>1$) or bowl-shaped pattern ($k<1$). The HDRF as observed by CHRIS and the BRF simulated by the RPV model are here assumed to be comparable.
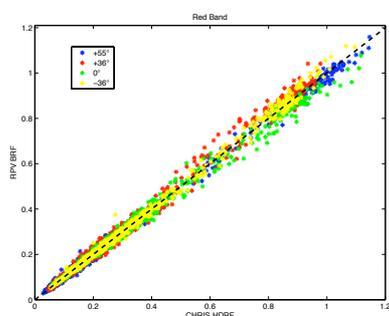


Figure 1. Comparison of the HDRF as observed by CHRIS and corresponding BRF simulated by the RPV model.

## 4. ASSESSMENT OF CANOPY STRUCTURE AND HETEROGENEITY BY RPV MODEL INVERSION

The inversion of the RPV model against the multi-angular data over a subset of the preprocessed CHRIS scene provided spatial fields of the RPV model parameters describing the anisotropy of the observed surface reflectance (e.g. Fig. 2). The performance of the inversion was affected by several factors 1) possible geolocation errors between the different view angles, 2) errors due to different targets contributing to a pixel's BRF signature (especially at the edges of forests and meadows or streets, 3) errors due to the dealing with HDRF instead of BRF

data, 4) errors due to an asymmetric distribution of viewing conditions around nadir, 5) errors due to the impact of horizontal radiation transport within the heterogeneous forest (i.e., adjacency effects) and 6) errors due to significantly sloping terrain (i.e., topography). Specifically, the last factor may affect the inversion results since the presence of topography may lead to target occlusions as well as enhanced degrees of backscattering. Tests showed that the significant slopes in the north and south-east of the target area had a substantial impact on the results of the inversion. Thus the subsequent interpretation of the retrieved model parameters was restricted to areas with slopes of up to 10° and inversion uncertainties below 10%. For those conditions, the measured data were fitted well by BRF simulated based on the retrieved RPV parameter sets (Fig.1).
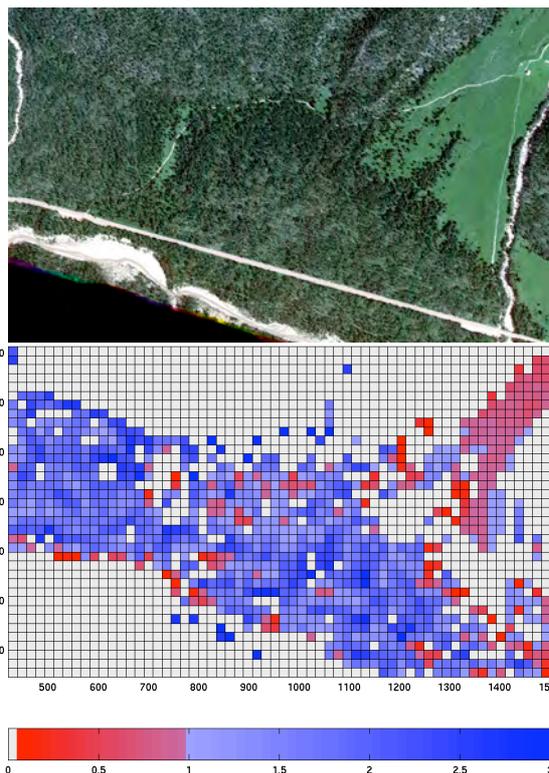


Figure 2. Map of the spatial distribution of the Minnaert parameter $k$ obtained by the RPV model inversion (x-, y-axis represent Swiss coordinates, masked data (slope >10°, inversion uncertainty >10%) in grey). The above RGB image is derived from an HRSC camera acquisition in summer 2003.

Generally two different surface types could be observed, an open snow-covered meadow and a coniferous forest, exhibiting distinctly different BRF shapes (Fig. 3). The snow-covered meadow was characterized by a bowl shape, whereas the forest surface mostly featured a bell-shaped BRF indicated in figure 2 by blue (bell shape) and red (bowl shape) color. If the tree crowns are so densely packed as to completely obscure the snow covered background then an otherwise bell shaped reflectance anisotropy will turn into a bowl-shaped BRF pattern due to insufficient spectral contrast between the canopy and the background. Similarly, a canopy that is so dense as to prevent the snow from actually being deposited on the ground will also lead to bowl-shaped BRF patterns. Additionally the rather low sun illumination decreases the background contrast by casting an increased amount of shadows. Other bowl-shaped

BRF are observed at the southern part of the subset where a street is transecting the forest. Here the BRF signatures that are associated to a pixel are actually due to different surface types being viewed through different view zenith angle configurations as the CHRIS-PROBA passes by.
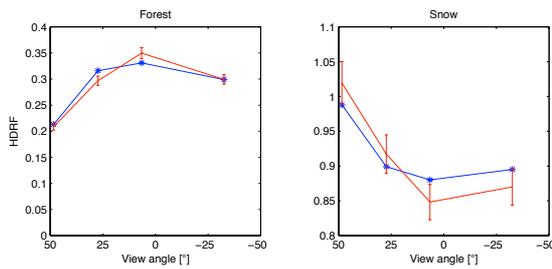


Figure 3. BRF signatures of observed typical surface types (measured HDRF (blue), BRF reconstructed by RPV with its inversion uncertainty (red))

Despite the presence of topography, the impact of horizontal radiation transport, and the usage of HDRFs instead of BRFs, Figure 4 provides initial results documenting the value of the Minnaert function parameter $k$ in a parameter space described by two proxies of the 3-D canopy structure. This parameter space was defined according to Widlowski et al. (2004) where the X-axis represents spatial canopy properties and the Y-axis relates to vertical canopy characteristics. The relevant 3-D information for the retrieval of the two surface structure proxies are provided by detailed LIDAR measurements of the observed canopy. In the resulting parameter space, Widlowski et al. (2004) observed bowl shaped BRF pattern for sparse and very dense canopy scenarios whereas canopies with medium density were found to take on different degrees of bell-shaped reflectance patterns. Due to the significant brightness of the underlying background in the CHRIS observations, one can assume an increase in the $k$ values for all scenarios (Pinty et al., 2002). For the observed surfaces this pattern cannot be clearly distinguished. Although bell-shaped BRF are indeed observed dominantly for canopies of medium densities, they are interspersed by bowl-shaped BRF observations. Some of these interspersed bowl-shaped BRF are explained by the dense canopies discussed above, which are not characterized by a higher stem density but by denser tree crowns and are thus not clearly discernable in the defined parameter space. Other bowl-shaped BRF over forest surfaces are probably affected by inconsistencies of the multi-angular observations and the fact that the RPV inversion may have been affected by asymmetry of the available view zenith angles. Efforts are under way to investigate these issues and also to include other spectral bands in this analysis

## 5. CONCLUSION

In this study the parametric RPV model was successfully inverted against the independent information source of multi-angular CHRIS-PROBA observations. The RPV inversion was able to describe and discriminate between different surface types based on the their inherent reflectance anisotropy. Also the Minnaert function parameter $k$, describing the degree of anisotropy, was successfully linked to LIDAR measurements representing the 3-D structure of the canopy. Results show the potential to distinguish within a forest stand between closed canopies and ones of medium density. Finally the serious effects of surface slope on the performance of the RPV model

inversion suggest the need of taking into account the topography for a consistent use of the RPV model.

One of the main recent advances in remote sensing of vegetated surfaces is complementing the spectral signature with additional (here directional) information for a more effective retrieval of biophysical canopy properties. Specifically the vegetation structure is of significant interest for applications related to ecosystem modeling, hydrology, fire risk and wildlife habitats. This is, however, a difficult task since the vegetation structure itself may introduce significant uncertainties in the retrieval of canopy properties from spectral data, in particular when heterogeneous vegetation is present. Additional information on the surface and canopy structure provided by multi-angular measurements is thus a sought complement to the present algorithms.
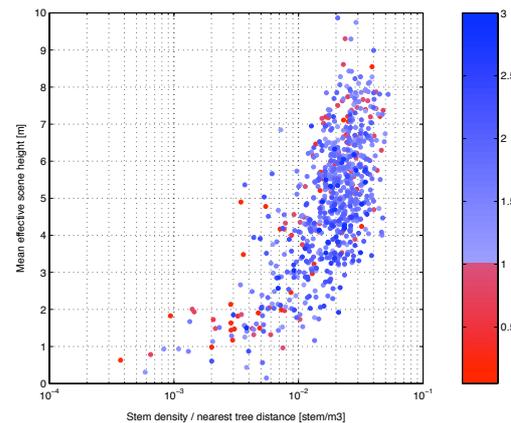


Figure 4. Organization of the k parameter in a parameter space describing the 3-D surface structure.

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