RETRIEVING CANOPY STRUCTURE FROM HYPERSPECTRAL MULTI-ANGULAR SATELLITE DATA

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ABSTRACT

The angular dependence of satellite-measured canopy reflectance has been shown to contain information on the structure of vegetated surfaces. The aim of the research was to explore the angular variability of spectral indices and to compare the suitability of angular indices and traditional vegetation indices for retrieval of forest structural attributes using Chris/PROBA data. With spruce the largest variability in NDVI occured in forward scattering direction. This variability strongly determined the correlations with canopy attributes. The results showed that off-nadir viewing improved NDVI performance considerably, particularly in forward scattering direction. The best relationship was found between NDVI at 44º view zenith angle and stand age (spruce: r= – 0.91, beech: r= – 0.77). Other directional indices (ANIX, NDAX or $NDVI_{HD}$) were in most cases less correlated with canopy attributes.

1 INTRODUCTION

Nadir-viewing passive multispectral sensors were shown to be limited in characterising the structure of forest canopies. For instance, some authors found good correlations (e.g., Running et al., 1986; Peterson et al.,1987; White et al., 1997; Franklin et al., 1997) but others found poor correlations (Badhwar et al., 1986; Spanner et al., 1990; Chen & Cihlar; 1996) between NDVI or ratio VI and leaf area index (LAI). Improved relationships compared to broadband VI were found between narrowband VI and forest canopy structure (e.g., Gong et al., 2003; Lee et al., 2004; Schlerf et al., 2005). However, in a study by Schlerf et al. (2005) using narrowband VI instead of broadband VI, the retrieval accuracy could be improved for LAI but not for stem biomass. Multi-angle data may better depict the full dimensionality of forest canopies (Asner, 1998), possibly including height and biomass related attributes. Indeed, multi-angular remote sensing has recently been used to detect structural attributes of vegetated surfaces including LAI, canopy cover and foliage clumping (Widlowski et al. 2004; Chen et al. 2005; Pocewicz et al. 2007; Gascon et al. 2007). Directional effects were found in VI similar to the effects observed in reflectance. Yet, the magnitude of angular effects in vegetation indices and the information content of angular indices to describe forest structure remain unknown for most indices (Verrelst et al. 2006).

Multi-directional sensors in orbit typically measure with a coarse spatial resolution and would be unsuitable to detect the variability in most of European forests. There, use of multi-angle remote sensing has recently been facilitated through high spatial resolution Chris/PROBA images. The central questions of this research were to explore the angular variability of spectral indices and to compare the suitability of angular indices and traditional vegetation indices for parameter retrieval using Chris/PROBA data.

2 METHODS

2.1 Satellite data and ground measurements

Chris/PROBA images were acquired at Idarwald test site (Germany) on 5 September 2005 in mode 1 (411-1004 nm) at five observation angels (-44°, -33°, -5°, +28°, and +44°). The sun zenith angle during the sensor overpass was 44° and the relative azimuth angle between sun angle and observation angle was 50°. The five images were geocoded to the local reference system using a parametric approach described in Kneubuehler et al. (2005). This parametric approach takes into account the viewing geometry and geometric distortion due to the sensor, platform and topography. The method had been shown to provide high accuracy, robustness and consistent results over a full image taken over mountainous terrain in Switzerland. To compute and refine the parameters of the mathematical model apart from orbit and sensor information a small number of ground control points (GCP) was needed. For each image, between 7 and 10 GCP were selected. Reference coordinates stemmed from digital topographic map sheets of scale 1:25.000. The digital elevation model (source: Topographic mapping agency, Rheinland-Pfalz) had a spatial resolution of 20 m. The images were resampled to the nominal ground resolution at nadir view (34 m). The root mean square errors of the respective scenes were for the –44, -33, -5, +28, and +44 images 1.11, 1.60, 0.78, 1.15, and 1.26 pixels, respectively. The images were radiometrically corrected to top-of-canopy reflectance using AtcPro Software Tool assuming standard atmospheric parameters.

Two weeks after the image acquisition, an extensive field campaign was conducted and the canopy structure of altogether 28 forest stands (15 plots of Norway spruce *(Picea abies L. Karst.)*) and 13 plots of Beech *(Fagus sylvatica)*) was measured. In each forest stand, a plot of 30x30 m^2 size was established and its central position determined using a hand-held GPS device. Measured attributes include leaf area index (LAI, measured with Li-Cor LAI-2000), crown diameter (CD), tree density (SD), crown cover (COcr), tree height (TH), and percent coverage of understorey vegetation (COus).

2.2 Vegetation Indices

Vegetation indices were computed from image pixels that represent the forest stands under investigation. For each plot, four image pixels were extracted from each image around the GPS-measured plot location and the mean spectral reflectance was calculated. Various angular indices may describe angular effects in relation to canopy structure (Sandmeier et al., 2004). Normalised Difference Vegetation Index (NDVI, Rouse et al. 1974) was calculated using bidirectional reflectance factor data from each of the five Chris/PROBA view angles.

$$NDVI(\theta) = \frac{\rho_{NIR}(\theta) - \rho_{red}(\theta)}{\rho_{NIR}(\theta) + \rho_{red}(\theta)}$$

Anisotropy index (ANIX, Sandmeier et al., 1999) describes the ratio of the maximum (hot spot) and minimum (dark spot) bidirectional reflectance in a spectral band. It enhances the anisotropy (angular variation of reflectance) of objects.

$$ANIX(\lambda) = \frac{\rho_{\theta \max}(\lambda)}{\rho_{\theta \min}(\lambda)}$$

Similar to ANIX, the Hotspot-Darkspot Index (HDS, Lacaze et al. 2002) is defined as

$$HDS(\lambda) = \frac{\rho_{\theta \max}(\lambda) - \rho_{\theta \min}(\lambda)}{\rho_{\theta \min}(\lambda)}$$

However, as correlation between ANIX and HDS equals 1, HDS was not further investigated.

Normalised difference anisotropy index (NDAX, Sandmeier et al., 1999) is computed from ANIX in a red band and ANIX in a NIR band. It attempts to eenhance spectral differences in anisotropy.

$$NDAX = \frac{ANIX_{red} \text{-} ANIX_{NIR}}{ANIX_{red} + ANIX_{NIR}}$$

The hotspot darkspot NDVI ($NDVI_{HD}$) that was recently suggested by Pocewicz et al. (2007) also combines information from different spectral bands and viewing angles.

$$NDVI_{HD} = \frac{\rho_{\theta \max NIR} - \rho_{\theta \min red}}{\rho_{\theta \max NIR} + \rho_{\theta \min red}}$$

Table 1: Overview of Vegetation Indices

Vegetation Index	Number of Indices
Traditional Indices	
- Nadir NDVI (NDVI–4)	1
Directional Indices	
- NDVI for off-nadir viewing angles	4
- ANIX in red, ANIX in NIR	2
- NDAX, NDVIHD	2

A summary of the investigated vegetation indices is given in Table 1.

3 RESULTS AND DISCUSSION

Analysis of the angular dependence of reflectance (Figure 1) revealed in the NIR a more bowl-like shape for erectophile canopies (spruce) than for beech forest. This is in agreement with the typical observation that conifers with their highly organised canopy architecture show a BRDF curve with relatively large amplitude (Chen et al. 2003). The red reflectance was very low and increases more from nadir to off-nadir in backward scattering direction (BSD) than NIR reflectance does. This had certain implications for the angular dependence of NDVI.

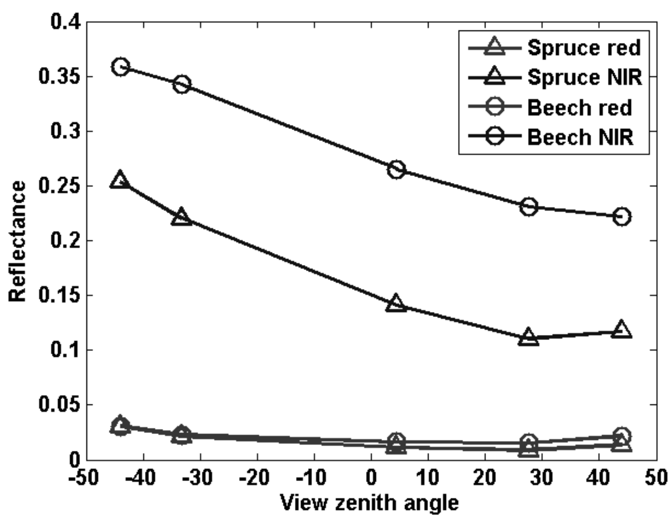

Figure 1: Angular dependence of reflectance in the red and NIR.

For spruce and beech forest, NDVI showed a bell shape, i.e., NDVI decreases with deviation from nadir observations (Figure 2). Several studies have investigated the angular dependence of NDVI in coniferous forests, also demonstrating a decrease in NDVI with increasing view angle (Ranson et al. 1994, Deering et al. 1994). This is due to greater multiple scattering of NIR photons than visible photons, which causes the contrast between sunlit and shaded canopies to be more pronounced at visible wavelengths than in the NIR. The NDVI decreases as visible reflectance increases more than NIR reflectance (Lobell et al. 2002).

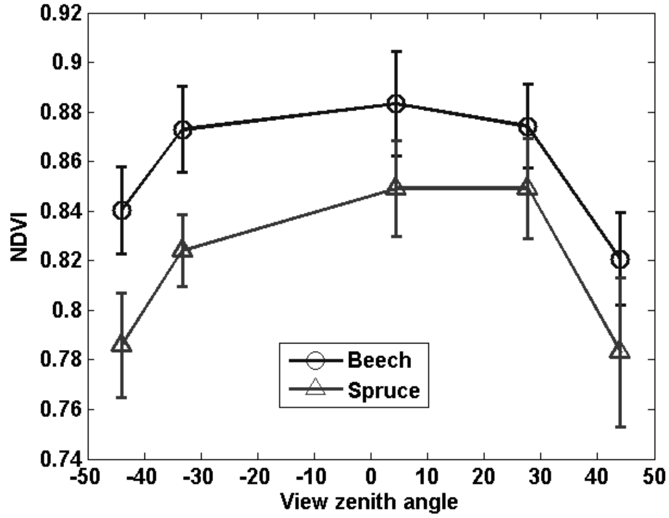

Figure 2: Angular dependence and inter-stand variability of NDVI. The plot shows mean NDVI plus/minus one standard deviation (beech: n=13, spruce: n=15).

With spruce the largest variability in NDVI occured in forward scattering direction (FSD) whereas with beech NDVI variability was largest in nadir direction (Figure 2). This variability strongly determined the correlations with canopy attributes (Table 2). Observed NDVI-LAI correlation was poor for spruce (comparable to results from Schlerf et al. 2005), but very good for beech. NDVI-SBM correlation was poor in nadir-image, but moderate correlation occured in FSD. Good NDVI-Tree height correlations were present in FSD (spruce). Very good (spruce) and moderate (beech) correlations were observed between NDVI and stand age in FSD (Figure 3).

Off-nadir viewing improved NDVI performance considerably, particularly at view zenith angle of 44º (FSD). There are two reasons that can explain the advantage of NDVI in FSD opposed to BSD and nadir direction. First, in FSD and BSD, NDVI is less sensitive to background variations compared to nadir direction as smaller proportion of background is observed (Gemmell and Donald 2000). Furthermore in FSD, the denser the crowns the more shadows on tree crowns are observed (Chen et al. 2003).

Table 2: Correlations between VI and stand attributes. LAI=Leaf area index, SBM=Stem biomass (t per ha), TH=Tree height (m), Age=Stand age (years)

VI	LAI beech	LAI spruce	SBM beech	SBM spruce	TH beech	TH spruce	Age beech	Age spruce
NDVI–44	0.78	**0.74**	-0.00	-0.62	-0.41	-0.70	-0.61	-0.83
NDVI–33	0.77	0.46	-0.03	-0.43	-0.35	-0.48	-0.54	-0.68
NDVI–4	**0.92**	0.47	0.03	-0.33	0.44	-0.45	0.48	-0.52
NDVI28	0.88	0.37	-0.09	-0.37	-0.51	-0.48	-0.70	-0.51
NDVI44	0.80	0.67	-0.20	**-0.69**	**-0.60**	**-0.79**	**-0.77**	**-0.91**
ANIX 675	0.58	-0.68	**0.60**	0.53	-0.38	0.63	0.07	0.75
ANIX 782	-0.10	-0.69	-0.06	0.53	0.16	0.71	**0.77**	0.79
NDAX	0.57	-0.26	-0.28	0.11	-0.48	0.05	-0.70	0.15
$NDVI_{HD}$	**0.93**	-0.32	-0.02	0.17	-0.52	0.23	-0.46	0.30

The ANIX spectra (Figure 4) demonstrated that reflectance anisotropy reaches a maximum at visible wavelengths and a minimum in the NIR. Similar results were found by Lobell et al. (2002). Anisotropy was generally more pronounced in spruce forest than in beech forest reflecting the more erectophile structure of spruce canopies. Correlations between ANIX675 or ANIX782 and canopy attributes were mostly weaker than the correlations obtained with NDVI44 (Table 2). The same holds for the correlations between NDAX or $NDVI_{HD}$ and canopy attributes except for the correlation between $NDVI_{HD}$ and beech LAI.

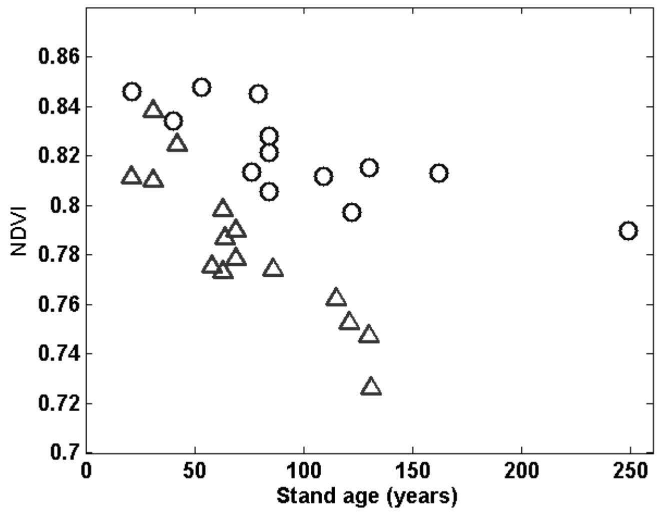

Figure 3: NDVI in forward scattering direction (view zenith angle: 44º) and stand age. Circles: beech, triangles: spruce.

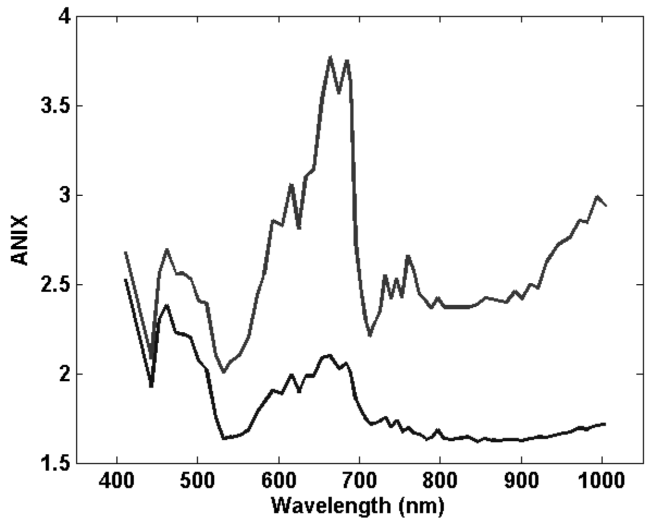

Figure 4: Spectral variability of mean values of ANIX (beech: n=13 (lower line), spruce: n=15 (upper line)).

CONCLUSIONS

Conclusions

- NDVI in forward scattering direction (at view angle of 44º) proofed to be the most suitable VI in characterising forest structure.
- Other directional indices (ANIX, NDAX) showed weaker correlations with stand attributes
- More sophisticated methods, e.g. radiative transfer models have to be incorporated to better explore the full dimensionality of complex vegetation canopies.

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