SUBARCTIC BOREAL FOREST ALBEDO ESTIMATION USING ENVISAT/ASAR AND SPOT

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ABSTRACT

Optical satellite albedo observations of forests suffer from understory contamination, but C-band microwave reacts mostly with the canopy. This paper studies whether or not adding ASAR backscattering information could enhance optical albedo retrieval accuracy. We compare SPOT-4-retrieved reflectances combined with ASAR backscattering ratios with solely optically retrieved SPOT-4 NIR albedo, and a MODIS 16-day NIR albedo product in a subarctic boreal forest test area. The results suggest that microwave augmentation of optical data can improve albedo retrieval accuracy.

1. INTRODUCTION

The boreal zone land cover type has a very significant influence to northern hemisphere albedo and it is the main factor in northern hemisphere carbon budget. Boreal forest is also a sensitive indicator to changes in local and global climate. Tree species distribution reacts to changes in mean temperature and moisture conditions in long term; forest leaf area index and defoliation indicate stress factors in shorter time scale. Also the time of the phenological phase transitions are important indicators of global climatological processes.

Surface albedo is one of the Essential Climate Variables (ECV) defined in the Implementation Plan for the Global Observing System for Climate in Support of the UNFCCC. Surface albedo is also one of the ECVs that are largely dependent on satellite observations. Parameters describing, on one hand the land cover classes in general and, on the other hand the forest properties in detail, are related to the bidirectional reflection distribution function (BRDF) affecting the surface albedo, which is needed as input for climate change modelling. The BRDF of land cover is estimated for operational surface albedo products using optical satellite images and land use classification information. For vegetated land cover semi-empirical relationships depending on the leaf area index (LAI) are used. Recently a method for boreal forest LAI retrieval using the VV and HH polarization of ENVISAT/ASAR has been developed [1, 2]. Thus there is potential also for finding a direct relationship between BRDF and the microwave essence of land cover.

The NIR band albedo of subarctic boreal forest was recently found to be correlated with the VV/HH polarization ratio of ENVISAT/ASAR multiplied by the SPOT NIR band reflectance [3] and it has been noticed that the VV/HH backscattering ratio is related to the BRDF as well [4], which is natural since the BRDF is essentially linearly dependent of the LAI in the typical range at the test site [5, 6]. Previous studies of the use of microwave for albedo estimation [3] were rather limited, it was considered important to test the method also in a larger area. For that purpose the MODIS black-sky NIR albedo product MOD43 was used as validation data set [5, 6, 7, 8]. The MODIS NIR albedo was first compared with a NIR albedo derived using only the SPOT image reflectance values. Then the MODIS NIR albedo was compared with the SPOT NIR reflectance multiplied by the VV/HH polarization ratio of ENVISAT ASAR. The NIR band albedo tends to dominate forest broadband albedo.

2. THEORY

2.1. Spectral albedo

Recently it has been shown that the forest albedo can be modelled using only a few parameters, of which only the LAI and forest floor albedo have to be estimated spatially [9]. Other parameters can be derived from LAI or taken from the literature.

Unfortunately the satellites do not measure directly the hemispherical reflected radiation, so that the bidirectional reflectance distribution function (BRDF) of the target has to be known, in order to be able to estimate the albedo on the basis of satellite derived reflectance values.

The computation of spectral surface albedos from satellite observations generally proceeds as follows:
1) The observed clear-sky radiances are converted to Top-of-Atmosphere reflectances,
2) The atmospheric effects are removed from the TOA reflectances, converting them into surface reflectances. Details of this stage are beyond the scope of this paper and will therefore be omitted.
3) surface reflectances are converted into spectral albedos by using BRDF data or model to remove anisotropy effects and integrate the reflectances into hemispherical spectral surface albedos.

Proc. of '4th Int. Workshop on Science and Applications of SAR Polarimetry and Polarimetric Interferometry – PolInSAR 2009', 26–30 January 2009, Frascati, Italy (ESA SP-668, April 2009)

2.2. Optical BRDF

Roujean et al. introduced a well-known optical BRDF model in 1992 [10]. The model was built around the idea that vegetation reflectance distribution may be divided into a geometric and a volumetric scattering component. The model uses LAI as the parameter characterizing the canopy scattering behaviour.

Wu et al. [11] created a semiempirical BRDF model using NDVI as the canopy parameter, making it well-suited for remote sensing applications. The BRDF model for forests may be described as:

$$\Omega_i(\theta_S, \theta_V, \varphi) = 1 + a_1 f_1(\theta_S, \theta_V, \varphi) + a_2 f_2(\theta_S, \theta_V, \varphi) \quad (1)$$

where the a-terms are the canopy scattering parameters, dependent on NDVI, and f_1 and f_2 are the geometric and volumetric scattering kernels, respectively. The BRDF is described as multiples of nadir-viewed reflectance, hence the first term equals one. For forest, a_1 is zero and the geometric scattering term vanishes. The volumetric scattering terms for the 0.8-micron NIR channel are [10, 11]

$$a_2 = 1.830 * NDVI^{-0.105}$$
$$f_2 = \frac{4}{3\pi(cos(\theta_s) + cos(\theta_v))}\left[\left(\frac{\pi}{2} - \xi\right)cos(\xi) + sin(\xi)\right] - \frac{1}{3}$$
$$\xi = cos(\theta_s)cos(\theta_v) + sin(\theta_s)sin(\theta_v)cos(\varphi) \quad (2)$$

Optical BRDF is also directly related to directional-hemispherical albedo of the surface. The relation is [10]

$$a(\theta_s) = \frac{2}{\pi}\int_0^{\pi} d\phi \int_0^{\pi/2} \rho(\theta_s, \theta_v, \phi) \cos\theta_v \sin\theta_v \, d\theta_v \quad (3)$$

Numerical integration of the forest BRDF therefore yields the following relation [10, 11]:

$$\alpha(\theta_s) = \rho(0, 0, \varphi) * (1 + a_2 I_2) \quad (4)$$

where

$$I_2 = -0.0137 + 0.0370 tan\,\theta_s + 0.0310 tan^2\,\theta_s - 0.0059 tan^3\,\theta_s \quad (5)$$

According to the photon recollision probability based simulations the bidirectional reflectance factor (BRF) in NIR wavelengths is essentially exponentially related to the leaf area index [5]. The range of the measured LAI values of the Sub-Arctic forest studied was 0.06 … 2.35 [6]. According to the simulations in this range the relationship between LAI and BRF is practically linear.

2.3. Microwave BRDF

The theoretical optical BRDF is parameterized using the leaf area index for characterizing the scattering behaviour in the canopy. It has been shown that the backscattering ratio of the vertical and horizontal polarizations VV/HH is linearly related to the leaf area index of boreal forest [1, 2, 12]. On that basis it is reasonable to assume that the microwave information can be used for BRDF estimation.

Since the BRF vs. LAI relationship is about linear in the LAI range in question [5], the backscattering ratio of the vertical and horizontal polarizations VV/HH was assumed to be linearly related to the BRF as well. Preliminary experimental results of a direct relationship between BRDF and the microwave signal have indeed been found [4].

3. MATERIAL

3.1. Test area

The test area was extended from the ground measurement site (67.368º N, 26.633º E, 179 meters above sea level) [3] to the intersection of one SPOT image and one ENVISAT/ASAR SLC image. The CORINE land use cover map of 25 m resolution was used as the basis for excluding other classes than forest from the SPOT and ASAR analysis. The forest/nonforest mask is shown in Fig. 1. The coarse forest classes found in the area were: coniferous forest (34%), mixed forest (10%) and deciduous forest (9%). The sparse forest classes (cc < 30%) were excluded from the analysis. In addition, a 10 m resolution digital elevation model (DEM) was available for a part of the area.

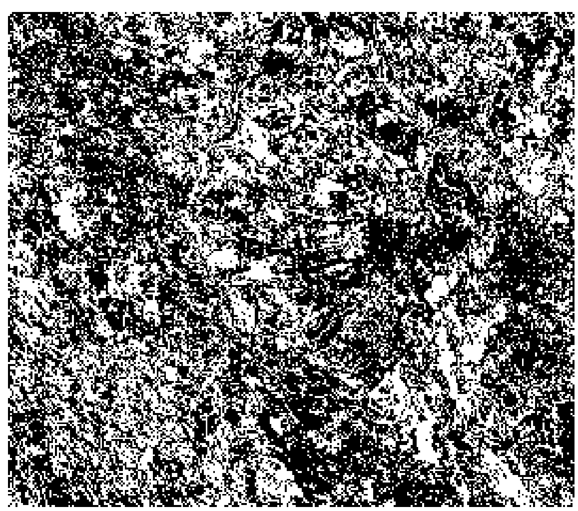

Figure 1. The forest covered regions in the test area. The white pixels are forested.

3.2. Satellite data

One cloud free SPOT image (June 7, 2006) and altogether seven ENVISAT/ASAR SLC alternating polarization (VV/HH) images were acquired for the test site during summer 2006 [Figs. 2 and 3]. However, this summer was extremely dry, in fact the driest summer ever measured in Finland since 1900. This was also manifested by the large amount of completely brown needles of the coniferous trees. Therefore the number of ASAR images fit for analysis was reduced from seven to two. Both images were of swath IS6. The first good image was taken in May 26 (descending pass) before the dry season and the other one in August 8 (ascending pass) right after a rain fall. The timing of the first image was closer to that of the SPOT image, therefore it was chosen for the analysis.

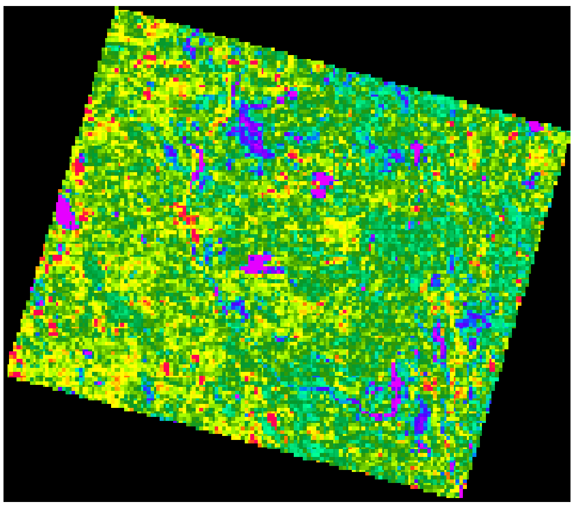

Figure 2. The SPOT NIR reflectance averaged to 500 m resolution covering the area used for comparison of the calculated albedo values based on SPOT, ASAR and MODIS.

The MODIS 16 days black-sky NIR albedo products (MCD43A3.A2006153) used for the study had been constructed using images from June 2 to June 18 [Fig. 4]. This time range contains the acquisition time of the SPOT image but not the acquisition time of the ASAR image.

4. METHODS

4.1. SPOT based albedo

Currently the BRDF for forest in summer condition is calculated using the formulas developed by Roujean (1992) and by Wu et al. (1995). The surface reflectances are first normalized to nadir sun, nadir viewing by

$$\rho(0,0,\varphi) = \frac{\Omega(0,0,\varphi)}{\Omega(\theta_s,\theta_v,\varphi)} * \rho_{surf}(\theta_s,\theta_v,\varphi) \qquad (6)$$

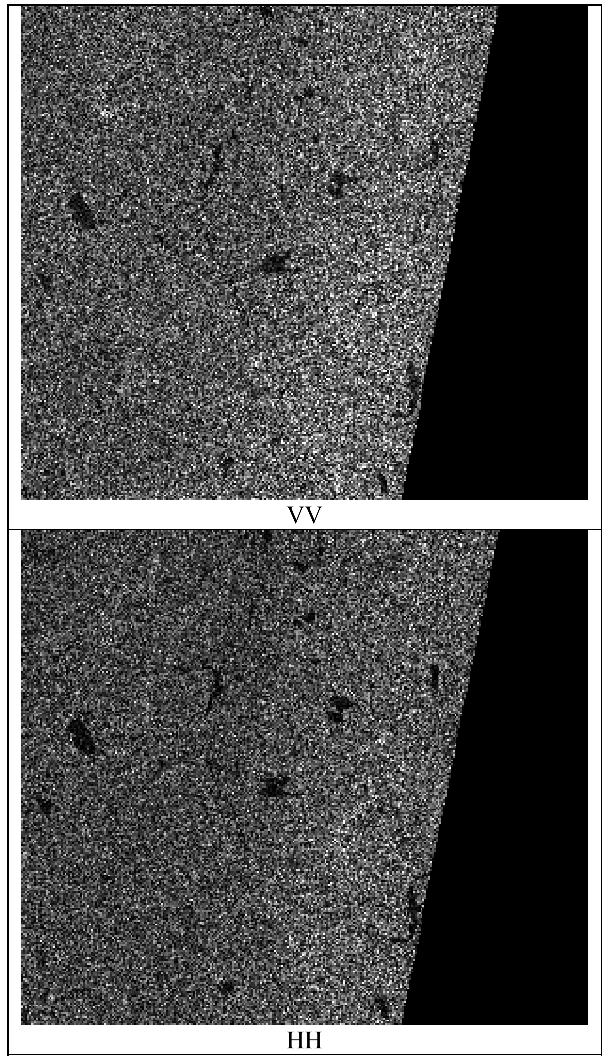

Figure 3. The ASAR VV and HH polarization SLC images for the area used to compare the various albedo estimates. ©ESA

where $\rho_{surf}(\theta_s,\theta_v,\varphi)$ is the observed surface reflectance, and Ω is the BRDF from Eq. (1). Once the surface reflectance has been normalized, Eq. (4) and Eq. (5) may be used directly to derive the spectral albedo of the forest pixel.

The SPOT albedo was based on the NIR reflectance and existing BRDF formula parameterized with NDVI. Although NDVI is sensitive to the leafing, it is not well suited to characterize the canopy LAI of boreal forest throughout the summer. In Sub-Arctic boreal forest actually the forest understorey vegetation, such as lichen, dominates the NDVI [6]. Therefore the variation of NDVI during the summer is not necessarily related to changes in the scattering behaviour of the canopy. This is a drawback in applying the formula of Eq. 6 in satellite based estimation of the surface albedo of boreal forest.

For the comparison with the MODIS albedo product the SPOT based NIR albedo image was first co-registered to the MODIS NIR albedo image. Then it was averaged to the 500 m pixel size of the MODIS albedo product including only forested pixels in the average values of the reflectances. The percentage of the forested pixels was determined for each 500 m x 500 m averaged albedo pixel using the forest mask derived using the CORINE land cover map.

4.2. SPOT/ASAR based albedo

First the MODIS and ASAR data sets were co-registered. Then the VV and HH backscattering coefficient values of the ASAR were averaged to the resolution of MODIS (500 m) using a truncating mean (50%) and masking pixels of other land use classes than forest according to the CORINE land cover information.

The SPOT/ASAR based NIR albedo was obtained in the 500 m resolution by multiplying the averaged SPOT NIR reflectance and the <VV>/<HH> backscattering ratio. It has to be emphasized that at this stage the <VV>/<HH> values were not multiplied by any coefficients, so that the calculated 'albedo' value is actually only expected to be linearly related to the true albedo, but it is not suppose to directly match the exact albedo value.

Since the relationship between LAI and the VV/HH backscattering ratio was the same in May and August, it was concluded that the effect of the forest floor is not large in the VV/HH backscattering ratio, when the incidence angle is as large in the swath IS6 (nominally 39.1° … 42.8°). For this reason it is anticipated that using the microwaves for the BRDF estimation would improve the surface albedo accuracy.

5. RESULTS

Since the product of SPOT reflectance and the ASAR VV/HH backscattering ratio is not directly expected to equal the albedo, but only to be linearly related to it, its dynamic variation might not match that of the quantitative MODIS albedo estimate. For this purpose the albedo data sets were first normalized according to

$$\alpha = \left(\alpha - <\alpha>\right)/\sigma_{\alpha} \qquad (1)$$

where α is the albedo, $<\alpha>$ is its mean value for the whole image and σ_α is the standard deviation of the albedo. The normalized MODIS NIR albedo is shown in Fig. 4 for the pixels for which the forest fraction is larger than 50% according to the CORINE land cover map. The normalized NIR albedo calculated using the SPOT image of June 7, averaged to match the MODIS albedo resolution (including only forest pixels) is shown in Fig. 5 for the same pixels as the MODIS albedo. The normalized product of the SPOT NIR reflectance and ASAR VV/HH backscattering ratio is shown in Fig. 6 for the same pixels. For all three images the colour scheme is the same, so that the comparison is valid.

Obviously the albedo and the averaged SPOT reflectance values deviate from each other in a complicated way, so that the effect of the BRDF can not be neglected [Figs. 2 and 4]. On the other hand the resemblance of the albedo images based on only optical data (MODIS and SPOT) is not striking [Figs. 4 and 5]. This is partly caused by the unfavourable season for comparison. Namely, the annual growth of the canopy and the greening of the forest floor start at the beginning of June, so that the average albedo value of 16 days (the MODIS product) can not be expected to equal the value of one day (SPOT). In fact, a large increase of the forest albedo takes place at this time of the season [13]. In addition, the SPOT based albedo is calculated using NDVI, which is known to be dominated by the forest floor in the sparse Sub-Arctic forests [6].

Comparing the MODIS albedo values corresponding to the total 500 m x 500 m pixels including also other land cover classes than forest and the SPOT averages derived using only forested 20 m x 20 m pixels is not directly justified. Therefore also unmasked SPOT averages were calculated and used for albedo retrieval. However, no marked difference was detected, when only MODIS pixels dominated by forest were included in the comparison.

The relationship between the MODIS based NIR albedo and the SPOT NIR reflectance multiplied by the ASAR VV/HH backscattering ratio seem to resemble each other more than the two albedo images derived using only MODIS or SPOT data [Figs. 4 and 6]. To concretize this notion, scatterplots of the albedo image pairs (SPOT vs. MODIS and SPOT/ASAR vs. MODIS) were derived.

The SPOT and MODIS based albedo values have quite large scatter in both cases, whether the BRDF is estimated using SPOT or ASAR. However, the SPOT/ASAR based albedo has stronger variation with the MODIS albedo than the solely SPOT based albedo, which has a very limited dynamic range. On that basis the inclusion of the microwaves in the albedo estimation improves the results.

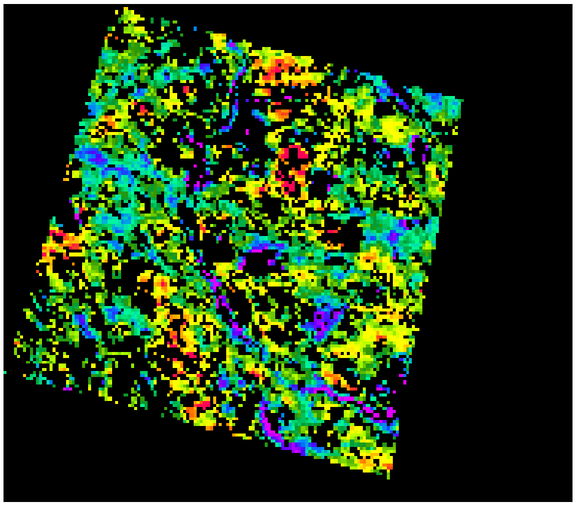

Figure 4. The normalized MODIS 16 days (june 2 to June 18) black-sky NIR albedo for the pixels dominated by forest. The rainbow colour scheme covers the range – 2.5 … 2.5.

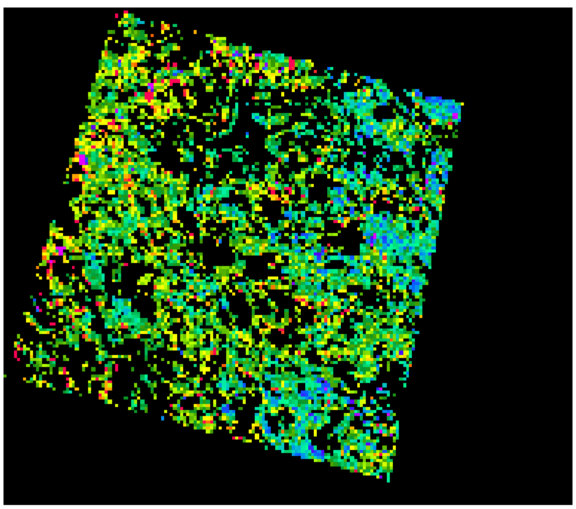

Figure 5. The normalized SPOT based NIR albedo for the pixels dominated by forest. The rainbow colour scheme covers the range – 2.5 … 2.5.

One reason for the modest correlation with the SPOT/ASAR and MODIS based albedo values is that the relationship of VV/HH backscattering ratio and LAI has a different slope for deciduous and coniferous canopies [14]. Unfortunately in the test area the purely coniferous areas are very small although their areal fraction is 34%. Thus it was not reasonable to limit the study to purely coniferous forests, although the results will inevitably suffer from this. Especially problematic the deciduous forests are at the time of interest, because it is about the leafing period, so that in the ASAR image (May 26) the leaves don't yet exist, in the SPOT image they are not fully grown and in the MODIS albedo

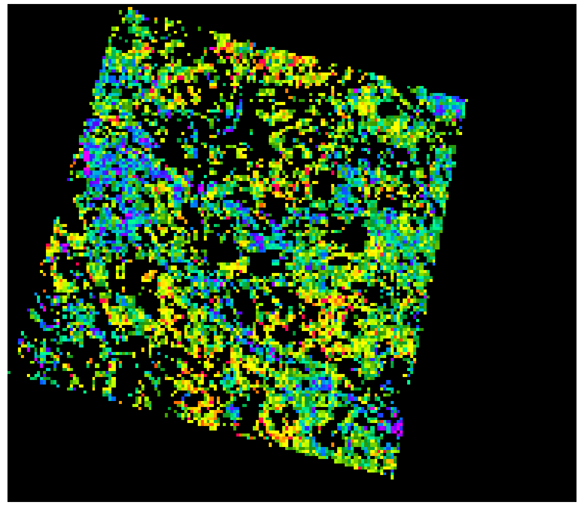

Figure 6. The normalized product of the SPOT NIR reflectance and the ASAR VV/HH backscattering ratio for the pixels dominated by forest. The rainbow colour scheme covers the range – 2.5 … 2.5.

product the status of the leaves in the diverse pixels is completely random due to varying cloud contamination.

As the MODIS albedo corresponds to the whole pixel and the SPOT and SPO/ASAR based albedos are retrieved only for forest dominated pixels, the effect of the forest fraction was checked. The relationship between the normalized SPOT and MODIS albedo values is shown in Fig. 7 with and without the ASAR inclusion. Clearly the scatter of the values decreases when the forest fraction increases from 50% to 90%, whether ASAR information is used or not. However, the solely SPOT based albedo lacks dynamic variation, so that using ASAR for the BRDF improves the dynamic behaviour of the albedo estimate.

The deviations of the normalized MODIS albedo and the normalized SPOT/ASAR based albedo are typically within the standard deviation [Fig. 8], but there are two larger areas, where the difference is systematically larger than twice the standard deviation. Also the solely SPOT based albedo estimates are here higher than the MODIS albedo values [Fig. 9]. For this region the CORINE land cover information is clearly obsolete and there are clear cuttings in the area which is classified as 100% forest [Fig. 10].

The lower region where the SPOT/ASAR albedo estimate clearly deviates from the MODIS albedo estimate is in a mountainous area [Fig. 11]. The range direction of the ASAR image is roughly along the mountain top direction. The systematic local incidence angle difference from flat terrain and possible shading of the successive slope certainly affect the SAR VV/HH backscattering ratio. For this reason it is understandable

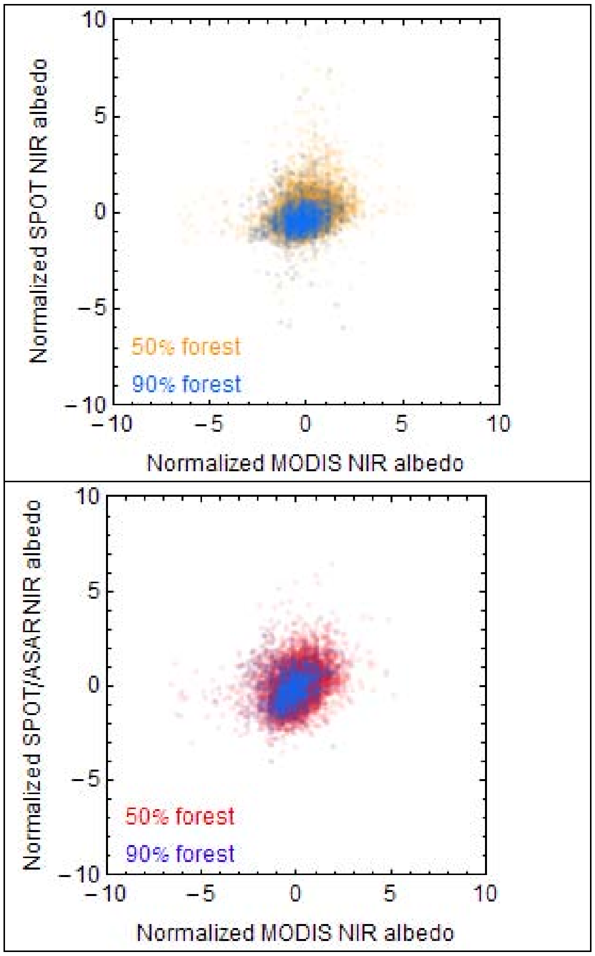

Figure 7. The normalized SPOT based albedo vs. the normalized MODIS albedo. The BRDF is either derived using the SPOT image (blue points) or the ASAR VV/HH backscattering ratio (red points).The opacitiy of the points is 0.1, so that individual outliers don't dominate.

that the first problematic area for SPOT/ASAR albedo is also problematic for the solely SPOT based albedo, whereas the latter area is not.

There are also areas, where the SPOT/ASAR albedo estimate is close to the MODIS albedo estimate, but the albedo estimated using only SPOT is not. One example is at the mid left edge of the test area [Fig. 9]. The original SPOT RGB image revealed that the reason is a small cloudlet and its shadow (the dark feature above the cloud). This example shows one of the basic problems with the optical image albedo estimates: when the image is completely cloud covered one does not get any estimate for the albedo, but when there are small cloud and their shadows, one will get erroneous albedo estimates. Even when cloud masking is used the risk of subpixel cloud contamination has to be taken into account, when using medium or coarse resolution data.

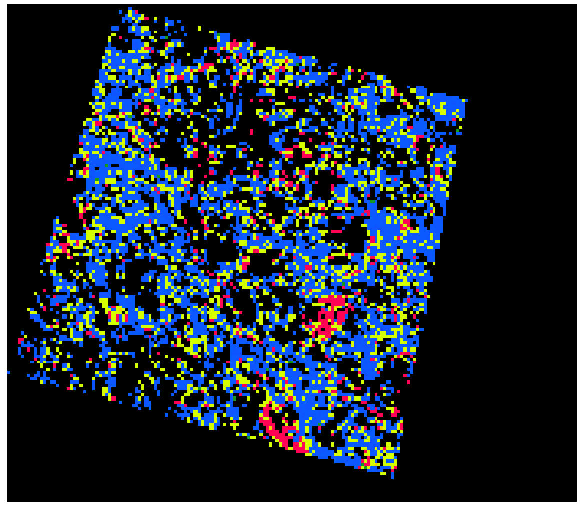

Figure 8. The difference of the normalized SPOT/ASAR based albedo and the normalized MODIS albedo. The colour code is: blue) smaller σ, yellow) smaller then 2σ and red) larger than 2σ, where σ is the standard deviation.

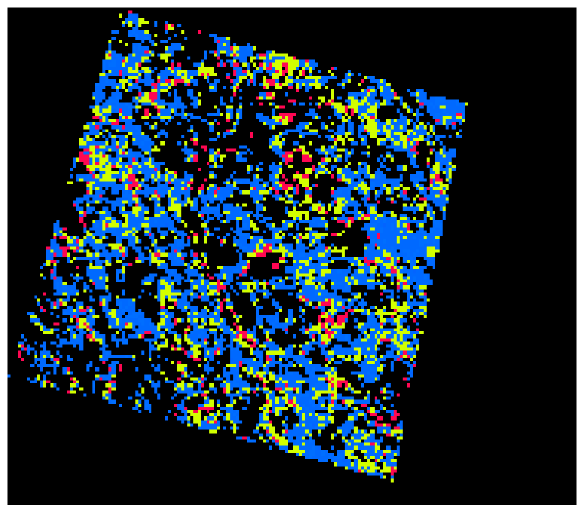

Figure 9. The difference of the normalized SPOT based albedo and the normalized MODIS albedo. The colour code is: blue) smaller σ, yellow) smaller then 2σ and red) larger than 2σ, where σ is the standard deviation.

6. CONCLUSIONS

The SPOT/ASAR based NIR albedo correlated better with the MODIS NIR albedo than the NIR albedo derived using only the SPOT image. The reason is that in the subarctic boreal forest NDVI is more related to the understory vegetation, such as lichen, than to the canopy, whereas the VV/HH backscattering ratio correlates well with the leaf area index of the canopy. Thus the conclusion is that the optical surface albedo products can benefit from the inclusion of microwave data.

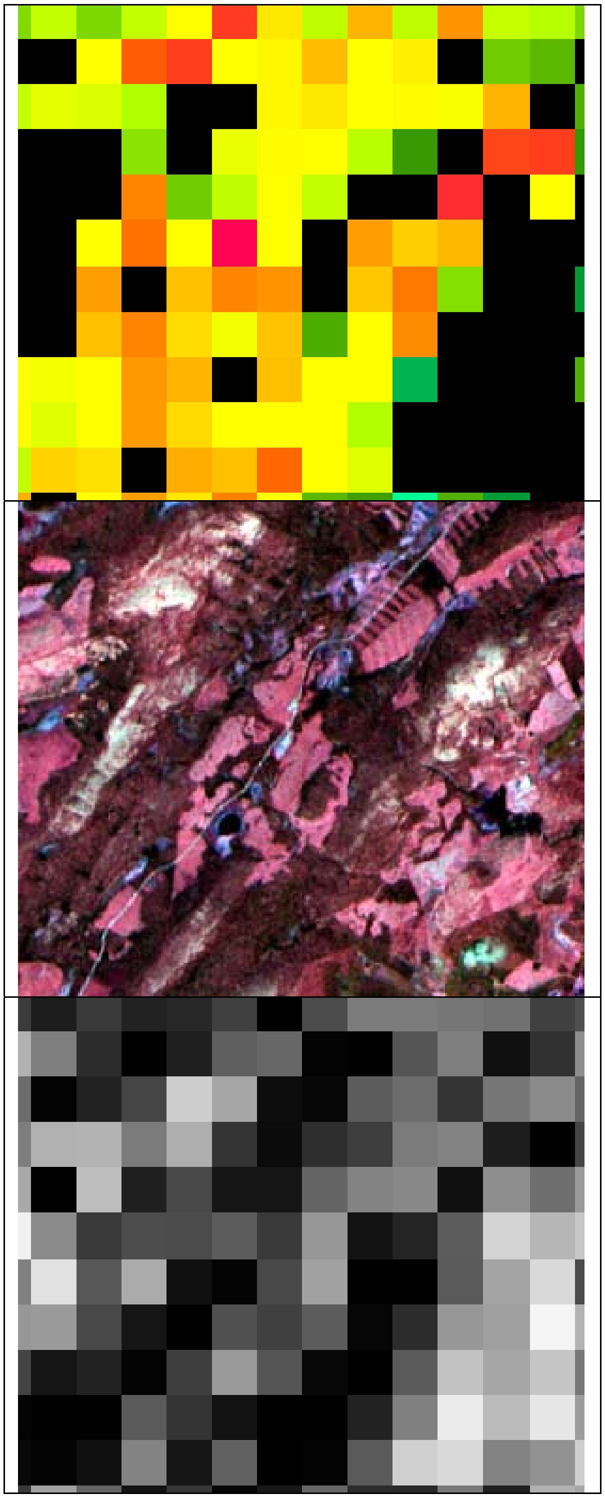

Figure 10. The difference between the SPOT/ASAR and MODIS normalized albedo values (top), the corresponding SPOT RGB (432) image (middle) and the fraction of forest in the pixels according to CORINE land cover mapt (bottom). The grayscale values for the forest fraction vary from 0 (white) to 100 % (black).

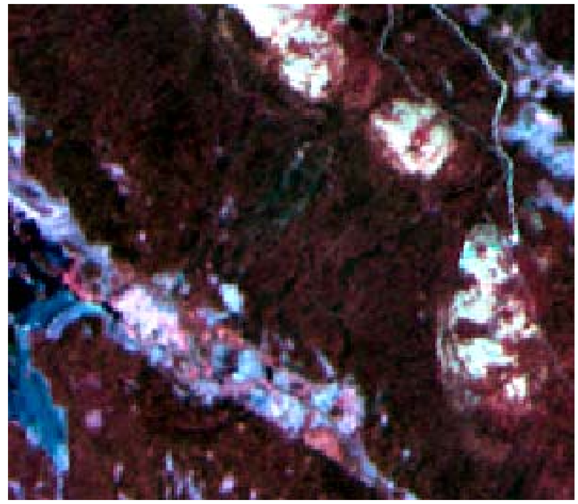

Figure 11. SPOT RGB (432) image corresponding to the lower area of large deviations between the MODIS and SPOT/ASAR normalized albedo estimates (marked in red) in Figure 8.

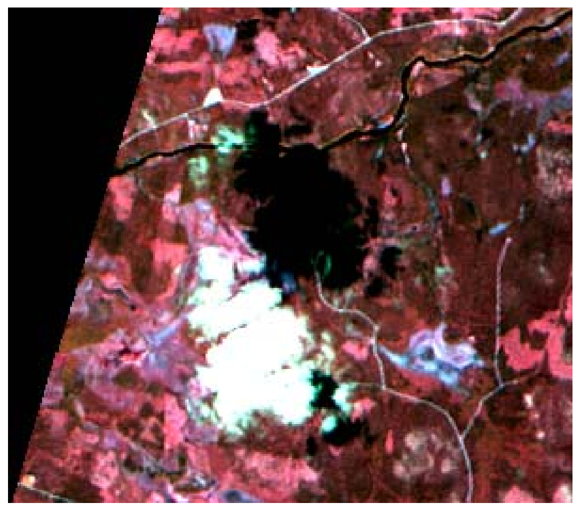

Figure 12. SPOT RGB (432) image corresponding to the area at the left edge of large deviations between the MODIS and SPOT normalized albedo estimates (marked in red) in Figure 9.

7. ACKNOWLEDGEMENTS

The authors are grateful to the NorSEN network of European Regional Development Funds and EUMETSAT (Climate SAF project) for financial support at various stages of the work.

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