PALSAR SENSITIVITY TO SURFACE SOIL MOISTURE IN THE VOLTA BASIN

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ABSTRACT

The sensitivity of backscatter changes in relation to soil moisture, relevant to change detection, has been investigated for L-band PALSAR Fine Beam data. The results have been compared to corresponding sensitivities derived from C-band SAR data. The study has been carried out over two sites in the Volta basin in western Africa. The influence of sub-pixel coverage of trees and herbaceous vegetation in the SAR pixels has been analysed. The sensitivity to soil moisture was higher for PALSAR than for ASAR, but both datasets showed a similar decreasing trend with increasing vegetation density.

INTRODUCTION

Soil moisture is a crucial component in the cycle of water and energy and has been recognized as an emerging Essential Climate Variable by the Global Climate Observing System [1]. Research into soil moisture retrieval from active and passive microwave sensors has been ongoing since the 1970's. Since 1991, the ERS1 and ERS2 satellites have supplied C-band scatterometer acquisitions. The development of a method for retrieving soil moisture estimates using change detection techniques has been carried out for almost a decade at the Vienna University of Technology [2]. A global, multiyear database of soil moisture measurements has been build up. The change detection method has recently been transferred to the SAR domain within the SHARE project, which is part of the European Space Agency's TIGER Initiative. By using data acquired by the ENVISAT satellite's Advanced Synthetic Aperture Radar (ASAR), a 1 km Surface Soil Moisture (1 km SSM) product has been derived [3]. The 1 km SSM is available via the web free of charge and is updated on a monthly basis over southern and central Africa and entire Australia. The Phased Array type L-band Synthetic Aperture Radar (PALSAR) onboard the ALOS satellite provides acquisitions at various spatial resolutions and polarisations, including fully polarimetric modes. The purpose of this paper is to evaluate the sensitivity of the PALSAR data to changes in soil moisture. This was done through a comparison of the dynamics of the backscatter, related to soil moisture, of the ASAR and the PALSAR data.

METHOD

Data sets and processing

PALSAR Fine Beam (FB) data was analysed in conjunction with ENVISAT ASAR Global Monitoring (GM) mode data. The two datasets differ in frequency, spatial and radiometric resolution and coverage as can be seen in Table 1.

Table 1. Specifications of the SAR data used in the study.

	PALSAR FB	**ASAR GM**
Frequency	1.270 GHz	5.331 GHz
Spatial resolution	25 m	1000 m
Radiometric resolution	1 dB	1.2 dB
Polarisation	HH	HH
Swath width	70 km	405 km

All datasets have been geocoded with the software SARscape® developed by Sarmap and distributed by CREASO. The ASAR images have been geocoded with the use of precise DORIS orbit information and SRTM30 digital elevation model (DEM) to 30 arcseconds resolution, corresponding to approximately 1 km. To compare the two datasets at the same spatial scale, the PALSAR FB images were also geocoded to 30 arcseconds resolution using a 90 m resolution SRTM DEM. With a reduction of resolution during the geocoding of the PALSAR data from 25 m to 1 km, the noise was reduced 40 times, resulting in a noise of 1/40 dB or 0.025 dB.

The acquisition dates of the PALSAR images were chosen with the annual distribution of rainfall in mind. PALSAR acquisition dates for Tamale and Ejura are given in Table 2. The third column indicates the expected soil moisture conditions based on the annual distribution of rainfall, displayed in Figure 1. Despite the small number of images used in case of the PALSAR data, it is assumed that reasonably wet and

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dry conditions were captured in the images due to the distinct rainfall distribution over the year.

Table 2. Acquisition dates and anticipated soil moisture conditions, based on annual distribution of rainfall, for PALSAR FB datasets used in the study.

	Date	Anticipated soil moisture condition
Tamale site	2007-02-03	Dry
	2007-08-06	Wet
	2008-02-06	Dry
Ejura site	2006-05-25	Wet
	2006-07-10	Wet/Medium
	2007-01-05	Dry
	2007-02-20	Dry/Medium

The PALSAR images for each of the test sites were co-registered and the sensitivity was calculated as the difference between the maximum and minimum backscatter measurement at each location. It should be noted that since the incidence angle range was only about 4 degrees in the PALSAR FB images, influence of varying incidence angles were assumed to be negligible.

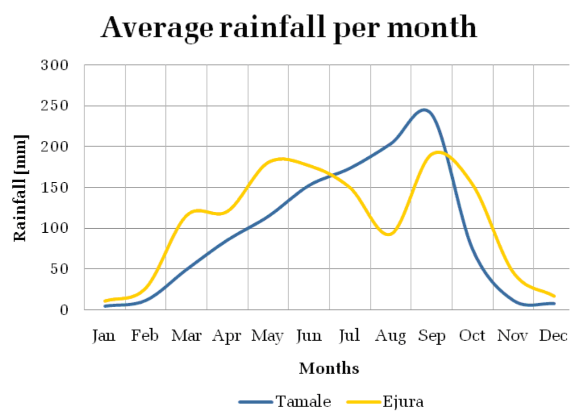

Figure 1. Annual rainfall distributions for Tamale and Ejura. The figure was adopted from [4].

Since no ASAR images matched the locations and acquisition dates of the PALSAR images, ASAR backscatter references for wet and dry soil moisture conditions were calculated according to the derivation of the 1 km SSM product. In an initial step, backscatter and local incidence angle images covering the sites were resampled to a grid and stored in a spatio-temporal database. Secondly, the local incidence angle dependency of the backscatter measurements was normalised by fitting the time series of data at each location and then reverting each measurement to a reference angle of 30 degrees. In a third step, backscatter references for wet and dry soil moisture conditions were derived from the time series of ASAR data for each location. The wet and dry references were calculated as the mean of the highest and lowest backscatter measurements respectively. The number of measurements used in the averaging was proportional to the probabilities for dry and wet soil surface conditions. These probabilities were derived from ERS1/2 scatterometer data, which characterises the soil wetness distributions well due to the long time series of the data. Finally, the sensitivity to soil moisture was calculated as the difference between the dry and wet backscatter reference.

To match the time period of acquisition of the PALSAR data used in the study, only one year of data was used for the derivation of the sensitivity for ASAR. In the case of the Ejura site, ASAR data from April 1 2006 to April 1 2007 was used (41 datasets). For the Tamale site, the corresponding period was February 1 2007 to February 1 2008 (61 datasets). The monthly mean soil moisture conditions, corresponding to the acquisition dates of the PALSAR images, are shown in Figure 2 and Figure 3. The monthly means are based on the 1 km SSM product derived from ASAR GM data. Values are in percent and basically correspond to a scaling between wilting level and field capacity.

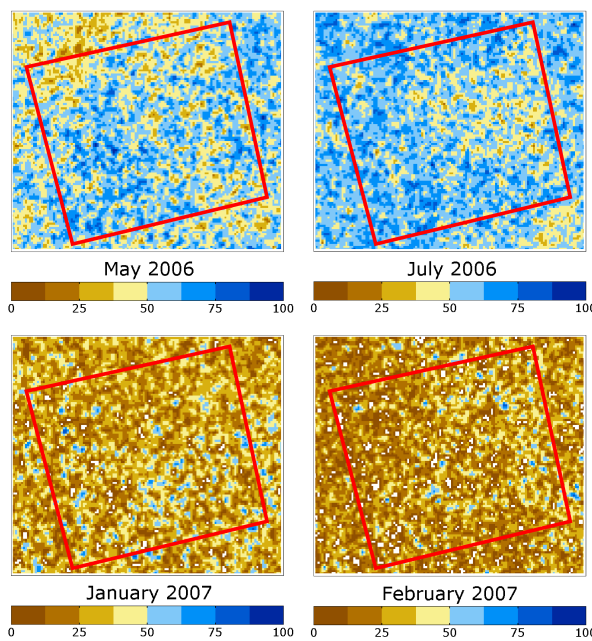

Figure 2. Monthly mean surface soil moisture in Ejura, derived from ASAR time series data, in units of percent of saturated soil. Between 2 and 5 images were used for each monthly mean. The 50x40 km Ejura test site is outlined in red.

By using the monthly mean images, an approximation of the range of soil moisture variation captured in the

PALSAR images could be estimated. This information could then used to correct the initial estimates of the mean PALSAR sensitivity over both test sites. Whenever results involving the corrected PALSAR sensitivities are presented, it is explicitly noted.

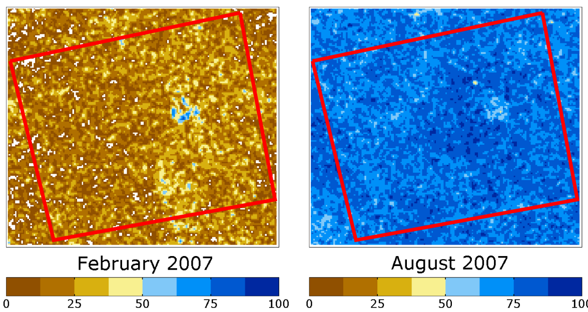

Figure 3. Monthly mean surface soil moisture conditions in Tamale, derived from ASAR time series data, in units of percent. For February 2007 only 2 images could be used in the averaging, while 6 images could be used for August. The 70x55km Tamale test site is outlined in red.

The density of the vegetation is an important parameter for the potential of estimating surface soil moisture using microwaves. Over areas of dense forest, the backscatter response from the soil surface is weak, resulting in a low sensitivity to soil moisture. Over areas such as open savanna, grassland and agricultural land, the backscatter is dominated by scattering for the lower layers of vegetation and soil surface, resulting in a higher sensitivity to changes in soil moisture. To quantify the vegetation density in the study sites, the Vegetation Continuous Fields (VCF) dataset, developed by the Global Land Cover Facility (GLCF) was used [5]. The VCF has a resolution of 500 m and gives for each pixel the fraction of coverage of trees, herbaceous vegetation and bare ground.

Study sites

The study was carried out over two test sites located in the Volta basin in Ghana. The Volta basin is a major river basin that drains an area of 407.000 km≤ into the Gulf of Guinea. With greater distance from the coast, aridity increases, the growing season becomes shorter, and rainfall is more erratic. One of the sites are situated in the region of Tamale, centered at 9.38N 0.96W. The second site is located in the region of Ejura, centered at 7.30N, 1.16W. The distance between the sites is about 230 km. Both Tamale in the north (Sudan Savanna Zone) and Ejura (Guinea Savanna Zone) in the south are located in the semi arid zone with rainfall limited to certain parts of the year as shown in Figure 1.

The Tamale test site is covered to 90% with savanna and about 9% with cropland according to the United States Geological Survey (USGS) Global Land Cover Characterisation (GLCC) dataset. The Ejura test site constitutes 95% savanna and 5% cropland. The sites are similar in land cover, but differ in vegetation density. Figure 4 and Figure 5 show the distributions of sub-pixel fractional coverage of trees, herbaceous vegetation and bare ground based on the VCF dataset. Both sites show a mean fractional coverage of herbaceous land cover of around 80%.

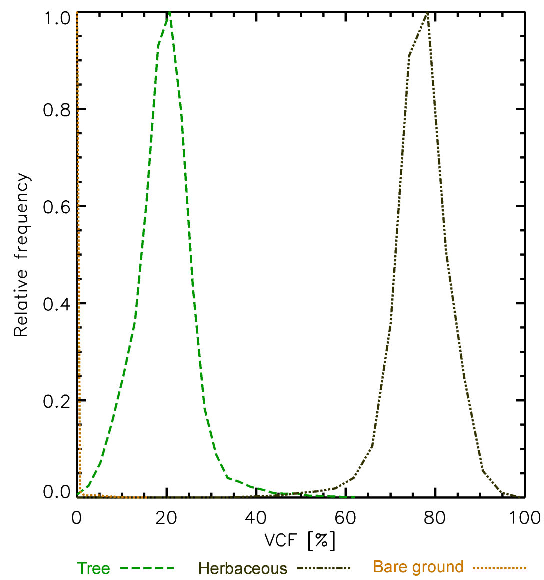

Figure 4. Distribution of Vegetation Continuous Fields (VCF) in the Ejura study area

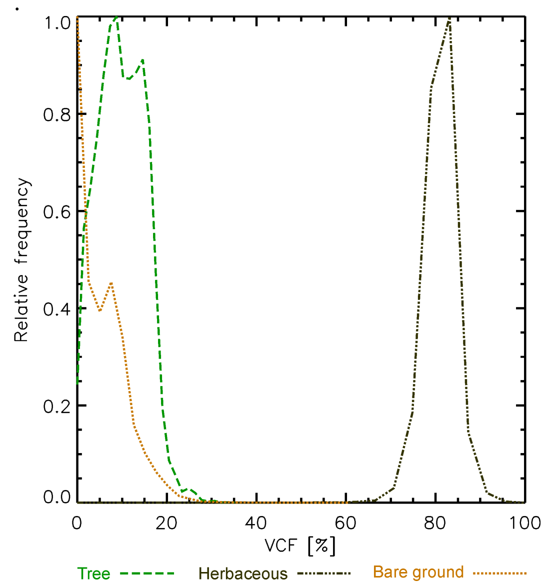

Figure 5. Distribution of Vegetation Continuous Fields (VCF) in the Tamale study site.

The coverage of trees however, differs between the sites with a mean of 10.5% for Tamale and 21.0% for Ejura. This reflects the higher density of trees on the savanna in Ejura than in Tamale.

RESULTS

Ejura test site

Figure 6 shows the sensitivity distributions for the Ejura test site. The mean sensitivity is 6.3 dB for ASAR and 3.5 dB for PALSAR. Figure 7 shows the mean sensitivity as a function of herbaceous vegetation cover. Both ASAR and PALSAR show similar dependency with about +0.2 dB per 10% increase in sub-pixel fractional coverage (here denoted "decade VCF"). The dependence on sub-pixel tree coverage has the corresponding trend of around 0.2 dB per decade VCF, as shown in Figure 8. According to the monthly mean soil moisture images in Figure 2, the PALSAR images would capture on average about 42% of the full soil moisture dynamics. Dividing the initial estimate of the mean PALSAR sensitivity by this value, the corrected mean sensitivity of 8.5 dB is obtained.

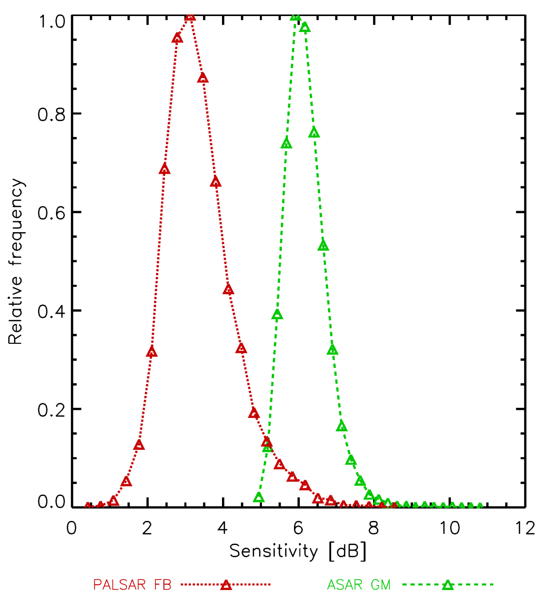

Figure 6: Sensitivity of ASAR and PALSAR in the Ejura region.

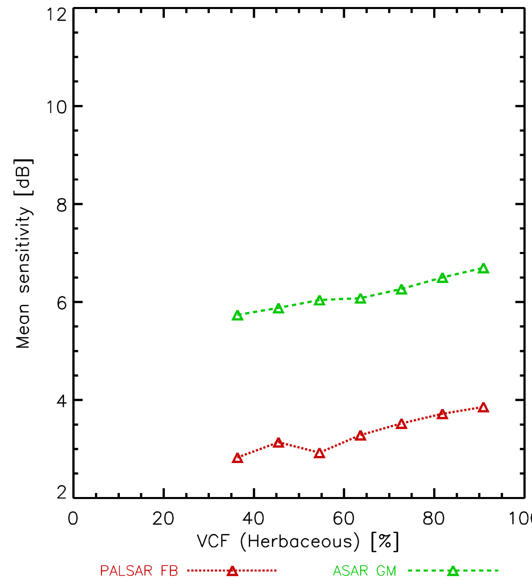

Figure 7: Sensitivity dependence on fraction of herbaceous vegetation for the Ejura test site.

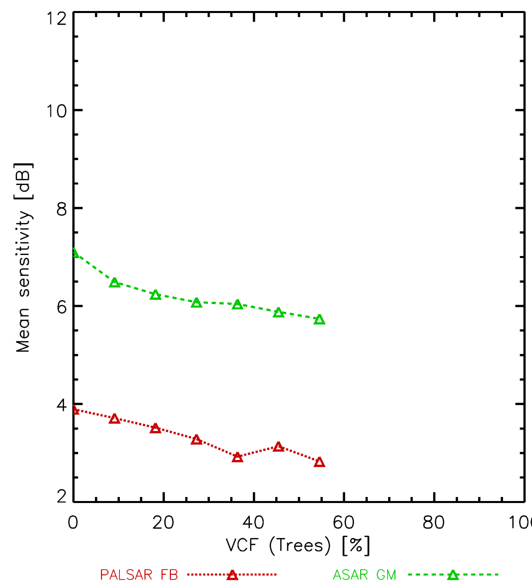

Figure 8: Sensitivity dependence on fraction of tree coverage for the Ejura test site.

Tamale test site

The sensitivity distributions for the Tamale test site are shown in Figure 9. The ASAR data had a mean sensitivity of 8.9 dB, while the uncorrected sensitivity for the PALSAR data was 2.5 dB. As can be seen in Figure 10, also the Tamale site exhibits an increasing trend in sensitivity with increasing fraction of herbaceous vegetation cover. Unexpectedly, the dependence on fraction of tree coverage, shown in

Figure 11, shows an increasing sensitivity with increasing tree coverage in the case of PALSAR. According to the monthly mean soil moisture images in Figure 2, the mean range of soil moisture between February and August was 56.2%. Dividing the PALSAR sensitivity by this value, results in a corrected sensitivity of 4.4 dB.

The trends in sensitivity as a function of vegetation cover fraction for both test sites are summarised in Table 3. The mean and standard deviation of the sensitivities are given in Table 4.

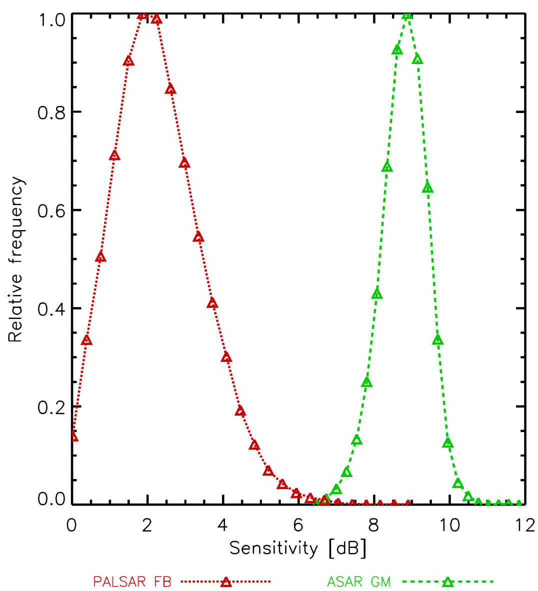

Figure 9. Sensitivity to soil moisture in Tamale. Mean sensitivity is 8.9 dB for ASAR and 2.5 dB for PALSAR.

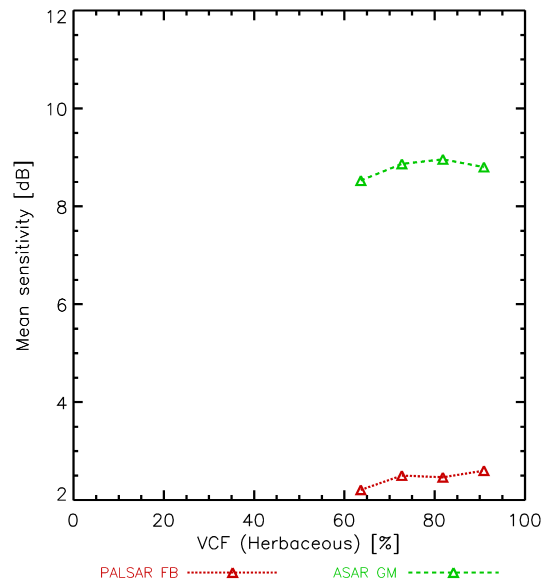

Figure 10. Sensitivity dependence on fraction of herbaceous vegetation cover in Tamale.

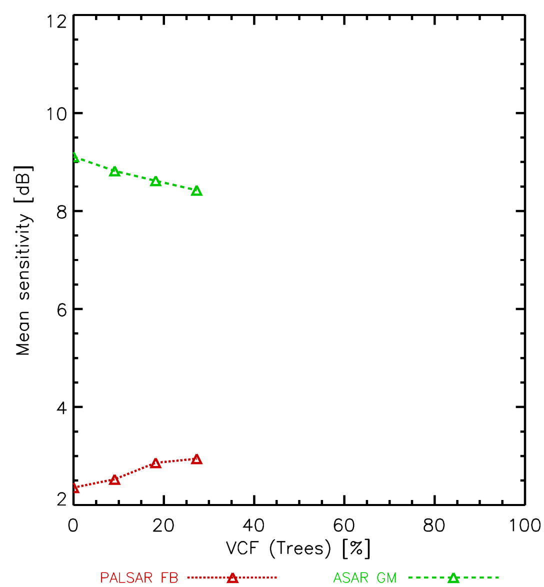

Figure 11. Sensitivity dependence on fraction of tree coverage in Tamale.

Table 3. Sensitivity dependence on fractional coverage of trees and herbaceous vegetation. Units are in decibels per 10% increase in sub-pixel coverage.

	Ejura		**Tamale**	
	ASAR	**PALSAR**	**ASAR**	**PALSAR**
Tree cover	0.22	0.19	0.25	0.23
Herbaceous vegetation	0.17	0.19	0.10	0.13

Table 4. Mean and standard deviation of sensitivities for both test sites, in units of decibel. The corrected sensitivity means have been adjusted to the estimated range of soil moisture variations captured in the corresponding data.

	Ejura		Tamale	
	ASAR	PALSAR	ASAR	PALSAR
Sens. mean	6.31	3.55	8.92	2.48
Sens. std. deviation	0.56	0.95	0.62	1.20
Corrected Sens. man	6.31	8.50	8.92	4.41

DISCUSSION

In order to interpret the results of the analysis, the representativeness of the data needs to be taken into account. The sensitivity estimates for ASAR are statistically more reliable since many measurements were taken into account in the calculation. Furthermore, in case of ASAR the estimates represent the sensitivity to the full range of soil moisture, basically from wilting level to field capacity. In the case of PALSAR, only 3 and 4 images were used for Tamale and Ejura respectively. Based on the site specific annual rainfall distribution, it was assumed that PALSAR images for reasonably wet and dry soil moisture conditions were included for each of the sites. However, it was neither an assumption, nor a requirement, to assume that the full range of soil moisture was captured in the PALSAR images. Instead, the initially derived sensitivities for PALSAR could be corrected by using information on the estimated range of soil moisture variation captured in the PALSAR images. This was done by using the 1 km Surface Soil Moisture product derived from the ASAR data. The corrected sensitivities for PALSAR could then be directly compared to the results for ASAR.

The higher value of the corrected sensitivity for PALSAR when compared to the ASAR sensitivity in the Ejura site (see Tab. 4) was expected, since the L-band backscatter was expected to be less disturbed by vegetation than the C-band backscatter. Furthermore, the ASAR sensitivity was lower for the Ejura site than for the Tamale site, as a result of the higher vegetation density in the Ejura region. The sensitivity estimates for PALSAR for the Tamale site, however, are not consistent with what would be expected. Instead, the corrected sensitivity for PALSAR is less than half of the ASAR sensitivity.

In general, the influence of vegetation on the dynamics of backscatter is not straightforward. An increase in vegetation density may decrease or increase the backscatter intensity, depending on the reflectivity of the underlying soil surface. A dense vegetation layer, such as a tree canopy, attenuates the response from the underlying surface signal while at the same time adding a volume scattering component which tend to increase the backscatter intensity [6]. This means that over a wet soil, a tree canopy will attenuate the total backscatter intensity, while over a dry soil, the result will be to increase total backscatter intensity. Either way, a dense vegetation canopy will always attenuate the sensitivity to soil moisture. This is demonstrated in Figure 8 for the Ejura test site. Since Lband microwaves interacts less with vegetation than does Cband microwaves, it was expected that an increase in canopy density would have a greater effect on the ASAR data. However, both the Cband ASAR and the Lband PALSAR sensitivity showed the same trend, with about 0.2 dB per 10% increase in sub-pixel tree coverage (see Table 3) over the Ejura test site. The finding also conforms to the corresponding trend for herbaceous vegetation with about +0.2 dB and +0.1 dB per 10% increase in fractional coverage for the Ejura and Tamale sites respectively. A peculiar trend is observed in the PALSAR data over the Tamale site with a +0.23 dB increase in sensitivity per 10% increase in sub-pixel tree coverage. Further work is required to explain this result. The ASAR data shows, as expected, a decreasing trend of 0.25 dB per 10% of fractional tree coverage over Tamale.

The magnitude of the sensitivities must be interpreted taking the noise of the data into account. Due to the high noise in the ASAR GM data (1.2 dB), only a few classes of soil moisture are expected to be distinguishable. For the Ejura test site, the 6.3 dB mean sensitivity would result in about 5 classes of soil moisture. The PALSAR FB data on the other hand, with a noise of approximately 0.025 dB when averaged to the ASAR resolution, would theoretically allow more than 100 classes. In the case of PALSAR, other factors, such as model uncertainties, would instead be limiting for the number of soil moisture classes.

Limiting for the potential of soil moisture extraction using change detection methods in the case of PALSAR is the relatively sparse temporal coverage, which results from the PALSAR Observation Strategy focusing on high spatial resolution and a typical coverage of 3-5 observations per year.

CONCLUSION

An approximately 35% higher sensitivity to soil moisture was found for the PALSAR data than for the ASAR data for the Ejura site. The results for the Tamale site in the case of PALSAR are not consistent with theory and require further work to be explained. The sensitivity for ASAR was lower for the Ejura site than for the Tamale site, as a result of the higher vegetation density in the Ejura region.

Taking into account the low radiometric noise of the PALSAR FB data when degraded to the spatial resolution of the ASAR GM data, more classes of soil moisture could theoretically be extracted from the PALSAR FB data than from the ASAR GM data.
In spite of the difference in wavelengths (L-band and C-band), the influence of increasing vegetation density on the sensitivities for the Ejura test site are similar for both datasets.

The potential of soil moisture retrieval using change detection methods is limited by the temporal coverage of PALSAR data.

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