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KEY WORDS: SAR, orthophoto, parcel, measurement, area accuracy

ABSTRACT:

In the frame of the Common Agriculture Policy, Member States have to measure parcels claimed for subsidies with a recommended precision. This is usually done using Very High Resolution (VHR) optical images with ground sampling distance of around 1m or better. However acquisition of such imagery may fail due to cloud cover. It is therefore worth examining the potential of almost weather independent VHR radar data for replacing VHR optical imagery: during this study, the identification of agricultural parcels and the assessment of the measurement accuracy on VHR SAR images were tested.

Airborne VHR X band SAR data were provided over 4 agricultural test sites in France. Three of these sites were covered with 1m monopolarized ("B&W") data from 2002-2004 whereas the remaining one was covered with 2m multipolarized ("colour") data from 2002. Orthophotos (1m B&W and 50 cm colour ADS 40) acquired over 2001-2004 were used as reference. All parcels falling on the frame of the VHR SAR images were digitized on the orthophotos and examined on the VHR SAR data.

Two sets of around 40 parcels each were selected on the two types of VHR SAR images (2m "colour" and 1m "B&W"). Each parcel was measured randomly 3 times by 3 operators on both the SAR imagery and the orthophoto. The errors on the parcel area were translated into buffer widths around the parcel perimeter. After the elimination of outlier measurements, the buffer variations were analyzed and a tolerance interval around the buffer estimated. The results indicate that (1) about 30% of the parcels were not visible on the X-band SAR data; (2) the estimated tolerance intervals of the buffer values were of 4.14 m and 4.81 m on 2 m colour composition and 1 m black-and-white SAR data respectively, which is larger than requested by the EU Regulation.

1 INTRODUCTION

In the frame of the Common Agricultural Policy (CAP), a number of agricultural parcels claimed for subsidies have to be measured with certain accuracy every year by the Member States Administrations. In 2007, about 50% of these area measurements will be carried out using Very High Resolution (VHR) optical satellite imagery acquired over 150 000 km2 and 220 zones. To account for the uncertainty inherent to any measurement tool, a technical tolerance (or maximum error) is used when comparing the claimed and measured areas to determine the validity of the claimed area. According to article 30 of EC Reg. N° 796/04, this technical tolerance shall not exceed either 5% of the agricultural parcel area or a buffer of 1.5 m applied to the perimeter of the agricultural parcel. Of the two types of tolerances, the buffer approach based on the parcel perimeter is recommended as it is technically sound (Bogaert et al., 2005, Hejmanowska 2005).

Because of the specifications set on the tolerance, orthorectified VHR images have to be used for parcel area measurement. Up to now, only optical VHR imagery has been used, however, the recent launch of VHR radar sensors (Cosmoskymed, TerrasarX) makes it worth assessing the use of 1m X-band Synthetic Aperture Radar (SAR) data for the controls of area based subsidies.

The main objectives of this study conducted in the frame of the Spot Pleiades and Cosmoskymed preparatory programme (ORFEO) were twofold: (1) assessing whether agricultural parcels could be identified on VHR SAR data as well as on optical VHR data and (2) assessing the measurement accuracy of VHR SAR data.

2 METHODS

Because the measurement error on a parcel area is a function of its perimeter, it is practical to model the maximum acceptable discrepancy between the measured area and the claimed area, i.e. the tolerance, as the parcel perimeter multiplied by a width. This width, also called buffer width or simply buffer around the parcel perimeter, is expected to vary as a function of the measurement tool, whether it is an image or a GPS. For a given parcel, the knowledge of its reference (i.e. true) area and reference perimeter allow to translate the error on the area (measured area – reference area) into this buffer width using:

$$B_i = (a_{m\_i} - a_{ref})/p_{ref} \quad (1)$$

where,
B_i –buffer width for measurement i
a_{m_i} - measured area for measurement i
a_{ref} – reference area of the parcel
p_{ref} – reference perimeter of the parcel

In order to derive a confidence interval for the buffer width, i.e. to derive the tolerance above which an inspector will reject the area claimed by the farmer with a risk of error alpha of 5%, the simplest way is to verify that the distribution of the buffer widths follows a normal law. The Shapiro-Wilk, Anderson-Darling, Lilliefors and Jarque-Bera tests were used to check the normality of the buffer values. To obtain the final buffer value, the theory of the tolerance intervals also should be applied. The tolerance intervals (also called confidence intervals) guarantee, that p percent of buffer population will not exceed an upper limit. This upper tolerance limit is computed from a series of measurements B_1, ..., B_N:

$$B_U = \overline{B} + k_1 s \quad (2)$$

where,
k_1 – factor determined, that the interval covers at least a proportion p of the population with confidence, γ
s – standard deviation of the buffer population
B_U – upper limit of the buffer value
$\overline{B}$ - mean buffer value

The calculation of an approximate k_1 factor for one-sided tolerance intervals comes directly from the following set of formulas (Natrella, 1963):

$$k_1 = \frac{z_{1-p} + \sqrt{z_{1-p}^2 - ab}}{a}$$
$$a = 1 - \frac{z_{1-\gamma}^2}{2(N-1)};\ b = z_{1-p}^2 - \frac{z_{1-\gamma}^2}{N} \quad (3)$$

Where $z_{(1-p)}$ is the critical value from the normal distribution that is exceeded with probability (1-p) and $z_{(1-\gamma)}$ is the critical value from the normal distribution that is exceeded with probability 1-γ.

Prior to verifying the normality of the buffer widths, a detection of outliers is recommended. According to ISO 5725 (1994), the detection of anomalous measurements within each group of observations (i.e. parcel) is made with the Grubbs' test whereas Cochran's test allows detecting outstanding measurements in all measurements made using one type of imagery in our case.

An analysis of variance was also performed to identify the main factors explaining the variability of the area measurements (image type, resolution, visibility of the parcel boundary on SAR data and operator).

3 DATA AND PREPROCESSING

3.1 VHR SAR images

Airborne VHR SAR images (X-band) acquired between 2002 and 2004 were provided by CNES over four test sites in the south of France (Cf. Table 1). All images are single polarized (HH) 32 bits images resampled to a 1m, except the Istres image which was acquired with 4 different polarizations (HH, VH, HV, VV) and was resampled to 2m. All 4 images were acquired in spring time (over February - March), to the exception of Les Baux which was acquired in July.

Zone	*Radar mode*	*Date of acquisition*	*Resolution (radial x azimuth)*	*Frequency [GHz] wavelength*	*Incident angle*
Les Baux	*Interferometric*	*7/02/2003*	*1.0x1.0 m*	*9.45 X-band (3cm)*	*60°*
Hyeres	*High resolution*	*3/04/2002*	*0.96x0.96m*	*9.46 X-band (3cm)*	*30°*
Istres	*Polarimetric: HH VV HV VH*	*20/03/2002*	*2.35x1.38 m*	*9.45 X-band (3cm)*	*30°*
Avignonet	*High resolution*	*22/07/2004*	*0.93-0.97m*	*9.46 X-band (3cm)*	*60°*

Table 1 Available radar data set

3.2 VHR optical images

As for the optical imagery, archive panchromatic aerial orthophotos acquired between 2001 and 2003 were provided for the 4 sites by the French Administration (AUP). These 8-bits 1 meter resolution orthophotos were used to geo-rectify the SAR images and to define reference parcels by photo-interpretation. In addition to these orthophotos, an orthorectified 0.5 m pixel ADS40 (multispectral digital camera) coverage of Les Baux from 05/2003 was available at the JRC.

3.3 Pre-processing of VHR SAR images

Since the VHR SAR data were not geocoded and the flight parameters were not accessible, a 1st order polynomial transformation was used to superimpose the SAR images to the orthophoto. The RMS errors achieved on ground control points (taken on the orthophotos) were between 2.3-3.3 m for the 1m SAR data and around 6.7 m for the 2m SAR data over Istres.

3.4 Acquisition of reference data

In order to assess the area measurement accuracy of any tool, reference parcels with a known area have to be selected. These parcels, which should not have any common boundary between themselves, will be randomly presented to the interpreters. Since measurements in the field with a high precision GPS were no more possible as the SAR images were acquired 3 to 5 years prior to this study, it was decided to identify reference parcels on the orthophotos. This is justified by the fact that VHR optical imagery is considered as a valid tool for delineating most of the agricultural parcels (only adjacent agricultural parcels with the same use may not be identified). It should however be borne in mind that the selection of reference parcels on the orthophotos may result in anomalous measurements on the SAR images since the date of the orthophoto and of the VHR SAR flight differ.

In the 4 test sites, 216 parcels were digitized on the orthophotomaps and checked visually on the SAR imagery. The average parcel areas vary between 0.1 ha to 8 ha. Three degrees of parcel visibility on the SAR images were defined: good visibility when the whole parcel boundary could be identified on the SAR image, poor visibility when part of the border had to be deduced and no visibility when most of the parcel boundary could not be distinguished.

The higher percentage of parcels with a good visibility was observed for Istres where 46% parcels (51 of 110) were easily recognized on the multi polarimetric colour composition despite the lower resolution of the image (2m). The single polarization 1m images of the remaining 3 sites showed from 23% to 32% of parcels with a good visibility.

3.5 Parcel identification on the VHR SAR imagery

From 25 to 40% of the 216 parcels digitized on the orthophotos could not be distinguished on the SAR imagery as follows:

Les Baux: 40% parcels not visible out of 30
Avignonet 22% parcels not visible out of 37
Hyères 44% parcels not visible out of 39
Istres 25% parcels not visible out of 110

This result, which may be due for some parcels to a change in land cover between the date of the orthophoto and of the SAR

image, shows that the control of claimed parcels could not rely at 100% on the sole VHR SAR image.

From the 216 parcels present on the orthophotos and the SAR images, 82 parcels were selected as reference parcels: 42 from Istres and the remaining 40 over the 3 other sites. In absence of any other reference area, the reference area of these parcels was set to be the area digitized on the orthophotos by the JRC.

4 AREA MEASUREMENTS

Each of the selected 82 parcels was measured 3 times by 3 different operators on the SAR images. The same operation was repeated on the orthophotos. In total, 1476 area measurements were acquired using an application based on Geomedia Professional. The operators were presented the parcels to be measured in a predetermined random order, first on the SAR images and later on the orthophotos. The parcels to be measured were labelled with their polygon number. Letters ("a", "b"…) indicated the different parts of the reference parcel, while "x" indicated parts to be excluded (e.g. adjacent parcels). The operators were also provided with the brief guidelines how to interpret SAR images (Pluto-Kossakowska, 2007).

4.1 The measurements on radar images

Most of the digitized parcels were "close" to the reference parcels. However in a few cases, large discrepancies were observed between the areas measured on the SAR images. On average, the standard deviation of parcel areas was around 8% of the parcel mean area. The highest standard deviation of areas reached almost 43% of the parcel mean area (cf. Figure 4).

The large differences between the measured and the reference areas can be explained by mistakes in the identification of the parcel boundary: omission of hedges or tree rows; non detection of the boundary between two adjacent parcels (e.g. due to a similar texture). The following figures illustrate cases of such mistakes (later detected as outliers).

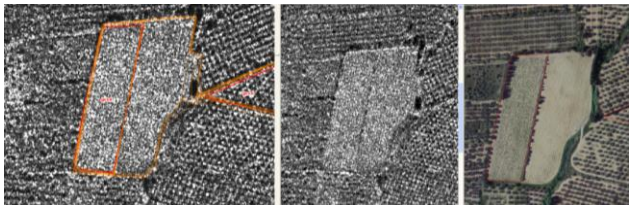


Figure 1 Example of outstanding measurement – Les Baux site. From left to right: 1m SAR data with different parcel measurements, the same SAR data showing the tree row between the 2 parcels of similar texture, and reference parcel on the ADS 40 data.

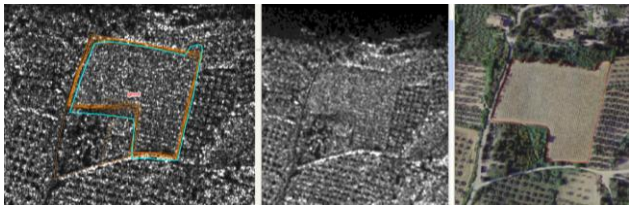


Figure 2 Example of outstanding measurement showing a change of texture not noticed by some operators in the SW part of the parcel (Les Baux site).

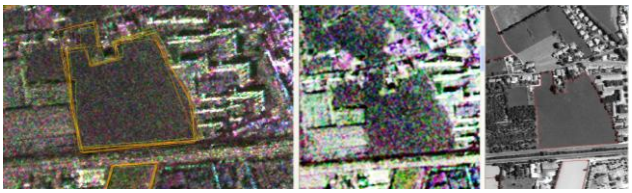


Figure 3 Example of outstanding measurement that could be due to a lack of contrast in the NW corner of the parcel (Istres site).

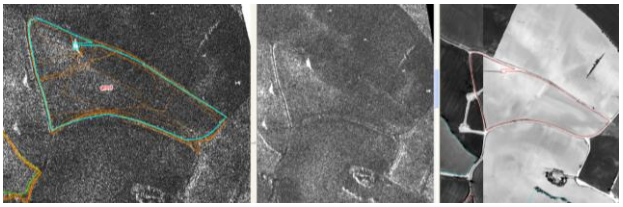


Figure 4 Example of outstanding measurement, probably due to lack of contrast between adjacent parcels combined with some intra parcel variability of the SAR response (Avignonet site)

4.2 The measurement on the orthophotomap

Not surprisingly, fewer discrepancies than with the SAR images were observed. However some obvious mistakes did occur because the correct object was not identified properly. On average, the standard deviation of parcel areas was less than 6% of the parcel average area. The highest standard deviation of area was almost 50% of the parcel average area.

5 RESULTS AND DISCUSSION

5.1 Detection of Outliers

The statistical analysis was carried out using the Standard Least Square (SLS) fitting procedure of JMP v.6 (SAS Institute).

Out of the 1476 buffer measurements, the Grubbs test (G1, G2, G3) and Cochran tests ($\alpha = 0.05$) identified 73 outliers (5%) in 25 of the 82 parcels. Out of these 73 outliers, 49 (67%) were made on the SAR images during the digitization of 19 parcels as follows: 37 and 12 on 1m and 2m SAR data respectively. The information provided by the multipolarization may explain the lower % of outliers on SAR 2m data with respect to SAR 1m data.
More surprisingly 24 outliers from 6 parcels were found on the orthophotos, which shows that some ambiguities remained in the information given to the operators at the time of digitizing (since the reference parcels were delineated on these same orthophotos, one would not expect outliers to occur).

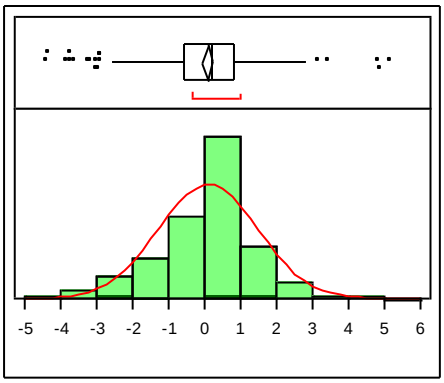
Of the 82 parcels x 2 types of images, 5 were removed completely: 3 from SAR1, 2 from ORTHO, of which 1 was common to both sets (see the parcel on Figure 4). Most outliers on SAR images correspond to buffers in the range +5m to +10m, while outliers from ORTHO had buffers between -10m and 0m.

Considering the factor visibility, 45 of the 73 outliers occurred in the "POOR" visibility subset of parcels while 28 were part of the "GOOD" visibility subset. In both cases, outliers were less than 6% of each subset. In addition, no large differences were

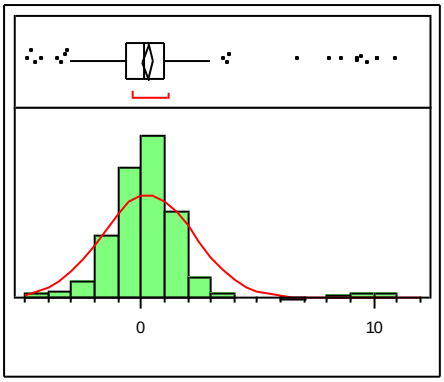
observed between operators: each operator had between 21 and 27 outliers.

5.2 Normality tests

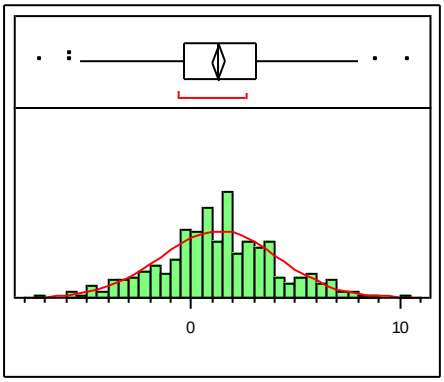
The normality tests showed that the buffer values do not follow a normal distribution ($\alpha = 0.05$), which is not surprising considering the size of the population. However, the buffer values obtained from the SAR-1m measurements were found to be normally distributed. Figure 5 shows the distribution of the buffers for each subpopulation (SAR 1m, SAR 2m, ORTHO 1, ORTHO 2, which has the same resolution as ORTHO 1 but corresponds only to the Istres site).



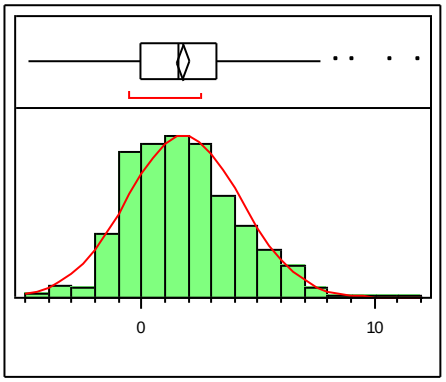
Ortho1 buffers (0.08714, 1.38282)



Ortho2 buffers (0.29179, 1.97763)



SAR1 buffers (1.3165, 2.82773)



SAR2 buffers (1.81023, 2.44845)

Figure 5 Distribution of buffer values populations with mean and standard deviation (Ortho1 and Ortho2 refer to 1m orthophotos from test sites covered by SAR1 and SAR2 respectively)

5.3 Results of the Analysis of Variance

Considering the large number of observations, parametric models (SLS) were applied to test the potential effects of the 4 factors (image type, resolution, visibility of the parcel boundary on SAR data and operator) and their respective interactions by parametric (Student) and non parametric (Wilcoxon & Kruskal-Wallis) tests using the SLS fitting procedure. The analysis of variance shows that there is a significant effect (Prob>F lower than 0.0001) with 18% of the variation (r^2) explained by the model.

First, the global model was tested with all the possible single factors and interactions (of 2nd, 3rd and 4th order). Non significant effects were removed one by one by deleting at each step the interaction with the higher relative level of non-significance and by reprocessing the SLS fitting procedure.

Significant ($p<0.05$, F>Fcritical) effects were found for all the four single factors: Image-type, F(1.490)= 152.54, p<.0001; Resolution F(1.490)= 13.676, p=.0002; Visibility, F(1.490)=17.311 , p<.0001 and Operator F(1.490)=11.617, p<.0001. Consequently, buffer values were significantly different between modalities for each factor when individually considered.

Concerning the 2nd and 3rd orders, the significant (95% level of confidence) interactions were RESOLUTION*VISIBILITY, IMAGETYPE*OPERATOR and IMAGETYPE* RESOLUTION*VISIBILITY. For the 3rd order interaction, table 2 showed that buffer values are significantly different between modalities of the interaction.

Level	*Least Sq Mean*	*Student's test classification*	*Std Error*
SAR,2m,B	*2.69*	*(a)*	*2.83*
SAR,1m,B	*1.52*	*(c)*	*2.91*
SAR,2m,G	*1.16*	*(c)*	*2.75*
SAR,1m,G	*1.05*	*(b)*	*1.88*
ORT,1m,B	*0.43*	*(d)*	*2.08*
ORT,1m,G	*0.02*	*(d)*	*1.38*

Table 2 Buffer values classification for each of 3rd order interaction modalities (levels not connected by same letter are significantly different)

The descending classification of the mean buffer value for each modality of the 3rd order interaction confirmed that SAR is the less precise type of image for parcel area delineation. Concerning the effects of visibility, "good" visibility always showed a lower buffer on parcel area delineation for orthophoto as well as for SAR. No clear hierarchy was observed between the SAR 1m and the SAR 2m. This may be explained by the fact that multipolarized information of the SAR 2m data compensated the lower resolution.
From these SLS results, the type of image could be considered as the prime factor influencing the precision in parcel area delineation. Factorial analysis performed on the "cleaned" dataset (results not showed) has showed that IMAGETYPE and RESOLUTION were the two main factors influencing the parcels area measurement. These two factors account for approximately 66% of the total buffer value variation observed.

For what concerns the factor OPERATOR, the mean buffer value from operator 1 was significantly different ($1.225^{(a)}$ ±0.098 m) from those of operators 2 and 3 (respectively equal to $0.836^{(b)}$ ± 0.098m and $0.632^{(b)}$ ± 0.097m – *levels not connected by the same letter are significantly different*). Operator 1, whatever the type of image, visibility and resolution, tended to overestimate the parcel area by 50% and 110% with respect to operators 2 and 3. Figure 7 shows on cube plots the two extreme behaviours met during the study.

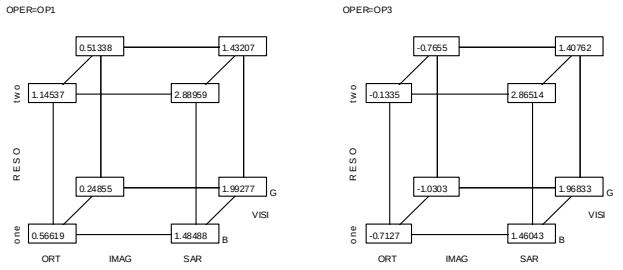


Figure 6: Cube plots presenting the variation of the mean buffer value for the two extreme behaviours (OP1 and OP3)

Whatever the combination of factors considered, operator 1 overestimated the parcels area: all the buffer values are positive. The use of orthophoto of better resolution and better "visibility" by operator 1 increased the accuracy of parcel area measurement by 2 or 3 times leading to a mean buffer value lower than 0.6m (which could be an effect of the test site since there is no better resolution and visibility on orthophoto). In contrast, on SAR images, the benefit of a better resolution and visibility did not appear clearly on the buffer values of operator 1. At the opposite, operator 3 (and operator 2) presented a different behaviour with respect to the two types of images: orthophoto led to underestimation whereas radar imagery led to overestimation of the parcel area.

In conclusion, this ANOVA showed that image type and resolution are the main factors affecting the precision of parcel area measurement.

5.4 Buffer values for the estimation of the tolerance

In addition to the parameters of the buffer value distributions (cf. figure 6), the tolerance interval has been calculated as the product of the standard deviation and the k factor (with p=0.95 and γ=0.99) followed the equation (2) and (3). Whereas the mean buffer value gives the bias of each method (image), the tolerance interval should help an inspector deciding whether a claimed area can be accepted or not with respect to a measured area. With 99% of confidence, it can be said that 95% of the buffer values will not exceed the tolerance limit: for orthophoto 2.87 m, for SAR1 4.81 m and for SAR2 4.14 m (see table below). Surprisingly, slightly better results were achieved on SAR2 colour composition than on 1m B&W SAR image, despite the coarser resolution. This is probably due to the multipolarized (colour) information, which is an additional attribute of the object (besides contrast or texture) used by the operator for parcel recognition. The results on the 1m orthophoto are better then on the SAR images but are poorer than expected.

image	*n*	*Average [m]*	*StDev*	*1.96*StDev [m]*	*K*	*K*sdev [m]*
ortho	*714*	*0.20*	*1.73*	***3.39***	***1.66***	***2.87***
SAR1	*314*	*1.32*	*2.83*	***5.55***	***1.70***	***4.81***
SAR2	*366*	*1.81*	*2.45*	***4.80***	***1.69***	***4.14***

Table 3: Moments of normal distribution for buffer values

The average buffer values are positive, especially on SAR data, which shows a trend to overestimate the parcel area. The average values (table 3) show that the bias on SAR 2m (colour) data is higher then on SAR 1m "B&W" data, which in turn is higher than the bias on the 1m orthophoto.

6 CONCLUSIONS

The following conclusions could be drawn from this preliminary study made with airborne VHR SAR data:

- From 25 to 40% of the parcels identified on the orthophotos could not be recognized on the VHR SAR data. Also some of the landscape features (e.g. hedges) were not visible. This lack of contrast between objects may be due to the characteristics of these particular images which were acquired with a prototype VHR SAR sensor. Moreover, the VHR SAR images were not orthorectified and the optical and SAR data were not acquired at the same time (crop season), which may explain some of the outliers found.
- The ANOVA showed that the image type and resolution were the main factors affecting the accuracy of parcel area measurements.
- Similar accuracies were observed on the 1m SAR black-and-white images and on 2m SAR colour compositions indicating that the multipolarized information compensated for the lower resolution of the data.
- The estimated buffer tolerances found in this preliminary study were the following: 4.81 m on SAR 1m black-and-white, 4.18 m on SAR 2m colour composition and 2.87 m on 1m orthophoto (B&W). These buffer widths are higher than the maximum 1.5m requested by the EU regulation.

This study should be repeated with data Cosmoskymed VHR SAR to be acquired this year nearly simultaneously with VHR optical satellite images. Also more attention will have to be given to the information provided to operators for identifying the objects to be measured.

Acknowledgements

Thank you to Javier Gallego for his statistical advice and to Beata Hejmanowska for the parcel area measurements. The airborne 1 and 2m SAR data were provided by CNES in the frame of the ORFEO project while the 1m black and white orthophotos were supplied by the French Paying Agency (AUP).

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